BASELINE SURFACE RADIATION NETWORK

WORLD CLIMATE RESEARCH PROGRAMME

AN OVERVIEW OF THE REQUIREMENTS AND OPERATIONAL ISSUES

Derived from the BSRN Operations Manual Version 2.1

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June 2009

INTRODUCTION

The BSRN manual represents the highest quality of solar radiation measurement currently achievable using commercially available equipment.

The individual user may not wish to apply to join the BSRN and may not share the specific objectives of the BSRN. Reasons of cost, location and local equipment preferences may restrict the ability to fully comply with all the requirements. However, the Manual still represents an excellent guide to best practice in the establishment of a 'reference' quality solar radiation monitoring station.

This overview is adapted from the BSRN Operations Manual Version 2.1 published in April 2004 and only covers solar radiation, not Aerosol Optical Depth or proposed ultraviolet and PAR measurements.

A list of the Kipp & Zonen products particularly suited to use in BSRN stations is given at the end.

ORIGIN OF THE BASELINE SURFACE RADIATON NETWORK (BSRN)

Solar radiation drives almost every dynamic process on the Earth's surface and above, from ocean current circulation to weather, climate and life itself in all forms. The accurate determination of the radiation budget at the surface of the Earth is fundamental to understanding the Earth's climate system, climate variability and also climate change resulting from human influence. Issues include Global Warming and Global Dimming. Small changes can have large and long-lasting effects.

Global estimates of the surface radiation budget cannot be inferred reliably from satellite observations. Instruments on-board satellites are usually some form of spectral device. They suffer large shocks during deployment and cannot be serviced or calibrated in space. Although designed to operate in extreme conditions they change characteristics with time and may be operational for up to 20 years, in fact the measurements are not traceable. Satellites require high accuracy surface-based measurements at various sites in contrasting climatic regions for calibration and validation. Long-term observations of the same high accuracy are also required to assess trends within climatic regions. Such measurements are essential in assessing theoretical treatments of radiative transfer in the atmosphere, verifying climate model computations, and for studying trends in surface radiation at scales smaller than normally associated with climatic regions.

To meet these requirements, the World Climate Research Programme (WCRP), jointly sponsored by the World Meteorological Organization (WMO), the International Council of Scientific Unions (ICSU) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO, initiated the Baseline Surface Radiation Network (BSRN). The goal of this network is to provide continuous, long-term, frequently sampled, **state-of-the-art measurements of surface radiation fluxes adhering to the highest achievable standards of measurement procedures, calibration and accuracy.**

Many nations have expressed strong interest in participating in the BSRN and a range of stations in locations as diverse as the Arctic, mid-latitude forests, plains, high mountainous regions, tropical rainforest, desert, and tropical islands have been established or are in the process of being installed.

The operation of each station, or group of stations, is managed by a qualified scientist who has expertise in the measurement of radiation. Some sites have been specifically established for making measurements to determine local climate trends and to provide accurate ground-truth for satellite observations. Other sites have been observing radiation components for many years, but have been enhanced to meet the accuracy and resolution objectives of the BSRN. Some sites were made part of the BSRN because of their importance with respect to climate or geography although they did not fully conform to the standards set out by the BSRN at the time. These observatories were given until 1997 to upgrade to meet the specifications as originally adopted and then set forth in the implementation documentation. Whether a site is new or has been in operation for many years, operators and scientists can learn from each other to improve the measurement of surface radiation budget parameters at there own observatories. Not all sites have been upgraded to the latest standard.

The purpose of the BSRN manual is to provide a standardized guide to measurement techniques for all stations involved in the programme based on the experiences gained from a variety of researchers and site scientists. Recognizing that site-scientists are responsible not only to the BSRN, but to their own agencies, some of the guidelines presented in the manual may not be implemented fully. Others, because of climatic conditions, may have special requirements such as an extended operating temperature range. As stated throughout the manual, the goal of the BSRN is to obtain radiation and ancillary measurements of **the highest quality possible**. This requires that each station manager adapt the techniques presented in the manual to the station for which they are responsible.

OVERALL GOALS AND PURPOSE OF THE BSRN

The original concept for the BSRN developed from the needs of both the climate change and satellite validation communities. The initial plan for a global network of radiation stations was developed by the WCRP Working Group on Radiative Fluxes (WGRF) in 1989, and refined at two workshops on the implementation of the BSRN, in Washington, DC in December 1990, and in Davos, Switzerland in August 1991.

The formal goals and objectives were set down as follows:

- To provide data for calibrating satellite-based estimates of the surface radiation budget (SRB) and radiation transfer through the atmosphere.
- To monitor regional trends in radiation fluxes at the Earth's surface.

With the important contribution to global climate research made by the BSRN, it is emphasized that countries assuming the responsibility of operating a BSRN station will benefit significantly from having a reference surface radiation measurement station, especially in the context of national efforts to exploit environmentally clean renewable energy resources and, to some extent, in enhancing agricultural production. These issues have increased in importance with respect to the impact and implications of the Kyoto Protocol.

The measurements from a BSRN station are also a key element in monitoring national and regional climate variations, and in assessing the associated economic implications. In countries where radiation networks already exist, the instrumentation and operational procedures developed for the BSRN can be used as effective arguments to upgrade equipment and methods of observation, and to enhance calibration traceability to the World Radiation Centre in Davos. In summary, BSRN data sets have a wide range of applications beyond climate research.

BSRN is also associated with the WMO Global Atmosphere Watch (GAW), the Atmospheric Radiation Measurement (ARM) Program, the WCRP Global Energy and Water Cycle Experiment (GEWEX) and the Global Climate Observing System (GCOS).

PURPOSE AND SCOPE THE BSRN OPERATIONS MANUAL

In developing a network like the BSRN, decisions need to be made on such questions as:

- Which equipment should be purchased, based upon the estimated accuracy, cost and maintenance requirements?
- Where, and for how long should the measurements be made?
- How will the instrumentation be maintained at each location?
- How will the data be quality controlled and archived?

In the BSRN, standards of measurement accuracy and archiving have been clearly defined, but the exact manner in which these standards can be achieved is left to national experts responsible for carrying out the measurements. This is because a number of commercially available instruments can perform to the desired accuracy when used properly and maintenance, quality control and data archival are determined by the circumstances of individual stations, national constraints and station procedures. The BSRN Operations Manual is a guide to achieving the best quality results.

This manner of developing a network has strengths and weaknesses. Its greatest strength is the ability for regional experts to operate a station designed especially for the regime in which it exists, and that the operation of each station is closely monitored scientifically. On the other hand, achieving a high degree of standardization in overall BSRN procedures is more difficult. For example, the solutions to problems at one station may not be applicable to any other stations because of the dependency on particular equipment or national requirements. Thus, while each station may be the best possible for any given set of circumstances, the ability to transfer expertise from one station to another is more difficult.

SPECIFIC OBJECTIVES AND RESEARCH ACTIVITIES

The specific objectives of the BSRN are:

- To measure the surface radiation components at strategic locations with a demonstrated accuracy and precision sufficient for revealing long-term trends.
- To obtain concurrent measurements of atmospheric constituents such as clouds, water vapour, ozone and aerosols that affect the radiation at the surface and at the top of the atmosphere.
- To assure uniform adherence to the highest achievable standards of procedure, accuracy and calibration throughout the network.

The associated activities and research goals are:

- Site Characterization: Acquisition of quantitative information on features such as the nature of the surface, average cloud cover and type, aerosols, etc., that characterize the site for satellite applications.
- Infrared Irradiance Measurements: Advancing state-of-the-art instrumentation and methods of observation for accurate measurement of down-welling radiance and irradiance measurements to meet Surface Radiation Budget (SRB) measurement standards.
- Extended-Surface Reflectance and In-situ Measurements: Development of methods for measuring surface reflectance over a larger area (e.g., 20 x 20 km) to collect in-situ information to validate remote sensing measurements.
- Atmospheric Inhomogeneities: Studies to improve the understanding and measurement of the radiative features of inhomogeneous and broken clouds.
- Special Measurements: Development of cost-effective instrumentation and methods for measurement of spectral ultraviolet and infrared SRB that will aid the improvement of satellite algorithm design and validation of satellite SRB determinations.
- Improvement of Instrumentation: Investigations to improve the design and performance of “standardized” instrumentation such as sun photometers and pyranometers, and to incorporate, improve, and develop more sophisticated remote sensing instrumentation to enhance the cloud-observing abilities of the BSRN.

While the objectives and goals have been laid down specifically for climate research, the impact of the BSRN concept is far wider than just this one community. By providing a standard means of measuring radiation to a known accuracy, other programs and countries can implement these ideas with little added effort. Other programs such as the Global Atmosphere Watch (GAW) and the Atmospheric Radiation Measurement (ARM) Program have implemented ideas presented in the early BSRN documents.

Countries presently developing radiation networks, or upgrading older networks, can also benefit from results of the ongoing research conducted specifically to improve the measurement of solar and terrestrial fluxes using commercially available instrumentation. The quality control and archiving procedures can be used with little modification for many other radiation networks. These improvements in measurement techniques, quality assurance and quality control can be used for networks involved in the measurement of solar radiation for such diverse applications as passive and active solar energy utilization and cloud absorption modelling. Moreover, efforts to install networks to observe UV and ozone could readily build on an established BSRN station designed to operate according to the highest achievable standards.

REQUIRED RADIATION MEASUREMENTS

The target accuracies are based upon state-of-the-art commercially available equipment. At the onset of the BSRN programme, a table listing the uncertainties about individual flux measurements was produced that included the uncertainties thought to be achievable by 1997. These uncertainty values have now been achieved, using new sensors and methods of observation, some being surpassed. Accordingly, new targets have been set in the 2004 Manual.

BSRN Target Measurement Uncertainty			
Quantity	**1991**	**1997 Target**	**2004 Target**
Basic BSRN Station			
Direct Solar Irradiance		1% or 2 W/m^2	0.5% or 1.5 W/m^2
Diffuse Solar Radiation	10 W/m^2	4% or 5 W/m^2	2% or 3 W/m^2
Global Solar Radiation	15 W/m^2	2% or 5 W/m^2	2% or 5 W/m^2
Down-welling Infrared Radiation	30 W/m^2	5% or 10 W/m^2	2% or 3 W/m^2
Expanded BSRN Station			
Reflected Solar Radiation	15 W/m^2	5%	3%
Up-welling Infrared Radiation	30 W/m^2	5% or 10 W/m^2	2% or 3 W/m^2

The International Standards Organisation (ISO) Guide to the Expression of Uncertainty Measurement (GUM) provides a standard method for the determination of uncertainty in measurement and this method is recommended by the BSRN.

Direct Solar Irradiance

- The pyrheliometer should have a flat spectral response in the range 290 nm to 4000 nm.
- The pyrheliometer body temperature must be monitored.
- Each station should have access to an Absolute Cavity Radiometer (ACR). This is to maintain a radiometric calibration linkage to the World Radiation Centre reference group in Davos, Switzerland and to periodically calibrate the working pyrheliometer and pyranometers on-site.

Diffuse Solar Radiation

- The pyranometer must be ventilated.
- The dome and detector must be completely shaded by a ball or disk on the sun tracker.
- The shading must be equivalent to a 5° field of view.
- The pyranometer body temperature must be monitored.

Sun Tracker

- The sun tracker for the pyrheliometer must have a positioning accuracy of ± 0.1°or better.
- Active tracking using a 4-element ‘quadrant’ sun sensor is recommended.
- The sun tracker must be capable of also mounting an Absolute Cavity Radiometer when required for periodic calibration of the pyrheliometer and pyranometers.
- The diffuse pyranometer must be accurately shaded at al times during measurements.

Global Solar Radiation

- The pyranometer must be ventilated.
- The pyranometer body temperature must be monitored.
- The pyranometer must be of the same type as used for the diffuse measurements.

Down-Welling Infrared Radiation

- The pyrgeometer must be ventilated.
- The dome and detector must be completely shaded by a ball or disk on the sun tracker.
- The shading must be equivalent to a 5° field of view.
- The pyrgeometer body temperature must be monitored.

Note: An Eppley PIR only meets the requirements when modified with 3 dome thermistors, which must be monitored and corrections applied, in addition to the body thermistor. The battery powered compensation circuit must be disconnected.

Reflected Solar Radiation
For stations with the Expanded Measurement Programme

- The pyranometer must be ventilated.
- The pyranometer body temperature must be monitored.
- The pyranometer must be of the same type as used for the diffuse measurements.
- A shield must be used to prevent low angle direct irradiance entering the dome of the pyranometer; the nadir angle should be not more than 5°.
- The pyranometer must be at least 30m above a representative surface.

Up-Welling Infrared Radiation
For stations with the Expanded Measurement Programme

- The pyrgeometer must be ventilated.
- The pyrgeometer body temperature must be monitored.
- The pyrgeometer must be of the same type as used for the down-welling measurements.
- A shield must be used to prevent low angle direct irradiance entering the dome of the pyrgeometer. The nadir angle should be not more than 5°.
- The pyrgeometer must be at least 30m above a representative surface.

DATA ACQUISITION SYSTEM

Instruments should be connected to differential inputs of the data acquisition system to minimise offsets within the system.

Measurement Sampling Frequency
All radiation variables shall be sampled at 1 Hz with an averaging time of one minute.
The final output for each variable should consist of:

- one-minute mean;
- minimum;
- maximum;
- standard deviation.

Some instruments may require the measurement of more than one signal for the calculation of a specific radiation element (e.g. for applying a 'correction' to the readings) but the archived data will consist only of the mean, minimum, maximum and standard deviation of the final calculated radiation element. The most common radiation observation made in the BSRN that requires multiple signals is infrared irradiance, where between 2 and 5 (Eppley PIR) measurements are made each second, depending on the instrument type.

Observations can be made of each of the required signals once per second and stored. Using this data, the one minute average can be calculated by applying the appropriate instrument responsivity to each voltage measurement and the appropriate effects of the case and dome temperatures (if any). The standard deviation can then be calculated from the individually calculated flux values.

Alternative methodologies for calculating the standard deviation of the fluxes are given in the BSRN Manual to allow for a variety of data acquisition systems.

Measurement Time Accuracy
The measurements must be logged with a relative time accuracy of 1 second and be capable of correction to an absolute accuracy of 1 second.

Data Acquisition Accuracy
The target uncertainty of the complete data acquisition system for radiation measurements is less than ± 0.01% of the reading or ± 1 μV, whichever is the greater. If the overall accuracy is worse than 10% of the accuracy required for the observation (e.g. 0.5 W/m2 where the required instantaneous uncertainty is 5 W/m2) a high quality amplifier should be used as close as possible to the instrument.

Many excellent data loggers that are very suitable for standard quality solar radiation measurements cannot meet the high accuracy requirements of the BSRN. In fact this requirement is only met by high performance laboratory type data acquisition systems. In practice most BSRN stations use the best quality of commercial meteorological data loggers.

METEOROLOGICAL MEASUREMENTS

When automatic data logging is employed to record such variables as pressure, temperature, humidity, wind speed and wind direction, providing these data at the same frequency as the radiation data is beneficial. Stations are encouraged to obtain these observations coincidentally with the radiation measurements using a one minute sample rate to aid in understanding the energy balance of the radiation. Complete recommendations can be found in the BSRN Operations Manual.

As a minimum requirement, all stations should record air temperature at the same location and at the same sampling frequency as the radiation measurements. The temperature measurement should have a resolution of 0.1°C and an uncertainty of less than ± 0.3°C.

INSTRUMENT PLATFORMS & CABLES

Supports for the instruments, in particular the sun tracker, must be robust and rigid. They must not warp with temperature and humidity changes or move or vibrate in strong winds. Wood must not be used. Ideally, platforms should be stable to better than ± 0.05°. Cable lengths should be minimised, and in any case signal cables from the instruments should be no more than 50m long.

LOCATION OF SITE

In selecting sites for the Baseline Surface Radiation Network, the objective is to choose a site which is representative of a relatively large area (greater than 100 km2) with common features. The site location should be consistent with the intended purpose for which the observations are being made. For example, a site which has a unique microclimate within a larger region should not be selected as a site for regional climate observations. This is particularly important for stations with the Expanded Measurement Programme measuring reflected solar radiation and up-welling infrared radiation.

The location should not be close to major roads, sources of dust, airborne pollution and aerosols and not regularly over-flown by aircraft. Ideally there should be a clear view to the horizon in all directions, but this is often not achievable. In practice it is acceptable if any obstructions within the azimuth range from sunrise to sunset over the year subtend an elevation angle of less than 5°. The main requirement is that the direct radiation should not be obstructed at any time.

Normally BSRN stations are co-located with high quality, fully manned, meteorological sites.

INSTALLATION OF INSTRUMENTS

This is done according to the manufacturers recommendations and with due regard to the local environmental conditions, such as protection from birds, insects and animals, waterproofing cable connections, etc. Particularly important is the levelling of the sun tracker and instruments to within ± 1° of horizontal.

Ventilation units are required for areas subject to dust, dew, frost and precipitation to increase the measurement up-time. Ventilation also stabilises the instrument against thermal shocks and reduces thermal offsets.

For stations with the Expanded Measurement Programme, measuring reflected solar radiation and up-welling infrared radiation, the downwards facing instruments should be mounted on arms from an open design tower at least 30m above the surface.

Careful attention should be paid to grounding / screening requirements and to lightning protection.

MAINTENANCE

Maintenance of the instruments in peak condition is essential for high quality measurement data.
All maintenance carried out, and corrective actions undertaken, should be recorded.

Daily Maintenance

- Clean optical windows and domes (including the sun position sensor of active trackers) using a soft lint-free cloth and inspect for marks or damage. If there are any deposits present use deionised water or an alcohol that will leave no residue to clean. Ideally cleaning should be before sunrise, to maximise measurement time.
- Where frost or ice cannot be removed by wiping, warm the dome gently (e.g. by using a hair-dryer). Never scrape ice off a dome or window.
- Check for condensation within the outer domes of pyranometers.
- Check that the instruments and sun tracker are level.
- Check that the pyrheliometer and shading balls are correctly aligned.
- Check cables for damage.
- Check ventilation unit fans are operating.
- Check that the data acquisition system is operating correctly.

Weekly Maintenance

- Check the desiccant in each instrument and replace if necessary, usually the desiccant will last several months. When replacing desiccant check the o-ring seal for damage and replace if necessary.
- Clean radiation shields.
- Check and record the resistance of each instrument at the data acquisition end of the signal cable (disconnect cable from DAS input first).
- Use a reference voltage source at each input to check the correct operation of the data acquisition system.

Note: For users not operating within the BSRN, the data acquisition system checks could be carried out less frequently, or only when a problem is suspected.

Six-monthly Maintenance

- Calibrate pyranometers and pyrheliometer with the ACR. Swap the global and diffuse pyranometers.
- Calibrate the pyrgeometers
- Replace any items showing signs of deterioration (e.g. cables).
- Check ventilation unit filters and clean or replace as necessary (more frequent inspection may be necessary in dusty environments.
- Check seals of weatherproof enclosures, apply grease if necessary.
- Service sun tracker as recommended by the manufacturer.

Annual Maintenance

- Calibrate Absolute Cavity Radiometer.
- Loosen, lubricate and retighten all fixings, connectors, etc.
- Calibrate the data acquisition system.

KIPP & ZONEN PRODUCTS SUITABLE FOR BSRN STATIONS

Sun Tracker

The 2AP Sun Tracker exceeds the requirements of BSRN and is widely used in measurement programmes around the world, including at Antarctic research stations.

For BSRN the 2AP is usually supplied with active tracking using a quadrant Sun Sensor Kit. The Shading Ball Assembly mounts and shades up to 3 ventilated instruments and there are mountings for up to 4 pyrheliometers. Mounting Kits are available for the PMOD-WRC PMO 6 and the Eppley HF/AHF Absolute Cavity Radiometers.

For ease of installation the 2AP has a strong and rigid Tripod Floor Stand. An optional Cold Weather Cover allows operation down to - 20°C and the optional Heater Kit extends it down to - 50°C.

Where the conditions are less extreme, the SOLYS 2 sun tracker can be used. This has mountings for one pyrheliometer, a similar Shading Ball Assembly to the 2AP and an optional Sun Sensor. There are mounting kits for a second pyrheliometer or an Absolute Cavity Radiometer.

Pyrheliometer
The CHP 1 Pyrheliometer meets all the requirements of BSRN. It has a quartz window to provide the required spectral response range and a double-tube construction to minimise the thermal shock effects of wind and rain. There are integrated alignment aids.

CHP 1 is supplied as standard with both 10K Thermistor and Pt-100 body temperature sensors and individually measured temperature dependence for the instrument sensitivity.

Pyranometers
The CMP 21 and CMP 22 Pyranometers meet all the requirements of BSRN. They have high quality waterproof connectors for ease of exchange and calibration. The desiccant cartridge can be simply unscrewed and the highly accurate bubble level can be seen without removing the clip-on sun shield.

The CMP 21 is a scientific standard pyranometer with precision glass domes for very good cosine response. It is supplied as standard with a 10K Thermistor body temperature sensor and individually measured temperature dependence for the instrument sensitivity. Each unit has the directional error (cosine response) measured and supplied.

The CMP 22 is similar to the CMP 21 but has quartz domes which extend the spectral range of the pyranometer to match the pyrheliometer requirement. It has the best cosine response and lowest thermal offsets currently available.

Note: For the user who does not wish to join the BSRN, the lower cost CMP 11 can be used. This is a CMP 21 without a temperature sensor fitted and without the individual testing and optimisation.

Pyrgeometer
The CGR 4 Pyrgeometer meets all the requirements of BSRN and has the convenient design features of the CMP 21 and CMP 22. CGR 4 has a specially designed Silicon meniscus dome with an internal solar-blind optical filter coating and an external hard-carbon (synthetic diamond) coating. The unique thermal coupling of the dome to the housing provides the lowest thermal offsets available and no dome temperature measurement or correction is necessary.

CGR 4 is supplied as standard with a 10K Thermistor body temperature sensor and individually measured temperature dependence for the instrument sensitivity.

Ventilation Unit
The CVF 3 Ventilation Unit is specifically designed for the CMP Pyranometers and the CGR 4 Pyrgeometer. The Ventilation Unit is mounted to the Sun Tracker and then the radiometer is mounted on the CVF 3 base plate. After levelling, the cover is fitted.

The fan and heaters run from 12 VDC and the fan inlet has a washable and replaceable foam air filter. To aid maintenance checks, the bubble level of the instrument can be seen without removing the Ventilation Unit cover. The heaters are normally switched by a user-supplied control thermostat. A pulse output allows the fan operation to be remotely monitored.

Data Logger
As explained previously, many excellent data loggers that are very suitable for high quality solar radiation measurements cannot meet the high performance targets of the BSRN; this requirement is only met by high performance laboratory type data acquisition systems.

Many BSRN stations use the CR 10, and later CR 10X, data loggers from Campbell Scientific Inc. These have been replaced by the CR 1000, which is significantly better. The CR 3000 is one of the best performance data loggers available, but is significantly more expensive. Kipp & Zonen can supply Campbell Scientific data loggers as part of a solar radiation monitoring system.

Kipp & Zonen usually supplies the COMBILOG 1020 data logger from Friedrichs in Germany (shown in the picture at right). This is easy to programme and has a built-in display and function control, performance is broadly similar to the Campbell CR 1000.

In all cases the data loggers require weatherproof enclosures, power supplies with back-up and a means of communication for downloading the data (this could be hard-wired, GSM modem, satellite modem, etc).

Absolute Cavity Radiometer (ACR)
The only ACRs currently available commercially are the Eppley HF and AHF models and the PMO 6, developed and manufactured by PMOD-WRC in Davos. These instruments are not supplied by Kipp & Zonen, but mounting kits are available to fit them to 2AP and SOLYS 2 Sun Trackers.

Both ACRs consist of a radiometer and a separate control unit. The PMO 6 is shown in the picture at right.

Solar Radiation Monitoring System
Kipp & Zonen can supply a complete Solar Radiation Monitoring System to BSRN standards, tested and ready for installation by the user. We can also offer on-site installation and training.

The exact system configuration depends on the location, data transfer options and user requirements. Kipp & Zonen is pleased to offer advice with regard to the most suitable combination of instruments.

FURTHER INFORMATION

Brochures and manuals for the Kipp & Zonen products listed above, and for the rest of our instrumentation range can be downloaded in pdf from our website at www.kippzonen.com.

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