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This report was authored by Dr. Christian Lanconelli [Unisystems, International Business Unit], Dr. Laura Riihimaki [National Oceanic and Atmospheric Administration (NOAA) Global Monitoring Laboratory (GML)], Dr. Amelie Driemel (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research) on behalf of the Baseline Surface Radiation Network (BSRN).

BSRN, part of the Global Energy and Water cycle Exchanges project (GEWEX) Data and Analysis Panel (GDAP), provides highly accurate worldwide radiative flux measurements to validate satellite-based measurements. It develops instrument requirements, establishes BSRN reference stations worldwide and assembles a database of these measurements.

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Executive Summary

This report details the proceedings of the 18th Baseline Surface Radiation Network (BSRN) Scientific Review and Workshop, held at the Japan Meteorological Agency in Tokyo, Japan from 1–5 July 2024. BSRN consists of volunteers who operate stations that measure surface solar and infrared (IR) radiation, creating a database of worldwide radiative flux measurements archived at the World Radiation Monitoring Center (WRMC) of the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research. Project scientists and other guests meet biennially to share updates on station operations, instrumentation and the state of the science through oral and poster presentations and by convening BSRN Working Groups. The 18th Review and Workshop addressed new station applications, improvements in instrumentation and data reduction methods, data management and quality control issues and ways the data are used by the larger community.

This report, despite not mentioning them explicitly, may refer to discussions held in previous BSRN Scientific Review Workshops not documented by dedicated reports. All digital resources of Workshops XVI and XVII, such as the agendas, presentations and posters, are available in the relevant sections of the BSRN website (bsrn.awi.de/meetings). The XVI session was held on 1st Oct. 2020 in a reduced virtual format due to the Covid 2019 pandemic, and the XVII session took place in 2022, in a hybrid form hosted by Dr. Christian Lanconelli and supported by Dr. Nadine Gobron and Dr. Mark Dowell of the Joint Research Centre of the European Commission, in Ispra, Italy (27-30 June 2022).

A concluding section summarizes the main achievements over the last 6 years, focusing on strengths and weaknesses of the network, and aimed at supporting the next management generation challenges in maintaining the high standards and reputation of the network in the global climate and energy research contexts.

I would like to personally acknowledge all the dedicated members of this committed and enthusiastic community and wish the best fortune to them and the coming generations for the evolution of such an important observational network.

Christian Lanconelli
BSRN Project Manager, 2018-2024

1. Introduction and Overview of 18th Meeting (2024)

Seventy-six scientists, station managers, and data users from 24 countries representing 49 different organizations presented 37 talks and 31 posters at the 18th Baseline Surface Radiation Network (BSRN) Scientific Review and Workshop held at the Japan Meteorological Agency (JMA) in Tokyo, Japan on 1st–5th July 2024. The workshop was hosted by JMA, and led by Dr. Christian Lanconelli, ably assisted by Dr. Laura Riihimaki and Dr. Amelie Driemel and the JMA local personnel. During the meeting, BSRN observations were reviewed, improvements in instrumentation and data reduction methods discussed, data management and quality control issues considered, and ways the data are used by the larger community were examined. In addition, two new sites (codes: QIQ and MIN) and were proposed for consideration to join BSRN (from China and Cape Verde).

The GEWEX Data and Analysis Panel (GDAP), co-chaired by Tristan L'Ecuyer and Hiro Masunaga, oversees and gives general guidance to BSRN. The BSRN project consists of volunteers operating stations that measure surface solar and infrared (IR) radiation. Most stations measure the surface radiation by making broadband solar and infrared downwelling and upwelling irradiances according to a set protocol and using the highest quality radiometers. Many stations also make ancillary measurements, such as ultraviolet radiation (UV), photosynthetically active radiation (PAR), and meteorological parameters. A few stations began operating in 1992 and have accumulated over three decades of high-quality data. Currently, 77 stations have submitted data to the BSRN Archive since 1992, totaling over 13400 data months, of which 17 have terminated their measurements and quite a few are in the process of restarting their operations after a long hiatus (mostly due to the Coronavirus pandemic), and the remaining 43 are fully operational and regularly sending data. The World Radiation Monitoring Center (WRMC) of the Alfred Wegener Institute of Polar and Marine Research (AWI) in Bremerhaven, Germany, archives the data produced by the stations (*https://bsrn.awi.de*).

Brief summaries of the oral presentations made at the meeting in the order listed on the agenda, followed by the various Working Group reports and a summary of the business meeting portion of the workshop, can be found in this report. After the summaries of the oral presentations, there are sample summaries of the poster presentations. Electronic versions of many of the presentations, including posters, are available for an undefined time period on the BSRN web site under the meetings section (*https://bsrn.awi.de/meetings*).

2. Meeting Sessions

A record of each session is available from the BSRN web site (link in the agenda published there) for a limited period. The abstracts of each presentation are available in Annex 5.

2.1. Day 1 – Welcome and Management reports, GCOS and GDAP

The speakers discussed various topics related to the network, including its history, current status, and future plans. **Hiraishi Naotaka** (JMA, Director Atmospheric Environment and Ocean Division, Japan), welcomed participants to the 18th BSRN workshop and expressed gratitude to the BSRN, Secretary, and participants for their cooperation. He highlighted the importance of maintaining the global radiation observation network and its accuracy, and noted that JMA has contributed to BSRN activities for about 30 years. **Kazuhiro Tsuboi** (JMA, Atmospheric Environment and Ocean Division, Atmospheric and Ocean Department, Japan), presented the geological radiation team's activities, including atmospheric environment observations, greenhouse gas observation (performed in the frame of the Global Atmospheric Watch, GAW), and relevant international collaborations. He highlighted the long-term data-series available at JMA, particularly those related to radiation measurements and the related atmospheric component retrieval. He also discussed the importance of quality control and calibration, and presented data on the concentration of greenhouse gases, including carbon dioxide and methane.

Laura Riihimaki (Cooperative Institute for Research in Environmental Sciences (CIRES)-NOAA, USA), the BSRN deputy project manager, presented a memorial to Frank Vignola, a renowned expert in solar radiation measurement who passed away in 2023. She shared stories and quotes about Frank's kindness, dedication, and passion for his work, and highlighted his contributions to the field, including his data record and publications.

Christian Lanconelli (on behalf of BSRN) summarized the status of the BSRN network, including its history, governance, and current challenges. The agreement with the Global Climate Observing System (GCOS) was renewed during the last few years and now BSRN is officially a recognized network of GCOS, delivering references for surface radiation essential climate variables (ECV). He remarked on the importance of maintaining high quality standards, calibration, and traceability, and presented data on the network's performance, including the timeliness of data submission and the number of active and inactive stations. He highlighted the critical problem for pending candidates of the previous meetings (Indonesia, Thailand, Korea-Antarctica, Cyprus, Ireland, and Chile) to conclude their path towards operational status in an expected timeframe, and the difficulty of respecting a 1-year timeliness requirement for more than half of the operational stations. He claimed to have presented on an yearly timeline a reporting presentation about the status of the network to GEWEX/GDAP, to GCOS/Atmospheric Observation Panel for Climate (AOPC), to the Network for the Detection of Atmospheric Composition Change (NDACC) and to the International Radiation Commission (IRC). Laura Riihimaki reported to the Ocean Best Practices System (OBPS), while Amelie Driemel reported on the status of BSRN to the German GCOS 2024 meeting.

He highlighted the efforts of a few particularly active BSRN Working Groups (WG), which maintained a constant connection by organizing joint monthly virtual meetings with their team members. Special thanks for this were addressed to the chairs of the Data Quality WG, Wouter Knap (Royal Netherlands Meteorological Institute, KNMI), and the Uncertainty WG, Laurent Vuilleumier (Meteoswiss).

He mentioned some main achievements, including 1) the delivering of the pyrgeometer raw data (net signal and temperatures), in a new LR4000 (operational for 17 sites); 2) the bsrn-qc.net online quality check (QC) tool; 3) the routine production of the QC files and the need to expand the BSRN Toolbox official tool currently limited to LR0100 and LR0300 logical records; 4) the BSRN RAW data system, a pilot cloud system aimed to support station scientists in data handling in a centralized and harmonic way; and 5) the centralized storage of calibration certificates.

Amelie Driemel (AWI, Germany), the World Radiation Monitoring Centre (WRMC) director, presented the status of the BSRN archive, focusing on its infrastructure, data sets, and usage statistics. The WRMC currently contains more than 13,000 monthly datasets from 77 stations, which amount to around 1,100 years of data. Of these 77 stations, 43 are active, 17 inactive (e.g., 2-years timeliness not respected), and 17 closed. She highlighted the challenges of maintaining the archive, including the need for a centralized data quality tool and the importance of supporting station scientists in the QC process. With data requests from 60 different countries, about 1,000 visits per month and 11,000 per year granted BSRN the status of the most human downloaded data product in the Data Publisher for Earth and Environmental Science, PANGAEA (www.pangaea.de). Lampedusa was the only new operational station (LAM, Italy). TNB (Antarctica) is in candidate status, and five stations are in pending status (no fully valid dataset submitted to the network so far).

Out of 77 stations, 27 stations have a complete radiation budget, including all BSRN polar stations.

Secure File Transfer Protocol (SFTP) protocol can now be used to interact with the BSRN archive along with the classical File Transfer Protocol (FTP), which remains active. Submitting LR4000 was considered also for legacy data without the need to resubmit all data. A program to check the consistency between the information given in LR4000 and the data logical records LR0100, LR0300, and LR30xx has been developed and adopted by WRMC to check data before acceptance. On PANGAEA, it is now possible to access data by collections per station (44 different collections) to speed up data access and selection and improve citability of many datasets at once (*https://www.pangaea.de/?q=%40BSRNcollection*).

The presentations concluded by reporting future plans and challenges for the BSRN network, including the expansion of the network to new regions, and the importance of maintaining high-quality data and calibration.

Tim Oakley [MetOffice, on behalf of GCOS/the World Meteorological Organization (WMO)], connected remotely and gave a description of GCOS, its purposes, and updates. He discussed the structure of GCOS, its sponsors [WMO, IOC of UNESCO, United Nations Environment Programme (UNEP), International Science Council (ISC)], and its panels [the Atmospheric Observation Panel for Climate (AOPC), the Ocean Observations Physics and Climate Panel (OOPC), the Terrestrial Observation Panel for Climate (TOPC)], and highlighted the importance of reference networks, including the GCOS affiliated networks reporting to AOPC: the GCOS Upper-Air Network (GUAN), the GCOS Surface Air Network (GSN), BSRN, the GCOS Reference Upper-Air Network (GRUAN), and the GCOS Surface Reference Network (GSRN, under current implementation). He described the six thematic areas of the GCOS – Implementation Plan (2022) from a) ensuring sustainability; b) filling data gaps; c) improving data quality, availability, and utility; d) managing data (with a focus on Action D1 and certifications of data repositories, **Figure 1**), e) engaging with countries; and f) other emerging needs. He also gave the GCOS view of the tier system of network, with a focus on what a reference network should be, recognizing BSRN in the tier of reference rather than baseline network, despite its name. The next status report is expected to be released in 2027, and a section about BSRN is expected. He then presented the role of BSRN in the wider GCOS community.

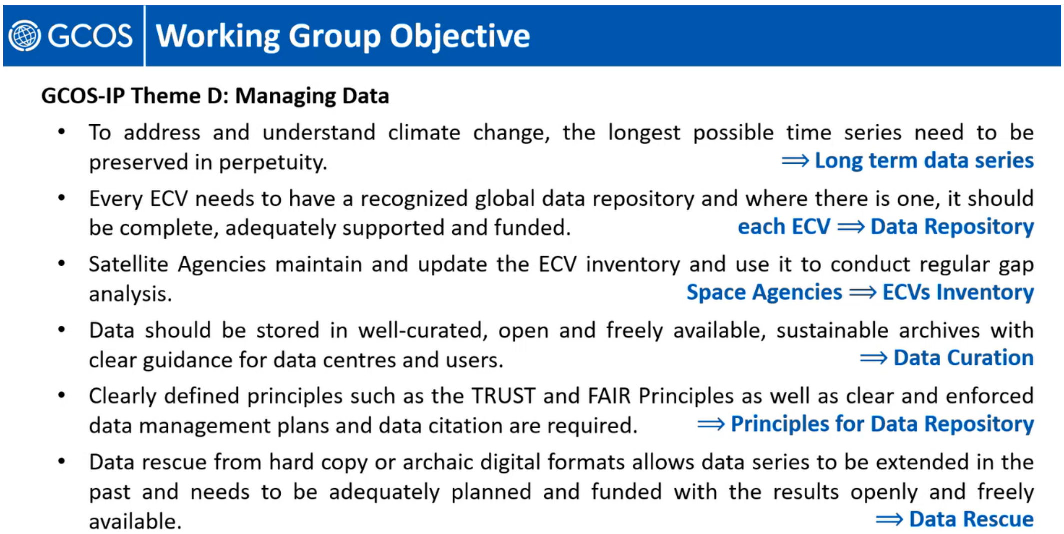

Figure 1: A Key slide from Tim Oakley presentation.

Hiro Masunaga from the GEWEX Data and Analysis Panel (GDAP) introduced GDAP and its goals, which include coordinating global scale observations of the Earth's energy and water cycles to accelerate research into guiding questions about climate change. Masunaga explained that GDAP has four panels, each focusing on different aspects of the Earth's energy and water budget studies. GDAP is the data and analysis panel, which oversees the development and assessment of global datasets to look into different aspects of the water and energy cycles (**Figure 2**). Masunaga highlighted the importance of surface networks, such as BSRN, in verifying the fidelity of satellite data products. GDAP activities include sponsoring the production and analysis of satellite datasets, reconstructing water and energy flux datasets, assessing datasets, and coordinating observations of incident and outgoing radiation. Masunaga also mentioned the importance of process-oriented studies, such as understanding cloud processes and water vapor feedback, to help interpret satellite data sets and understand the climatological state of the climate system. The discussion focused on the emphasis on climatology and the need to look at trends rather than just climatology. Masunaga acknowledged the challenge of separating internal or decadal variability from climatological averages and suggested that understanding processes underlying climatology can help interpret satellite data sets and understand the climatological state of the climate system. Overall, the presentation provided an overview of GDAP goals and activities, highlighting the importance of surface networks and process-oriented studies in understanding the Earth's energy and water cycles and accelerating research into climate change.

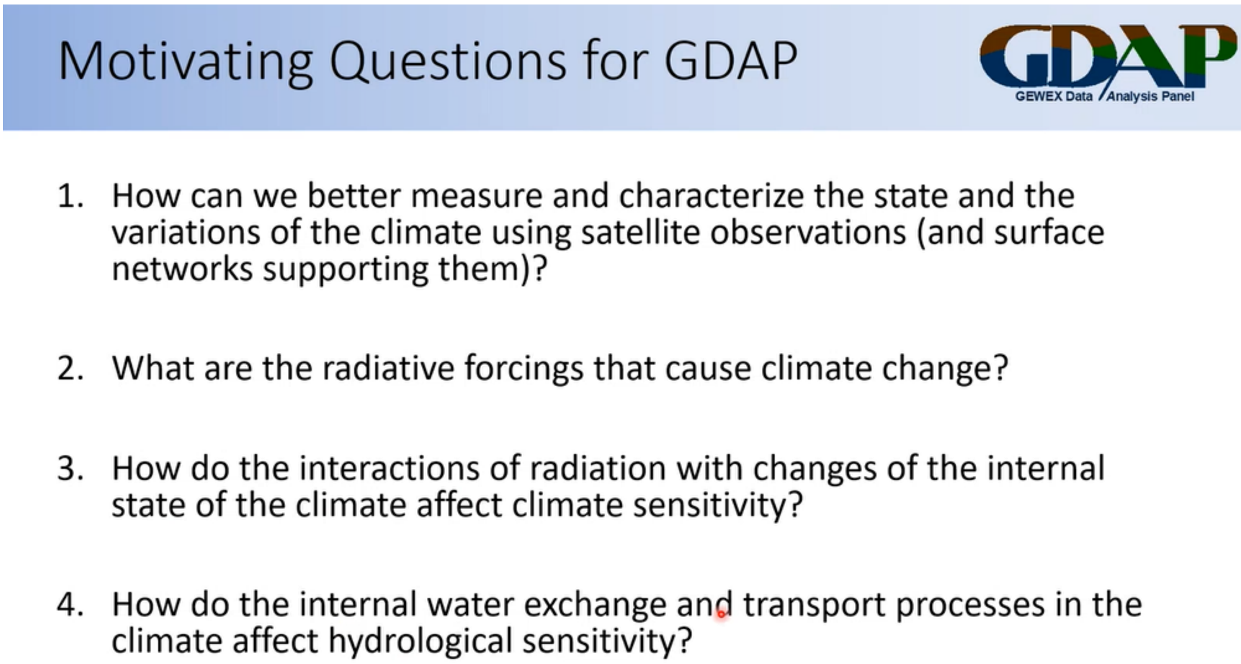

Figure 2: Main questions driving the GEWEX-GDAP mission.

2.2. Day 1 – Keynote presentations

Prof. Venkata Ramaswamy [NOAA/Geophysical Fluid Dynamics Laboratory (GFDL), USA] illustrated the importance of surface fluxes to the Earth's radiative heat balance and climate change. He discussed the energy and water cycle and highlighted the importance of accurate measurements of surface fluxes, including radiation, latent heat, and sensible heat modeling studies, particularly those related to the Earth Energy Imbalance (EEI) driving climate change since the industrial era. The EEI, lying in the order of ~1 W/m^2 and defined as the difference between the Solar constant S_0 and the sum of reflected shortwave (SW) radiation and emitted longwave (LW) radiation at Top of Atmosphere (ToA), is increasing at a rate of 0.38±0.24 W/m^2/decade over the last 20 years [Clouds and the Earth's Radiant Energy System (CERES) data], mostly attributed to aerosol content reduction in the atmosphere and the indirect effect on cloud properties. The imbalance is reduced by the combination of radiative forcing, feedback, and internal variability effects (El Nino/La Nina, etc.). **Figure 3** shows the concluding remarks given by Prof. Ramaswamy, highlighting the role of aerosol unmasking (aerosol reduction) in temperature changes, evaporation, and precipitation vigor.

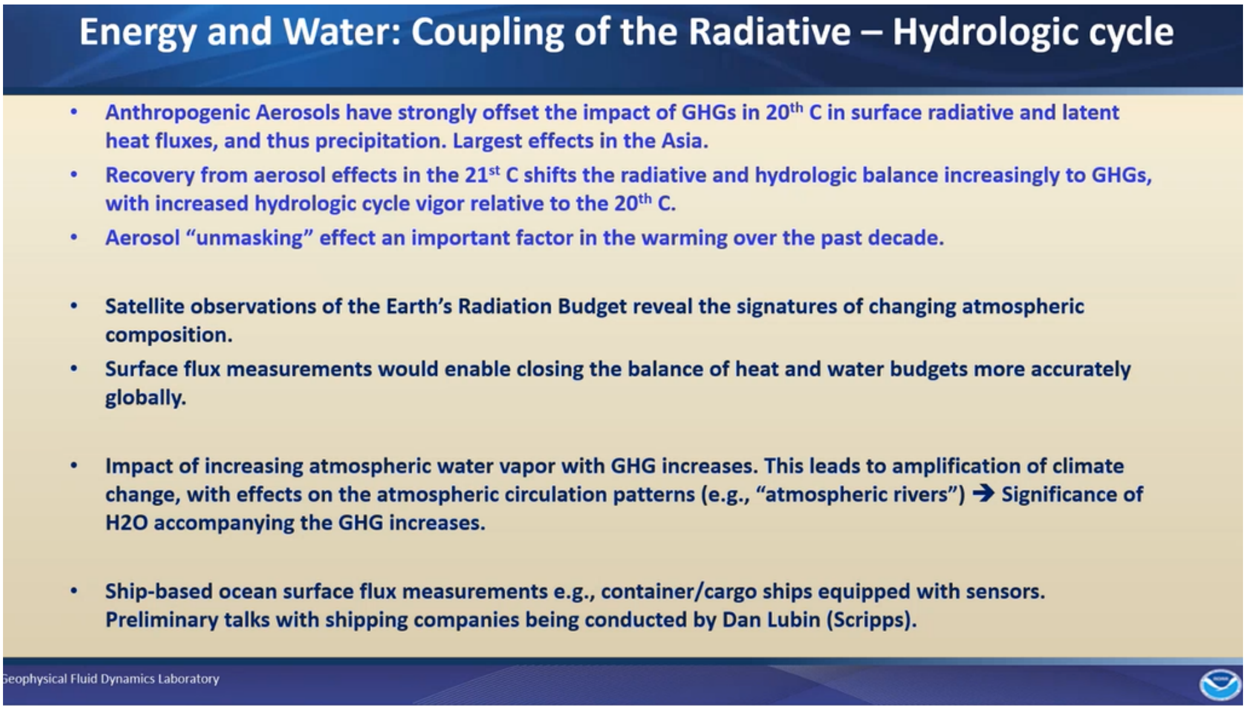

Figure 3: Concluding remarks as presented by Prof. V. Ramasvamy.

Dr. Jörg Trentmann [German Weather Service (DWD), Germany] presented the approach used by the Climate Monitoring Satellite Application Facility (CM-SAF) to assess the quality of satellite-based surface radiation data. CM-SAF provides a variety of global and regional climate data records (CDR) on clouds, radiation, surface parameters (LST), and precipitation (ocean) from 1979 to date, with different spatial (0.05° to 1°) and temporal resolutions (sub-daily – monthly) (www.cmsaf.de). He discussed the use of BSRN data as a reference for evaluating the accuracy and stability of satellite data and the preparation of the data for internal needs following recommended QC and averaging methodologies, highlighting typical user needs (**Figure 4**). He presented the bias and absolute bias between Surface Radiation Data Set - Heliosat (SARAH) - Edition 3 (SARAH-3) and CM-SAF's Cloud, Radiation, and Surface Albedo data record, AVHRR-based, Edition 3 (CLARA-A3) against BSRN, mentioned a few recent site representativeness studies, and reported on three sites showing the larger bias trends. Similar statistics were presented for the daily data with average bias of 2.2 and 1.6 on average for SARAH-3 and CLARA-A3, respectively. Concerning downwelling longwave radiation, CLARA-A3 showed a -5.8W/m^2 offset against BSRN data. In terms of surface radiation budget (SRB), he reported a general overestimation of the SW budget and underestimation of the monthly LW budget over the BSRN stations providing the complete budget, which rather compensate on total SRB.

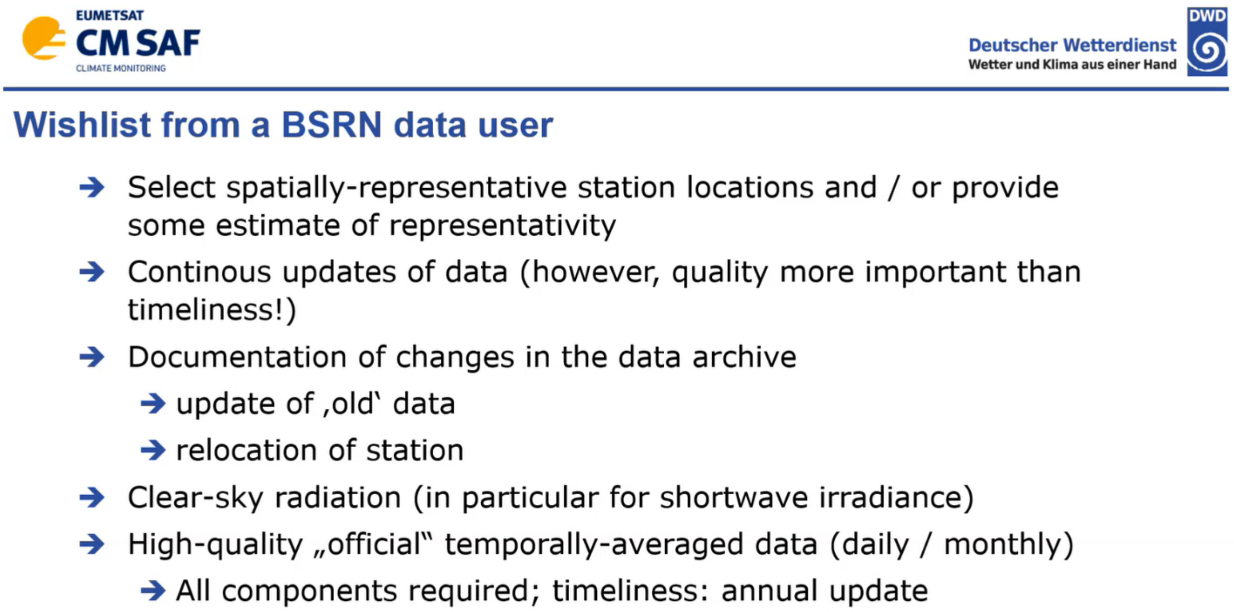

Figure 4: Wishlist of a BSRN data user as imagined by J. Trentmann.

Dr. Adam Jensen (Technical University of Denmark, Denmark) presented on the availability of solar radiation measurements outside of BSRN. He discussed the challenges of finding high-quality data and highlighted the importance of metadata and data sharing. He also presented a project (https://solarstations.org), which aims to catalog metadata for solar radiation stations around the world (**Figures 5 and 6**), and their classification in tier 1 and tier 2 depending on the quality of the equipment and the presence of a tracker. Another initiative led by Adam consisted of the development and maintenance of the Python library *Pvlib* (https://pvlib-python.readthedocs.io/en/stable/). It has very handy functions to access data from different networks, as well as modeled and remote sensing radiation data (Figure 6).

The presentation was followed by a question-and-answer session, during which the speakers addressed questions from the audience on topics such as data quality, metadata, and the interaction between BSRN and other organizations.

Overall, the presentation and discussion highlighted the importance of accurate measurements of surface fluxes, including radiation, and the need for high-quality data and metadata to support climate research and modeling. They also emphasized the importance of collaboration and data sharing between different organizations and networks.

Largest networks

Network	Country	Active stations
SRRA	India	123
ESMAP	Africa/Asia	63
BSRN	Global	59
WMO GAW and RRC	Global	18
IOS-net	East Africa	15
QEERI	Qatar	15
AEMET	Spain	14
Mexican Solarimetric Service	Mexico	13
enerMENA	North Africa	10
SOLRAD	USA	7
SURFRAD	USA	7
SRML	USA	7
CBSRN	China	7

Figure 5: List of networks handled by the solarstation.org initiative and the active number of stations. More than 50% of the data is not freely accessible.

```python
import pvlib

df, meta = pvlib.iotools.get_bsrn(
    station='CAB',
    start=pd.Timestamp(2018,6,1),
    end=pd.Timestamp(2018,7,14),
    username=bsrn_username,
    password=bsrn_password,
)
df.plot()
```

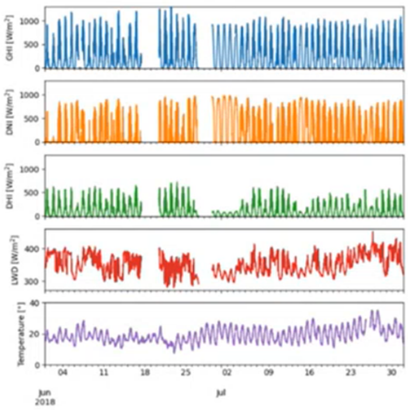

Figure 6: Using pvlib library to directly load BSRN ftp data into a pandas dataframe and plot them.

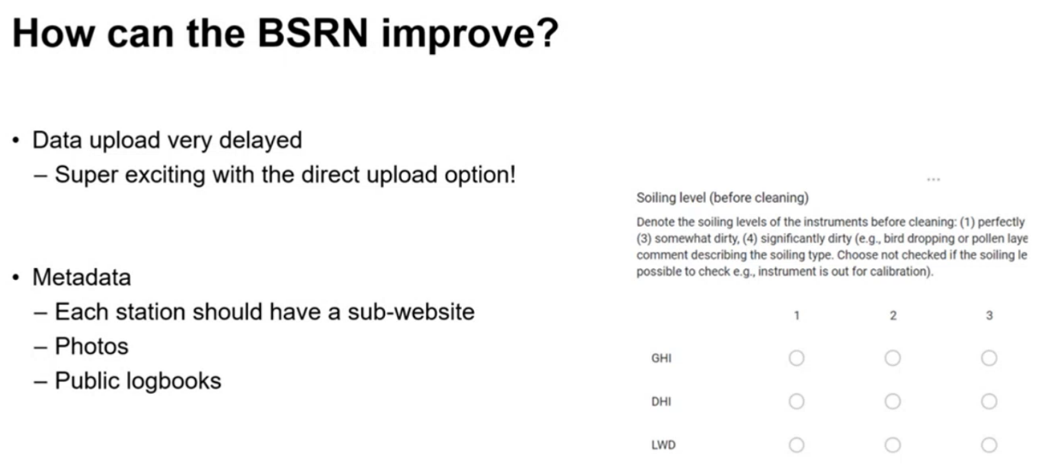

Figure 7: Adam Jensen's main suggestions towards BSRN improvements.

2.3. Day 2 – Radiation Reference and Standards

Day 2 focused on radiometric references and standards, specifically addressing time series, instrument calibrations, and specifications. The first session, chaired by Dr. **Wouter Knap** (KNMI, Netherlands), featured several presentations, but the main topics of discussion centered around the World Radiation Reference (WRR) and its limitations, as well as efforts to improve radiometric standards for both the shortwave (SW) and thermal (LW) components, and address issues related to calibration and instrument performance. The first speaker, Dr. **Laurent Vuilleumier** (Meteoswiss, Switzerland), by illustrating the mission of the Expert Team on Radiation Reference (ET-RR) established by the WMO (*https://library.wmo.int/viewer/66287*), discussed the World Standard Group (WRG) and the World Infrared Standard Group (WISG) maintained at PMOD/WRC in Davos. The first group of absolute cavity radiometer (ACP) instruments issue the World Radiometric Reference (WRR) with an uncertainty of 0.3 W/m^2. He highlighted the fact that it is not directly traceable to the International System of Units (SI). He also mentioned that the WRR is established through a consensus set of instruments maintained at the Physikalisch-Meteorologisches Observatorium Davos und Weltstrahlungszentrum (PMOD/WRC) in Davos, but that there are recognized minor issues with the accuracy of the WRR due to the diffraction effects not being correctly considered. Vuilleumier also discussed the need for a new reference instrument, citing the Cryogenic Solar Absolute Radiometer (CSAR) as an example. However, he noted that there are concerns about the availability and reliability of such an instrument.

The next speaker, **Aron Habte** [National Renewable Energy Laboratory (NREL), USA], discussed international radiometric standards, specifically those related to solar irradiance calibration, measurement, and modeling. He highlighted the work of various standardization committees, such as the International Organization for Standardization (ISO, 16 standards) and the American Society for Testing and Materials (ASTM, 6), the International Commission on Illumination (CIE, 1), and the International Electrotechnical Commission (IEC, 1), and emphasized the importance of participation from the research community in developing and updating these standards. Habte also discussed the use of standards in transferring the WRR value to field applications and the importance of uncertainty quantification in radiometric measurements. He noted that there are ongoing efforts to update and improve radiometric standards, including the development of new standards for UV irradiance estimation and reference solar spectra (**Figure 8**).

The final speaker, **Manajit Sengupta** (NREL, USA), discussed a study on the correction of biases in solar radiation measurements due to changes in reference instruments over time. He presented a method for correcting these biases using a shade/unshade calibration technique and applied it to data from the NREL Solar Radiation Lab. The results showed that the corrected data had a significantly reduced bias compared to the original data.
The discussion following the presentations centered around the limitations of the WRR, the importance of uncertainty quantification, and the need for improved radiometric standards. There were also questions about the specifics of the shade-on-shade calibration technique and the performance of different instruments.

Overall, the session highlighted the importance of accurate radiometric measurements for climate studies and the need for ongoing efforts to improve radiometric standards and address issues related to calibration and instrument performance.

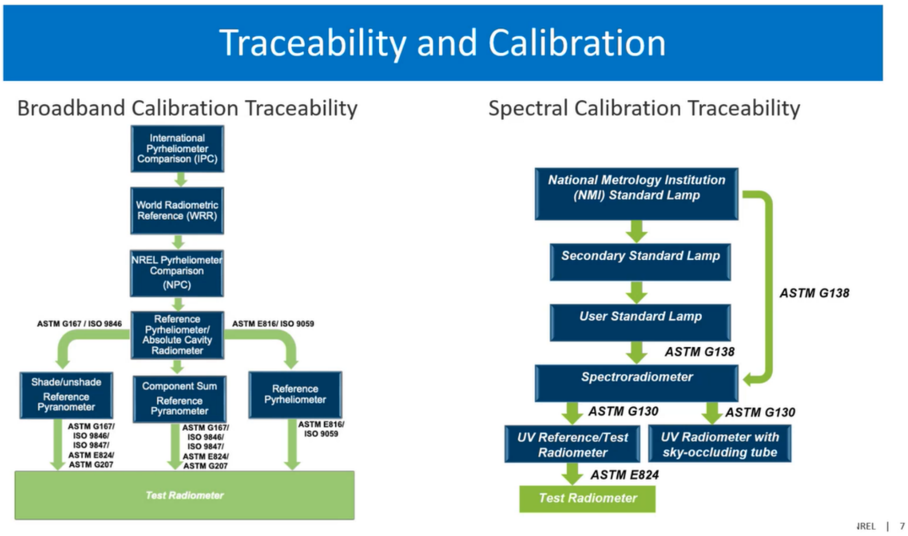

Figure 8: Illustration of the traceability chain and the relevant standards (from A. Habte presentation)

Lin Yien (Central Weather Administration of Taiwan, Taiwan) presented their approach to indoor calibration of solar radiation instruments. He advocated for indoor calibration to reduce operational workload, given the large number of solar radiation observation stations in Taiwan requiring regular calibration. He discussed the methods used for indoor calibration against a PMOD/WRC calibrated primary reference calibrated outdoor with shade/unshade methodology, including a dark room and the use of a solar simulator and a class AAA solar simulator as a light source. He also explained the evaluation of the solar simulator, including spectral match, spatial non-uniformity, and temporal instability and their effects on uncertainty evaluations and calibration consistency though En metric (ISO-13528).

The discussion then turned to the development of test methods for radiometer specifications, presented by **Aron Habte** (NREL, USA). He aimed to improve the interpretation of instrument classification according to ISO 9060, discussing the need for standardized test methods to classify radiometers and presented some examples of tests that can be used, including non-linearity tests and directional response tests. **Laurent Villeumier** (Meteoswiss, Switzerland) then presented a talk about time series of thermal infrared radiation and the importance of homogeneity. He highlighted data homogeneity issues illustrating a project about trend evolution at four stations in Switzerland. He discussed the need for homogenous integrated water vapor and temperature time series to test for homogeneity and introduced a method for doing so. **Figure 9** presents a good example of reporting about the operational setup history over time, which may support the detection of the origin of biases and performance inhomogeneity.

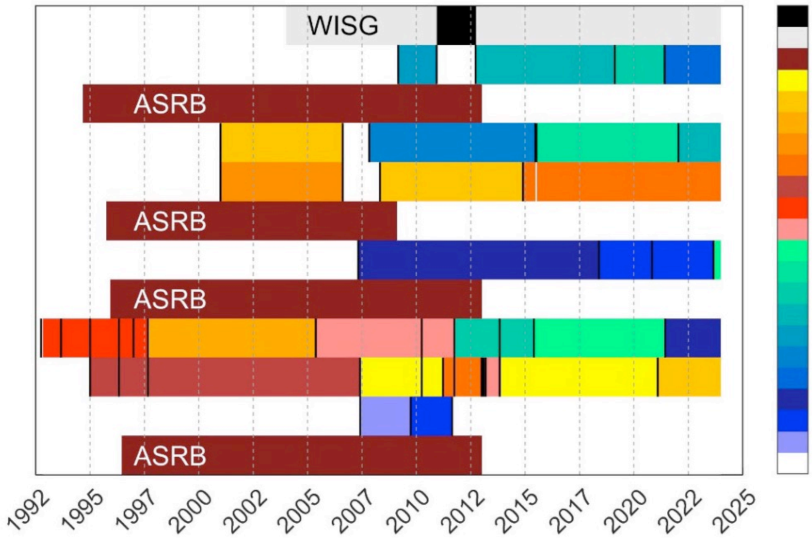

Figure 9: representation of the operational setup phases in four different sites over Switzerland as given by L. Vuilleumier.

Stefan Wacker (DWD, Germany) presented a talk about 30 years of observations of radiated fluxes at one of the very first BSRN sites, Lindenberg (LIN). He discussed the evolution of the station and the setup, including the use of multiple independent systems for the observation of downwelling fluxes. He presented some results from the measurements, including the cloud-negative effect and trends in the downwelling long-wave radiation. LIN scientists adopted operational field calibration procedures for pyrheliometers based on ISO-9059 (50-60 per year), and for pyranometers (ISO-9846 sun-and-shade methodology, 15-40 per year). Both calibrations are performed against a reference windowed cavity radiometer PMO6. Redundancy allows minimizing the gaps in data series.

The discussion then turned to the topic of references, with the BSRN Project Manager mentioning that, with the current documentation under revision, the next version of the manual should incorporate the latest developments in calibration methodology. He also mentioned that the community should adopt standards and BSRN should be clearer on recommendations for standards, including calibration. The discussion continued with various speakers commenting on the topics presented, including the need for homogeneity in time series, the importance of using standards, and the need for clear guidance on thermal offset correction.

2.4. Day 2 – Data Quality & Uncertainty session

The discussion continued in the session chaired by Dr. Laurent Vuilleumier, focusing on data quality issues in the context of BSRN. The first speaker, Dr. **Wouter Knap** (KNMI, Netherlands), presented an overview of the BSRN Data Quality Working Group's progress over the past two years. The group has been meeting monthly to discuss various topics related to data quality, including consistency tests, calibration, and uncertainty budgets. The speaker reported on the achievements of the group, e.g., new tools and systems to evaluate BSRN data quality, including a web visualization of data quality (bsrn-qc.net) and a raw data system for near-real-time monitoring, which were integrated to possibly run in cascade.

The group has also evaluated data from many stations and provided feedback to the corresponding station scientists. Frequently emerging issues were identified, including pyranometer offsets, calibration problems, and missing data. He emphasized the importance of checking data daily and using redundancy to identify problems. The discussion touched also the topic of artificial intelligence (AI) and its potential application in data quality control, recognizing that machine learning (ML) could be approached to support QC activities, and scouted for volunteers.

The discussion then turned to the topic of data quality in the context of NOAA GML stations, especially focusing on polar ones, as presented by Dr. **Laura Riihimaki** (CIRES/NOAA, USA), who highlighted the challenges of operating remote stations and the importance of upgrading instrumentation and infrastructure. It was noted that the South Pole station has been particularly challenging due to the extreme cold and the need for manual clock-driven trackers. South Pole station (SPO) data presented a diurnal cycle that could not be explained by the solar declination. The hypothesis of a correlation with the anisotropic reflectance of the snow surface was advanced. The presentation then touched on the topic of optically leveling pyranometers and the potential for an experiment at the South Pole. Dr. Riihimaki lamented the lack of studies documenting the correction of sensitivity in the range of temperatures below -20°C, which is normal for the operations in the Antarctic Plateau.

The session continued with a presentation held by Dr. **Daniela Meloni** [Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Italy] about the radiance measurements at the Lampedusa Oceanographic Observatory and the comparison with the similar measurements carried out at the BSRN new site on land (LAM). She presented the results of the comparison and discussed the advantages of having close measurements on land and sea. Lampedusa activities carried on by Meloni and her colleagues were considered fundamental to bridge the gap between the BSRN and Ocean communities, and to feed the activities of the BSRN Ocean WG led by Dr. Riihimaki.

The main subject of the next talks was the uncertainty in solar radiation measurements, with a presentation by Dr. **Aron Habte** (NREL, USA) about the development of a software package (Solar UNcertainty Integrator, SUNI) to quantify the uncertainty of solar radiation measurements. He explained the method and presented some results from the application of the software to Atmospheric Radiation Measurement (ARM) data. Their approach goes beyond the manufacturer's instrument uncertainty, or the uncertainty assigned by the calibration process, aiming instead to "acknowledge additional sources of error during field operations that cannot be accounted for prior to the measurement". It integrates the results from instrument uncertainty estimates and automated data quality assessments [Solar Energy Research Institute (SERI) NREL package] consistent with the Guide to the Expression of Uncertainty in Measurements (GUM) (additional information could be found online at the following link: *https://www.nrel.gov/docs/fy24osti/86936.pdf*).

Dr. **Ruben Urraca** [European Commission Joint Research Centre (EC JRC), Italy] explained the need for uncertainty characterization and presented the design of a GUM-based methodology for quantifying the uncertainty of solar radiation measurements. He categorized the parameters influencing radiation uncertainty as either station-dependent or time-dependent. The methodology developed was applied to BSRN stations for the entirety of 2011 (selected as the year with more data available, 49 sites) and presented in terms of En metric. The analysis showed that about 21 sites have a En<1 in more than 95% of the cases indicating that the individual uncertainty might be overestimated, 20 sites with En<1 in 80% to 95% cases, while the remaining 8 sites have a En<1 in below 80% cases that should trigger a strong alert on the underestimation of the overall uncertainty, including operational conditions. The activity is under refinement and aimed mostly to issue recommendations useful to correctly calculate operational uncertainty, BSRN-wise.

Prof. **Atsumu Ohmura** (ETHZ, Switzerland) then presented a talk about the variation of long-wave radiation and its relationship to temperature and greenhouse gases. He presented results from 22 BSRN sites and discussed the implications of the findings for climate modeling and radiative forcing. Prof. Ohmura showed some examples of the strong correlation between the temperature increase and incoming LW increase over the last 30 years over BSRN (but not only) sites. The rate of interannual change in temperature ranged between -0.02 and 0.12 K/year (since 1998), while the rate of downwelling longwave ranged between 0.0+ and 0.5 W/m^2/year. They were also very strongly (linearly) correlated, with a slope of about 3 $W/m^2/K$, and an intercept of 0.1 W/m^2. Because of the importance of the net radiation, including the upwelling components over all representative sites was further recommended.

Discussion

During the discussion about the impact of uncertainty and QC, the BSRN project manager mentioned the importance of associating uncertainty to climatological averages. The discussion also touched on the topic of cloudiness and its impact on radiation measurements, with Dr. Vito Vitale [National Research Council (CNR), Italy] suggesting the use of hyperspectral sensors and artificial intelligence to improve cloud observation. The session finished with a discussion about the following points (the initials of the individual promoting each point are in brackets): [LV] 1) Temporal aggregation effect of data gaps and inhomogeneity of data distribution. BSRN should keep interacting with modeling and remote sensing communities to adopt standards and continue to improve them; 2) Cleaning, maintenance, and calibration procedures are not well documented in BSRN, even because no clear and harmonized approaches are documented by BSRN. This is something to be improved, and that should accompany the submission of a station-to-archive file to WRMC, without possibly overloading the AWI staff maintaining it. 3) [VV] the concept of tiered networks and the possibility of having different levels of achievement in terms of data quality and uncertainty within BSRN: BSRN could consider, after 30 years of operations, updating its list of objectives to adapt the mission to current challenges and stakeholders' requests. [LV] resources are the main bottleneck. [AH] commented and supported the logbook idea, and new initiatives such as the automatic association of uncertainty could support station scientist in triggering problems; [RU] defined what information is mandatory to calculate uncertainty related to operational problems; in lack of some of them, a conservative approach should be adopted, considering that an uncertainty overestimation could occur.

2.5. Day 3 – Applications

The third day was dedicated to scientific studies based on applications. It was chaired by Laura Riihimaki (CIRES, NOAA), the BSRN deputy project manager.

John Augustine (NOAA) discussed multidecadal brightening and dimming and recent effects from greenhouse gas warming, focusing on possible causes triggering them. Over the Surface Radiation Budget (SURFRAD), +7 W/m^2/decade increased in the 1995–2010 period, then it dropped after 2011. He noticed that early studies attributed dimming from the 1950s to the 1980s to aerosols, and brightening that followed to clouds and aerosols, but no mechanism was offered. Recent studies suggest that the primary cause of long-term surface solar variability is meteorological, large-scale, and tied to sea surface temperature (SST) patterns. The Pacific Decadal Oscillation (PDO) appears to be strongly correlated with SW dimming/brightening oscillations observed globally. The mechanism proposed is related to the effect triggered by slowly changing SST patterns altering the mid-level tropospheric planetary wave structure, encouraging multidecadal brightening and dimming over adjacent continents through cloud manipulation. Increasing marine heat waves related to greenhouse gas effects is triggering brightening by reinforcing anticyclones. **Taiping Zhang** [National Aeronautics and Space Administration (NASA), USA] illustrated the use of BSRN data in validating the Prediction of Worldwide Energy Resources remote sensing product (POWER). All-sky diffuse overestimation and direct underestimation compensates on an hourly basis. A bias correction of both direct normal irradiance DNI and diffuse horizontal irradiance (DHI) based on cloud fraction, solar zenith angle (SZA), and latitude was adopted in the POWER algorithm. Monthly means are calculated from bias corrected data. global horizontal irradiance (GHI) daily passed the K-S test if GHI>30W/m^2, demonstrating that the larger uncertainties are related to low GHI values (**Figure 10**).

DNI Comparison Statistics after the Correction

Time Scale	Bias	RMS	ρ	σ	μ_{DATA}	N
DNI (Direct Normal Irradiance)						
Hourly	-1.59	186.60	0.8416	186.59	395.82	3,012,283
Daily	1.84	56.56	0.9290	56.53	179.99	273,873
Monthly	1.71	22.93	0.9719	22.87	178.11	7,260

DHI Comparison Statistics after the Correction

Time Scale	Bias	RMS	ρ	σ	μ_{DATA}	N
DHI (Diffuse Horizontal Irradiance)						
Hourly	0.01	62.99	0.8420	62.99	137.62	3,453,105
Daily	-0.07	19.49	0.9070	19.49	70.58	277,630
Monthly	0.03	9.24	0.9674	9.24	69.28	7,592

Figure 10: statistics of POWER performances against BSRN data after bias correction applied.

Wouter Knapp (KNMI) presented a talk on the applications of BSRN data for meteorological and solar energy applications. He showed results from several studies that used BSRN data to analyze the relationship between solar irradiance variability and cloud size distribution, and to evaluate large eddy simulations using BSRN data. In particular, he showed how the Covid-19 lockdown affected solar irradiance using Cabauw (CAB) BSRN data, originating from a combination of high pressure, low water vapor, and low aerosol loads. Fast responding instruments (1hz) could help understand cloud size distribution. BSRN best practice recommends storing 1hz RAW data which could be also used in future to deliver additional value-added product to the community (**Figure 11**). He also presented results from studies that used BSRN data to analyze high frequency solar energy fluctuations and to forecast day-ahead one-minute variability from numerical weather prediction (NWP) using statistical post-processing.

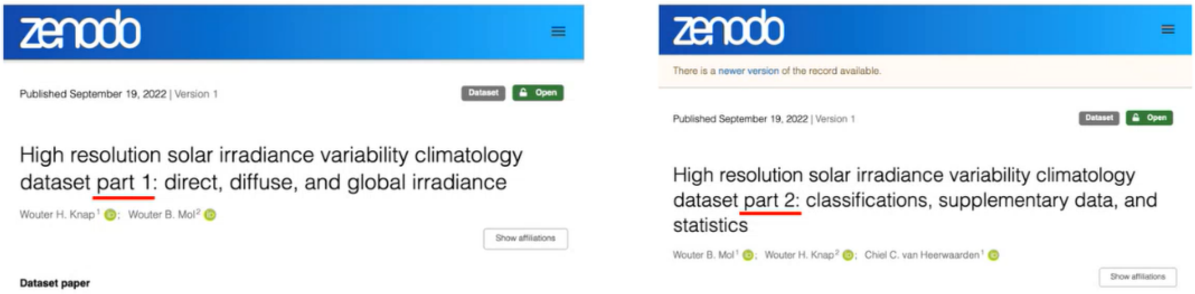

Figure 11: Data and Classification studies published on Zenodo by KNMI, on high-frequency radiation sampling and its potential in determining cloud size distribution.

The final speaker, **Christian Lanconelli** (BSRN project manager), presented a talk on the value-added product working group activities, specifically on the development of a clear-sky model using BSRN data. He showed results from a study that used the clear sky model to retrieve clear-sky coefficients A and B, and to evaluate the transmittance of the atmosphere. He also presented results from a study that used the clear-sky model to compare the cloud fraction derived from longwave and shortwave components.

The session concluded with a discussion of the applications of BSRN data and the development of value-added products using BSRN data.

2.6. Day 3 – Instruments & Methods

Here is a summary of the content of the session on instruments and methods, chaired by Gary Hodges (NOAA, USA). The first speaker, **Nozumu Ohkawara** [Mitsubishi Research Institute (MRI), Japan], gave a talk on the development of a new ground-based spectral radiometer system for spectral albedo and flux. He discussed the challenges of monitoring the cryosphere and the importance of accurate albedo measurements. He introduced the ground-based spectral radiometer system (GSAF), which uses a spectral radiometer to measure albedo and flux (global and diffuse), and presented results from a field test of the system where snow impurity and snow grain size were retrieved from the combination of three (seven in a new system) different spectral bands. The new system abandoned the rotating system (needed to rely on a single sensor for both the downwelling and upwelling components) in favor of two different sensors which instead should be intercalibrated.

The next speaker, **Carlo Wang** [National Central University (NCU), Taiwan], presented on the estimation of solar radiation using an all-sky camera and validation with BSRN data (**Figure 12**). He discussed the challenges of predicting solar radiation at different temporal scales (relying on different methodologies) and the importance of accurate cloud cover estimation. He illustrated the solar stations (29, 3 BSRN) and all-sky cameras (13) available over Taiwan. He presented a method for estimating cloud cover and GHI using an all-sky camera at very short timescales (10 minutes) and compared the results with BSRN data. The training (testing) data pertained to 2 (6) months of GHI, all-sky and aerosol optical depth (AOD) observation over three test sites. A *red-to-blue* ratio (RBR) had been used to address problems related to high haze (AOD>0.3). The model was able to maintain 93.1% of the differences between the GHI from the all-sky camera against BSRN measurements within 100 W/m^{-2}. The nowcast of GHI showed a performance of r^2 of 0.81 and *rmse* of 102 W/m^{-2}, which were even better for the smallest temporal ranges (2-8 minutes).

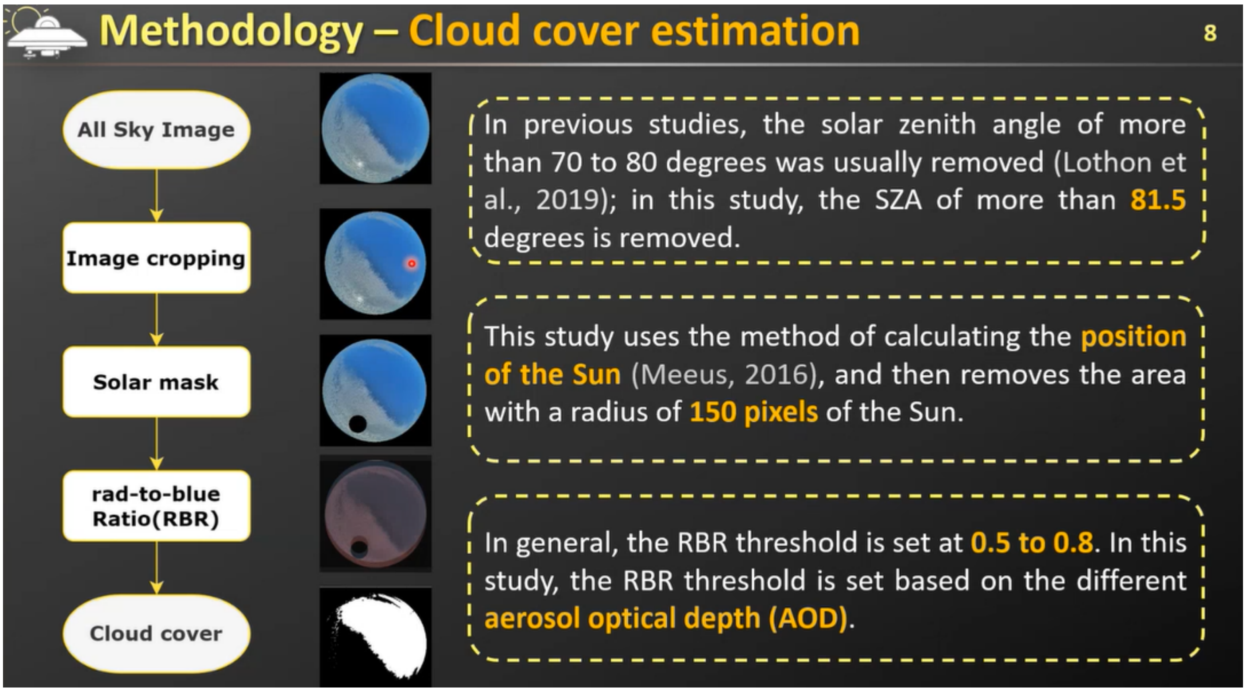

Figure 12: methodology followed to retrieve cloud cover from all-sky camera as implemented by Carlo Wang's team.

The next speaker, **Wayne Burnett** (EKO Instruments, USA), presented on solar radiation measurements with an ISO 9060:2018 class A pyranometer coupled with a rotating shadow band. He discussed the challenges of measuring DHI and DNI and introduced the MS-80SH pyranometer, which meets the requirements for class A sensors, including spectrally flat response across the whole solar spectrum, a major improvement against existing rotating shadowbands typically based on silicon sensors (hence a sensitivity confined in between 400-1000 nm). He presented results from a field test of the system and discussed the correction methods (two different approaches) used to improve the accuracy of the system. Tested against component sum GHI (and DNI), the system showed a performance of r^2 = 1.00 (0.98), *rrmse* = 2.3% (7.8%), and *rbias* = -0.61% (1.1%). As BSRN always recommends implementing instrument redundancy of the various components, systems such as the one presented by EKO could be a good option for GHI and DNI gap filling, especially because it is based on class A pyranometer.

The next speaker, **Bryan Fabbri** (NASA, USA), presented a talk on the component summation technique for measuring upwelling longwave irradiance in the presence of an obstruction. He discussed the challenges of measuring upwelling longwave irradiance and introduced a new technique that uses a combination of measurements to estimate the upwelling longwave irradiance. He presented results from a field test of the technique and discussed the advantages and limitations of the method.

The final speaker, **Ruben Urraca** (EC JRC, Italy), presented a talk on a methodology for characterizing and correcting the spatio-temporal mismatch between satellite and in situ solar radiation data. He discussed the challenges of comparing satellite and in situ data and introduced a methodology that uses an independent high-resolution measurement to calculate the mismatch between the two. He presented results from a study that applied the methodology to the downwelling-survey radiation variable and discussed the implications of the results for satellite product validation.

The session concluded with a discussion on the applications of the methodologies presented and the challenges of measuring solar radiation and albedo.

2.7. Day 3 – Visit to Tateno Aerological Observatory

The afternoon of Day 3 was devoted to a visit to the Tateno Aerological Observatory, hosting a wide range of meteorological observations and the BSRN radiation station. The observatory was established in 1920 and the first solar and infrared-radiation measurements started back in 1957. Tateno joined BSRN in 1996 with both downwelling and upwelling components (**Figure 13**). The observatory hosts several facilities such as an upper air observation field, surface weather observation field and an ozone, UV, and radiation field on the roof of the main building, and is part of GCOS networks such as GRUAN, GSN, and GAW. The calibration of BSRN instruments is performed by means of direct comparison with primary standards in the field, while for the characterization of the temperature dependence and the directional errors of the instruments a chamber is available. Similarly, pyrgeometer calibrations are maintained with outdoor comparison with an instrument traceable to the WISG, and by means of a blackbody cavity, to determine k1, k2 coefficients of the Albrech-Cox equations, and temperature sensitivity of the calibration coefficient.

Figure 13: Atsushi (JMA) illustrating the main Tateno BSRN radiometric platform (collecting LR0100).

2.8. Day 4 – Operational Stations

Shun Sasaki (JMA, Japan) illustrated the status of the BSRN stations in Japan. He discussed updates to apparatus at four domestic stations: Abashiri, Ishigakijima, Minamitorishima, and Tateno. He also presented results from a field test of the new system and discussed the advantages and limitations of the method. **Roberto Bonifaz** [National Autonomous University of Mexico (UNAM), Mexico] presented the status of the Selegua Basin Station in Mexico. He discussed the challenges of predicting solar radiation and the importance of accurate cloud cover estimation. He showed a method for estimating cloud cover using an all-sky camera and compared the results with BSRN data.

Sidi Baika (Office National de la Meteorologie, Algeria), presented the status of the Tamanrasset Station in Algeria. He discussed the challenges of measuring solar radiation in the Sahara Desert and presented results from his station. Finally, **Andre Goncalves** ([ational Institute for Space Research (INPE), Brazil] presented a talk on the status and results of the Brazilian stations, discussing the challenges of maintaining a long-term measurement program.

Short presentations illustrating the poster content related to station activities followed, with the aim of highlighting the challenges of maintaining a long-term measurement program and presenting the main results of the stations (all posters are available on the BSRN website). In this context, **Mathieu Delsaut** (Reunion University, La Reunion**)** presented a talk on the status of the relatively new BSRN station La Reunion (RUN). **Laurent Vuilleumier** (Meteoswiss) illustrated his approach on the documentation of the data processing workflow for BSRN station Payerne (PAY). **Allan Starke** [Federal University of Santa Catarina (UFSC) Brazil] presented on the Florianopolis (FLO) site. **Florian Geyer** (Geosphere, Austria) presented Sonnblick (SON) in Austria. **Kun-Wei Lin** (NCU, Taiwan) presented the Taiwanese BSRN stations Lanyu Island and Yushan (LYU, YUS). **Bryan Fabbri** (NASA, USA) presented the U.S. stations Granite Island (GIM) and Langley Research Center (LRC). **Dénes Fekete** (HungaroMet, Hungary) presented the BSRN station hosted in Budapest (BUD), Hungary.

The last part of the session was chaired by Christian Lanconelli, and it included a presentation by **Gary Hodges** (NOAA, USA) on the design of a new tower for upwelling measurements. He discussed the motivations for the new tower, including the need for a single person to safely lower and raise the tower, and the desire to increase the carrying capacity of the tower. He presented the design of the new tower and discussed the advantages and limitations of the method.

2.9. Day 4 – New station proposals

Dazhi Yang (Harbin University, China) presented a talk to promote the creation of a new BSRN site in Qiqihar Station (QIQ, China), allowing us to have the country back to the network after the decommission of previous sites. He discussed the motivation for building the station, including the lack of BSRN stations in mainland China and the opportunity to fill this gap. He presented the location of the station belonging to the dry winter (Dw) climate of continental China (47.8°N, 124.5°E), the equipment used (CM22, CHP1, CGR4, Solis2, Campbell CR3000), and the data quality issues that have been encountered. He also discussed the calibration of the instruments, planned every two years, the field check protocols such as daily cleaning and monthly leveling, and the plan for submitting data to the BSRN archive. Recording started on October 2023, the tracker was installed on a dedicated platform at a height to avoid obstructions from surrounding buildings, respecting the requirement of 5° horizon in all directions. Meteorological, precipitation, and cloud amount sensors (Vis and Nir cameras) are in place as well. QIQ already exploits the support of the **bsrn-qc.net webtool** to screen monthly data, and was able to discuss proficiently some of the problems typically affecting the radiation data such as calibration issues, thermal offset, tilting or tracker misalignments. Long term plans include developing another BSRN station in Yichun (Wuying county), to the northeast of QIQ (48.1° N, 129.2°E), chosen for the role of the surrounding forests as a carbon sink, and the related valuable studies.

Jonas Witthuhn [Leibniz Institute for Tropospheric Research (TROPOS), Germany] proposed a new station to be included in BSRN network, Mindelo Cape Verde (MIN). He illustrated the recently set-up station hosted by the Ocean Science Center (OCM), and already belonging to the Aerosols, Clouds, and Trace gases Research Infrastructure (ACTRIS) research infrastructure. ACTRIS is a pan-European research effort aimed at measuring and producing high-quality atmospheric data. The site is characterized as a hot, steamy, and arid climate, with high temperatures and humidity levels throughout the year. The site is affected by easterly winds, which bring aerosols from the Sahara Desert, and is also influenced by trade winds. The station is equipped with a range of instruments, including: broadband radiation sensors (MS-57, MS-80), spectral radiance sensors (ECOVISOR system), an all-sky imager (EKO IS-

161), pyrgeometer (CGR-4), and pyranometer (CMP-21). The station also has a poly XT Raman lidar system and a Doppler lidar cloud radar.

Concerning data quality and calibration, MIN aims to produce high-quality data, with a focus on radiation measurements by routine re-calibrations at the German calibration laboratory in Lindenberg, and an operational quality control system in place, with daily data processing and monitoring. The team was involved in several scientific campaigns, including the Ocean Radiation Campaign (ORCA) in August and September 2023, and is planning to participate in future campaigns, including the EarthCare joint ESA-JAXA Earth observation mission. Jonas remarked on the long-term nature of the commitment, with funding secured until 2043, and plans to continue operating and maintaining the station for the next 20 years.

Vito Vitale [Institute of Polar Sciences (ISP), CNR, Italy] presented an update on efforts to establish an Antarctic Radiation Regional Network (ARRN) in the frame of AntClim^{now} under the umbrella of the Scientific Committee on Antarctic Research (SCAR). He highlighted the critical need for accurate surface radiation data in this extreme environment and outlined current progress, including four BSRN active monitoring stations among other initiatives working at either yearly, seasonal, or campaign-based timescales. He emphasized the importance of coordination across initiatives, standardizing practices, and broad data sharing. Vitale introduced tools like a metadata catalogue and a documentation template to support consistency and showcased the hosting webpage and help desk for public access and support. The session concluded with a discussion on the technical challenges of polar measurements and the value of collective knowledge-sharing and open data accessibility.

2.10. Training session

Here is a summary of the content of the training session on available software endorsed by BSRN to process radiation data. The session started with **Amelie Driemel** (AWI, Germany) illustrating the BSRN toolbox, a desktop-based tool for downloading and checking BSRN data. She discussed the advantages, including the possibility to perform the analysis on multiple files, but also the limitations of the tool, including its outdated design and limited flexibility. The BSRN toolbox is the program used at WRMC to perform the initial QC, in combination with PanPlot, used to produce graphical representation of the QC outcomes. The next presentation was by **Wouter Knap** (KNMI, Netherlands), who introduced his tool, BSRN-QC, a web-based tool for quality checking BSRN data. He demonstrated the tool's capabilities, including its ability to generate plots and tables, and to identify errors and outliers. **Mathieu Delsaut** (La Reunion University, La Reunion) then presented his tool, PyBSRN QC, a Python library for quality checking BSRN data. He discussed the methodology behind the tool, which uses kernel density estimation to identify outliers, and demonstrated its capabilities.

The session then turned to a discussion of the tools, with participants asking questions and sharing their thoughts on the tools' strengths and limitations. One of the main themes of the discussion was the need for a more flexible and modern tool that can handle the complexities of BSRN data. Participants also discussed the importance of data quality and the need for tools that can help identify errors and outliers.

The discussion also touched on the idea of creating different levels of data products, similar to the satellite community's product levels L0 to L3 (radiometric measures to time aggregated geophysical products). This would allow for different types of users to access the data, including those who need near real-time data. The session concluded with a discussion of the importance of sticking to the basis of BSRN, which is to deliver high-quality data, and the need to prioritize accuracy and precision. Overall, the session provided a useful overview of the available software tools for processing radiation data and highlighted the need for continued development and improvement of these tools to meet the evolving needs of the BSRN community.

The following table shows the list of the currently endorsed tools for which an updated webpage is available at https://bsrn.awi.de/software/other-software/.

Tool name (refer to)	Link
BSRN Toolbox (BSRN)	https://bsrn.awi.de/software/bsrn-toolbox/
Pilot BSRN-QC (W. Knap)	bsrn-qc.net
Pvlib (A. Jensen)	pvlib-python.readthedocs.io
Pybsrnqc (M. Delsaut)	pypi.org/project/pybsrnqc/
SolarDataQC (Y.M. Saint Drenan)	github link
SolarData (D. Yang)	github.com/dazhiyang/SolarData
BQC (R. Urraca)	www.bqcmethod.com

3. Day 5 – Working group reports

Data Quality Working Group (Chair: W. Knap)

The group discussed the challenges of data quality and uncertainty in radiation measurements. They proposed a new format for the meeting, with a core group convening monthly and a larger group meeting every three months. They also discussed the need for a clear vision and strategy for the group, including a document outlining the steps necessary to achieve their goals. [LV] advanced the idea to touch on the quality assurance matter within this WG, with the aim of releasing guidelines on the maintenance practices. [VV] asked to clarify standard operation when deploying redundant instruments, such as the distance from multiple radiometers or also from radiometers themselves. Nevertheless, adding quality assurance to the activities handled by the WG would disperse the minimum effort that could be dedicated to this activity, focusing on clear and feasible tasks dedicated to data quality analysis. The proposal to merge data quality and uncertainty working groups was rejected for similar reasons. The discussion continued on to IT support/web hosting issues. [WK] summarized that BSRN currently has three tools, the BSRN Toolbox, the BSRN-QC tool, and the BSRN raw data system (BsrnRDS), which may be merged somehow. Presumably the best thing would be to have a centralized online tool, which has a long-term perspective (stability) and is maintained by an institute, set of people, or volunteers. [MD] could support the process to upload BSRN-QC at least on a dedicated BSRN GitHub repository, for collaborative development.

Uncertainty Working Group (Chair: L. Vuilleumier)

Three ongoing activities on the uncertainty of shortwave radiation are carried out at NREL, EC JRC and Mines-ParisTech by different groups. There is thus the opportunity of validating the outcomes of the algorithms across them, or using instrument redundancy, through metrics such as E_n-score (ISO-13528:2015), for instance.

The group also discussed the need for a questionnaire to gather information from station scientists about their procedures and instruments. Two subgroups were proposed, one for shortwave and one for longwave, to focus on specific topics. They also discussed the need for a document summarizing the uncertainty contributions, even during calibration efforts (also at PMOD/WRC) and a clear description of the uncertainty calculation. The idea of a web-based centralized logbook ("language agnostic") would be extremely useful to support data quality and uncertainty calculations. This activity should be supported by a preliminary questionnaire, to be circulated and amended by the BSRN community, before becoming operational. [AH] mentioned ARM studies/functionalities and quality assurance standards (listed in his presentation) which could inspire the progress of this task. They should also contain information on weather effects such as sea-salt deposition, rain, dust, and temperature and humidity extremes, which can affect uncertainty computations. If redundancy is mandatory by design for SW downwelling components, concerning LW, it is necessary to scout BSRN sites for the presence of pyrgeometer redundancy, in order to implement the verification step of any robust uncertainty assessment. It might be worth providing guidelines on how to use uncertainty for specific tasks.

Ocean Working Group (L. Riihimaki)

[LR] reported on the best practices for ocean radiometer measurements (Riihimaki et al., 2024)[1]. They discussed the challenges of making measurements on ocean platforms, including the need for a different set of recommendations than those for land-based stations. The group proposed developing a chapter in the BSRN manual with recommendations for the ocean community. They also discussed the need for intercomparison experiments to validate the measurements made on ocean platforms. The group noted that the ocean community is interested in being part of BSRN, but that the standards for BSRN are not currently compatible with the needs of the ocean community. [LR] noted that the general question is to address what BSRN's interaction with the ocean measurement group should be; [VV] stated that BSRN should act as a community to support other communities, providing research recommendations; [LR] said that an intercomparison campaign would be valuable; [VV] proposed inviting the ocean community to the next BSRN meeting with a session on ocean measurements.

The group discussed the gap-filling approach proposed by the former Chesapeake Lighthouse BSRN site (CLH) team to recover data affected by the tower structure on upwelling data. [LR] gave the example of CLH data (upwelling) with the comparison of measured values (with obvious errors) and calculated/derived values. [GH] argued that this is a long-time topic in BSRN (calculated values), but BSRN always came back to the original (only take measured values), and that this is also a strength of BSRN; [CL] noted that the analysis of CLH scientists is rather specific for their structure (Chesapeake Lighthouse), but the type of assessment could also support land-based measurements; however, he agreed in general that calculated values should not be included in BSRN. [VV] pointed out that different platforms have totally different characteristics (buoy, ship, tower, etc.), but it is important to have a dialogue, be connected, and try new technologies (e.g., diffuse also possible now). [BF] suggested that if BSRN does not want derived values, maybe they can at least be linked to on the website, and have them on PANGAEA. [AD] also suggested considering subfolders within the ftp CLH repository such as "Derived_upwelling" (or similar) to host derived values.

[1] LD Riihimaki et al., 2024, Ocean surface radiation measurement best practices, *Frontiers in Marine Science* 11, 1359149.

[LR] suggested considering lowering the standards to include ocean-based measurements into BSRN, as the current observation capability does not allow us to meet all the requirements currently set. She noticed a general consensus towards maintaining the current standards of land-based network. A general willingness to continue the dialogue and provide supports was noted.

Value-Added Products Working Group (C. Lanconelli)

The group reported on the progress made on value-added products, including the deployment of the Radiative Flux Analysis (RADFLUX) to calculate shortwave clear-sky fluxes. They discussed the need for a clear-sky fitting and cloud radiative effects/forcing product. The group proposed extending the analysis of clear sky products to the whole archive and making the product operational. They also discussed the need for a temporal aggregation product initiated under the umbrella of the European Commission's Copernicus program and supported by the European Centre for Medium-Range Weather Forecasts (ECMWF), and a representative index for BSRN sites after initial studies performed by EC JRC. The group noted that they need to assess the quality of the products and associate uncertainty with them.

A brief discussion on the importance of further promoting BSRN site representativeness and the strategies to be adopted to assess it was held. Drones equipped by multispectral cameras may be a solution for some sites, although at network scales starting from high-resolution data such as Sentinel-2 MSI or Landsat-8 imagery would be an asset for albedo products, while 1 km products from the Moderate Resolution Imaging Spectroradiometer (MODIS) could be used to assess representativeness in terms of cloud cover.

It was emphasised by [VV] to always keep in mind who the stakeholders and users of any deliverable product are, and to involve the community (climatology, remote sensing, etc.) in the design phase of any new value-added product.

Solar Energy Working Group (J. Badosa, A. Goncalves)

The group reported on the activities of the solar energy community, including the development of new tools to provide access to BSRN data. They discussed the need for a common initiative to make BSRN data accessible to the renewable energy community. The group proposed three key questions for the working group: i) how to facilitate the development of new tools, ii) what BSRN can provide right off the shelf, and iii) whether the renewable energy sector is willing to invest in long-term measurements or tools. They also discussed the need for a high-level discussion between the solar energy associations and BSRN.

A progress update was provided on developing new tools and data access methods (e.g., netCDF) for renewable energy (RE) applications. Participants emphasized the value of products like clear sky fluxes and cloud impact assessments for the RE sector and highlighted alignment with the Value-Added Products Working Group (WG). Collaboration between BSRN and RE organizations [e.g., the International Energy Association (IEA), International Society of Exposure Science (ISES)] was recommended to advance tools such as a quality control (QC) platform and ensure long-term measurements.

[CL] noted that these goals align with the value-added WG and synergies should be exploited. [LR] mentioned existing cloud coverage time series from NOAA. [VV] distinguished between assessing solar energy *potential* (relevant to BSRN) and *forecasting* (modeler domain), arguing that cloud impact on energy is more critical than general cloud coverage. [KL] supported engaging RE companies in acquiring instruments to sustain long-term observations.

Spectral Working Group (K. Lantz)

The Spectral Working Group provided an update on their initiative to evaluate Photosynthetically Active Radiation (PAR) instruments. They emphasized the need for a systematic approach to both field testing and laboratory calibration, with the goal of improving measurement accuracy and ensuring consistency across different instruments. A campaign is being planned to support this effort, along with the eventual publication of a final analysis report. The group is currently seeking volunteers both to participate in the field campaign and to help lead the coordination committee. [KL] underscored the importance of identifying which institutions are currently measuring PAR and what instruments they are using, suggesting that this could be done through a community-wide survey. During the discussion, [CW] and [RB] noted that while they have collected PAR data, they have yet to analyze it. [BF] from GIM/LRC mentioned that his team purchased a PAR instrument three years ago, though its current status wasn't specified. [JA] offered his expertise in data validation and analysis and volunteered to support BSRN colleagues with their PAR datasets.

Albedo Working Group (Z. Wang)

The group reported on the activities of the albedo working group, including the development of a protocol for the validation of satellite products in the frame of the Committee on Earth Observation Satellites Land Product Validation (CEOS LPV) Team[2]. They discussed the need for in situ reference data to validate satellite products and the importance of surface broadband and spectral measurements. The group proposed a strategy for the validation of satellite products, including a direct comparison and an indirect comparison using a reference satellite product. They also discussed the need for characterizing BSRN stations against their spatial representativeness, also resolved in time to represent the conditions of the different seasons, in terms of surface reflectance and albedo.

In more detail, the height of the instrument installation was emphasized as it sets the extension of the footprint. From 2 m the diameter of the scanned area is nominally around 25 m, while for an instrument at 30 m, the diameter grows up to 380 m. The footprint of remote sensing products varies from 20 m for high resolution products, such as those derived from Sentinel-2 or Landsat, to hector-metric scale 0.5-1 km [MODIS, the Visible Infrared Imaging Radiometer Suite (VIIRS), the Project for On-Board Autonomy–Vegetation (PROBA-V), the Spot-Vegetation (SPOT-VGT) mission] up to 3-6 km for geostationary platforms (Meteosat Second Generation (MSG) Spinning Enhanced Visible and InfraRed Imager (SEVIRI), Meteosat) or low Earth orbit (LEO) satellites [the Advanced Very High Resolution Radiometer (AVHRR), Polarization and Directionality of the Earth's Reflectances (POLDER), Multi-angle Imaging SpectroRadiometer (MISR)]. Direct comparison with in situ data, product inter-calibrations over Pseudo Invariant Calibration Sites (PICS), and the upscaling approach to validating low spatial resolution products were illustrated. It was pointed out how, in the frame of the CEOS LPV surface reflectance and albedo working group, BSRN is considered the gold standard for Cal/Val activities[3]. However, for the time being, only seven sites (out of potentially 30 sites, in July 2024) systematically provide fresh data to the archive, limiting the opportunity to upgrade the validation stages[4] as defined by CEOS LPV (currently at stage 2 concerning albedo and

[2] https://lpvs.gsfc.nasa.gov/SurfRad/SurfRad_home.html
[3] https://lpvs.gsfc.nasa.gov/PDF/CEOS_ALBEDO_Protocol_20190307_v1.pdf
[4] https://lpvs.gsfc.nasa.gov/index.html

BSRN), and actions should be taken to improve this limited timeliness performance. To achieve the 4th level (e.g., the maximum) of the validation stage, a Surface ALbedo VALidation Tool (SALVAL) was developed by EOLab and supported by ESA. It implements transparency and traceability of the validation process, different validation metrics, guaranteeing consistency across product versioning.

Infrared Working Group (S. Wacker)

The group reported on the activities of the infrared working group, including the development of a new reference for infrared radiation measurements. They discussed the need for a recalibration of the WISG and the importance of traceability to SI. The group proposed a new equation for the Absolute Cavity Pyrgeometer (ACP) and a determination of the convection coefficient variation with air temperature and humidity. They also discussed the need for a database to archive and process ACP data and the importance of considering the consistency between blackbody calibrated pyrgeometers and pyrgeometers calibrated with respect to the WISG. In more detail, [SW] described the ongoing efforts within the IR community to establish a new World Infrared Standard Group (WISG). The goal of Task 1 is to evaluate ACPs and Infrared Integrated Sphere Radiometer (IRIS) radiometers as potential instruments for providing traceability of longwave radiation to SI units. Key partners involved include PMOD WRC, NREL, WMO, JMA, and DWD.

The ACP is a modified net pyrgeometer where the dome is removed, and a cold concentrator is placed above the thermopile. Its throughput was characterized at the National Institute of Standards and Technology (NIST). Responsivity is determined at night during cloud-free conditions by cooling the ACP's case and observing the thermopile output voltage. Calibrations are typically conducted every two hours and are independent of outdoor irradiance and spectral distribution. Stated uncertainties are less than 4 W/m² at a 95% confidence level. On the other hand, IRIS utilizes a pyroelectric detector within a windowless, gold-plated integrated sphere. Its responsivity is determined indoors using a blackbody. Stated uncertainty is about 2 W/m². ACPs and IRIS radiometers have participated in eight intercomparisons, showing good consistency (within 2 W/m² at 95% confidence). However, seasonal variability in their differences, likely due to factors like humidity or incomplete ACP equations, has been observed. To address this, a modified ACP equation (Forgan et al., 2023)[5] has been developed. This new equation, when combined with indoor blackbody or darkroom calibrations, significantly improves consistency and provides more stable responsivity determinations compared to outdoor calibrations. Outdoor calibrations are less suitable in humid environments or when ambient temperatures differ significantly from the instrument. Despite these improvements, an offset of about 4 W/m² between the IRIS, ACP, and the current WISG suggests the WISG may be too low for certain conditions.

Efforts are also underway to improve longwave irradiance data sets for BSRN radiometer recalibration. This involves ensuring the delivery of L4000 records to the BSRN archive for traceability to WISG, as well as considering historical data calibrated against blackbodies (which can differ from WISG calibrations by up to 2%). A consistency checker has been developed, and it's crucial for stations to submit temperature data in L4000 records with two decimal places to maintain precision and avoid significant errors in calculated irradiance.

[5] Forgan, B.W., Gröbner, J. and Reda, I., 2023. New Absolute Cavity Pyrgeometer equation by application of Kirchhoff's law and adding a convection term. *Atmospheric Measurement Techniques*, 16(3), pp.727-743.

Future tasks include further characterizing ACPs (e.g., convection coefficient variation), conducting the fourth international pyrgeometer comparison, and ultimately recalibrating and redefining the WISG using ACPs and IRIS radiometers. Continued efforts to ensure proper L4000 record submission and data consistency are also paramount.

BSRN Manual review discussion (G. Hodges)

A discussion on the BSRN manual and documentation update occurred on Day 4. The idea of updating the manual was launched in 2018, during the 15th BSRN meeting. The manual updating committee has currently 11 members, and it has met sporadically during the last 6 years. The updated table of contents has been developed, and the lead of most of the sections defined, but some sections (e.g., Section 5. Instrumentation & Equipment; 7. Data Acquisition; 10. Operation & Maintenance) still need leads. Google Docs has been used for collaboration, but the committee wants to transition to a different platform, possibly Overleaf, to reduce problems related to document format, figure, and table numbering, and sharing and growth of the project itself. The committee needs leaders for unassigned sections, then membership additions or subtractions will be considered in the follow-up of the activity. A reference to existing standards, largely discussed during the current meeting, should be considered to ensure homogeneity across all stations. A complete cosine correction guidance and an update of the thermal offset correction for pyranometers should be included. Calibration frequency and procedures, preferably with firm reference to existing standards, should be addressed. They should also consider homogeneous ways to report calibration information, the environmental conditions, application of correction to the data, and uncertainties. The current manual's appendices should be reviewed and updated.

The group discussed the possibility of defining a co-chair role to help with organization and motivation. It was suggested to maintain quality assurance and data quality control in separate chapters. [JA] suggested that the introduction section should be written by the chair. All discussed the possibility of having an executive summary written by someone outside of BSRN, but aware of the importance of the manual. [GH] will follow up with the committee members to confirm their roles and progress.

4. Concluding remarks

Christian Lanconelli's concluding remarks at the BSRN meeting in Japan highlighted key discussions and future directions for the network. He expressed appreciation for the strong attendance, both in-person and online, noting the engagement of many returning and new faces. He emphasized several critical areas as follows.

Standardization and Traceability: A clear need to clarify and align BSRN's manual and procedures regarding calibration standards was identified. This includes establishing a standardized format for BSRN to record and share information about internal instrument tuning and accredited laboratory calibrations, drawing on previous suggestions from the data quality working group. Methodologies like Bruce Forgan's approach and other promising examples were discussed for clear calibration procedures.

Metadata and Station History: The importance of improving metadata and the historical knowledge of BSRN stations was stressed as an ongoing effort.

Value-Added Products and Uncertainty: the need to prioritize the development and release of value-added products to the community, focusing on what is most useful initially, was highlighted. A significant amount of work is anticipated in computing measurement uncertainties. The availability of new tools makes it feasible to meet the long-standing requirement from space agencies and the broader community to associate BSRN measurements with uncertainties. This will benefit the entire community, including weighted averaging of data.

Upwelling Measurements and New Data Streams: Discussions included the proper methodology for upwelling measurements, emphasizing the importance of installation height considering site heterogeneity. The potential for Brighton studies to be formally included in future BSRN information delivery was raised. There's also a strong interest in delivering one-hour data to the community, particularly for renewable energy studies.

Ancillary Measurements and Redundancy: [CL] encouraged more BSRN stations to host spectral irradiance measurements to benefit the satellite community. He also suggested delivering information about sky camera availability through BSRN tables for cloud forcing studies. The importance of redundancy in instrumentation, even with lower-cost options like SPN1 pyrgeometers, was emphasized to help fill data gaps. Harmonization of logbook calibration, traceability, QC, and site documentation remains crucial.

Partnerships and Support: A key point was the need for concrete support from companies and space/environmental agencies. [CL] argued that if companies use BSRN's endorsement as an advertisement for their instruments, they should offer special agreements or treatment for BSRN sites given the effort involved in maintaining them. Similarly, space agencies, which rely heavily on BSRN data for validation, should provide pragmatic support to the network, potentially through initiatives like GCOS and the GDAP Panel.

[CL] concluded by reiterating that there will never be a "final answer" or perfect solution. Instead, the approach should be to deliver available solutions to the community, even if not perfect, and continuously improve them through collaborative effort.

Finally, Christian expressed profound gratitude to the JMA staff, Amelie, and Laura for their exceptional support in organizing the workshop and the effort spent together to handle its management. He also reflected on his six years of service, acknowledging the challenges overcome and the organizational improvements made, as he prepares to transition his responsibilities.

Annex 1 – List of Participants

Last Name/Name	Institution
Andresson Epp	Envir
Aoyagi Toshinori	Japan Meteorological Agency
Augustine John	NOAA - Global Monitoring Laboratory
Badosa Jordi	Laboratoire de Météorologie Dynamique, Ecole Polytechnique
Baika Sidi	Algerian meteorological agency
Bonifaz Roberto	Servicio Solarimétrico Mexicano, Instituto de Geofísica, UNAM
Burnett Wayne	EKO Instruments USA Inc.
Carlund Thomas	Swedish Meteorological and Hydrological Institute
Carstea Emil	National Institute of Research & Development for Optoelectronics (INOE)
Choi Taejin	Korea Polar Research Institute (KOPRI)
Delport Melissa	GeoSun
Delsaut Mathieu	La Reunion University
Driemel Amelie	Alfred Wegener Institute
El Shahat Badawy Ayman	Egyptian Meteorological Authority
Fabbri Bryan	Nasa Langley Research Center
Fekete Dénes	Hungarian Meteorological Service
Frangipani Claudia	Chieti University
Garcia Cabrera Rosa Delia	Meteorological State Agency of Spain
Geyer Florian	Geosphere
Gill Michael	Met Éireann
Goncalves Andre	Instituto Nacional de Pesquisas Espaciais (INPE)
Habte Aron	National Renewable Energy Laboratory (NREL)
Hisamitsu Junji	Japan Meteorological Agency Headquarters
Hodges Gary	NOAA GML/CIRES
Hoogendijk Kees	EKO instrument
Huang Stefani	National Central University
Jensen Adam	Technical University of Denmark
Kawahara Hiroaki	EKO Instruments Co., Ltd.
Knap Wouter	KNMI
Lanconelli Christian	BSRN/GEWEX
Lantz Kathleen	NOAA Global Monitoring Laboratory, Boulder
Lin Kun-Wei	National Central University
Lin I-Jen	National Central University
Liu Bai	Harbin Institute of Technology
Lupi Angelo	Institute of Atmospheric Sciences and Climate of the Italian National Research Council, Bologna
Masunaga Hiro	Nagoya university
Maturilli Marion	Alfred Wegener Institute

Meloni Daniela	Laboratory for Measurements and Observations for Environment and Climate
Milidonis Kypros	The Cyprus Institute
Morel Beatrice	Univ. Reunion
Nagai Yasuyuki	Japan Meteorological Agency Headquarters
Oakley Tim	WMO
Ohkawara Nozomu	Meteorological Research Institute
Ohmura Atsumu	ETH Zurich
Olano Martiarena Xabier	National Renewable Energy Center CENER
Peter Van Oevelen	GEWEX
Pomeres Luis Martin	DEWA
Ramaswamy Venkata	NOAA/GFDL
Riihimaki Laura	NOAA/CIRES
Rutan David A	NOAA
Saint-Clair Manfo Lontsi	Department of National Meteorology Cameroon
Saito Kazuyuki	Japan Meteorological Agency Headquarters
Saito Atsushi	Aerological Observatory
Sasaki Shun	Japan Meteorological Agency Headquarters
Schroedter-Homscheidt Marion	DLR (German Aerospace Centre)
Sengupta Manajit	National Renewable Energy Laboratory (NREL)
Sepúlveda Araya Edgardo	Universidad de Santiago de Chile.
Shi Chenlie	Northwest University
Soldo Logan	NOAA GML/CIRES
Starke Allan Ricardo	Federal University of Santa Catarina (UFSC)
Tazvinga Henerica	South African Weather Service
Tohsing Korntip	Silpakorn University
Trentmann Jörg	Deutscher Wetterdienst (DWD)
L'Ecuyer Tristan	University of Wisconsin-Madison
Tully Matt	Bureau of Meteorology
Ulina Yesi	Badan Meteorologi Klimatologi Dan Geofisika (BMKG)
Urraca-Valle Ruben	European Commission Joint Research Centre
Vitale Vito	National Research Council, Institute of Polar Sciences
Vogt Roland	University of Basel
Vuilleumier Laurent	Federal Office of Meteorology and Climatology MeteoSwiss
Wacker Stefan	Deutscher Wetterdienst (DWD)
Wang Carlo	National Central University
Witthuhn Jonas	TROPOS
Yang Dazhi	Harbin Institute of Technology
Yonekawa Naoyuki	Japan Meteorological Agency
Zhang Taiping	AMA/NASA LaRC

Annex 2 – Agenda

Agenda of the 18th WRCP/BSRN Scientific Review and Workshop
1-5 July 2024, Tokyo, Japan

Version 2024-07-05

All times are in UTC+9: *https://time.is/Tokyo*

Monday – 1 July 2024

13:00 – 14:00 Registration

Welcome and management reports (Chair: Lanconelli)			
14:00 – 14:10	Lanconelli BSRN	Setup and BSRN Project Manager Greetings	
14:10 – 14:20	Hiraishi JMA Director Env./Ocean Division	Welcome and Opening remarks	
14:20 – 14:50	Tsuboi JMA GAW Senior Coordinator	The activities of JMA on the global atmospheric environment observations (greenhouse gases, ozone, aerosol, and radiation)	T
14:50 – 15:00	Riihimaki CIRES/NOAA	In memoriam: Frank Vignola (1945-2023†)	T
15:00 – 15:30	Lanconelli/Riihimaki BSRN Management	BSRN status, current challenges, and perspectives	T
15:30 – 15:50	Driemel AWI	BSRN/WRMC update – status, challenges, tasks	T

15:50 – 16:10 Coffee break

GCOS and keynote presentations (Chair: Augustine)			
16:10 – 16:30	Oakley GCOS/WMO	BSRN in the wider WMO GCOS community	R
16:30 – 16:55	Ramaswamy NOAA/GFDL	Earth's radiative heat balance and climate change: Importance of surface fluxes	K
16:55 – 17:20	Trentmann DWD	Using BSRN data for the evaluation of the satellite derived surface radiation climate data records from the EUMETSAT CM SAF	K, R
17:20 – 17:45	Jensen DTU	Availability of solar radiation measurements outside the BSRN	K, R
17:45 – 18:00	All	Discussion	

(Legend last column: K = keynote speech, R = remote talk, T or empty = talk, P = poster/invited to give a short summary)

Tuesday – 2 July 2024

9:00 – 9:05	Lanconelli BSRN	Intro to Day 2	
GEWEX/GDAP (Chair: Lanconelli)			
9:05 – 09:30	Masunaga GEWEX/Nagoya University	GEWEX GDAP status and BSRN engagement	T

Reference (Chair: Knap)			
9:30 – 9:50	Vuilleumier MeteoSwiss	Future changes of primary radiation references at PMOD/WRC	T
9:50 – 10:10	Habte/Sengupta NREL	Overview of International Radiometric Standards	T
10:10 – 10:30	Sengupta/Habte NREL	Towards Developing Accurate Long-term Solar Irradiance for Climate Studies	T

10:30 – 10:50 Coffee Break

10:50 – 11:10	Lin CWA	Indoor calibration of pyranometer in Taiwan	R
11:10 – 11:30	Habte NREL	Development of Test methods for Radiometer Specifications	T
11:30 – 11:50	Vuilleumier Meteoswiss	Homogeneity of Downward Thermal Infrared Radiation Series	T
11:50 – 12:10	Wacker DWD	30 years of observations of radiative fluxes at the Lindenberg BSRN site	R
12:10 – 12:30	All	Discussion on References	

12:30 – 14:00 Lunch Break

Data quality & Uncertainty (Chair: Vuilleumier)			
14:00 – 14:50	Knap KNMI	Review of BSRN data quality and report from the working group (2022-2024) and open discussion	T
14:50 – 15:10	~~Lanconelli~~ ~~BSRN~~	~~The BSRN RAW system: a tool in support of timeliness~~	T
15:10 – 15:30	Riihimaki CIRES/NOAA	Ensuring Consistency for the NOAA Remote Observatory Stations: An Update on Operations at NOAA GML Polar Stations	~~T~~

15:30 – 15:50 Coffee Break

15:50 – 16:10	Meloni/Di Sarra ENEA	Irradiance measurements at the Lampedusa Oceanographic Observatory: strengths and disturbances	R
16:10 – 16:30	Wilcox/Habte SRS, NREL	Determining the Expanded Uncertainty of Three-Component Solar Radiation Measurements	

16:30 – 16:50	Urraca EC JRC	Uncertainty budget of BSRN shortwave radiation measurements	R
16:50 – 17:10	Ohmura (*) ETH	Decadal variation of longwave downwelling surface radiation and its effect on net radiation: Based on pyrgeometer measurements at the surface.	R
17:10 – 17:40	All	Discussion (moderators Knap & Vuilleumier)	

(*) Due to time zone constrains, this presentation anticipates the session of Wednesday morning pertaining to "Applications"

Group dinner (18:30 - 20:30) – Official event, offered by JMA

Wednesday – 3 July 2024

Applications (Chair: Riihimaki)			
8:55 – 9:00	Lanconelli BSRN	Intro to day 3	
9:00 – 9:25	Augustine NOAA	A probable cause of multidecadal brightening and dimming and recent effects from greenhouse gas warming	T
9:25 – 9:50	Zhang NASA	The Use of the BSRN Data as A Benchmark for the POWER hourly DHI and DNI and In Validating Derived Hourly GTI	T
9:50 – 10:15	Knap KNMI	The use of BSRN data for meteorological and solar energy applications	T
10:15 – 10:35	Lanconelli BSRN	BSRN Temporal aggregation and Operational "Long and Ackermann" Clear-Sky parameters (current status)	T

10:35 – 10:45 Coffee Break

Instruments and methods (Chair: Hodges)			
10:45 – 11:05	Ohkawara JMA	Development of a new ground based spectral radiometer system for albedo and flux (GSAF)	T
11:05 – 11:25	Wang NCU	Estimation of solar radiation using all-sky camera and validation with BSRN data	T
11:25 – 11:45	Burnett EKO	Solar radiation measurements with an ISO9060:2018 Class A pyranometer coupled with a rotating shadow band	T
11:45 – 12:05	Fabbri NASA LRC	The Component Summation Technique for Measuring Upwelling Longwave Irradiance in the Presence of an Obstruction	T
12:05 – 12:25	Urraca EC JRC	Characterizing and correcting the spatiotemporal mismatch between in-situ and satellite solar radiation measurements.	R

12:30 – 21:00 Lunch and Excursion to Tateno, Dinner on the way back

Thursday – 4 July 2024

Station status, review of the pending sites and NEW SITES

8:55 – 9:00	Lanconelli	Intro day 4	

Operational stations (Chair: Driemel/Riihimaki)

9:00 – 9:20	Sasaki JMA Radiation Staff	Status of BSRN stations in Japan (ABS, FUA, ISH, TAT)	T
9:20 – 9:40	Bonifaz UNAM	Status of the “SELEGUA” BSRN Station in Chiapas, México (SEL)	T
9:40 – 10:00	Goncalves INPE	Update on PTR, BRB and SMS stations operated by INPE in Brazil (PTR, BRB, SMS)	T
10:00 – 10:20	Baika National Meteorological Office of Algeria	Results of measurements at GAW station Tamanrasset/Assekrem (TAM)	T
10:20 – 10:40 (*)	Morel/Delsaut Reunion Univ.	Status and operations of Reunion Island (RUN) BSRN station (RUN)	P
	Vuilleumier MeteoSwiss	Status of the Payerne BSRN station (2024) (PAY)	P
	Starke UFSC	Status of the BSRN station # 3, located in Florianopolis (Brazil) (FLO)	P
	Geyer Geosphere	Status update of BSRN station Sonnblick (SON)	P

– (*) Submitted as a poster presentation, required to give a short introduction to the poster. Approx. 5 min.

10:40 – 11:00 Coffee Break

11:00 – 11:20 (*)	Lin CWA, NCU	Status and Operations of the BSRN Stations (Yushan and Lanyu) in Taiwan (YUS and LAN)	P
	Fabbri NASA LRC	Status and Operations at the Granite Island, Michigan (GIM) BSRN Station, Status and Operations at the Langley Research Center (LRC) BSRN Station	P
	Fekete HungaroMet	Status of BSRN station Budapest-Lorinc - past, present and future (BUD)	P

– (*) Submitted as a poster presentation, required to give a short introduction to the poster. Approx. 5 min.

New Stations (1) (Chair: Lanconelli)			
11:20 – 11:45 11:45 – 12:00 (discussion)	Yang Harbin Univ.	Shortwave radiometric measurements under a cold climate during winter (QIQ)	T

Regional networks			
12:00 – 12:25	Vitale ISP CNR	Improve Radiation measurements in Antarctica: the Antarctic Radiation Regional Network (ARRN) Initiative	T

12:25 – 14:00 Lunch Break

Training session *rec*				
14:00 – 14:25	Driemel AWI	*BSRN_Toolbox*	The official BSRN tool to produce quality flags	T
14:25 – 14:50	Knap KNMI	bsrn-qc.net	A pilot effort developed by Wouter to produce quality check plots and flags, table report and temporal trends	T

14:50 – 15:15	Delsaut Reunion Univ	Pybsrnqc	A library for BSRN Quality Control (QC) https://pypi.org/project/pybsrnqc/	T
15:15 – 15:40	ALL	Discussion on QC tools	Discussion about the need for BSRN official QC tool updates/other QC initiatives/station-to-archive formatters/ collecting feedback	

15:40 – 16:00 Coffee Break

General Discussions *rec*			
16:00 – 17:00	Hodges NOAA	BSRN Manual Review committee report and discussion	T
	Driemel AWI	Next Meeting venue: Collecting expression of interests	
	ALL	Any Other Business	

(*) Please note that the former session scheduled in this timeslot, dedicated to pending stations review, was withdrawn.
A short recap will be given by Lanconelli/Driemel on Day 1.

New Stations (2) (Chair: Lanconelli)			
17:00 – 17:25 17:25 – 17:40 (discussion)	Witthuhn TROPOS	Mindelo (Cape Verde) - TROPOS ACTRIS Radiation Observatory (TARO)	R

Friday, 5 July 2024

Working group discussion and wrap-up (Chair: Riihimaki/Lanconelli)			
09.00 (40min)	Wouter Knap	Data Quality	
09:40 (40min)	Laurent Vuilleumier	Uncertainties	T
10:20 (20 min)	Laura Riihimaki/ Vito Vitale	Ocean	T
10:40 – 11:00		Coffee Break	
11:00 (20min)	Christian Lanconelli	Value Added Products	T
11:20 (20 min)	Andre Goncalves/ Jordi Badosa	Use of BSRN in SRE	T
11:40 (20 min)	Kathy Lantz	Spectral/UV	T
12:00 (20 min)	Zhuosen Wang	Albedo/Satellite	R
12:20 (20 min)	Stefan Wacker	Infrared	R

Remarks: Working group chairs are free to organize online meetings before the BSRN workshop, or during the week at alternative/informal venues, to summarize their achievements. The first part of the morning is meant for any in-person breakout session for those WG with enough local attendees. The second part of the morning is dedicated to the WGs' reports. Grey cells refer to remote participation of the chair.

12:00 – 13:00 Concluding Remarks and Adjourn

Poster session (whole week) [A0 – portrait – max size 800x1550 mm]

Lupi CNR	Ship cruises as an opportunity to obtain surface radiation flux measurements in a marine polar environment
Kawahara EKO	Novel concept for Solar Duration measurements
Hodges NOAA	New SURFRAD 10 m Tower
El Shahat Badawy Egyptian Meteo Authority	Impact of the dust and sandstorm on the Global Surface Radiation over Egypt (*to be confirmed*)
Morel (RUN) Reunion Univ.	Status and operations of Reunion Island (RUN) BSRN station
Vuilleumier (PAY) MeteoSwiss	Status of the Payerne BSRN station (2024)
Starke (FLO) UFSC	Status of the BSRN station # 3 (FLO), located in Florianopolis (Brazil)
Lin (YUS and LAN) CWA, NCU	Status and Operations of the BSRN Stations (Yushan and Lanyu) in Taiwan
Fabbri (GIM, LRC) NASA LRC	Status and Operations at the Granite Island, Michigan (GIM) BSRN Station, Status and Operations at the Langley Research Center (LRC) BSRN Station
Fekete (BUD) Hungarian Meteo Service	Solar radiation measurements at Budapest-Lorinc station - past, present and future
Cabrera (IZA) Meteorological State Agency of Spain	Status of the Izaña BSRN station (IZA)
Geyer (SON) Geosphere	Status update of BSRN station Sonnblick (SON)

(*) The authors of the poster illustrating BSRN station status are invited to summarize their achievement in Thursday morning session from 10:20 to 11:20 (~5 min presentation).

Participants at the 18th BSRN Scientific Review and Workshop hybrid meeting

Annex 3 – Listing of Posters

BSRN Site Posters

1) BSRN station PAL at SIRTA Observatory, Paris Region: Status and news (Jordi Badosa)
   - BSRN station of Carpentras (France): Status and news (Stephane Mevel)
2) Status of the Payerne BSRN station (2018) (Laurent Vuilleumier)
3) Status of Tartu-Tõravere (TOR) BSRN station (Kai Rosin)
   - The Dome-C Antarctic BSRN station (Angelo Lupi)
   - Status of De Aar BSRN and Solar Radiometic Activities at South African Weather Services (Saws) (Brighton Mabasa)
4) Status of the active BSRN sites in Brazil (Enio Pereira)
5) Status of Japanese BSRN stations (Nozomu Ohkawara)
   - Radiation measurement at Leodo & Socheongcho Ocean Research Station in South Korea (Jeongpil Jang)
   - Radiation measurement on South Korea: In focus on observation environment and quality control (Il-Sung Zo)
   - Status of the Arctic BSRN site Ny-Ålesund (Marion Maturilli)
   - U.S. SURFRAD BSRN station update (Gary Hodges)
   - ARM BSRN station update (Gary Hodges)
6) Status of the Lindenberg BSRN station (Stefan Wacker)
   - Status of four Indian BSRN stations (Karthik Ramanathan)
7) Status update of BSRN station Sonnblick (SON)-(Jul 2018) (Elke Ludewig)
8) Status of the NASA Langley Research Center (LRC) BSRN station (Fred Denn)
   - Status of the Izana BSRN station in July 2018 (Rosa Garcia Cabrera)

Proposed Site Posters

1) New proposed BSRN stations in the Western Pacific region: Mt. Jude and Orchid Island (Carlo Wang)
2) Solar radiation measurements at Budapest-Lőrinc station (Dénes Fekete)
3) Status and plans for BSRN stations in the northern CAA and Greenland (Chris Cox)
4) Granite Island in Lake Superior, a new BSRN water site proposal (Bryan Fabbri)
   - Assessing surface solar radiation variability and trends in the South-West Indian Ocean from BSRN-like measurements over Reunion Island: Proposal for a new site (Béatrice Morel)
   - Toward the implementation of a new Candidate BSRN station in the Ross Sea Area, Antarctica (Mauro Mazzola)
5) Preliminary results of the first six months operation of the Selegua Station in Southern Mexico (Roberto Bonifaz)
6) A proposed new BSRN site near Dubai, UAE (Ansgar Delahaye)

Science Posters

   - Validation of CM SAF satellite-derived surface radiation data records using BSRN measurements (Stefan Wacker for Jörg Trentmann)
   - Use of BSRN data to assess changes in the shortwave surface flux simulation for three generations of the GFDL Coupled Climate Model (Stuart Freidenreich)
1) Distributed radiation measurements at MOSAiC (Matt Shupe)
   - Intercomparison of seven solar radiometers on a tilted plane for photovoltaic applications: Preliminary results (Jordi Badosa)
   - Data analyses of 1.5 years field testing of the Razon+ DNI & diffuse system (Joop Mes)

2) Direct spectral irradiance measurements from rotating shadowband EKO grating spectroradiometer (Will Beuttell)
   - Comparison of observed and modeled cloud-free longwave downward radiation (2010-2016) at the high mountain BSRN Izaña station (Rosa Garcia Cabrera)
   - Partitioning of solar energy in the climate system (Matthias Schwarz)

Annex 4 – Acronyms

ACP	absolute cavity pyrgeometer
ACTRIS	Aerosols, Clouds, and Trace gases Research Infrastructure
AI	artificial intelligence
AOD	aerosol optical depth
AOPC	Atmospheric Observation Panel for Climate
ARRN	Antarctic Radiation Regional Network
ASTM	American Society for Testing and Materials
AWI	Alfred Wegener Institute of Polar and Marine Research
BSRN	Baseline Surface Radiation Network
BsrnRDS	BSRN raw data system
BUD	Budapest BSRN site
CAB	Cabauw BSRN site
CDR	climate data records
CEOS LPV	Committee on Earth Observation Satellites Land Product Validation
CERES	Clouds and the Earth's Radiant Energy System
CIE	International Commission on Illumination
CIRES	Cooperative Institute for Research in Environmental Sciences
CLH	Chesapeake Lighthouse BSRN site
CM-SAF	Climate Monitoring Satellite Application Facility
CNR	National Research Council (Italy)
CSAR	Cryogenic Solar Absolute Radiometer
DHI	diffuse horizontal irradiance
DNI	direct normal irradiance
Dw	dry winter climate
DWD	German Weather Service
EC JRC	European Commission Joint Research Centre
ECMWF	European Centre for Medium-Range Weather Forecasts
ECV	essential climate variables
EEI	Earth energy imbalance
ENEA	National Agency for New Technologies, Energy and Sustainable Economic Development (Italy)
FTP	file transfer protocol
ET-RR	Expert Team on Radiation Reference
FLO	Florianopolis BSRN site
GAW	Global Atmospheric Watch
GCOS	Global Climate Observing System
GDAP	GEWEX Data and Analysis Panel
GEWEX	Global Energy and Water Exchanges project
GHI	global horizontal irradiance
GIM	Granite Island BSRN site
GML	Global Monitoring Laboratory (NOAA, USA)

GRUAN	GCOS Reference Upper-Air Network
GSAF	ground-based spectral radiometer system
GSN	GCOS Surface Air Network
GSRN	GCOS Surface Reference Network
GUAN	GCOS Upper-Air Network
GUM	Guide to the Expression of Uncertainty in Measurements
IEA	International Energy Association
IEC	International Electrotechnical Commission
INPE	National Institute for Space Research (Brazil)
IOC	Intergovernmental Oceanographic Commission
IRIS	Infrared Integrated Sphere Radiometer
ISC	International Science Council
ISES	International Society of Exposure Science
ISO	International Organization for Standardization
ISP	Institute of Polar Sciences
JMA	Japan Meteorological Agency
KNMI	Royal Netherlands Meteorological Institute
LAM	Lampedusa BSRN site
LEO	low Earth orbit
LIN	Lindenberg BSRN site
LRC	Langley Research Center BSRN site
LST	land surface temperature
LW	longwave radiation
LYU	Lanyu Island BSRN site
MISR	Multi-angle Imaging SpectroRadiometer
ML	machine learning
MODIS	Moderate Resolution Imaging Spectroradiometer
MRI	Mitsubishi Research Institute
MSG	Meteosat Second Generation
NASA	National Aeronautics and Space Administration (USA)
NCU	National Central University (Taiwan)
NDACC	Network for the Detection of Atmospheric Composition Change
NIST	National Institute of Standards and Technology (USA)
NOAA	National Oceanic and Atmospheric Administration (USA)
NREL	National Renewable Energy Laboratory (USA)
NWP	numerical weather prediction
OBPS	Ocean Best Practices System
OCM	Ocean Science Center measurement station
OOPC	Ocean Observations Physics and Climate Panel
ORCA	Ocean Radiation Campaign
PAR	photosynthetically active radiation
PAY	Payerne BSRN site
PDO	Pacific Decadal Oscillation

PICS	pseudo-invariant calibration site
PMOD/WRC	Physikalisch-Meteorologisches Observatorium Davos und Weltstrahlungszentrum
POLDER	Polarization and Directionality of the Earth's Reflectances
POWER	Prediction of Worldwide Energy Resources remote sensing product
PROBA-V	Project for On-Board Autonomy–Vegetation
QC	quality check
QIQ	Qiqihar BSRN site
RADFLUX	Radiative Flux Analysis
RBR	red-to-blue ratio
SALVAL	Surface ALbedo VALidation Tool
SCAR	Scientific Committee on Antarctic Research
SERI	Solar Energy Research Institute
SEVIRI	Spinning Enhanced Visible and InfraRed Imager
SFTP	Secure File Transfer Protocol
SI	International System of Units
SON	Sonnblick BSRN site
SPO	South Pole BSRN site
SPOT-VGT	Spot-Vegetation satellite mission
SRB	surface radiation budget
SST	sea surface temperature
SURFRAD	Surface Radiation Budget Network
SW	shortwave radiation
SZA	solar zenith angle
ToA	Top of Atmosphere
TOPC	Terrestrial Observation Panel for Climate
TROPOS	Leibniz Institute for Tropospheric Research
UFSC	Federal University of Santa Catarina
UNAM	National Autonomous University of Mexico
UNEP	United Nations Environment Programme
VIIRS	Visible Infrared Imaging Radiometer Suite
WISG	World Infrared Standard Group
WG	working group
WMO	World Meteorological Organization
WRG	World Standard Group
WRMC	World Radiation Monitoring Center
WRR	World Radiation Reference
YUS	Yushan BSRN site

Annex 5 – Abstracts (authors in alphabetical order)

A probable cause of multidecadal brightening and dimming and recent effects from greenhouse gas warming

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Observed multidecadal brightening and dimming trends of surface solar radiation over Northern Hemisphere (N H) continents since the 1950s have been similar and approximately in phase. Over a decade ago, reports in the literature noted a close association between multidecadal sea-surface temperature (SST) variability and continental brightening and dimming, but no physical explanation was offered. The large spatial and temporal scales of these trends imply that the primary forcing is meteorological and large scale in nature. Although, aerosols dominate surface solar radiation in some regions such as India, West Africa, and industrial parts of China. Our recent studies have shown how slowly shifting large areas of warm and cool SSTs over the North Atlantic and North Pacific, manifested by the Atlantic Multidecadal Oscillation (AMO) and Pacific Decadal Oscillation (PDO), slowly alter the mean upper-air circulation (Figure 1) to cause multidecadal brightening and dimming over adjacent continents. For example, the reversal of the PDO in the mid-1980s coincides with circulation changes at 500 hPa that support the change from dimming to brightening over North America. A recent study at ETH in Zurich used CMIP6 models to confirm the association between slowly changing SST patterns and dimming and brightening over the adjacent continents globally. These, and former model-based studies show no link between brightening/dimming and atmospheric greenhouse gas (GHG) warming. Ocean heating has been especially strong since about 1990 and is presumed to be caused by GHG warming because 90% of GHG-induced excess heat has gone into the oceans. Consequently, marine heat waves have increased both in intensity and number since 1990, and their selective positioning appear to have influenced recently observed surface radiation trends over the U.S. and Europe.

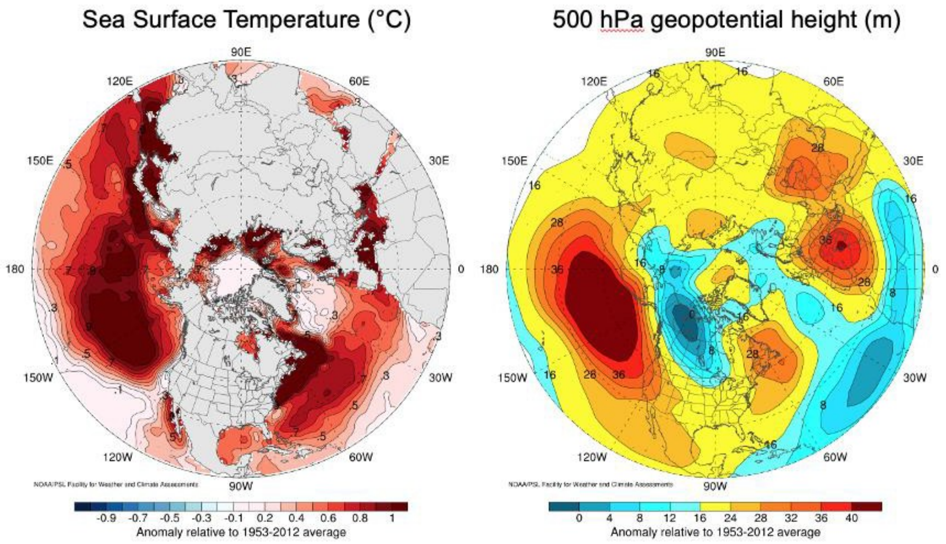

Figure 1: Sea surface temperature anomalies (left) and corresponding 500 hPa anomalies (right) for 2020-2022 relative to the base period of 1953-2012, which covers well documented dimming and brightening periods over the Northern Hemisphere.

Impact of the dust and sand storm on the Global Surface Radiation over Egypt

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Dust and sand storms can have significant impacts on global surface radiation, affecting both incoming solar radiations. Studying the monthly and seasonal variation of sand and dust storm and (GSR) over Egypt stations using observed, satellite, ERA5 data is figured. A descriptive study of frequency occurrence and its impact on (GSR) was shown. Anomaly and the percentage variation of (GSR) has been detected. The relation between GSR and aerosol optical depth has been detected using pm10, AERONET data.

It was found that Dust and sand storms can block incoming solar radiation from reaching the Earth's surface. The presence of dust particles in the atmosphere scatters sunlight, reducing the amount of solar radiation that reaches the surface.

It was found that dust storms can reduce the daily Global Surface Radiation by 60% compared to the same monthly mean depending on factors such as the intensity and duration of the storm, as well as local geographical and meteorological conditions. In regions prone to frequent dust and sand storms, such as deserts and arid areas, the effects on surface radiation can be more pronounced.

Results of measurements at GAW station Tamanrasset/Assekrem

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Algerian Meteorological Agency, Algeria

The phenomenon of climate change appeared at the end of the 80s and beginning of the 90s following the results of scientists who showed that the chemical composition of the atmosphere is changing very significantly. This observation was established on the basis of observations and measurements carried out in certain stations such as those located in the Hawaiian Islands (USA) and in Antarctica.

These measurements have shown that the concentration of certain greenhouse gases (GHG) is increasing significantly, such as carbon dioxide (CO_2) and methane (CH_4).

Following this observation, the World Meteorological Organization (WMO) established a global network of meteorological observations in the early 1990s to monitor all the gases constituting the Earth's atmosphere. This network is made up of around 20 stations spread across the planet, including the Hoggar station in Assekrem, and located in places far from any source of urban pollution in order to detect any change having an influence on the climate.

The two sites of GAW program are selected in 1992 by experts from WMO, this region is situated so far from any anthropogenic activities and at a high altitude. The remote site of Assekrem is located at the summit of mountain of Hoggar at about 50 km north of the city of Tamanrasset. The region of Hoggar is a desertic region, the mean rainfall at Tamanrasset is 45 mm and 120 mm at Assekrem. Geographical positions: Tamanrasset: 22°47'N, 05°31'East, 1377 masl, Assekrem: 23°16'N, 05°38'East, 2710m.

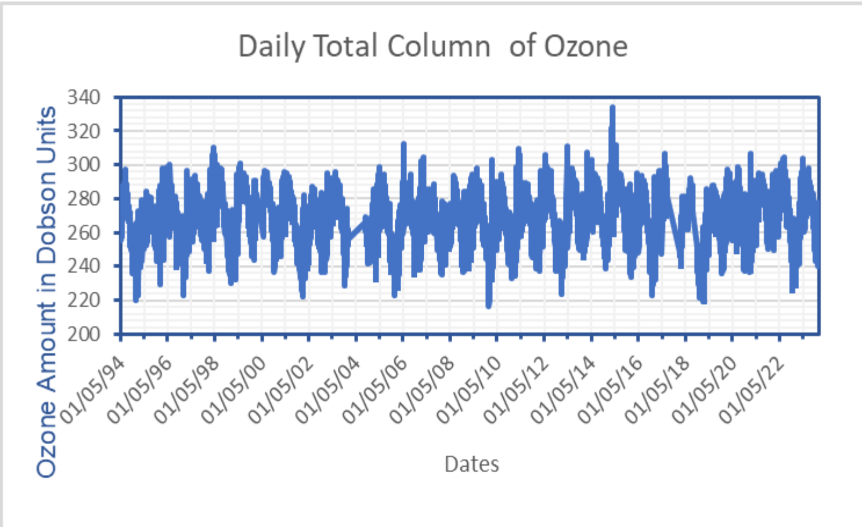
OBSERVATIONAL ACTIVITIES:
The program of measures for these 02 sites is:

Tamanrasset	Assekrem
• Turbidity • Total ozone Radiation: • direct, global, diffuse, Rg8, atmospheric infrared • Aerosol Optical Depth (AOD) • Meteorology	• Surface ozone • Monoxide carbone Sampling • gas: CO_2, CH_4, CO, H_2, N_2O, SF_6 • Meteorology

Activities at Tamanrasset

Turbidity: is measured since January 1995 with sun photometer 03 times /days. At wave 500 nm. The values of turbidity are very high in summer period with haze, in winter period the values are very low.

Total ozone: is measured 03 times/day with spectrophotometer Dobson N°11 since April 1994, this instrument was calibrated 02 times in a regional campaign in Africa: in 2000 at Pretoria (South Africa), 2004 at Dahab (Egypt) and In 2017 at El Arenosilo (Spain). The values of total ozone measured are very stable since 1994 with seasonal variations, maximum in summer and minimum in winter between 280 DU and 250 DU.



Solar and Atmospheric Radiation: the solar radiation is performed since September 1994 with the measure of parameters: direct, global, diffuse and RG8, with eppley instruments each 01 minute. The atmospheric radiation is measured since mars 2000 with infrared radiometer. The instruments are calibrated in situ with the reference AHF.

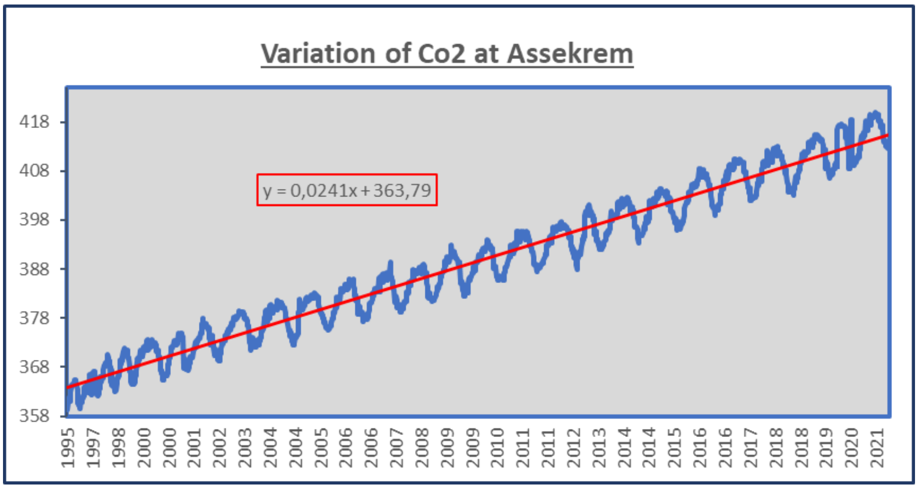
Aerosol Optical Depth (AOD): the instrument of measure is photometer Cimel, installed in October 2006 with the institute of Spanish meteorology for the AERONET project.

Activities at Assekrem

Surface ozone: is measured since mars 1997 with Teco49 C in collaboration avec the laboratory EMPA(SWISS). The calibration of the instrument was made in situ by the EMPA In February 2003 and May 2007 and the others year in Switzerland. The values of surface ozone vary from 30 to 60 ppb.

Monoxide carbone: this measure was installed in October 2006 with the collaboration of EMPA. The instrument of measure is Horiba, it is a continued measured each 01 minute.

Sampling Gas: the sampling is made each 01 week with the collaboration of group Carbon Cycle Greenhouse Gases (CCGG) of NOAA/ESRL. Samples are analysed in Boulder (USA) to determine CO2, CH4, CO, H2, N2O SF6. This sampling has been made since September 1995. The results of analyse show an increase of all GHG particularly for CO2, since 1995, the CO2 at Assekrem increase from 358 ppm to 418 ppm in 2021, with a rate of 2 ppm/year.



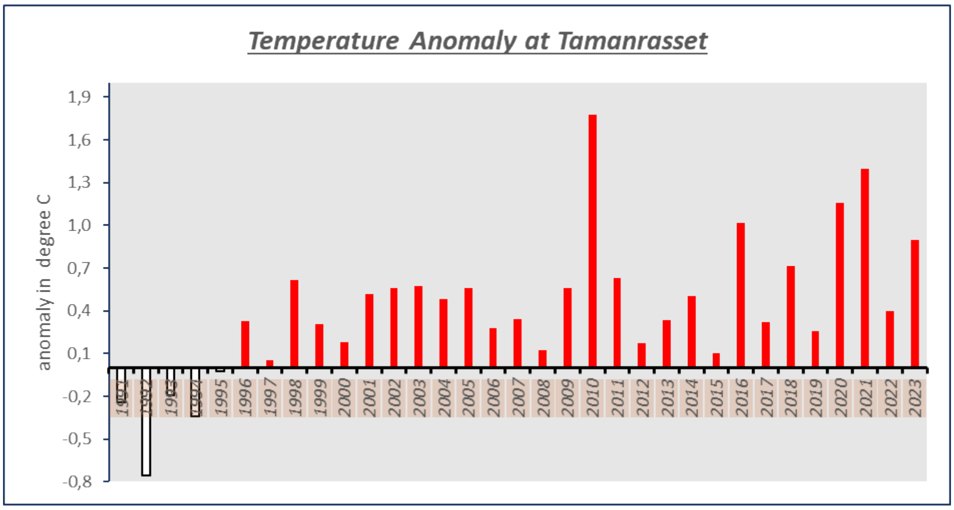
THE EFFECT OF GREENHOUSE GASES (GHG)

The main greenhouse gases are carbon dioxide (CO2), methane (CH4), and nitrogen oxide (N2O). Without these gases, life on earth would be very difficult with an average temperature of -18°C, but the existence of these gases with a reasonable concentration as during the preindustrial era (19th century) maintains an average temperature on earth of 15°C. These gases have the following characteristic: they absorb infrared radiation emitted by the ground and thus maintain a certain balance of radiation in the lower atmosphere. When the concentration of these gases increases sharply, as is currently the case, all the energy emitted by the ground is returned to the lower atmosphere, which creates a surplus of energy and causes the temperature to increase.

In the 19th century, the concentration of CO_2 was on average around 280 ppm (parts per million), today it is close to 285 ppm with an increase of 50%, methane has increased by around 150%.

CONSEQUENCE OF THE INCREASE OF GHG

The first consequence of the increase in concentrations of greenhouse gases is the increase in temperature in the lower layers of the atmosphere. Scientists have found that since 1997, all annual average temperatures have been above normal compared to the current reference period which is 1961-1990. The year 1998 was the warmest with an anomaly of +0.47°C followed by the years 2005 and 2003. These warming anomalies were observed in the Hoggar region at the Tamanrasset and Assekrem station with practically the same values. For example, the winter of 2009-2010 from November to February was exceptionally warm in Tamanrasset with records for the 03 months of winter ever observed.



The consequences of the increase in temperature on a planetary scale are disastrous for several regions located in lowlands and ocean islands as well as deltas. The increase in temperature causes a rise in ocean levels, which causes the disappearance of certain islands and the flooding of several regions. In the field of health, there will be the appearance of certain diseases such as malaria in certain regions outside the equator.

For precipitation, the consequences of these climate changes are not known too precisely, but the general trend is towards an increase in precipitation in the temperate regions of northern Europe and North America and a decrease in the Sahelian region. In addition, the rains are becoming more violent and cyclones in the oceans will be more frequent.

Status of the "SELEGUA" BSRN Station in Chiapas, México

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The current operation status of the station is described including the network configuration which used a virtual private network (VPN). This configuration allows in a straightforward way the administration and operation of the dataloggers. The graphs of the LoggerNet program are displayed in almost real-time. Also, the data is published in a web site using the Campbell Scientific LoggerNet programs.

A suite of programs was developed to analyze the data in a daily basis prior to the generation of the station to archive file. Current version was developed in R and the next version will be a web-based analysis data frame complementary to the BSRN official tools.

Last year un the month of July, heavy winds put upside down the main platform. The global and UVB instruments suffer damage. After a few days the data was again logged except by the UVB sensor which suffered a major damage and is in the process of change by a new one.

On October 14th an annular solar eclipse cross by the eastern part of the Mexican country and on April 8th a full solar eclipse cross by the northwest of Mexico. Data from the station of both events are presented.

WRMC Update 2024–Status, challenges, tasks

Amelie Driemel[1], Christian Lanconelli[2], Laura Riihimaki[3]

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The World Radiation Monitoring Center (WRMC) at the Alfred Wegener Institute is the official Data Archive of the BSRN. The WRMC consists of the ftp server (*ftp.bsrn.awi.de*) and the PANGAEA data archive *https://dataportals.pangaea.de/bsrn/* - both of which contain the same data in different format (PANGAEA being CoreTrustSeal certified). An optional sftp access was installed for the ftp server in 2024, folders for the legacy LR4000 records were created and already filled in parts, and the “raw” (near real-time data check) system was fully set-up. In PANGAEA, data collections for 39 stations were already created (*https://www.pangaea.de/?q=%40BSRNcollection*), to facilitate the citation of BSRN data, and with the introduction of a BSRN license, the access restrictions on PANGAEA datasets were removed. In July 2024, around 13400 monthly datasets are available in the WRMC, encompassing data from 77 stations (43 active, 17 inactive and 17 closed). Since 2022 one station was declared closed (Fukuoka), 8 were declared inactive (now totaling 17), one station was officially added (Lampedusa) and a few others received a or remained in candidate or pending status. The challenge ahead will be to help inactive stations to become active again (i.e., submit data to the archive), to help candidates/pending stations to become fully fledged stations, and to maintain or improve data quality in general.

In the near future, the rather outdated BSRN Toolbox needs to be refurbished or replaced, a centralized data quality online tool should be established if possible, the LR4000 data (current and legacy) needs to be collected from all active stations and the continuity of the WRMC needs to be secured.

The Component Summation Technique for Measuring Upwelling Longwave Irradiance in the Presence of an Obstruction

Bryan E. Fabbri [1], Gregory L. Schuster[2], Frederick M. Denn[1], Bing Lin[2], David A. Rutan[3], James J. Madigan[1], Robert F. Arduini[4], Norman G. Loeb[2]

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[3]*ADNET Systems Inc, Hampton, Virginia, U.S.A.*
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The CERES Ocean Validation Experiment (COVE) was an instrument suite located at the Chesapeake Light Station (BSRN abbreviation: CLH), approximately 25 kilometers east of Virginia Beach, Virginia (36.9° N, 75.7° W). COVE provided surface verification for the Clouds and the Earth's Radiant Energy System (CERES) satellite measurements for 16 years. However, the large light station occupied approximately 15% of the field of view of the upwelling longwave flux measurement (LW^{-}), so radiation from the structure artificially perturbed the measurements. Hence, we use data from multiple instruments that are not influenced by the tower to obtain LW^{-}; we call this the longwave component summation technique. The instruments required for the component summation are an infrared radiation thermometer to measure sea surface temperature, a pyrgeometer to measure downwelling longwave irradiance, and air temperature. We find a strong negative bias between the upwelling pyrgeometer measurements and the component summation LW^{-} in the colder months, less so in the warmer months; the bias ranged from -8% to +4% for the lifetime of COVE (years 2000–2016). This range of biases are larger than the BSRN targeted uncertainties of 2% or 3 W-m^{-2} (whichever is greatest). This work documents how we determined the component summation LW^{-} irradiances and presents guidelines for how this method could be used at other locations.

Figure 1: Fish-eye photograph taken near the end of the 8-meter boom where the upwelling pyrgeometer was installed. The right side of the picture shows the lighthouse legs/structure occupying a significant portion of the static pyrgeometer field of view.

Status and Operations at the Granite Island, Michigan (GIM) BSRN Station

Bryan E. Fabbri[1], Gregory L. Schuster[2], Frederick M. Denn[1], James J. Madigan[1], Kathryn A. Smith[3], Norman G. Loeb[2]

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The Granite Island, Michigan (GIM) BSRN station has been in operation since July 2018. GIM measures photosynthetic active radiation, lake temperature, downwelling longwave, and downwelling shortwave (direct, diffuse, and global). Redundant meteorological measurements are temperature, relative humidity, and pressure. Two instruments measure aerosol optical depth: an AERONET sunphotometer and a 4 channel Middleton sunphotometer. The GIM site is solar powered with some hardware remotely accessible to troubleshoot and manage the challenging winters that can have significant ice accumulation on equipment and instrumentation. This poster will present the current status, work, and its role in the Clouds and the Earth's Radiant Energy System (CERES) satellite project and the CERES Radiation and Validation Experiment (CRAVE), https://science.larc.nasa.gov/CRAVE/.

Figure 1: Granite Island, Michigan (GIM) BSRN station (looking Southeast).

Status and Operations at the Langley Research Center (LRC) BSRN Station

Bryan E. Fabbri[1], Gregory L. Schuster[2], Frederick M. Denn[1], James J. Madigan[1], [3]Kathryn A. Smith, Norman G. Loeb[2]

[1]Analytical Mechanics Associates, Nasa Langley Research Center, Hampton, Virginia, U.S.A.
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The Langley Research Center (LRC) BSRN station has been in operation since December 2014. LRC measures photosynthetic active radiation, downwelling longwave, and downwelling shortwave (direct, diffuse, and global). There are two sets of shortwave instruments on two solar trackers for redundancy. LRC also records the following meteorological parameters: temperature, relative humidity, pressure, wind speed and direction. Lastly, an AERONET sunphotometer measures aerosol optical depth, microphysical and radiative properties. This poster will present the current status, work, and its role in the Clouds and the Earth's Radiant Energy System (CERES) satellite project and the CERES Radiation and Validation Experiment (CRAVE), *https://science.larc.nasa.gov/CRAVE/*.

Figure 1: Langley Research Station (LRC) BSRN station (looking North).

Status of BSRN station Budapest-Lorinc - past, present and future

Denés Fekete (Poster)

Unit of Measurement Technology and Energetics Development, HungaroMet, Hungary

The Budapest-Lorinc station was found in 1952, with solar radiation measurements starting 15 years later. This site had been accepted as a provisional BSRN site in the 1990s, but failed to ever successfully submit any data to BSRN Archive. At the 15th BSRN Workshop in 2018, it was re-candidated, and the station has been sending data since July 2019. The components of the operational measurement program are as follows: global solar radiation, reflected shortwave radiation, longwave downward radiation, longwave upward radiation, direct solar radiation, diffuse solar radiation and aerosol optical depth measurements. Other parameters, including total ozone and spectral UVB and UVA measurements with Brewer spectrophotometer, spectral visible and near-infrared measurements with SolarSIM spectrophotometer, which can determine aerosol optical depth, are also available. Air pressure, air temperature, humidity and ceilometer data are also measured. Automatic data collection and quality checking operated by working instructions of the International Organization for Standardization (ISO) quality control/assurance system are applied. The calibration of solar instruments is done yearly in situ in autumn where weather conditions are best with a PMO6-CC Absolute Cavity Radiometer System. In the coming years, we are planning the following improvements: we will change all our radiation measurement devices, including the sun tracker. We will expand our measurement program with global UV-A and UV-B, PAR, and AOD.

Improving Radiation measurements in Antarctica: The Antarctic Radiation Regional Network (ARRN) Initiative

Claudia Frangipani[1,2], Vito Vitale[1], Angelo Lupi[1], Maurizio Busetto[3], Giulio Verazzo[1], Mauro Mazzola[1], Boyan Petkov[1,2], Francesca Becherini[1], Alice Cavaliere[1], Simone Pulimeno[1], Chiara Ripa[1]
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[3]*Institute of Atmospheric Sciences and Climate, CNR-ISAC, Bologna, Italy*

In the Antarctic continent, the assessment on a continental scale of radiation budget and related parameters is challenging due to the limited number of stations and observations. A wide heterogeneity exists from one station to another in terms of observed parameters, ancillary measurements, maintenance procedures and even sampling frequency and instrumental setup, with the exception of Baseline Surface Radiation Network (BSRN) stations which collect data with strict protocols for high quality data, but only since 1990s.

Antarctica has a unique geographic position in radiation climatology: the net radiation at the Earth surface is expected to rise rapidly, and, due to peculiar environmental conditions and temperature regime, Antarctic stations are the only ones that can cover the lower range of the relation rate of long wave change vs. temperature change rate. So, in order to get a full picture of this relation, it is important to improve/increase the observations in the continent.

With the aim to obtain a clear picture of the ongoing activities regarding surface radiation observations and elaborate strategies to better assess radiative regimes and related processes in the different areas of the continent, a workshop and a side-meeting at the IUGG 2023 in Berlin were organized. The final and ambitious goal is to move toward the creation of an Antarctic Radiation Regional Network (ARRN). In this respect, BSRN represents a precious source for best practices and at the same time a natural set of reference stations for ARRN.

We will provide information on what achieved so far and ongoing activities, with a particular attention to efforts to create a unique point where to collect information on what is currently measured and at disposal. And at the same time, we would like to promote a discussion on how BSRN best practices could be used and on which parameters, in addition to basic radiation components, the network should focus.

Status of the Izaña BSRN Station

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[2]*Izaña Atmospheric Research Center, State Meteorological Agency (AEMET), Spain*
[3]*Atmospheric Optics Group. University of Valladolid (GOA-UVA), Spain*

The Izaña Observatory (IZA; BSRN, station #61) is part of the Global Atmospheric Watch (GAW) programme and is managed by the Izaña Atmospheric Research (IARC; *https://izana.aemet.es*) from the State Meteorological Agency (AEMET, Spain). It is a subtropical high-mountain observatory, located in Tenerife (Canary Islands, 28°18' N, 16°29' W, 2367 m a.s.l.) above a quasi-permanent inversion layer, consequently it offers excellent conditions for *in-situ* measurements. The environmental conditions (stable total ozone column, very low column water vapour and low aerosols content) and the high frequency of clean and pristine skies, makes IZA optimal for measurements and calibrations of radiation (more information in Cuevas et al., 2024). Since 2009, IZA contributes with basic radiation measurements, such as global shortwave, direct, diffuse and longwave downward radiation, extended measurements, including ultraviolet ranges, shortwave and longwave upward radiation and other ancillary measurements, such as radiosondes (WMO, station #60018) and total column ozone from the brewer spectroradiometer (*https://eubrewnet.aemet.es/*). These measurements are daily tested against physically possible and globally extremely rare limits, as defined and used in the BSRN recommended data quality control. Besides, the basic radiation measurements are daily compared with simulations, modelled with the LibRadtran model (*https://bsrn.aemet.es/*; García et al., 2019).

Since 2016, the radiation program has been complemented with spectral measurements. In particular, measurements of spectral direct solar radiation performed with an EKO MS-711, global and diffuse spectral performed with an EKO RSB, covering a wavelength range from 300 to 1100 nm, and infrared global spectral radiation (900-2500 nm) performed with an EKO MS-713 spectroradiometer. Moreover, in late 2020, an EKO sky scanner model MS 321-LR was installed at IZA. This instrument is provided with two sensors, one measures the sky luminance (Kcd/m^2) and the other sky radiance (W/m^{2}sr).

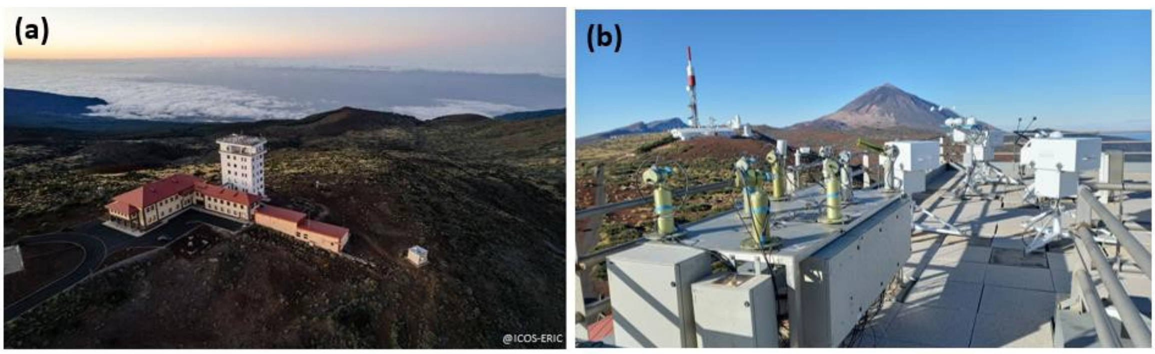

Figure 1.- (a) Image of Izaña Observatory. (b) Roof terraze of Izaña Observatory.

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Update on PTR, BRB and SMS stations operated by INPE in Brazil

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INPE operates three radiometric stations (PTR, BRB and SMS) included in BSRN since 2006. These stations are part of SONDA network, alongside another six stations all over Brazil, covering distinct biomes like “Pampa”, “Cerrado” and “Caatinga”. These stations measure short-wave and long-wave downward components, combined to 50-m wind masts and basic meteorological variables. Some are also part of AERONET network. Those stations stretch from 980 km to 1800 km far from INPE headquarters in S.J. Campos - SP, what demand local support for regular and corrective maintenance. BRB and PTR are installed in units from Brazilian Agricultural Research Corporation (Embrapa) while SMS is installed in INPE southern space observatory (OES) facility. After almost 18 years in operation, circumstances have changed, and stations are lacking local support while SONDA network is lacking enough funding for costly logistics. Meanwhile, maintenance is made mostly remotely by our lab research team, with scarce visits, and priority is given for data collecting and storage. The good news is that PTR and SMS stations are running uninterruptedly since Jun-2019 and Dec-2018, respectively. BRB station became out of service in Sep-2021 but it was restored in Oct-2023. Our main challenge remains on getting regular financing to keep those stations operational but alternative solutions like engaging local staff for supporting is also on course. We are aware that this scenario impacts sensors periodic calibration and replacement, radiometer dome cleaning and solar tracker misalignments, imposing quality issues in our data. Uploads to BSRN archives is also out of date. An updated plan for submissions of station-to-archive files will be provided. Nevertheless, we would like to add that two new stations with far better support were deployed and are operating uninterruptedly in the last two years: Santarém - STM (2°41'00.0"S 54°32'06.0"W) in the Amazon biome and Cachoeira Paulista – CPA (2°41'00.0"S 54°32'06.0"W) in the Atlantic Forest biome. Those stations may become BSRN candidates in the future as soon we improve our operational standards.

Figure 1: Santarém (STM) radiometric station deployed in the Amazon region in 2021.

Towards Developing Accurate Long-term Solar Irradiance for Climate Studies

Aron Habte, Manajit Sengupta, Afshin Andreas, Shawn Jaker, Jaemo Yang, Ibrahim Reda, Yu Xie

National Renewable Energy Laboratory (NREL), U.S.A.

Solar radiation is primarily measured using high-quality radiometers (e.g., pyranometers and pyrheliometers). These instruments need to be calibrated regularly (every two years at a minimum). They are also susceptible to various sources of uncertainties. Therefore, rigorous data quality assessment is required to obtain high-confidence data from these radiometers. This is especially true when the data is used to understand climatic trends and/or extreme weather events.

In this study, a high-quality solar radiation data is used from the NREL's Solar Resource Research Laboratory (SRRL) which is located on the top of South Table Mountain on the north side of NREL's Campus in Golden, Colorado. Dataset from 1985 to present including direct normal irradiance (DNI), global horizontal irradiance (GHI) and diffuse horizontal irradiance (DHI) were selected. The data underwent rigorous data quality check and regular calibration using the NREL's broadband outdoor radiometer calibration (BORCAL) method. The BORCAL method is used for pyranometer calibration using shade and unshade method for reference DHI instrument and component sum method using reference DNI determined by an Eppley Laboratory, Inc. Model AHF windowed cavity radiometer and a shaded reference pyranometer which was calibrated using the shade and unshade method (both these methods are described in [1], [2]. Moreover, test pyrheliometers are calibrated against the

AHF cavity. Additionally, thorough calibration of the AHF is carried out through the NREL pyrheliometer Comparison (NPC) and the International Pyrheliometer Intercomparison procedures (see [3], [4] for details about these methods). It is seen that the reference DNI does not change significantly from year to year. However, the reference DHI instrument in BORCAL has changed from one model of pyranometer to another during various periods. The reason for these changes is detailed in [5] and [6].

These changes of reference DHI can cause artifacts (up or down shifts) in the long-term data. These artifacts are not due to the changes of climate/weather but due to changes in DHI reference instrument.

As illustrated in Figure 1, the process of correcting the reference DHI starts by calibrating the various types of pyranometers used as DHI references through time to the current standard reference - model SR25.

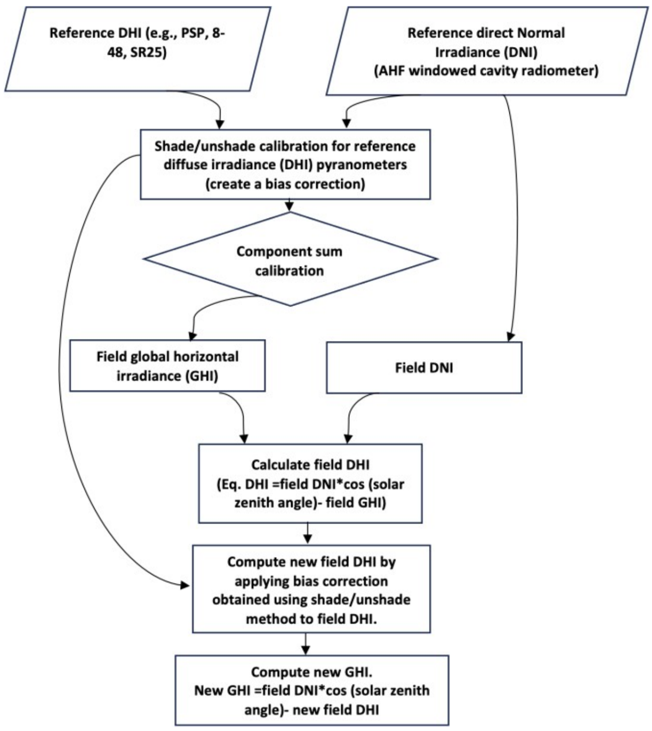

Figure 1: Flowchart demonstrating the process of correcting the bias in the reference diffuse.

In this study, we create a continuous and reliable dataset by correcting the underlying data which we believe contains bias due to reference pyranometers swap procedures. These biases can be significant and reach up to two percentage points thereby influencing the interpretation of climate changes and/or extreme events. This study elaborates on the biases and methods to correct those biases.

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Overview of International Radiometric Standards

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Standardization and best practices of data sets and models enable the climate community and industry to develop widely accepted protocols that can then be used for various research projects and development and operations. In collaboration with the International Standardization Organization (ISO), ASTM and other standardization organizations, the National Renewable Energy Laboratory (NREL) leads the development and regular update of various radiometric standards. These standards contribute to increased accuracy in the measurement of the solar resource available for various applications and support the development and improvement of radiative transfer models. These measurements and models can then provide the long-term geographic or climatic distribution of solar radiation. Further, these standards play a preeminent role in all aspects of climate studies, solar energy projects, including standard conditions, methods and instrumentation, accelerated testing, and service lifetime of materials.

The development of consensus standards for solar resource modeling and measurement includes various topics: (i) calibration, measurement, application, and data processing; (ii) guidelines or standard procedures for calculating data uncertainty; (iii) test procedures for optical radiation applications; and (iv) best practices for measurement activities. All the standard covering these topics provide essential information for various stakeholders. Figure 1 illustrates a calibration set up described in ASTM G138-12 Standard Test Method for Calibration of a Spectroradiometer Using a Standard Source of Irradiance. Example standards such as this enables users to collect spectral data of know accuracy.

The presentation will provide an overview of the current standards under development for the collection and use of solar resource data for various applications.

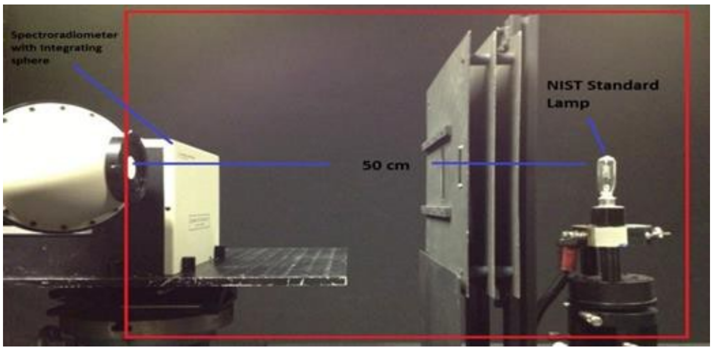

Figure 1: NREL's spectroradiometer calibration setup traceable to the National Institute of Standards and Technology: a tungsten-filament, 1,000-W quartz-halogen FEL.

References:

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Development of Test methods for Radiometer Specifications

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Accurate measurement of solar irradiance is important for assessment of solar energy resources, solar energy performance and acceptance testing, and climatology among a host of other applications. Radiometers are used to measure total hemispherical solar radiation (pyranometers) and direct beam solar radiation (pyrheliometers) and these instruments have been classified using international standards from International Standards Organization (ISO) -

ISO 9060:2018 (“Solar Energy: specification and classification for measuring hemispherical solar and direct solar radiation”). This standard has many elements in common, with the WMO Committee on Instrumentation and Measurements (CIMO) Guide No. 8, chapter 7 on radiation measurements. On the other hand, these two documents are not totally consistent, especially in classification terminology. However, both documents have similarity in enumerating the characteristics/specifications of radiometers for various levels of performance, with achievable uncertainty. The classification criteria are chosen in such a way that they define maximum (worst-case) levels of uncertainty in practical field applications. However, there are no consensus-based standards and/or procedures that test these specifications listed in the ISO 9060:2018 or CIMO guide in a repeatable and reproducible way. Recently, ISO TC180/SC1 subcommittee on Climate – Measurement and data and ASTM G03.09 subcommittee on Radiometry started to investigate this limitation and develop test method consensus standards that would justify the specification values listed in the in the ISO 9060:2018 or CIMO guide. The test methods can also be used to develop tolerance limits if needed from those described in the ISO 9060:2018 or CIMO guide.

The methods will be explicit experimental procedures and reproducible. Independent

National Metrology Institutes (NMI) such as the National Renewable Energy Laboratory (NREL) could play a role in developing and performing tests for each specification and ultimately developing the relevant standards. As an example, NREL carried out a nonlinearity experiment using a solar simulator. The pyranometer response measurements were carried out from 0.1 to 1.2 suns. This wide range of irradiances was achieved by changing lamp current and/or placing screens between the lamp and the test bed.   Figure 1 demonstrates the nonlinearity setup and Table 1 shows the results of the nonlinearity for a set of pyranometers.

In this presentation we will demonstrate, some of the test method procedures performed at NREL an discuss possible path forward to develop relevant standard test methods.

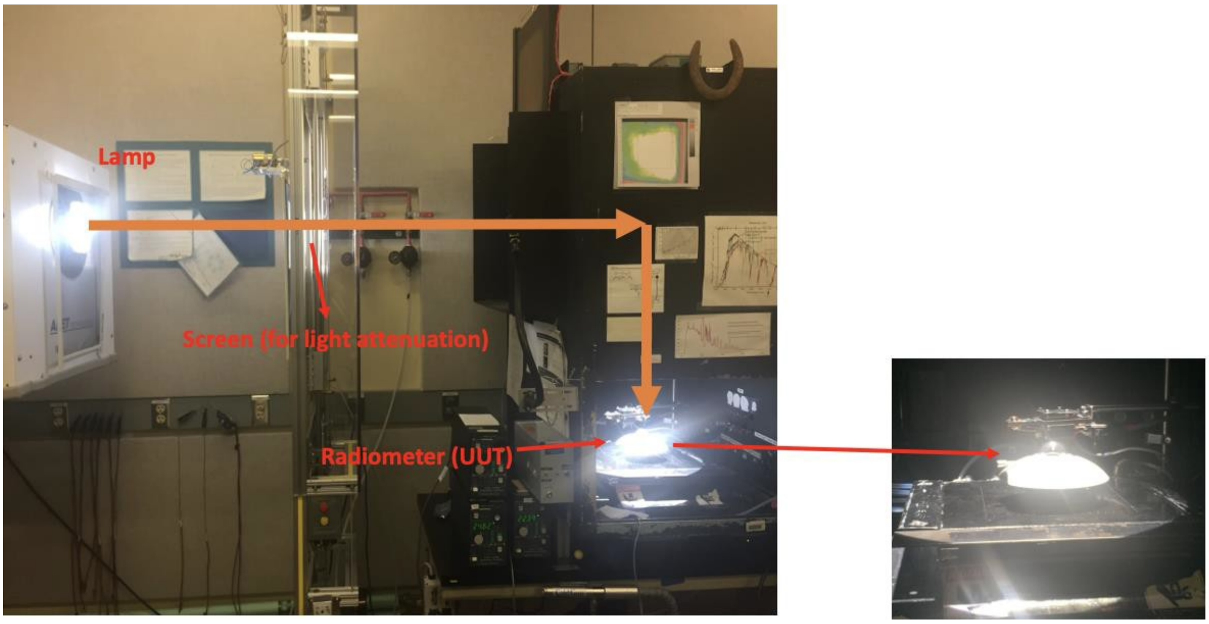

Figure 1: NREL's X25 solar simulator setup to measure the nonlinearity of pyranometer.

Table 1. Nonlinearity test results for various types of pyranometer using the NREL compared to ISO 9060 and factory values

Model	ISO9060 Class	ISO9060 Nonlinearity acceptance intervals and width of the guard bands	Nonlinearity (Factory)	Nonlinearity (NREL)
SR25	A	±0.5% (0.2%)	< ± 0.2 %	0.26
8-48			1%	0.28
CMP11	A	±0.5% (0.2%)	< 0.2 %	0.42
MS-80	A	±0.5% (0.2%)	± 0.2 %	0.36

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[13] ASTM G183-15, “Standard Practice for Field Use of Pyranometers, Pyrheliometers and UV Radiometers,” ASTM International, West Conshohocken, PA, 2015, www.astm.org.

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New SURFRAD 10 m Tower

Gary Hodges (Poster)

NOAA Global Monitoring Laboratory, Boulder, Colorado, U.S.A.

A new counter-weighted tilting tower has been designed that will replace the current triangle-style instrumented towers at all SURFRAD stations. While the triangle towers have been used successfully for over 25-years, deficiencies with the design have motivated replacement with a modern solution. The two main drawbacks of continuing with the triangle towers are the requirement that at least two physically capable people raise and lower them for instrument access, which leads to the second main downside of limiting the additional equipment that can be hosted due to weight considerations. A tower that can be safely lowered by a single person frees personnel thereby reducing travel costs while expanding the number of stations that can be maintained at a high level. This is of particular importance for the SURFRAD network as funding is in place to add 2-4 stations. The new tower design has other desirable attributes as well such as positioning the down-pointing radiometers at 10 m, rather than at ~8.5 m with the triangle towers. With the weight limit generally alleviated plans are being made to bolster the suite of instrumentation the towers host. Additional equipment will include infrared thermometers and webcams to monitor surface conditions. The tower design will allow for instrumentation to be installed at 2 and 5 m as well, so wind and temperature profiles will be possible. Without a need for guy wires, the new towers can be installed in locations that would be problematic for triangle style towers. For example, without guys the towers could be installed in an active agricultural field to provide albedo characterization of different crops. The purchase process has been initiated, and it is hoped the new towers will be installed at the Bondville, Illinois (BND) and Goodwin Creek, Mississippi (GWN) SURFRAD stations before the end of the year.

Availability of solar radiation measurements outside the BSRN

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High-quality solar radiation measurements are expensive and time-consuming to carry out, hence solar radiation monitoring stations are scarce. With 47 active stations, the Baseline Surface Radiation Network (BSRN) represents the only global network for solar radiation measurements and consequently sees widespread usage (Driemel, A., 2018). Apart from the BSRN, only a handful of countries feature a national network. Predominantly, solar radiation monitoring stations are operated by meteorological institutes, universities, or research organizations. Regrettably, most of the existing monitoring stations are difficult to locate for novice users, and retrieving data is often cumbersome or impossible. As a result, most solar resource and radiation model development studies only use a fraction of the available data globally, almost always relying on the BSRN and a limited number of well-known stations.

To overcome this barrier, the authors have developed a comprehensive catalog of solar radiation monitoring stations. The catalog is available in an interactive form at SolarStations.org and contains metadata of the majority of the solar radiation monitoring stations worldwide. The available metadata includes location, station owner and network, data availability, instrumentation, and measurement period. This information enables users to make quick, informed decisions about what stations to use for a potential study, ultimately increasing the usage of high-quality solar radiation data with improvements in scientific rigor to follow.

Figure 1: Overview of solar radiation monitoring stations worldwide from SolarStations.org.

The presentation will give an insight into the distribution of the almost 600 stations identified worldwide, as well as instrumentation, data availability, and networks.

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Review of BSRN data quality and report from the working group (2022-2024)

Wouter Knap[1], Amelie Driemel[2], Christian Lanconelli[3], Jordi Badosa[4], Johan Parra [4], Laura Riihimaki[5], Laurent Vuilleumier[6]

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[2]*Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung, Germany*
[3]*Uni Systems, Italy*
[4]*Ecole polytechnique, France*
[5]*CIRES | NOAA ESRL GMD, U.S.A.*
[6]*Federal Office of Meteorology and Climatology, Switzerland*

The general aim of the Data Quality Working Group (DQ WG) is to assess and improve BSRN data quality and to support station scientists (new and existing) with identifying problems and improve data quality. Furthermore, one of the key activities is to develop evaluation tools. The three main quality control (QC) tools are: 1. The BSRN toolbox, 2. A web-based visualization tool and 3. A raw system for near-real time monitoring. The members of the DQ WG met online on a monthly basis and apart from data quality many other topics were addressed covering practical issues as well as organizational aspects of BSRN and connections with other parties/projects (such as GAIA-CLIM, ECMWF CDS, GSRN, GCOS/GEWEX). Further topics that were addressed are e.g.: implementation of a consistency check of LR4000 (addendum to GCOS report 174), uncertainty budgets, calibration traceability and more generally: the integration and operationalization of QC systems.

The main conclusion of the DQ WG is that, although the situation has improved during the last years, still too many stations are submitting data of insufficient data quality to the central BSRN archive at AWI. The efforts of the DQ WG need to continue and station scientists are strongly advised to check their data before submission. Analysis also showed that not all of the existing data in the database is of sufficient quality and that timeliness of newly submitted data should be improved.

Despite the issues mentioned above the DQ WG kept moving forward and appeared to be a fruitful platform to stay connected and discuss a wide variety of themes. Many interactions with station scientist have prevented bad data going into the database and generally improved data quality. One of the main challenges that lie ahead is to produce a complete and preferably quantitative picture of BSRN data quality, identify bad data and clean up the data base. Furthermore, there is a strong need for the establishment of a more formalized workflow for the handling of submitted station data and define objective criteria for the rejection/acceptance of data. The assessment of an uncertainty budget will be an important task in the next period, as well as the integration of tools for quality control.

The use of BSRN data for meteorological and solar energy applications

Wouter Knap

Royal Netherlands Meteorological Institute (KNMI), The Netherlands

An overview is given of several peer-reviewed papers and datasets that were recently published in the fields over meteorology, large eddy simulation, and the forecast of solar radiation. All papers and data are based on then use of BSRN data of Cabauw, The Netherlands. The research efforts have been done by researchers from the Meteorology and Air Quality Group at Wageningen University & Research, with collaborations with various universities and institutes (KNMI, Utrecht University, Aliander, Free University Amsterdam, PMOD, Cologne University, HEC Bonn/Cologne). As for BSRN Cabauw, special credits are given to the IT and technical support staff of KNMI.

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BSRN Temporal aggregation and Operational "Long and Ackermann" Clear-Sky parameters (current status)

Christian Lanconelli

Uni Systems, Italy

The procedure developed by Long and Ackermann [1, 2] was made operational over BSRN archive with a schedule of 10 days. The presentation describes the theoretical background, including the cloud screening, clear-sky model fitting ($Y = A\mu^b$), atmospheric transmittance and cloud radiative forcing evaluation steps. The current results were described by means of distributions of *A* and *b* clear-sky parameters over individual sites as obtained from the analysis of all available station to archive files at 1-minute resolution starting from 2000. A higher clear-sky transmission was observed at higher latitudes and elevations with A parameters' averages/median ranging between ~1100 and ~1300 W/m^2. The clear-sky model performance was assessed over arctic sites obtaining a for a period of nearly 12 years (375*k* clear-sky minutes), obtaining a *bias* against clear-sky measurements ranging between -0.8 and 0.0 W/m^2 with a *rmse* of ±5 to ±7 W/m^2. The atmospheric clear-sky transmittance *T* at 60° sun zenith angle was observed to vary between 0.9 in early spring to 0.75 in summer over selected Arctic sites, and a representation of *T* as a function of *A* and *b* parameters was proposed. The presentation summarizes the current implementation and the possible way forward towards a full integration with the Product section of the BSRN web pages.

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The BSRN RAW system: A tool in support of timeliness

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Timeliness is one of the main issues affecting BSRN performances, along with geographical gaps. While delivering state- of- the-art quality data to the community is the principal objective of BSRN, limiting the time from data collection to their official distribution is recognized as another important property, as stated by GCOS implementation plan, which defines a timeliness requirement for each Essential Climate Variable measurement. Only part of BSRN is able currently to deliver data within few months, about half of the operational sites deliver data within 1-2 years, while more than half of the sites are lagging more than two years. To support station scientist with preliminary analysis of the data, a set of routines has been developed to collect tabular formatted ascii data (csv) though the BSRN (s)ftp infrastructure provided by AWI. Data may be flowing as 1-second (or 1-minute aggregation) calibrated components in any arbitrary order as defined by a standard header. The programs perform the calculation of averages and 1-minute statistics (std, min, max) whenever needed and produce a data section compliant with station-to-archive's file format requirements. The routine is integrated with the Quality Tool developer by W Knap (KNMI) [see this report] for an easy and shared access to a QC graphical interface, designed to support a preliminary evaluation of the data. The routine is actively running, checking the FTP server for newly uploaded data every 15 minutes. Access to the system is currently available upon request. It is capable of handling data not only from BSRN stations but also from external sources or users engaged in BSRN-related activities, data analysis, and quality control. Future enhancements are planned to include advanced analytical features—such as offset and cosine corrections—implemented through processor directives embedded within the data files.

Indoor calibration of pyranometer in Taiwan

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In order to respond to climate change and the needs of agriculture and green energy development, Taiwan government had set-up hundreds of radiation observation stations in the past decade. However, only two solar radiation calibration laboratories, National Central University (NCU) and the Central Weather Administration (CWA), use outdoor calibration methods to perform relevant calibration work. Both laboratories are located in northern Taiwan, where it rains and cloudy all year round, there are very few cloudless days available for outdoor calibration. Therefore, to meet the needs of domestic pyranometer calibration and improve the quality of solar radiation observations, the CWA invited the Industrial Technology Research Institute to jointly develop an indoor solar radiation calibration system in 2023, using a 3A class (test result of spectral match to all intervals, non-uniformity of irradiance and temporal instability are all class A) solar simulation light source. After reviewing the result of interlaboratory comparison, we can preliminarily confirm that our indoor calibration procedure has a certain degree of credibility. We will briefly introduce our laboratory's indoor calibration procedure and the analysis result of interlaboratory comparisons on the poster. In the future, more data will need to be collected to ensure the quality of solar radiation observations in Taiwan.

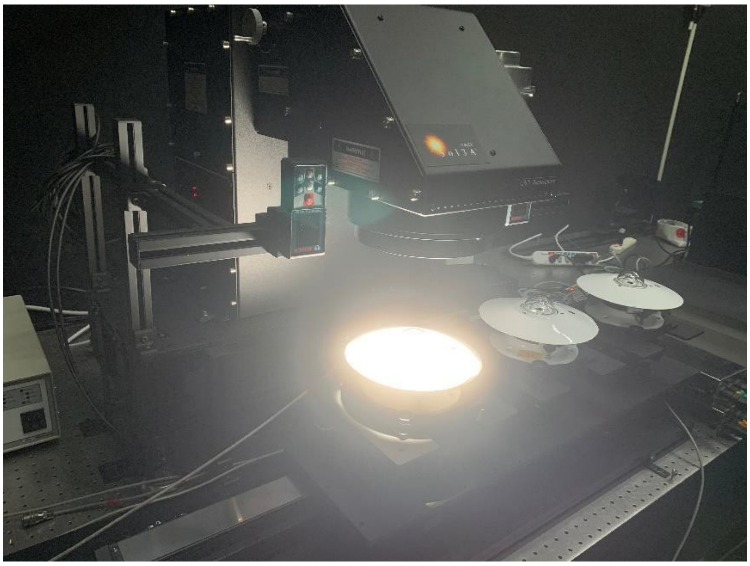

Figure 1: Indoor calibration of pyranometer in CWA Lab

Status and Operations of the BSRN Stations (Yushan and Lanyu) in Taiwan

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In Dec. 2018, Lanyu (LYU, BSRN station no: #79) and Yushan (YUS, BSRN station no: #84) submitted their first data pitch and officially became BSRN stations. Lanyu is an island station located 70 km offshore of eastern Taiwan (coordinates: 22.04°N, 121.56°E, 324 m a.s.l.), and Yushan is a high-mountain station located at the summit of Mt. Yushan (coordinates: 23.49°N, 120.95°E, 3858 m a.s.l.). Both of them contribute with basic radiation measurements, such as global shortwave radiation (SWD), direct radiation (DIR), diffuse radiation (DIF), and longwave downward radiation (LWD), and extended measurements, including all-sky image, ultraviolet index (UVI), global shortwave radiation and sunshine duration and other basic weather parameters, such as temperature, humidity, air pressure, cloud amount and wind. LYU and YUS have daily maintenance and automatic QC tests; usually, the instrument operation rates for both stations are above 95%, and after the BSRN data QC processing, the data availability exceeds 90%. There are environmental challenges at these two stations. In YUS, the instruments will frost or freeze during the winter because of the rime or freezing rain, resulting in instrument damage or data inaccuracies. In LYU, the high salt content environment in the island can cause equipment corrosion. In addition, LYU Station is situated along the path of typhoon impacts, leading to annual exposure to typhoon effects; in 2023, Typhoon Koinu affected LYU, leading to the solar tracker being damaged (Typhoon Koinu also setting a record for the historical strongest maximum gust wind in Taiwan, 95.2 m s^{-1}).

Ship cruises as an opportunity to obtain surface radiation flux measurements in a marine polar environment

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The Italian project CAIAC (oCean Atmosphere Interactions in the Antarctic regions and Convergence latitude) and the European project MoRaCCA sub-proposal (Monitor Radiation and Clouds Characteristics over Arctic Ocean) are projects which aim to investigate solar and terrestrial radiation fluxes, exploiting the Laura Bassi R/V and the Polar Expedition Ship "Le Commandant Charcot" Cruises during the whole world campaign. Specific radiation unmanned observatories were installed onboard the ships, collecting online measurements of downwelling (both shortwave [global and diffuse] and longwave) radiative fluxes.
In this work some results are presented, together with challenges and issues.

Mindelo (Cape Verde) - TROPOS ACTRIS Radiation Observatory (TARO)

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Skupin, Ronny Engelmann

Leibniz Institute for Tropospheric Research (TROPOS), Germany

Within the framework of the European “Aerosol, Clouds and Trace gas Research Infrastructure” ACTRIS, TROPOS will establish and maintain several long-term in-situ and remote sensing observatories at climate hot spots. One of these stations is set up in Cape Verde (Cape Verde Atmospheric Observatory CVAO) with remote sensing instrumentation to retrieve vertical profiles of aerosol and cloud properties. In combination with ground-based radiation measurements, the effects of aerosols and clouds on the surface radiation budget will be investigated. To this end, the TROPOS ACTRIS Radiation Observatory (TARO) was set up to measure broadband downwelling solar and terrestrial irradiance with secondary standard sensors (EKO MS-57, MS-80 and MS-21). TARO was installed on the roof of the Ocean Science Centre Mindelo (OSCM) in Cape Verde in September 2023 and has been measuring continuously with a high sampling frequency of 10 Hz since then. In addition, spectral irradiance is measured with the EKO WISER system and sky conditions are continuously monitored with the All-Sky Camera ASI-16. These observations are complemented by active remote sensing according to the CloudNET standard (cloud radar, aerosol lidar, microwave radiometer). Data are processed daily and quality checked against BSRN recommended thresholds. On-site personnel are available on weekdays for general maintenance and frequent cleaning of the instruments.

Measurements at this remote site on the island of Cape Verde at about 17 N are largely under maritime influence. It is also located in the tropical trade wind zone, where mineral dust from the Sahara and biomass burning aerosol from Central Africa are major contributor to the overall atmospheric aerosol composition. The station is south of BSRN station #61 in Tenerife, Spain (28 N), and would add a unique location to the network.

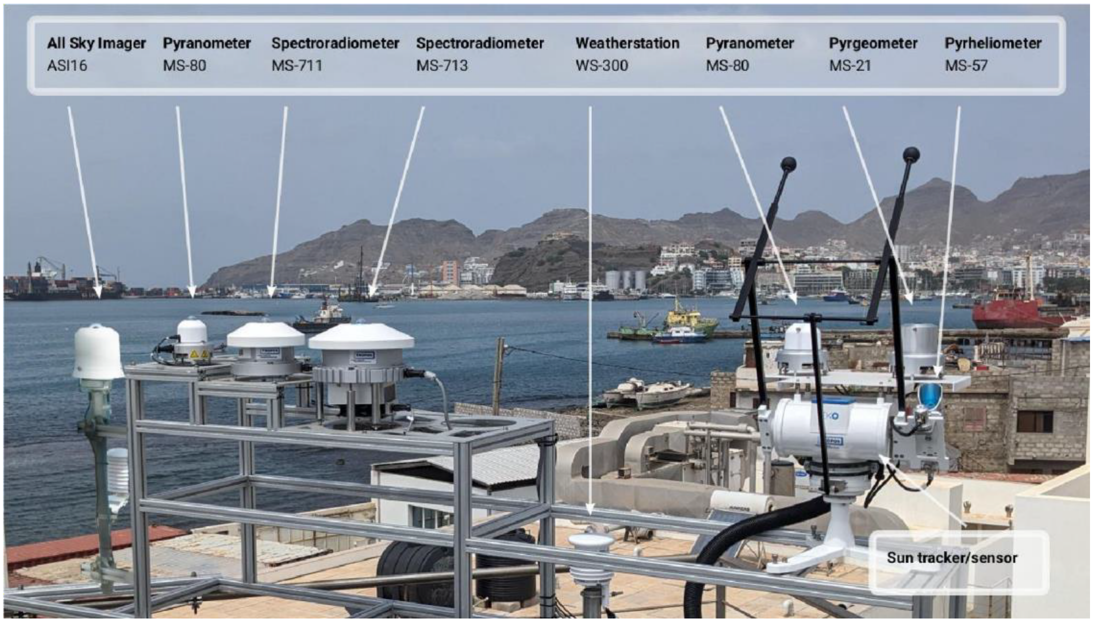

Figure 1: TARO station on the roof of the Ocean Science Centre Mindelo (OSCM), Cape Verde

The status of Lampedusa Climate Observatory as BSRN candidate site

Daniela Meloni[1], Alcide G. di Sarra[2], Damiano Sferlazzo[3], Fabrizio Anello[4], Lorenzo De Silvestri[1], Tatiana Di Iorio[1], Francesco Monteleone[4], Giandomenico Pace[1], Salvatore Piacentino[4]

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The small and flat Lampedusa island, in the southern central Mediterranean, hosts the ENEA integrated Climate Observatory (35.518 °N, 12.63° E, 45 m amsl) since 1997. Downward shortwave and longwave irradiance measurements started in 2004, and many other measurements of aerosol column properties and vertical distribution, meteorological parameters, ozone, UV radiation, cloud properties, precipitation, and greenhouse gases concentration, are carried on. The site is involved in many international networks (ACTRIS, AERONET, EMEP, ICOS, WMO-GAW).

The BSRN measurement system is made up of Kipp&Zonen CMP21 and CMP22 pyranometers, CHP1 pyrheliometers, CGR4 pyrgeometers, regularly calibrated, and an AP2 solar tracker, installed on the roof of the main building of the Observatory. Data are collected every second by a Campbell Scientific datalogger. The horizon is free from obstructions, apart from the lighthouse at about 150 m distance, which represents a narrow obstacle of 2.7° above the horizon around 110° azimuth. The meteorological parameters are measured by a Vaisala weather station.

The site is at about 50 m above sea level, and close to the coast (about 40 m from the sea). Typical meteorological conditions include high humidity and moderate to strong winds, with relatively frequent (about 20% of the time) occurrence of Saharan dust transport to the central Mediterranean. The radiometers are ventilated, but often this do not prevent the deposition of small droplets and dirt on the domes, especially during windy and dusty days. The on-site personnel regularly checks and cleans the radiometers.

The station-to-archive data files are submitted to the BSRN data center since December 2023. The 1-minute data are checked and the spikes due to the cleansing of the instruments are manually removed.

Status and operations of Reunion Island (RUN) BSRN station

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In island regions, the transition to a low-carbon energy mix presents a significant challenge, particularly in increasing the proportion of locally sourced renewable energy (RE). This challenge arises from the fluctuating nature of RE resources, which can cause imbalances between the energy supply and demand. In this context, the spatiotemporal characterization of these local RE is essential for effectively planning and managing production, consumption reduction, and energy storage. This characterization is all the more necessary for variable RE such as Solar Energy (SE) due to its dependency on weather and climate conditions. This is particularly evident for Reunion Island in the South West Indian Ocean, which aims to achieve energy autonomy and a 100% renewable electricity mix by 2030. Despite abundant SE resources, the large variability of the island's local climate still limits the integration of SE in the electric mix. Integrated into the BSRN in 2021, the radiation station established by ENERGY-lab University of Reunion Island) contributes to the efforts of the laboratory in characterizing the variability of SE on the island. The main goal of this work is (1) to present the status of the RUN BSRN station between 2019 and 2024, and (2) to assess the impact of relocating a solar weather station on meteorological observations, providing insights into the consistency and reliability of data collected at different nearby sites. The main operation at the station in 2023 was the installation of a second set of radiation sensors (identical to the initial one) on a dedicated platform a few tens of meters from the original location. In this regard, we will specifically present the intercomparison results between the two locations during a 6-month campaign through the quality control conducted post-data submissions. Methods employed encompass rigorous data cleaning, statistical analysis, and examination of temporal trends to elucidate the effects of the station's relocation on observed meteorological parameters, while also considering potential masking effects.

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Development of a new ground based spectral radiometer system for albedo and flux (GSAF)

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The ground based spectral radiometer system for albedo and flux (GSAF) was developed to measure spectral albedo at our laboratory, and we installed the system at Ny Ålesund station (NYA) with kind cooperation of the Alfred Wegener Institute (AWI) in 2012. We have been monitored the spectral albedo of snow, the mass concentration of BC in the snow and snow grain size retrieved from the spectral radiation data, which affect the rapid snow and ice melt in the recent warming period, since then (Tanikawa T., et al. [2020], Kuchiki, K., et al. [2009]). Unfortunately, the GSAF system broke down in the rotating system for a sensor unit up and down in the winter of the year before last, and observations are currently suspended. We have developed a new GSAF system which has two sensors to measure upward and downward spectral radiation independently instead the rotating system for a sensor unit up and down, and plan to install the new system at NYA this August. In this presentation, we will introduce features of the new GSAF system, the calibration method of the sensors and initial measurement results of the system.

Figure 1: New GSAF system

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Decadal variation of longwave downwelling surface radiation and its effect on net radiation: Based on pyrgeometer measurements at the surface

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Decadal change of longwave downwelling radiation was investigated based on 22 stations for 23 years data from 1998 to 2021, obtained in the Baseline Surface Network (BSRN) and Surface Radiation Budget Monitoring (SURFRAD) measurements. The longwave downwelling radiation has been increasing at all sites. The least square regression analysis showed the mean increasing rate of +0.215 Wm^{-2}/a, of which 46% is due to greenhouse gases (including water vapor) and the remaining 54%, to temperature increase. Scaling the present result with respect to [CO_2], the increasing rate excluding temperature effect is +0.05 Wm^{-2}/ppm CO_2. During the same period, surface net radiation also increased at all stations but one site at South pole. The mean rate is +0.312 Wm^{-2}/a, and considerably larger than that of longwave radiation. The contribution for the net radiation is due to longwave downwelling radiation, shortwave global radiation, and the albedo decrease, by 61%, 31%, and 9%, respectively. The temperature sensitivity of the climate system for the last half century was updated to be 0.053 K/Wm^{-2}. A concept of radiative forcing for the earth's surface is proposed.

Unlike conventional forcing defined with respect to the tropopause, this proposal is possible to measure at the surface. The mean radiative forcing for the surface during the first two decades of the 21st century is 0.05 Wm^{-2}/ppm CO_2. To improve the present networks, the author proposes to include the upwelling irradiances in the Basic Observations in the BSRN.

Solar radiation measurements with an ISO9060:2018 class a pyranometer coupled with a rotating shadow band

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We explore a cost-effective in-situ solar monitoring solution that provides the broadband solar irradiance components, Global horizonal (GHI), Diffuse horizonal (DHI) and Direct normal (DNI), using a single ISO9060:2018 Class A pyranometer.

A Rotating Shadow Band (RSB) configuration utilizes a motorized rotating band to automatically shade and un-shade a single stationary irradiance sensor. This approach offers an attractive alternative to the traditional more costly and complex 2-axis solar tracker system. The procedure allows the measurement of both the GHI and DHI, while determining the DNI from the measured components. It minimizes the number of irradiance sensors required for the measurement of the irradiance components, as well as the maintenance costs associated with routine cleaning and calibration.

For broadband irradiance measurements the RSB approach has been broadly applied to non-spectrally flat with fast response silicon-based irradiance sensors. While the measurement approach benefits from the silicon sensor fast response time (< 1 ms), the non-spectrally flat response has a large contribution to the measurement error, which only through extensive characterization and correction can be minimized.

We introduce a rotating shadow band (RSB-02) developed for the EKO MS-80SH Class A fast response and spectrally flat pyranometer, and explore this configuration to measure the GHI and DHI and determine the DNI by its two operation modes (Rotating Shadow Band/Tracking Shadow Band). We also study simple correction methods to improve the DHI and DNI outputs. To quantify the accuracy of the methodologies a comparison is made against state- of-the-art solar tracking monitoring system at our research facility at the AMI solar park in Japan. The reference data quality is assessed using BSRN Quality check procedures [1–5], and the clear sky conditions are detected using Reno, M.J. and C.W. Hansen (2016) methodology [6].

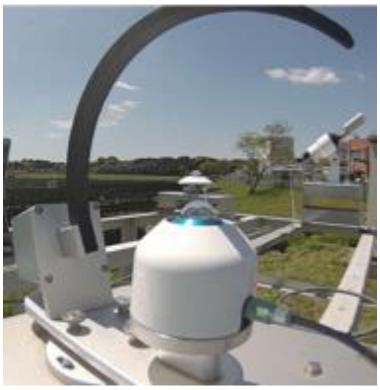

Figure 1. EKO RSB-02 Installed at the AMI Solar Park

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Novel concept for Solar Duration measurements

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We introduce the recently developed EKO MS-95S sunshine duration sensor, which combines an ultra-wide-angle lens with a silicon photodiode array sensor. The sensor is designed to accurately measure sunshine duration while maintaining a compact, low-cost, and easy-to install form factor. Notably, this sensor does not include any moving parts or require on-site adjustments. In this concept, the array quadrant sensor receives a part of the sky directed from the wide-angle lens, and through an algorithm that compares signals from each quadrant, the sunshine presence can be determined. To quantify the accuracy of the methodologies, we compare them against a state-of-the-art solar tracking monitoring system in Japan. We compare the sunshine duration data obtained from the MS-95S sensor with reference data acquired using Direct Normal Irradiance (DNI) data from an MS-57 pyrheliometer mounted on a sun-tracker. This comparison is based on the sunshine duration threshold outlined by the WMO criteria, which defines sunshine duration as the period when DNI from the sun surpasses the 120W/m^2 threshold, illuminating the Earth's surface [1].

In the presented test results we show sunshine duration measurements from the MS-95S and two commercially available SD sensors. The seasonal variations of each sunshine duration sensor model are shown in Figure 1. The seasonal variations of EKO's MS-093 and MS-955 were 5% or less.

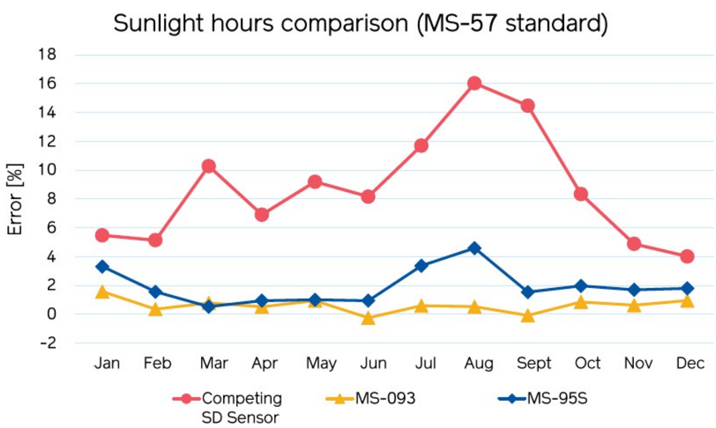

Figure 1. Comparison of monthly sunshine hours conducted in Japan from January to December 2022

References:

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Earth's radiative heat balance and climate change: Importance of surface fluxes

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We investigate the radiative heat balance of the surface-atmosphere system over the past half-century and its projection under future emission scenarios. A prime focus is the evolution of the solar and longwave fluxes, both at the top-of-the-atmosphere and surface. By comparing model simulations with satellite observations at the top and with surface flux measurements at the bottom, we examine how the radiative flux evolution has caused corresponding changes in temperature and precipitation. Using spectral line-by-line 'benchmark' radiative transfer computations, and making use of the state-of-the-art GFDL climate model, we analyze the governing factors behind the observed changes, including the roles of anthropogenic well-mixed greenhouse gases and aerosols. We analyze how the different radiative forcing agents have perturbed the surface fluxes from the past to present, the consequence this has had on the surface heat and moisture balance leading to, in turn, perturbations to evaporation and precipitation. Emission scenarios for the future spell further impacts to the surface balance relative to the present, with accompanying increase in the vigor of the hydrologic cycle. Of crucial importance is the need for sustained high-quality global surface radiation measurements in order to monitor the severity of the changes in the surface fluxes and consequently the hydrologic cycle.

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Ensuring Consistency for the NOAA Remote Observatory Stations: An Update on Operations at NOAA GML Polar Stations

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[2]NOAA Global Monitoring Laboratory, Boulder, CO, U.S.A.

The NOAA Global Monitoring Laboratory runs surface radiation measurements at several remote observatories including the South Pole, and Utqiagvik (Barrow), Alaska, which are BSRN stations. Our team has the privilege of being the second generation to run these long-term measurements, inheriting an already long record from those who started and set up the stations, and in recent years undergoing an almost complete turnover of staff running these measurements. With this change, we are taking the opportunity to modernize equipment and catch up on a historical backlog of data processing that built up during staff turnover. The Barrow station has been upgraded with a new instrumentation system when a new building was installed in 2021. We are also in the process of upgrading the system at South Pole. In particular, at the South Pole, manual clock driven trackers have been used throughout the record because the cold temperatures, below -70 deg C, were below the specifications and tolerance of the electronics of the automated trackers. However, these trackers depend on the weather and station personnel to manually adjust for declination, resulting in more missing data than an automatic tracker. Efforts are underway to modify modern tracking system that will survive the cold temperatures. In addition to these updates, we will describe some of the challenges of running stations in remote locations from unexpected events like volcanic eruptions, vandalism, and cut Arctic subsea internet cables.

Irradiance measurements at the Lampedusa Oceanographic Observatory: Strengths and disturbances

Alcide G. di Sarra[1], Damiano Sferlazzo[2], Daniela Meloni[3], Fabrizio Anello[4], Lorenzo De Silvestri[1], Tatiana Di Iorio[1], Francesco Monteleone[4], Giandomenico Pace[1], Salvatore Piacentino[4]

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The ENEA Oceanographic Observatory (OO, 35.49° N, 12.47° E) at Lampedusa island is an elastic beacon buoy designed to minimize rotations and oscillations, thus to allow as accurate as possible radiation measurements over the sea. Kipp&Zonen CMP21 pyranometers and CGR4 pyrgeometers for measurement of the downward shortwave and longwave irradiance,

respectively, are installed at about 8 m amsl. The East-West and North-South levelling is monitored with electronic levels. Data are collected every second with a Campbell Scientific datalogger. The radiometers are calibrated with reference instruments at the Atmospheric Observatory (AO, 35.52° N, 12.63° E) before and after installation at the buoy.

The installation on the buoy limits the possibility of using ventilation systems and of regular cleaning of the instruments. Nonetheless, the comparison of OO radiation measurements with those carried out at the AO suggests that the impacts of the moving platform and poor dome cleaning are minor at this site [di Sarra et al., 2019]. The availability of the additional measurements at the AO represents a great advantage not only for the radiometers' calibration, but also for interpreting irradiance measurements changes at the buoy due to either atmospheric phenomena or other disturbances.

This presentation provides an insight into the marine radiation measurements, addressing issues linked to the effects of precipitation, steep changes in irradiance values after cleansing of the instruments, disturbances such as birds and possible remedies. For example, we explored the possibility of using a 0.3 mm diameter nylon wire above the radiometers to discourage birds from staying upon them. Conducted tests show that the wire produces a detectable effect on pyranometer signals in cloud free conditions for a limited portion of the day, while no detectable effect is found on the pyrgeometer data.

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Status report of BSRN stations operated by JMA

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JMA has conducted surface radiation observation as a part of BSRN at Syowa (SYO) in Antarctica since January 1994, Tateno (TAT) since February 1996 and other 4 stations (Abashiri (ABS), Fukuoka (FUA), Ishigakijima (ISH) and Minamitorishima (MNM)) since March 2010. These stations represent the radiative characteristics of each climate district (EF(SYO), Dfb (ABS), Cfa (TAT and FUA), Af (ISH), Aw (MNM), in the Köppen climate classification). The observation network of surface radiation has been helpful to monitor the radiative energy balance as well as for validation of climate models and satellite observations for the wide coverage area from tropical to boreal zone.

The apparatus for radiation observation at these stations had been operated steadily without long interruption for more than 10 years but the degradation of the apparatus had gradually appeared, and JMA planned to update the apparatus at BSRN stations in 2022. At the update, the plan of domestic surface radiation observation was reviewed to maintain the network for a long-term in the near future, and we decided to terminate of observation at FUA because the characteristics of surface radiation were similar to those of TAT. The observation at FUA was ceased in March 2024. The update had been carried out for about one and half years with very short missing periods up to 5 days and completed successfully this February.

The new instrumentation of all stations completely meets the BSRN requirements, and JMA has been conducting observations steadily at all Japanese BSRN stations and regularly reporting data to WRMC. JMA will continue to contribute to BSRN activities.

Status of the BSRN station # 3 (FLO), located in Florianopolis (Brazil)

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The BSRN station # 3 (FLO), which is located in Florianopolis, Brazil, started its operation in 1994 and operated uninterruptedly from 1994 to 2007. After battling for several years with hardware and software issues related to the solar trackers, which led to intermittent data acquisition, the station was completely renewed in 2013. On that year, a Sollys 2 solar tracker and Kipp & Zonen radiometers were acquired and installed, and the FLO station has been fully operational since then with only minor issues. For instance, during the COVID-19 pandemic, our laboratory operated with a reduced staff group, who is responsible monitoring and maintaining the station. Despite this, the FLO station has been operating with only a few problems that caused the interruption of measurements, such as, for example, the breakage of the main belt driving the solar tracker and power supply failures. Motivated by these issues, we have been developing some strategies to minimize data loss, including: (i) implementing a supervisory dashboard (Grafana) to visualize real-time data acquisition (depicted in Figure 1). It is our intention that an upgraded version of this dashboard will also perform real-time quality control in the future; (ii) adding redundancy to all radiation measurements to reduce data gaps. We already have a secondary Sollys 2 solar tracker and radiometers (though calibration is required); (iii) installing the Absolute Cavity Radiometer (calibrated in 2020 by NREL) for in-situ calibration of our sensors. Additionally, we are planning to map the horizon at the station's current location (new residential buildings were constructed nearby). Depending on the degree of obstruction, the station could be moved to our secondary facility.

Figure 1: FLO BSRN station monitoring dashboard in Grafana.

Using BSRN data for the evaluation of the satellite derived surface radiation climate data records from the EUMETSAT CM SAF

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The EUMETSAT Satellite Application Facility on Climate Monitoring generates and provides satellite-based climate data records. Recently, new editions of the SARAH and the CLARA data records, which include data on short- and longwave surface radiation, have been released: SARAH-3 (Pfeifroth et al., 2023) and CLARA-A3 (Karlsson et al., 2023). The quality of these instantaneous, daily, and monthly data records has been assessed by comparison with BSRN surface reference measurements. Here we will present our evaluation approach and the results of the comparison.

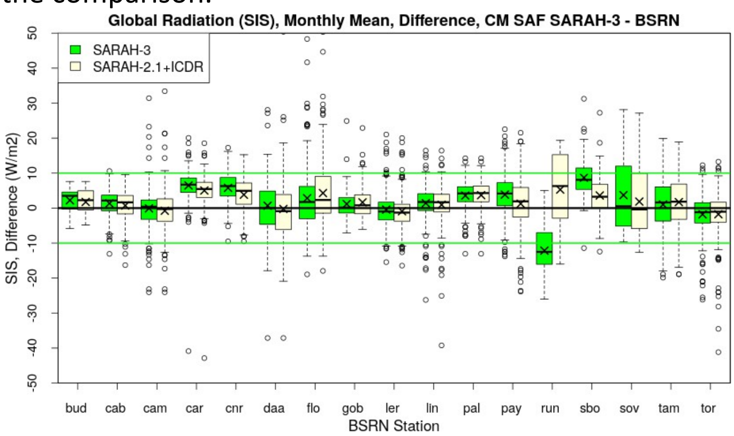

Figure 1: SARAH-3 validation results of the monthly irradiance

compared to data from the available BSRN stations.

References:

[1] Pfeifroth, Uwe; Kothe, Steffen; Drücke, Jaqueline; Trentmann, Jörg; Schröder, Marc; Selbach, Nathalie; Hollmann, Rainer (2023): Surface Radiation Data Set - Heliosat (SARAH) - Edition 3, Satellite Application Facility on Climate Monitoring, DOI:10.5676/EUM_SAF_CM/SARAH/V003, https://doi.org/10.5676/EUM_SAF_CM/SARAH/V003

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Characterizing and correcting the spatiotemporal mismatch between in-situ and satellite solar radiation measurements

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One of the main objectives of the BSRN is to provide high-quality measurements for the validation of satellite-based and model-based estimates of surface radiative fluxes. However, the different spatial and temporal characteristics of gridded and point measurements create a mismatch that can be the dominant component of the comparison.

This study proposes a data-driven framework to characterize and correct the spatiotemporal mismatch between satellite and in-situ measurement using high-resolution data, building upon the work started by Schwarz et al. 2017. First, SARAH-2 and BSRN measurements are used to characterize the spatial and temporal mismatch, respectively, at different BSRN stations. At least five years of data are needed to characterize the mismatch, which is not constant throughout the year due to the seasonal and diurnal cloud cover patterns. Second, we quantify the impact of the spatiotemporal mismatch in the validation of satellite products of different spatial and temporal resolutions. Though increasing the mismatch can artificially improve the validation metrics under some circumstances, the mismatch must be always minimized for a correct product validation. Third, we used SARAH-3 to correct the spatial mismatch of degree-scale products, CERES-SYN 4A and NASA-GEWEX SRB, evaluating how different types of up-scaling methods are affected by the quality of the high-resolution data used for upscaling.

The study analyzes BSRN stations inside the Meteosat disk (Europe, Africa, East America) to exploit the high-temporal resolution of geostationary-based products. The next step should be to apply this framework, together with the lessons learnt in the study, to polar-orbiting products (e.g., MODIS-based), deriving spatial representativeness indexes of each BSRN site to help users screen the best stations for their validations.

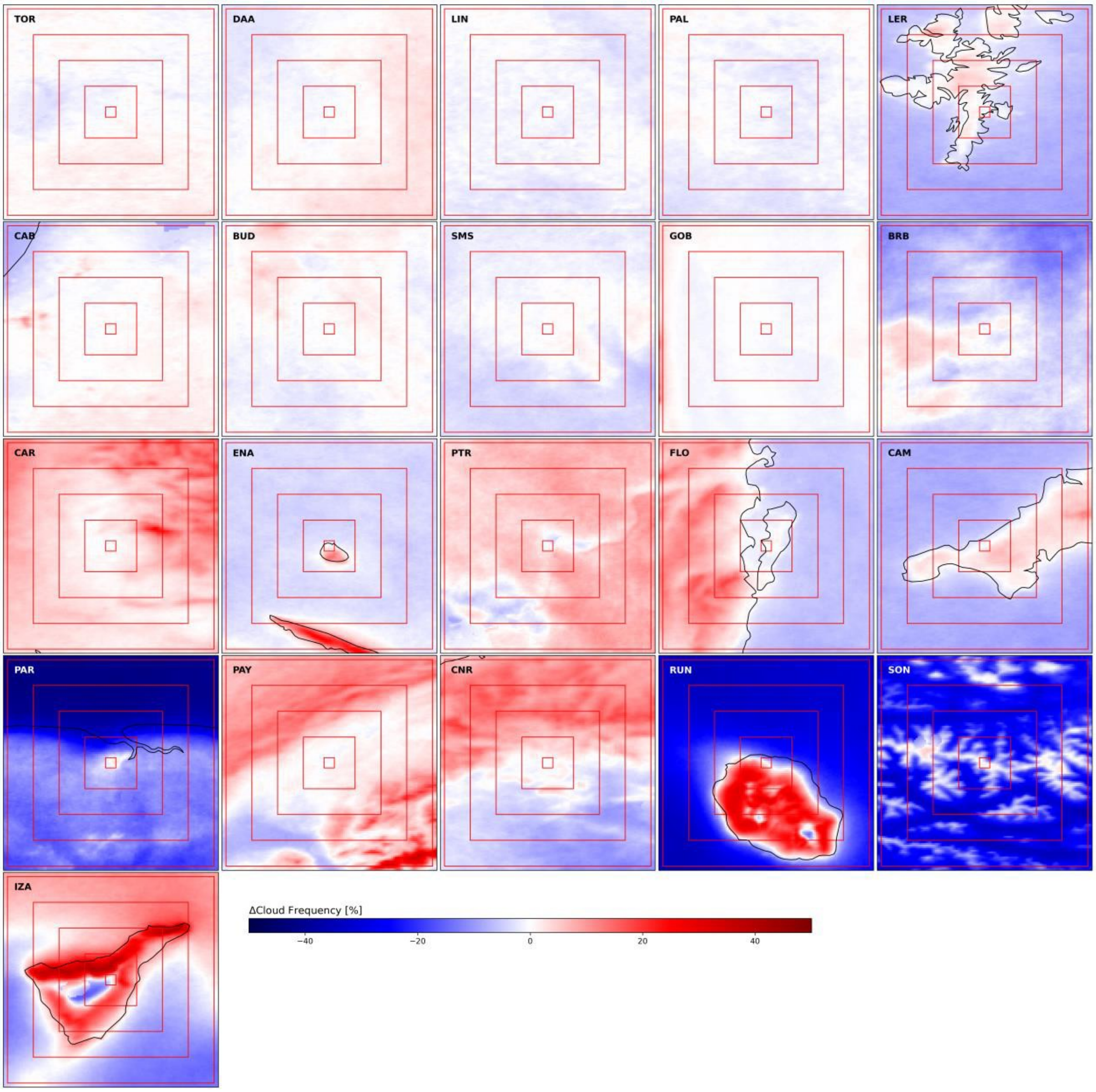

Figure 1: Cloud frequency variability around BSRN stations inside the Meteosat disk. Squares show areas of 0.05°x0.05°, 0.25°x0.25°, 0.5°x0.5°, 0.75°x0.75° and 1°x1°.

References:

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Uncertainty budget of BSRN shortwave radiation measurements

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The satellite community is moving from validation statistics to uncertainty estimates, working on providing traceable pixel-level uncertainties. In-situ measurements traditionally used as a reference for validation metrics will now be used to validate the uncertainty budgets of the satellite measurements, which implies that these networks must characterize the uncertainty of their measurements. In this context, the concept of Fiducial Reference Measurements (FRM) (Goryl et al 2023) has been developed highlighting the need for precise and well-characterized in-situ measurements tailored for the validation of satellite data. One of the main requirements of FRM networks is to provide an uncertainty characterization of the measurements traceable to reference standards. However, many reference networks, including BSRN, currently do not provide this characterization.

Building upon the work started by Vuilleumier et al. 2014, this study develops the uncertainty budget of BSRN shortwave radiation parameters including all the potential uncertainty sources affecting shortwave measurements. We evaluate the challenges to characterize all these uncertainty sources. For instance, some uncertainty sources change temporally or spatially, i.e. between stations, but the data needed to characterize them is not systematically collected. Based on this analysis, we implement a first prototype of the uncertainty budget calculating the uncertainty of each 1-min measurement at all BSRN stations. We validate the uncertainty budget by taking advantage of the redundant measurements made by BSRN: the difference between global irradiance and the global sum (direct + diffuse irradiance) has to be consistent with their total uncertainty. The validation allows (i) to assess the quality of the uncertainty estimates and (ii) to evaluate the presence of undetected quality control errors that increase the expected uncertainty of BSRN measurements. The validation exercise can be seen as a feedback loop that allows the continuous improvement of both the uncertainty budget and quality control procedures.

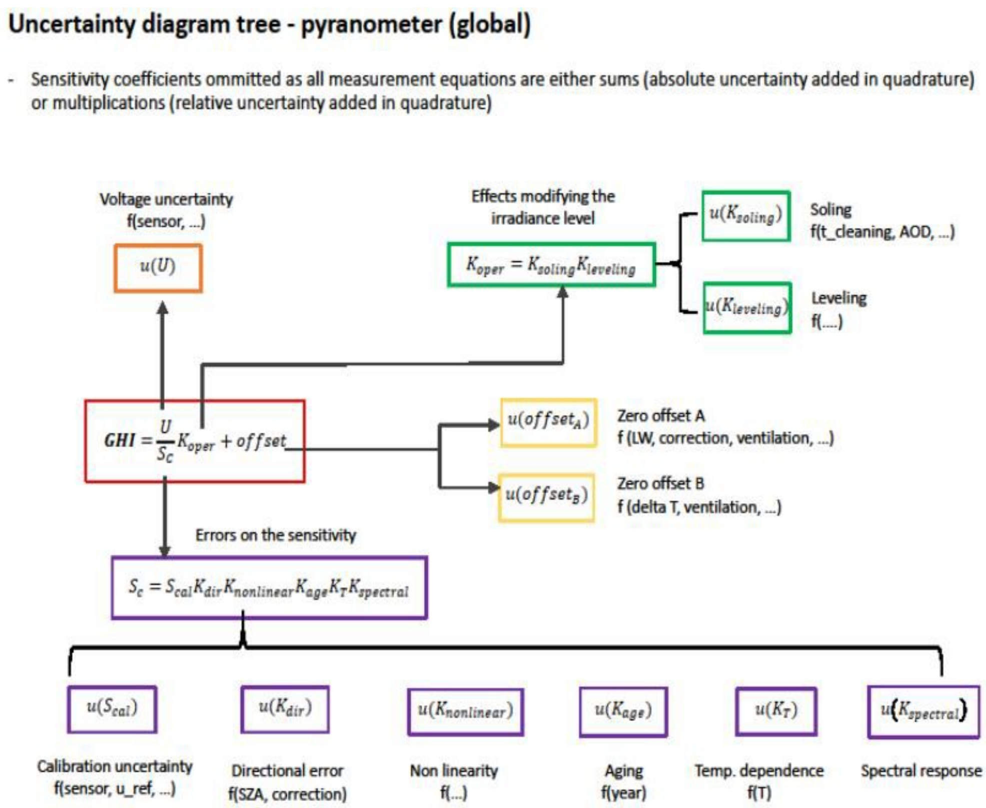

Figure 1: Uncertainty diagram tree for global horizontal irradiance measurements.

References:

[1] Goryl, P., Fox, N., Donlon, C. and Castracane, P., 2023. Fiducial Reference Measurements (FRMs): What Are They? *Remote Sensing*, 15(20), p.5017.

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Homogeneity of Downward Thermal Infrared Radiation Series

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Nyeki et al. (2019) determined trends in 20-years long time series (1996–2015) of downward thermal infrared radiation (DTIR, also called longwave downward irradiance). These time series were measured at four stations of the Swiss Alpine Climate Radiation Monitoring (SACRaM) network, including the BSRN Payerne station. Positive trends were detected at all four stations. Clear-sky trends were significant at all stations (90% confidence level), while all- sky trends are significant at all but one station. However, when extending the trend analysis beyond 2020 and analyzing the trends on different periods or using different instrument sets, the results are less coherent. While all-sky trends for 1997-2021 are significant, they are not for other periods and the values of the trends vary significantly depending on the chosen period (TABLE 1).

TABLE 1. DTIR trends in Wm^{-2}/decade computed over selected periods by Nyeki et al. (2019) and this study using the least-squares method. Trend values in italics (bold) are significant at the 90% (95%) CL.

Station	Nyeki et al. clear-sky	1996-2015 all-sky	1997-2021 all-sky	2002-2021 all-sky	2007-2021 all-sky
LOC	2.9 ± 1.8	*2.5* ± 1.9	2.8 ± 1.9	3.2 ± 2.5	3.8 ± 3.5
PAY	2.4 ± 1.9	0.9 ± 1.6	2.7 ± 1.6	4.4 ± 2.1	7.2 ± 2.9
DAV	4.8 ± 1.7	2.7 ± 1.5	4.5 ± 1.7	6.0 ± 2.3	6.2 ± 3.3
JUN	5.4 ± 1.6	4.3 ± 2.1	3.2 ± 2.4	*3.4* ± 3.5	-3.2 ± 4.5
JUN2			0.8 ± 2.5	0.1 ± 3.6	-8.1 ± 4.6

When possible, DTIR measurements were conducted with more than one collocated instrument (redundancy). For example, At Jungfraujoch (JUN), data from a second instrument are available since 2000, with an interruption during 2006-2007 and a stable configuration since the end of 2015. Only data from one instrument (main) at any given time were considered for the analysis of Nyeki et al. (2019), but a second trend analysis was performed by replacing the main instrument data with those of the other instrument since the end of 2015 (before, the same data are used). These trends (JUN2 in TABLE 1) are significantly different suggesting inhomogeneous data.

Assessing the homogeneity of radiation data is difficult due to the large variability incurred by the cloud signal. The possibility of using clear-sky data and modelling results using gridded data sets for homogeneity analysis will be explored.

References:

[1] Nyeki, S., Wacker, S., Aebi, C., Gröbner, J., Martucci, G., Vuilleumier, L., 2019, Trends in surface radiation and cloud radiative effect at four Swiss sites for the 1996–2015 period. *Atmos. Chem. Phys.*, *19*, pp. 13227–13241.

Status of the Payerne BSRN station (2024)

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The Payerne station measures the BSRN basic set of parameters since November 1992. In addition, other parameters including long-wave (LW) and short-wave (SW) irradiance at 10 and 30m a.g.l., spectral direct irradiance and UV erythemal irradiance are measured. Many measurements are made with redundant instruments, and there are many opportunities for quality control (QC) checks. These QC checks are applied daily in a first step by automatic flexible algorithm combining multiple tests. These automatic QC tests single out suspicious data that is afterward assessed visually by human operator. Following the recent BSRN request to provide Logical Records with raw data for terrestrial irradiance (monitoring with pyrgeometers of IR thermal emissions by the atmosphere and the surface), a search and compilation of raw data for all Payerne BSRN measurements since the station inception was performed. Raw data for all measurements could be found (not only terrestrial radiation) and the final data could be reconstructed with only a few exceptions: for a few periods and a couple parameters, the agreement between the final data recorded in the MeteoSwiss data base and the corresponding data reconstructed again from the raw data was less good than 1 permille, in all other cases it was better than 1 permille. Since the data transmitted to BSRN are final data extracted from the MeteoSwiss database, the same agreement should be expected with PAY data within WRMC, with the added consideration of the data precision used for the station to archive transfer files.

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30 years of observations of radiative fluxes at the Lindenberg BSRN site

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The BSRN Lindenberg site was established at the Meteorological Observatory Lindenberg – Richard Aßmann Observatory (MOL-RAO) of the German Meteorological Service (DWD) in October 1994. Since then, incoming direct, diffuse and total solar irradiance as well longwave irradiances have been observed continuously and redundantly with high accuracy using secondary standard radiometers from Kipp&Zonen. Calibrations are conducted and monitored in-situ with respect to absolute cavities and a pyrgeometer standard group directly traceable to the World Standard Group (WSG) and World Infrared Standard Group (WISG), respectively.

We will also present some results from the BSRN radiation records. While the observed increase in the incoming longwave radiation of 3.5 Wm^{-2} per decade due to increasing air temperature, humidity and greenhouse gas concentrations is consistent with the corresponding projections from climate models, the interpretation of the continuous increase in total solar irradiance of 3.5 Wm^{-2} per decade since the 1990s - referred to as brightening - is more complex. The first period of this brightening may be solely attributed to the decrease in the aerosol load. However, aerosol loads have then stabilized at low levels at the beginning of the 21st century and thus the direct aerosol effect might have been less dominant in recent years. Instead, changes in cloudiness may have become more important. Indeed, calculations of the cloud radiative effect indicate a decrease in the magnitude over the past

30 years, which may imply a decrease in cloud cover, a shift towards a different cloud type and/or changes in microphysical cloud properties.

Estimation of solar radiation using all-sky camera and validation with BSRN data

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This presentation will demonstrate a method for estimating solar radiation flux based on all-sky camera imagery installed at the Chiayi weather station. One year of all-sky images has been collected and analyzed to calculate cloud cover and solar radiation using image processing and red-blue threshold methods. The results are validated by comparing them with high-resolution radiation observation data obtained from a full set of BSRN-style instruments installed at the same weather station. Our findings indicate that incorporating Aerosol Optical Depth (AOD) in cloud amount algorithms to assess atmospheric haze, along with setting different threshold calculations, yields more accurate cloud cover estimations in images affected by high pollution haze compared to the original cloud amount products from the all-sky camera manufacturer. The radiation estimated method developed in this study exhibits a high level of consistency with BSRN data, achieving a determination coefficient (R^2) of 0.94 and a Root Mean Square Error (RMSE) of only 55.8 W m^{-2}. After adjusting for differences between estimates and BSRN observations, 93.1% of the data shows less than a 100 W m^{-2} difference, indicating the effectiveness of the method in capturing radiation flux. Furthermore, our results highlight the ability to distinguish temporary high radiation values through different radiation calculation scenarios, suggesting opportunities for further scenario refinement. Additionally, we will present short-term predictions of changes in cloud cover and radiation.

Determining the Expanded Uncertainty of Three-Component Solar Radiation Measurements

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Accurate solar irradiance data are fundamental for many applications such as understanding radiative forcing and the design and performance characteristics of photovoltaic systems. The uncertainty of solar irradiance measurements depends on many factors including radiometer design, calibration, installation, maintenance, and operational environment. The key contributors to this uncertainty can be classified as the measurement uncertainty of a particular radiometer and the operational uncertainty determined at the time of

measurement. Radiometer measurement uncertainty estimates can be based on well-established methods used as part of the radiometer calibration process. Estimates of operational uncertainties require consideration of additional site-specific factors that affect data quality. A method is needed for establishing the accuracy of solar irradiance data by integrating an existing data quality process and measurement uncertainty estimates for specific radiometers. A Solar Uncertainty Integrator (SUNI) application has been developed to integrate data quality analyses and measurement uncertainty estimates for three-component solar irradiance data: global horizontal (total hemispheric) irradiance, direct normal (beam) irradiance, and diffuse horizontal (sky) irradiance collected at one- to 60-minute intervals. The algorithm has been tested using one-minute irradiance measurements. The goal of the project is to distribute a user-friendly software package based on the new algorithm. A core uncertainty function has been implemented in Python and a graphical user interface has been developed. SUNI consolidates all necessary inputs and determines an operational uncertainty based on departure of the three coupled measurements from an expected relationship.

Figure 1 shows the process of the SUNI algorithm.

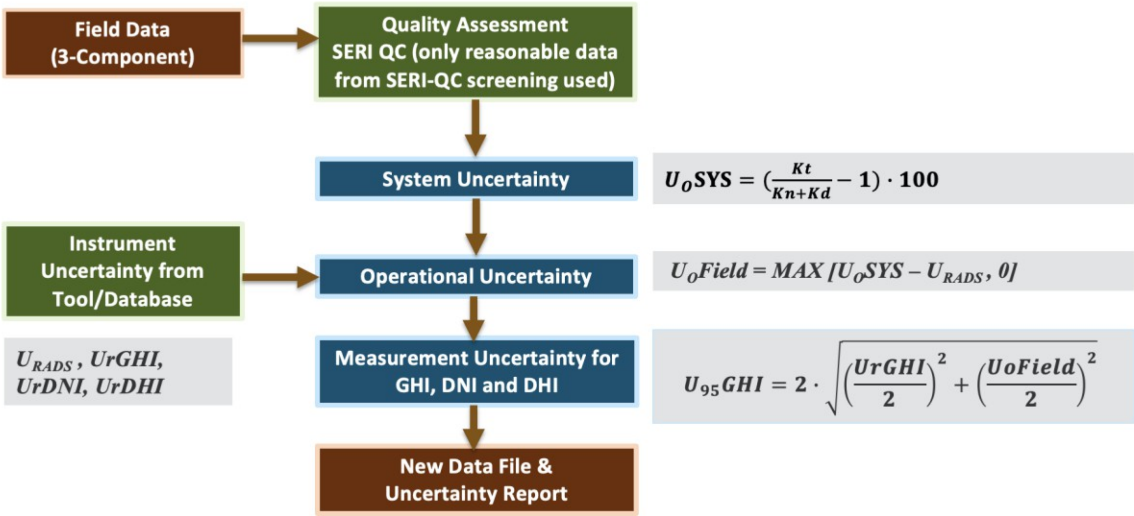

Figure 1: Flowchart demonstrating the process of SUNI application.

The goal of the SUNI algorithm is to integrate the measurement uncertainties of radiometers with detectable operational uncertainties that are caused by suboptimal environmental, equipment, or maintenance conditions. Using measured solar irradiance data sets, the application has shown that such errors are detectable and quantifiable, and the resulting process adds valuable information for consideration by operators and analysts performing due diligence.

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Shortwave radiometric measurements under a cold climate during winter

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To support the Baseline Surface Radiation Network initiative [1], a new radiometric station was set up in Qiqihar, China, which has a monsoon-influenced hot-summer humid continental climate (Dwa) under the Köppen–Geiger climate classification, which is extremely rare in the world. Through a two-month operation in winter, it was observed that the station suffered from some closure problems that impacted the quality of its measurements—the summation of the beam and diffuse components do not agree well with the global one. This work therefore investigates the possible causes of the problems and presents a set of quality checks to identify the causes. It is found that the problems originate from the mis-leveling of the sun tracker and frost deposition on the pyrheliometer, and once they are fixed, the closure relationship is maintained.

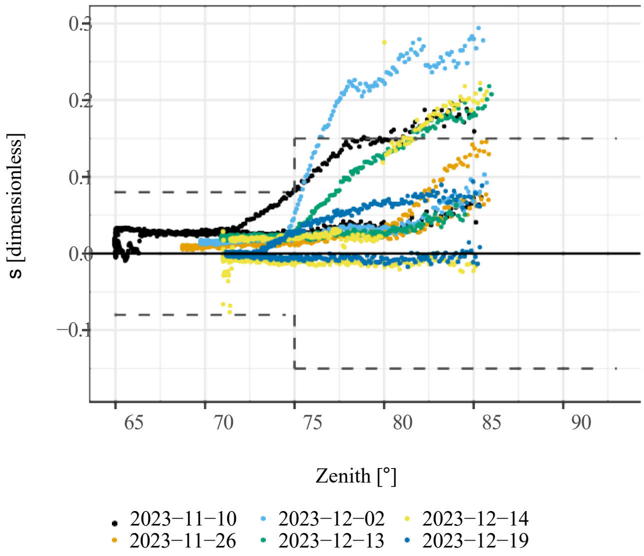

Figure 1: The non-closure problem of shortwave irradiance components on six selected days.

References:

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The Use of the BSRN Data as A Benchmark for the POWER hourly DHI and DNI and In Validating Derived Hourly GTI

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The satellite-based CERES SYN1deg hourly data is the source data of the POWER GIS solar data that covers 2001 to near present. The SYN1deg (Ed4.1) hourly GHI agrees well with the BSRN data, but the hourly DHI and DirHI (Direct Horizontal Irradiance) are positively and negatively, respectively, biased with appreciable magnitudes. The hourly DNI, derived by dividing the DirHI by cos (SZA), or the cosine of the solar zenith angle, is therefore negatively biased. Based on the statistics of comparisons with the BSRN data, we performed bias corrections on the hourly DHI and DNI. The corrections were executed in the 3-D phase space of latitude, cos (SZA), and cloud fraction (CLFR). The isotropic model is then used to derive the hourly global tilted irradiance (GTI). For validation purpose, we applied the isotropic model to the BSRN data at the original 1-, 2-, 3- or 5-minute interval. The satellite-based hourly GTI shows good agreement with their BSRN counterpart. We also examined two monthly-mean- based methods that empirically derive monthly mean GTI and DNI from monthly mean GHI and from both monthly mean GHI and DHI. The monthly-mean-based results compare favorably with the hourly-mean-based results.

The GEWEX SRB (V4-IP) provides POWER with daily mean GHI for the years before the CERES era, and the data were corrected using quantile mapping by referencing the CERES SYN1deg data. We used the Kolmogorov -Smirnov test (K-S test) and Cramer-von Mises test to examine how well the results agree with the BSRN data. We found that if we set the lower limit for the daily mean GHI to 30 W m^{-2}, the data can pass the K-S test at 0.01 significance level and the Cramer-von Mises test at 0.001 significance level. If no lower limit is set on the daily means, the data fail both tests.