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WORLD CLIMATE RESEARCH PROGRAMME

BASELINE SURFACE RADIATION NETWORK (BSRN)

Report of the

SIXTH BSRN SCIENCE AND REVIEW WORKSHOP

(Melbourne, Australia, 1 - 5 May 2000)

July, 2001

WCRP Informal Report No. 17/2001

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SIXTH BSRN SCIENCE AND REVIEW WORKSHOP

1. INTRODUCTION AND OBJECTIVES OF MEETING

The Sixth Science and Review Workshop for the World Climate Research Programme (WCRP) Baseline Surface Radiation Network (BSRN) was held in Melbourne, Australia from 1 - 5 May 2000 at the kind invitation of the Australian Bureau of Meteorology (BoM). The meeting was opened at 0900 on Monday 1 May by Dr. Ellsworth Dutton, BSRN International Programme Manager and Dr. Bruce Forgan, Head of the Regional Instrumentation Centre of the BoM, who acted as host and Chairman of the meeting. Dr. Geoff Love, Deputy Director of the BoM, welcomed participants (Annex I) on behalf of the BoM and its Director, Dr. John Zillman, who was in travel status at the time of the meeting. Dr. Love reiterated the strong support of the BOM for the BSRN and its activities, noting that BoM scientists had participated in BSRN since its inception in 1990. He was also pleased to confirm the intention of the BOM to establish a second Australian BSRN station on the Cocos Islands in the Indian Ocean north west of Australia, in response to the request that had been received from the WMO/WCRP. This station was expected to become operational toward the end of 2000 and would fulfil a major requirement for another BSRN oceanic site. Dr. Hans Teunissen of the WCRP/Joint Planning Staff (JPS) welcomed participants on behalf of the WCRP and expressed the thanks of both the WCRP and the JPS to the BoM for their kind hosting of the meeting.

The Draft Agenda was reviewed and accepted after agreement of a few minor adjustments (Annex II).

Dr. Teunissen briefly reviewed the action items from the previous workshop. Most of these had been completed and/or would be addressed as part of the agenda for this meeting, including reports from the ad-hoc Working Groups that had been established at the Budapest meeting.

Dr. Dutton provided the meeting with an overview of the status of the BSRN from his perspective as the International Project Manager for the last five years and an operator of five BSRN stations. He noted the major accomplishments to date, including the establishment of a long-term archive; an operational network of 19 stations which was still growing; major advances in radiation instrumentation; development of high-quality, standardized measurement techniques and strategies; utilization of the results for scientific applications; and the biennial meetings of the BSRN community at these workshops. Dr. Dutton identified some of the major challenges facing the BSRN at the moment, including development of reference standards for infra-red (IR) irradiance and diffuse solar radiation; specifications for ultra-violet (UV), photosynthetically-active radiation (PAR) and aerosol optical depth (AOD) measurements; all-weather cavity radiometer measurement issues; adding new sites to the network and removing non-performing stations; resolving difficulties that had been encountered at the archive in recent months due to equipment and software problems; and updating the BSRN Operations Manual. All of these issues and others would be the subject of discussions during this workshop. Dr. Dutton also noted some of the current scientific applications of BSRN data, including validation of satellite measurements and algorithms; comparison with radiative transfer models and global climate model (GCM) outputs; research into atmospheric absorption and scattering; and measuring trends and variability in surface radiation at the various sites, and he looked forward to the identification of new and future scientific needs for BSRN measurements. Dr. Dutton concluded by expressing his great pleasure at the unselfish sharing of ideas and results embodied in the BSRN programme.

2. BSRN STATION STATUS

2.1 Status Reports from Existing Stations (Oral and Poster Presentations)

(All stations are 'Operational' unless otherwise noted. See Section 3 for definitions of Operational, Pending and Candidate stations. Designations indicated below include those resulting from decisions taken at this workshop.)

Billings, USA (ARM/CART SGP) (C. Long)

Dr. Chuck Long presented an overview of the status of the Billings BSRN station, which is located on the US Department of Energy, Atmospheric Radiation Measurement Program (ARM), Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site near Lamont, Oklahoma. The site includes state-of-the-art measurement systems for retrieving cloud and atmospheric properties in addition to typical BSRN-style surface radiation budget instruments. The SGP Network features a total of 21 surface radiation sites located in the north-central Oklahoma and south-eastern Kansas area, in addition to the more sophisticated resources at the SGP Central Facility. All ARM data are freely available to the scientific community. More information, and access to the ARM Data Archive, are available via the Web at http://www.arm.gov.

ARM SGP Central Facility surface radiation and meteorological data are rendered into BSRN format by the NOAA Air Resources Laboratory (ARL) Surface Radiation Research Branch (SRRB) prior to submission to the BSRN archive. Data for 1995-1997 have been entered into the archive and those for 1998 and 1999 have been submitted and await resolution of the current difficulties at the archive (see Section 3 below) for final insertion. Streamlining of the submission procedures should allow routine data submission on a monthly basis as soon as the archive is back to full operation.

Ilorin, Nigeria (R. Pinker)

Prof. Rachel Pinker, on behalf of Dr. T. Olatunde Aro, reported on recent activities at the Ilorin station. A site visit had been carried out by a team from the University of Maryland, USA, from 26 August to 10 September 1999, during which refurbishment of various instruments and installation of several new ones (UV-B sensor, two Micro Tops multi-channel sunphotometers, replacement of the CIMEL sunphotometer) had been carried out. Upgrades to data-logging equipment and software had also been effected, as well as training of local personnel in the operation of instrumentation and procedures for the station. Data from 1992 to mid-1995 were already in the BSRN archive and data to mid-1999 had been submitted.

A serious problem was highlighted involving the lack of local funding available for continuous operations at the site, as well as the difficulty in identifying and retaining adequately-trained personnel to carry out operations. It was agreed during discussions at the workshop to pursue several options which might lead to resolution of such problems, including the possibility of establishing a partnering arrangement between the University of Ilorin and the Nigerian Meteorological Services[1].

Florianopolis and Balbina (Pending), Brazil (S. Colle)

Prof. Sergio Colle presented an overview of the two stations operated in Brazil by the Solar Energy Laboratory (LABSOLAR) of the University of Santa Catarina in Florianopolis. The Florianopolis station had been submitting data continuously since 1994 and records to

[1] Such an arrangement was successfully established following the workshop.

mid-1999 were now available in the archive. Recent equipment failures were being addressed and it was expected to resume transmissions to the BSRN archive in the next few months. At the newer (and more remote) Balbina station, all radiation instruments were operational, but a number of repairs to solar trackers and ancillary sensors were still outstanding. Common to both stations was a shortage of spare parts and the availability of personnel needed to appropriately oversee the sites, especially at Balbina where lightning strikes and infestation by rodents and insects were particularly problematic. Support was being drawn from other LABSOLAR projects in the short term, but this was becoming increasingly difficult in light of shrinking budgets and current economic circumstances. A proposal aimed at overcoming some of these difficulties had recently been submitted which would involve a partnership with ELETROBRAS (Brazilian electric power agency), the Brazilian Weather Service and the Brazilian Ministry of Mines and Energy. If successful, this could overcome some of the logistical problems regarding the Balbina site but the problem of spare parts and long-term technical personnel still needed to be resolved.

Prof. Colle also briefly reviewed some of the research activities being carried out at LABSOLAR in conjunction with the BSRN station activities. These included the statistical generation of solar radiation data to fill gaps in existing records, the estimation of cloud cover using images from a digital camera together with meteorological observations and satellite imagery, and modelling the effect of forest fires on the attenuation of solar radiation at the surface.

Toravere, Estonia (A. Kallis)

The Toravere (Tartu) BSRN station is located in undulating, rural terrain in the south-eastern part of Estonia. It became operational to BSRN standards in early 1999 and is now submitting data regularly to the BSRN archive. It is hoped to upgrade some of the basic instrumentation in the near future as funding permits, as well as to expand the measurements taken to include PAR (Li-Cor quantum sensor) and ozone (Micro Tops II). It is also hoped to install a sunphotometer, in cooperation with Tartu Observatory and Tartu University.

Lindenberg, Germany (K. Behrens)

The Lindenberg BSRN site is located about 40 KM south-east of Berlin. Operations began in 1994 and improvements to the instrumentation and operation have been made regularly since that time. The transfer of the Potsdam Meteorological Observatory to the Lindenberg site has necessitated the shifting of the radiation instruments about 50 m to the west to accommodate the installation of a new laboratory building and measurement platforms. At present the complete suite of BSRN basic radiation measurements (global solar, diffuse solar, direct solar and downward long-wave) are made to full BSRN standards. Data have been submitted to the archive to the end of 1999 and additional records are awaiting resolution of current problems at the BSRN archive.

Regina (Bratt's Lake), Canada (B. McArthur)

Major improvements in the performance of the Bratt's Lake station became possible following the arrival in April 1999 of a new site scientist, Dr. David Halliwell. A number of ancillary measurements have been added and several on-site data quality assurance programmes have been improved. Access from the station to the Web has been upgraded from telephone service to a high-speed wireless connection which has dramatically reduced the time needed for data downloads to Toronto. Backlogged radiation data for 1996-1998 have been submitted to the archive and 1999 data will soon follow after solstice calibration of the pyranometers used for diffuse and global irradiance measurements. This information, when combined with that of the 1999 calibration, will allow for interpolation based on instrument responsivity changes. Automated on-site meteorological observations are expected to be incorporated into the data stream in the near future, possibly with the 1999 radiation data submission. Past records will be sent to the archive shortly thereafter.

Bratt's Lake station data (uncorrected data from the main radiation platform; direct solar, diffuse solar, global solar, and long-wave measurements; temperature and pressure) are posted on an ftp site, normally the next day, for use by the ECMWF and other interested parties (ftp://exp-studies.tor.ec.gc.ca/pub/solar/daq). Redundant measurements of the first four variables show the typical variation that can be found in instruments measuring the same quantity using standard methods of data reduction.

Payerne, Switzerland (A. Heimo)

Basic and extended measurements to full BSRN standards continue to be obtained at the Payerne site, operated by SwissMeteo. Data to December 1999 have been submitted to the BSRN archive and the first three months of year 2000 are ready to be sent as soon as the corresponding radiosonde data, including ozone profiles, become available. Following an upgrade of the field facility in September 1997, routine comparisons have been performed between operational and reference instruments and have yielded the following estimates of measurement accuracy:

- short-wave hemispherical irradiance: < 1%
- short-wave direct irradiance: < 1%
- long-wave hemispherical irradiance: < 1%
- UV effective erythemal irradiance: ~ 3%.

Corrections of the previous records are presently underway thanks to a first set of parallel measurements performed in 1994/1995 at all measurement levels (2, 10 and 30 meters). This will lead to a new version of the data towards the end of year 2000, which will then be submitted to the archive.

A new sun-tracking system, RASTA/2, has been developed which will fully meet BSRN standards (see Section 4.1.8). This new system is currently operated in a test mode in parallel with the older sun-tracker. The two units will be toggled during the coming weeks, following which a new Precision Filter Radiometer (PFR) developed by PMOD/WRC (wavelengths 368, 412, 500 and 862 nm, possibly more) will replace the older SPM photometers. This new generation of instruments, combined with the pointing accuracy of the RASTA/2 system, should allow more reliable optical depth measurements in the future.

The Payerne BSRN station is part of a wider network called the Swiss Atmospheric Radiation Monitoring (CHARM) network, of which the goals are twofold:

(i) Investigate the basic nature and distribution of radiation in the Alps in the ultraviolet, visible and infrared spectral ranges to the same accuracy standards as for BSRN stations;

(ii) Increase synergy in the field of radiation measurements among relevant Swiss institutions, which are currently the following:

- SwissMeteo, Federal Office of Meteorology and Climatology;
- Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center (PMOD/WRC);
- Institute for Climatic Research, Swiss Federal Institute of Technology (IKF/ETHZ);
- Institute for Applied Physics (IAP), University of Bern.

Tateno, Japan (Y. Hirose)

Radiation measurements currently being obtained at Tateno are: global solar, diffuse solar, direct solar and downward long-wave (i.e. the four basic BSRN measurements) as well as reflected solar, upward long-wave, and net total radiation. UV-B, AOD and ancillary variables such as surface meteorological data, radiosonde data, and atmospheric ozone are planned to be added to the routine data reports, with some of these data for the period back to 1996 soon to be submitted to the archive. During 1999 the signal cables between radiation instruments and the data logger terminal in the outdoor box were replaced with shielded cables, thereby substantially improving the signal-to-noise ratio in the measurements. Submission of data to BSRN archive is normally done on a monthly basis without delay, with data up to March 2000 having already been submitted.

USA/CMDL Sites (E. Dutton)

The NOAA CMDL program continues to operate five BSRN sites: Pt. Barrow, Alaska; Boulder, Colorado (BAO, Erie); Bermuda; Kwajalein, Marshall Islands and South Pole. All sites are operating to full BSRN specifications with the exception of a continuous absolute cavity radiometer. Measurements of albedo at 2m and about 20m at both Barrow and South Pole began in 1999. Submission of recent data to the BSRN archive has been delayed due to revision of some earlier data. Spectral aerosol optical depth measurements are made at each site and the results are available for the site scientist but have not yet been submitted to the archive, pending agreement on a standard format. Broadband UV-B and PAR measurements have been made at some of the sites but are subject to further evaluation following resolution of uncertainties in specifications and spectral requirements for these observations within the BSRN programme.

Alice Springs, Australia (B. Forgan)

The Bureau of Meteorology continues to operate the Alice Springs station in central Australia. The station is operating to full BSRN specifications with the exception of a continuous absolute cavity radiometer and ventilation of the pyranometers and pyrgeometers. Data submitted to the BSRN archive to date includes only a mean daily correction for zero irradiance signal offsets, but future submissions will include revised data with algorithmic correction for the zero offset of each one-minute record. Spectral transmission measurements are made with a variety of automatic instruments and are available directly from the site scientist, pending the establishment of a standard format for these data at the BSRN archive. Hyper-spectral UV-B measurements are expected to commence in mid-2001.

Syowa, Antarctica (Y. Hirose)

Measurement of upward radiation components (reflected solar and upward long-wave radiation) began at Syowa in April 1998, following installation of an instrument tower on the snow-covered field near the site. Consequently, radiation measurements currently carried out at Syowa, as well as the data sampling and processing system, are almost same as at Tateno (see above), the exception being the net radiation measurement at Tateno only. Problems still to be resolved at Syowa include improved cabling and grounding of the measuring system to obtain stable data and hence eliminate the signal noise which caused some of the radiation data for 1999 to be lost. Data reports with SYNOP and radiosonde measurements for 1996-1998 have been submitted to the BSRN archive via CD-ROM.

Budapest (Lorincz), Hungary (G. Major) *(Pending)*

The Lorinc station is located at the Budapest Meteorological Observatory near the southern edge of the city of Budapest. In addition to the basic suite of BSRN measurements, UV-B and spectral irradiances are also obtained. Column ozone measurements are obtained using a Brewer spectrophotometer. The first formal submission of data to the BSRN archive began with the month of October 1999.

De Aar, South Africa (D. Esterhuyse) *(Pending)*

Data collection began at the South African Weather Bureau (SAWB) De Aar station in mid-1999 following successful installation of the instruments supplied through the BSRN programme. The basic suite of BSRN measurements is recorded on a PC at the site and accessed in Pretoria (800 km away) through the SAWB Wide Area Network. Temperature, pressure and humidity are also measured as part of the routine observational programme at the site, albeit as five-minute averages at the present time. Plans are in place to upgrade to the one-minute-standard averaging time for BSRN data. Standard hourly synoptic observations are also available form the site, as well as once-per-day radiosonde flights (10:00 GMT). Data are processed and prepared for BSRN archiving in Pretoria using a set of locally-developed FORTRAN programs running on the Weather Bureau's mainframe UNIX machines. The first data-set (August 1999) was submitted to the archive earlier this year and will be followed by additional records pending feedback as to its acceptability and subsequent refinement of the processing software.

In January 2000, the following upgrades were made at the station:

- Installation of a Solar-Lite UV-biometer as part of the SAWB UV-network and UV-awareness programme;
- Installation of a Garmin GPS-36 clock for precision timekeeping, thereby eliminating the need to poll an atomic clock using the network;
- Upgrading the station PC with a multi-port serial card for quick data downloading and site archiving;
- Installation of multi-core cables from the instrument camp to the office building for carrying all instrument signals envisaged for the future (total of 72 spare cores, mostly shielded);
- Extension of lightning protection to cover all cabling;
- Improvement of routine station maintenance procedures (daily, weekly, monthly and six-monthly).

Additional upgrades planned for the near future include measurement of upwelling and reflected radiation from a 10-metere tower and cloud height measurements using a ceilometer. It is also hoped eventually to add sunphotometer measurements at the site.

Sedeh Boqer, Israel (A. Manes) *(Pending)*

The Sedeh Boqer station is operated by the Israeli Meteorological Service as part of the Solar Radiation Station Network in the Negev Desert of Israel. It is equipped with Eppley radiation instruments including an NIP pyrheliometer, PSP pyranometers and a PIR pyrgeometer. Ancillary meteorological measurements include temperature, pressure, humidity, wind speed and direction, and rainfall. A Campbell Scientific CR10 data logger is used to record the measurements. An Eppley Model AHF Absolute Cavity Radiometer (ACR) is used for regular calibration of the NIP. A second AHF instrument which was used in the 1995 International Pyrheliometer Calibration at PMOD/WRC Davos (Physikalisch-Meteorologisches Observatorium Davos/World Radiation Centre) is used for calibration traceable to the World Standard Group (WSG). The first sample set of formatted data (for February 2000) was recently sent to the BSRN archive for evaluation and feedback, in preparation for routine submission on a continuing basis in the near future.

Chesapeake Lighthouse, USA (K. Rutledge)

The Chesapeake Lighthouse ocean platform radiation measurement site is supported by the NASA CERES project. It is located in the coastal waters of the Atlantic Ocean (36°54'N, 75°42'36"W), about 25 kilometres from the coastline of Virginia, USA. The site represents a coastal case 2 water type in Jerlov's optical classification. The four basic BSRN measurements are submitted regularly to the BSRN archive. Aerosol, ocean optics, surface-wave metrics and meteorological parameters are also being archived. An automated dome/optical window cleaning system has been installed to comply with the BSRN recommendation for daily cleaning. Parallel measurements using automatically-washed, manually-washed and unwashed instruments showed the unwashed pyrheliometer windows to be seriously affected by the marine environment, with the sea-salt residue reducing the direct irradiance by as much as 20 percent. Results with the automated washing system remained within 1% of those from instruments which were manually cleaned.

2.2 New and Proposed BSRN Stations

Lauder, New Zealand (R. McKenzie) *(Pending)*

Since the 1992 re-organization of science in New Zealand, the National Institute for Water and Atmospheric Research (NIWA) has assumed responsibility for the measurement and archival of radiation data. There are approximately 50 sites with LI-COR silicon-diode sensors and 4 sites with higher-quality data (e.g. Eppley, Kipp and Zonen pyranometers) including global, diffuse, and normal incidence radiation. One of the sites with high-quality instrumentation is NIWA's atmospheric research facility at Lauder, Central Otago, New Zealand (45°2'S, 169°41'E, 370 m a.s.l.). Since 1979, the focus of research at Lauder has been on investigating the causes and effects of ozone depletion. In addition to the measurement of ozone (total column amounts and profiles) and spectral UV radiation, a large suite of trace gas measurements relevant to both ozone depletion and global warming are being made, as well as aerosol measurements (vertical profiles and optical depth parameters). Lauder is one of five global sites that comprise the international Network for the Detection of Stratospheric Change (NDSC), and as such is one of the most well-instrumented sites in the world for atmospheric research.

Since 1996, continual improvements have been made in the measurement of broad-band radiation at Lauder. This has been achieved in close collaboration with Dr Bruce Forgan at the Australian Bureau of Meteorology, with a view to eventually incorporating the radiation measurements at Lauder into the BSRN. These improvements include the addition of multi-wavelength AOD measurements to complement the existing database of aerosol profiles from LIDAR and backscatter-sondes. The new measurements have shown the Lauder site to be extremely clean, with annual mean optical depth at 1 micron of about 0.01, which is a factor of ten smaller than observed at what are generally considered to be unpolluted areas of the northern hemisphere. Such low optical depths are an important factor contributing to the relatively high levels of UV radiation observed at the Lauder site. Large geographical differences in AOD have obvious implications for programmes which seek to derive surface irradiances from satellite platforms (e.g. UV radiation from TOMS instruments).

The availability of a historical record of high-quality measurements, including relevant ancillary data, in a pristine, data sparse region of the globe make Lauder an ideal site for future BSRN activities. NIWA has an ongoing commitment to maintaining a high level of technical and scientific expertise at the site.

Cocos Islands, Australia (B. Forgan) *(Pending)*

The Bureau of Meteorology was invited to establish another site, and will establish measurements at the airport meteorological facility on the remote Cocos (Keeling) Island group in the Indian Ocean. The Cocos (Keeling) Islands (12°10'S, 96°52'E) are located in the Indian Ocean 2,950 km north-west of Perth, Australia; 3,700 km west of Darwin, Australia; and 900 km south west of Christmas Island. There are 27 coral islands in the group, with a total land area of approximately 14 km^2 and a total population less than 700. The islands form a typical horseshoe-shaped atoll surrounded by a coral reef. Each island has rough coral beaches to seaward and sandy beaches or mudflats on the lagoon side. The Islands are low lying and most are thickly covered with coconut palms. Wildlife consists mainly of seabirds, such as frigate birds and boobie birds, which are restricted to uninhabited islands. Land crabs are common on all islands. The climate is tropical with high humidity and temperatures range from 23°C to 30°C. The average rainfall is 2000 mm per annum, falling mainly from January to August. The south-east trade winds blow most of the year, producing pleasant weather conditions. The meteorological facility is a fully-staffed radiosonde station on West Island, which has a maximum elevation of 8 m a.s.l. and a population less than 150, made up mainly of staff and families of Australian government agencies. Measurements of irradiance to BSRN specifications (identical to those at the Alice Springs station), and of spectral transmission at 5 wavelengths, will commence during 2001.

Tropical West Pacific [Manus, Papua New Guinea (Pending); Nauru (Pending); Christmas Island/Kiritimati, Kiribati (Candidate)] (C. Long)

Dr. Long presented an overview of the status of the ARM Tropical Western Pacific (TWP) CART sites. Two of these island sites (Manus, Papua New Guinea and the island nation of Nauru) are currently equipped with ARM Atmospheric Radiation and Cloud Stations (ARCS), which are state-of-the-art systems for measuring BSRN-standard surface radiation budget data as well as retrieving cloud and atmospheric properties. The ARCS are designed for primarily autonomous operation in remote and hostile environments such as the salty and moist tropics and require only local observers for relatively unsophisticated daily maintenance. Data from the ARCS are monitored daily via GOES satellite transmissions. The Manus ARCS (at 2°6'S, 147°24'E) began operation in October 1996 and Nauru (0°3'S, 166°54'E) in November 1998. A third site, Kiritimati (Christmas Island), Kiribati (1°40'N, 156°52'W), could be added in the future. All ARM data are freely available to the scientific community via the ARM Web site (http://www.arm.gov).

The ARCS surface radiation and meteorological data will be rendered into BSRN format and transmitted to the BSRN archive by the Surface Radiation Research Branch (SRRB) of the NOAA Air Resources Laboratory (ARL). It is intended to begin submission of historical data in mid-2000, followed eventually by routine submission of new data at two-monthly intervals.

Zvenigorod, Russian Federation (B. Koprov) *(Candidate)*

The new BSRN station at Zvenigorod will be co-located with the Zvenigorod Scientific Station (ZSS), which is situated in pine forest near Moscow at 55°41'N, 36°46'E and an elevation of roughly 200m a.s.l. The ZSS was founded in 1959 and is operated by the Obukhov Institute of Atmospheric Physics of the Russian Academy of Sciences. The site is used for special programmes such as measurements of atmospheric spectral transmission, cloud radiation, aerosols, trace gases, clouds, and air-glow of the middle and upper atmosphere. The measurement platform for BSRN instruments will be placed on the roof of the main laboratory building at a height of 15m above ground level. All necessary preparations at the site have been completed and it is expected to begin installation of the BSRN equipment in the near future. Plans for the site include extension of the basic BSRN measurements to include actinometric and aureole photometric measurements in three spectral bands using a new sun-tracker developed by Dr. Shoukurov. A 50m mast has been erected for multi-point turbulence and radiation measurements aimed at studying the near-surface heat budget and the interaction of radiative and convective mechanisms of heat exchange between the atmosphere and the underlying surface.

3. BSRN DATA MANAGEMENT AND ARCHIVE

3.1 Status of the BSRN Archive

Dr. Olaf Albrecht, BSRN Archive Manager at the World Radiation Monitoring Centre (WRMC) of the Eidgenössische Technische Hochschule (ETH) Zürich, reported on the latest status of the archive and submissions/withdrawals of data. Considerable difficulty had been encountered since the beginning of 2000, primarily as a result of Y2K problems in the database software in use and also due to space limitations on the archive disk array. In general, the database was at least partially-operational in that users could view and download data which were entered before 1 January 2000. The main restriction involved the data entry function, which precluded the insertion of new data at the present time. The space problem had been solved through the addition of new hardware, but the software problem was taking more time. A complete replacement of the software (to Oracle 8.0.4) was required and was currently in progress. A number of additional improvements related to the identification of specific instruments and the presentation and downloading of data through the Web site were also being made. It was intended to complete this work by the autumn of 2000[2].

As of the present meeting, nineteen 'Operational'[3] BSRN stations were included in the BSRN archive (see Table 1). A total of 918 monthly files had been entered for the period from 1992 to end 1999 and were available for extraction by users. An additional 220 files had been submitted and awaited completion of the archive upgrades to permit their insertion. Fifty-two active users had withdrawn data from the archive, with that number representing a steady increase over time (29 new users in the preceding 15 months). The number of downloads per month had increased from a maximum of 70 in 1998 to over 150 in March of 2000. The average number of connections to the BSRN Web site ('hits') had reached about 9000 per month. Archive personnel were aware of the of BSRN data in 11 refereed journal papers and a number of reports and scientific presentations since January 1998 (specific references were to be placed on the archive Web site in the near future).

[2] Completion of this work has subsequently been delayed until early 2001 due to personnel changes at the BSRN archive.

[3] '**Operational**' BSRN stations are those which have submitted, and had accepted by the BSRN archive, at least one monthly data file from their site. '**Pending**' stations are those which are currently measuring data that are expected to be submitted in the near future. '**Candidate**' stations are potential future BSRN stations, or may be existing stations which are currently obtaining data for purposes other than the BSRN but which could eventually contribute to the BSRN archive.

TABLE 1

Status of the BSRN/WRMC database, May 2000

Station	Year								Total	Files not yet entered in database
	1992	1993	1994	1995	1996	1997	1998	1999		
Ny Alesund	5	12	12	12	12	12	12	3	**80**	5
Barrow	12	12	12	12	12	12	-	-	**72**	1
Toravere	-	-	-	-	-	-	-	11	**11**	4
Lindenberg	-	-	3	12	10	-	-	-	**25**	26
Regina	-	-	-	2	-	-	-	-	**2**	36
Payerne	3	12	12	12	12	12	12	1	**76**	11
Carpentras	-	-	-	-	4	12	12	8	**36**	1
Boulder	12	12	12	12	12	12	-	-	**72**	1
Chesapeake	-	-	-	-	-	-	-	2	**2**	1
Billings	-	-	-	12	12	12	-	-	**36**	24
Tateno	-	-	-	-	12	12	12	12	**48**	4
Bermuda	12	12	12	12	12	12	-	-	**72**	3
Kwajalein	9	12	12	12	12	12	1	-	**70**	-
Ilorin	4	12	12	-	-	-	-	-	**28**	54
Alice Springs	-	-	-	12	12	12	12	-	**48**	-
Florianopolis	-	-	6	12	12	12	12	7	**61**	-
Syowa	-	-	12	12	-	-	-	-	**24**	36
G. von Neumayer	9	12	12	12	12	12	12	2	**83**	12
South Pole	12	12	12	12	12	12	-	-	**72**	1
Total	**78**	**108**	**129**	**158**	**158**	**156**	**85**	**46**	**918**	**220**

3.2 BSRN Data Processing Software

Dr. Yasuo Hirose informed the meeting of upgraded BSRN data processing software that had been developed at the Japan Meteorological Agency (JMA) for use at individual BSRN stations. This software (RadProc Version 2.6) assists in all aspects of the management of local stations and ultimate preparation of data files for submission to the BSRN archive in full accordance with the specifications called for in the 1998 BSRN Technical Plan for BSRN Data Management. Copies of the software were distributed on CD-ROMs to all workshop participants.

4. INSTRUMENTATION STUDIES AND RECOMMENDATIONS

4.1 Solar Radiation Instrumentation and Technical Issues

4.1.1 Effect of Diffusometer Shading Geometry (G. Major)

Dr. Gyorgy Major reviewed the latest results of experiments carried out to estimate the variations in diffuse solar radiation measured by a range of shaded pyranometers (diffusometers). This variation results from the differing amount of direct and scattered solar radiation that may be blocked by shading devices of differing geometry. The irradiance arising from the circumsolar radiation for any instrument can be calculated from the instrument geometry and the hemispheric distribution of the circumsolar radiance (sky function). The sky function was estimated from field measurements over a period of 18 months, to include a large range of environmental conditions, and was applied to the geometries of ten diffusometers. Four of these had almost the same geometry and were treated as a 'standard' group. Corrections were then determined which could be applied to the other instruments to normalize them to the standard group.

4.1.2 Errors Due to Shading Disks for Diffusometers (A. Ohmura)

Prof. Atsumu Ohmura reviewed some recent results of analytical studies into the errors associated with shading discs on the diffuse radiation received (in the case of pyrheliometers) and blocked (in the case of diffusometers). These studies followed on from the work reported at the Budapest workshop and involved the shading discs that had been recommended at that time (8.0 mm radius for pyrheliometers and 28.0 mm for pyranometers). It was confirmed that these shading geometries satisfied the BSRN accuracy requirements for these measurements. **[1]** [4]

4.1.3 Determination of Uncertainty in Solar Irradiance Measurements (N. Hyett)

Dr. Hyett introduced the basic concepts of an uncertainty analysis as per the ISO Guide to the Uncertainty in Measurement (GUM, 1991) and demonstrated their use with examples from solar radiometry. Examples for pyrheliometer calibration and direct irradiance uncertainty showed how the GUM provides a uniform framework to establish estimates of uncertainty within BSRN. Dr. Hyett also demonstrated the utility of an uncertainty analysis in determining which components of the measurand made the highest contribution to uncertainty.

4.1.4 Stability of the Australian/WMO Region V Solar and Terrestrial Standards (P. Novotny)

Dr. Peter Novotny of the BoM described some of the activities underway in Australia concerning radiation standards for SW and LW measurements. In the case of SW, BoM maintains the national and WMO Region V regional standard group of pyrheliometers and conducts regular intercomparisons of the seven instruments within the group. Three of those instruments participate regularly in the International Pyrheliometer Comparison (IPC) experiments held every five years in Davos, Switzerland. Intercomparisons between 1980 and 1999 have shown produced variations in the long-term mean value of ratios between individual instruments to be less than 0.11%, with no identifiable trend.

The Australian terrestrial radiation standard is represented by a black body cavity radiator maintained at a uniform and constant temperature of approximately 400°K. The radiometer under test is placed inside a water-cooled chamber maintained at a constant temperature (near room temperature) and attached to the heated cavity radiator. A water-cooled shutter apparatus allows exposure of the instrument to the LW black body radiation for controlled periods of time. The 95%-confidence-level uncertainty in determining the sensitivity of an Eppley PIR pyrgeometer using this facility was originally estimated as 2.7%. Regular calibrations of a standard unit over the period 1992-1999 showed variations of less than 0.5% during this period. However, calibrations of the same unit in other laboratories showed significant differences which necessitated a re-evaluation and revision of the uncertainty estimate to 5%. A new calibration apparatus which will allow realistic simulation of field exposure conditions is currently under construction and is expected to permit determination of pyrgeometer sensitivity to better than 1.5%.

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[4] Numbers in square brackets **[ ]** refer to the Consolidated List of Decisions, Recommendations and Action Items in Annex VI.

4.1.5 Experiments with Windowed Cavity Radiometers (D. Nelson)

Preliminary results of comparisons between cavity radiometers with and without protective windows had been presented at the previous BSRN workshop in Budapest in 1998. The window material used for those measurements was a water-free quartz (Suprasil300). Results from those comparisons had not produced conclusive evidence to support the standard use of a windowed cavity radiometer for direct beam solar measurements at BSRN stations. It had been observed in particular that the measured differences between the un-windowed and windowed radiometers were variable and correlated well with modelled spectral effects of column water vapour.

Investigations have continued at the NOAA/CMDL in Boulder using calcium fluoride as a window material. The extended long-wave cut-off of calcium fluoride (~11 ì) reduces considerably the effects of atmospheric column water vapour at a location such as Boulder. Clear-sky linear regressions of windowed versus un-windowed instruments have shown residuals on the order of one watt or less throughout the day for the range of zenith angles experienced at Boulder (40°N). Investigations of the relative performance and long-term viability of the calcium fluoride and quartz windows are being continued through installation of both types of instrument at three of the BSRN sites operated by NOAA/CMDL. **[2]**

4.1.6 Thermal Offsets in Pyranometers (E. Dutton)

Recent work within and outside the BSRN community has highlighted the impact of thermal offsets in the pyranometers widely used for diffuse solar irradiance measurements. These offsets, which result from pyranometer internal domes being at significantly different temperatures than the detector surface, have long been recognised, and manufacturers have endeavoured to minimise their effects in pyranometers used for total solar irradiance measurements. It is now apparent that these thermal offsets require further consideration if the accuracy standards for the BSRN are to be achieved. Dr. Dutton reviewed methods of identifying and evaluating the offset errors, including comparisons to near-Rayleigh scattering conditions, IR-reflective capping, comparisons to black-and-white differential-absorption detectors, and night-time mapping to pyrgeometer responses, noting that a paper reporting the results of comparisons involving the pyranometer used at a number of BSRN sites would soon be published[5].

Additional work is needed to asses the impact of the offsets in the various types of instruments used. Dr. Dutton, on behalf of the Ad-hoc Working Group on Pyranometer Offsets which is monitoring this issue for the BSRN community, proposed that a 'capping experiment' (detailed in Annex III) be carried out at all BSRN stations to investigate the degree of daytime thermal offsets in the shaded pyranometers used for diffuse solar radiation measurements. **[3,4,5]**

4.1.7 Investigations of Night-Time Zero-Offset Effects on Short-Wave Radiation Measurements (K. Behrens)

Two specific recommendations from the Budapest workshop concerning night-time offsets in pyranometers were: "to determine offsets in the exact configuration in which the instrument is used in the filed, including all shielding and ventilation techniques", and "to identify any offsets in the data acquisition and processing system". Klaus Behrens reported on a series of filed experiments that had been carried out in response to these

[5] Subsequently published as: Dutton, E.G. et al., Measurement of Broadband Diffuse Solar Irradiance Using Current Commercial Instrumentation with a Correction for Thermal Offset Errors. *J. Atmos. Oceanic Technol.,* **18,** 297-314, March 2001.

recommendations using three new CM21 pyranometers with differing degrees of ventilation, an ultrasonic anemometer to monitor field conditions and an Eppley PIR pyrgeometer. The main conclusion of this work was that it is not necessary to correct for night-time zero offsets in correctly installed and properly ventilated pyranometers.

4.1.8 Algorithms and Methods for Dealing with Pyranometer Zeros (B. Forgan)

Dr. Forgan described work that had been done in the Bureau of Meteorology to establish algorithms capable of correcting historical and future diffuse irradiance measurements from the Australian radiation network. Results to date indicated that in the Australian context there was little benefit in using ventilators to reduce the zero contribution, since each different ventilator design introduced its own problems from increasing variance to collection of dew at the top of the domes. Rather, data from over 14 sites in Australia with CM11 pyranometers and Eppley pyrgeometers showed that a simple linear algorithm utilizing the IR thermopile signal and the IR contribution from the case-dome could provide a representative correction for night-time zero signals. Application of these algorithms during the day showed that: use of the IR thermopile-only algorithm underestimated the zero signal by 50%; use of the case-dome-only algorithm provides useful zero signal values, but were relatively noisy; and use of a combined case-dome and thermopile correction provided a smoother slightly smaller magnitude estimate of the correction. Spectral measurements of diffuse irradiance from an MFRSR (Multi-Filter Rotating Shadowband Radiometer) based at Alice Springs together with a spectral model provided a measure of the true irradiance to verify the results. In addition, the Bureau's historical record of diffuse irradiance measured with Eppley 848 pyranometers was compared with clear-sky day measurements in the recent network using CM11s. It was found that there was a +10% difference (848 – CM11) in diffuse daily exposures if CM11 measurements were not corrected for zero contributions.

4.1.9 Pyranometer Thermal Offset Research at NASA Langley (K. Rutledge)

Ken Rutledge presented some results obtained by a pyranometer workgroup recently established at the NASA Langley Research Center to address short-wave radiation instrument characterization issues. The group consists of researchers from the Radiation and Aerosols Branch of NASA Langley and the Mechanical Engineering department of the Virginia Polytechnic Institute and State University (VPI&SU), under the leadership of Martial Haeffelin of VPI&SU.

The workgroup has focused initially on the thermal offset problems associated with diffuse short-wave irradiance measurement using classical pyranometers. A method using a single thermistor located on the inner surface of the inner dome of the pyranometer and another thermistor located near the cold junction of the thermopile allowed direct monitoring of the thermal field within the instrument. The development of a non-isothermal field was shown to contribute systematically to the thermopile output voltages, producing a systematic dynamic bias. By using temperature manipulation trials with no short-wave input, it was shown that the influence of the directly-measured thermal field on the output voltages could be easily modeled. The thermal effect was shown to contribute as much as -15 W/m**2 under clear sky conditions while being close to 0 W/m**2 for low overcast clouds. The method of using the PIR net-IR signal to model the radiation effect of the offset showed good agreement with the present method during night-time and under overcast skies. Details of this work can be found in a paper published in Applied Optics, Vol. 40 no. 4, pp. 472 - 484.

4.1.10 Development of a New Sun-Tracker for BSRN Stations (A. Heimo)

In 1998, work was begun at the Payerne BSRN station to develop an improved sun-tracking system which would fully meet the accepted standards for BSRN measurements (" 0.1°). The new system is based on the 'intelligent' sun-tracker ('INTRA') developed by the

Swiss enterprise BRUSAG and can achieve the desired accuracy of better that 0.1°, as measured by a four-quadrant sensor. It was also necessary to develop a protective enclosure for up to five instruments mounted on the tracker. This was done by a combination of a movable blind at the front of the enclosure which can be rolled up and down depending on the sun position and meteorological conditions; a ventilation/heating unit at the rear of the enclosure which blows slightly heated air on to the instruments and the front blind, thereby preventing the formation of dew and/or ice on the entire system; a convenient, modular instrument mounting system; and a simple but efficient rain detection system for automatic closing of the front blind. The new system is controlled using a set of Campbell Scientific data loggers which perform house-keeping measurements and compute the solar position, thus facilitating night-time closing of the protective enclosure.

The new system has been named 'RASTA/2' and was tested successfully at the Payerne station during the winter of 1998/99. A first operational unit was installed at the Arosa CHARM station in mid-1999 and has performed successfully, and a second unit is now operated in parallel with the original system at Payerne. It is planned to install the new system at all CHARM stations within the next few years.

4.2 Thermal Infra-red Irradiance Instrumentation and Technical Issues

4.2.1 Calibration of PIR Pyrgeometers at JMA (Y. Hirose)

Dr. Hirose described recent improvements to the pyrgeometer calibration facility developed at the Japan Meteorological Agency and some comparisons of calibration results for two PIR pyrgeometers in this facility and at PMOD in Davos, Switzerland. The calibration factors obtained in the two facilities showed some differences which may in part be due to the different temperature range of the cavity and the body of the instrument. Additional calibrations in the JMA facility are planned to investigate these differences.

4.2.2 Comparison Between Measured and Calculated Values of Atmospheric Long-Wave Radiation (K. Behrens)

Klaus Behrens described the results of some comparisons between field measurements of downwelling LW irradiance using several PIR pyrgeometers and values predicted by the LOWTRAN 7 radiative transfer model under conditions of a cloudless sky, and sky covered with a homogeneous layer of clouds. Good agreement was found in cases concerning newer PIRs together with new calibrations and algorithms, while discrepancies were found using older instruments and traditional formulae. The latter meant that some older measurements would have to be corrected, but it was not as yet clear as to how this should be done. It was planned to carry out further investigations with a larger number of measurements.

4.2.3 International Pyrgeometer and Absolute Sky-Scanning Radiometer Comparison (IPARSC-1) (R. Philipona)

In response to the decision taken at the previous BSRN workshop in Budapest, the first International Pyrgeometer and Absolute Sky-scanning Radiometer Comparison (IPASRC-I) was held in the autumn of 1999 at the Southern Great Plains (SGP) site of the U.S. DOE Atmospheric Radiation Measurement (ARM) program in Oklahoma, USA. Results showed remarkably good agreement between downward long-wave radiation measurements and calculations of different instruments and radiative transfer models. The difference, averaged over four night-time cases, between the Absolute Sky-scanning Radiometer (ASR) and pyrgeometers, AERI, LBLRTM and MODTRAN was less than 2 $Wm^{-2.}$ These results strengthen confidence in the correctness of current clear-sky night-time long-wave irradiance measurements and calculations, indicating that absolute uncertainty levels as low as ± 1.5

Wm^{-2} or 0.5 percent are practicable and realistic at least for mid-latitude summer conditions. The use of the ASR as a reference standard instrument for field-calibrating the pyrgeometers produced remarkable improvements in pyrgeometer precision compared to standard blackbody calibrations. IPASRC-I demonstrated that state-of-the-art pyrgeometers are truly "Precision Infrared Radiometers" (PIRs) if they are correctly calibrated and deployed. A second IPASRC campaign is planned to investigate long-wave radiation measurement issues and intercomparisons under Arctic winter conditions at the ARM site in Barrow, Alaska in early 2001.

The IPASRC-I results were summarized in a paper entitled "Atmospheric Long wave Irradiance Uncertainty: Pyrgeometers compared to an Absolute Sky-scanning Radiometer, AERI and Radiative Transfer Model Calculations" which was submitted for publication to the *Journal of Geophysical Research*. **[6,7]**

4.2.4 Pyrgeometer Characterization (K. Hoogendijk)

Mr. Hoogendijk described the characteristics of a new pyrgeometer with an improved window design which reduced the so-called 'window heating offset' caused by absorption of solar radiation in the window material. Field experiments had demonstrated temperature variations between the window and sensor of less than 0.3°C, representing a window heating offset of less than 4 W/m^2.

4.3 Spectral Measurements

Aerosol Optical Depth (AOD)

4.3.1 Combining the WRR with Spectral Irradiance in a Travelling Standard (B. Forgan)

A novel method and instrumentation for providing spectral measurements of direct solar irradiance by linking broadband pyrheliometry with hyper-spectral CCD array measurements was presented. The purpose of the instrument was to remove the necessity of using lamp calibrations or top-of-the-atmosphere extrapolations to verify the stability of a spectral radiometer, and to provide a direct linkage of spectral irradiance to the World Radiation Reference (WRR) within one instrument. A similar labour-intensive method was used in 1976 to calibrate a filter radiometer, but advances in spectral sensors have allowed the method to be incorporated into one field-ready instrument. The instrument (designated ASR, for Absolute Spectral Radiometer), uses Schott glass filters to divide the solar irradiance into broad bands of known spectral irradiance (related to the WRR through standard calibration of the pyrheliometer in the ASR), and also measures the spectral irradiance signals from two CCD arrays spanning overlapping regions of the UV/Vis/Near-IR parts of the solar spectrum. A measurement cycle consisting of a zero, open, aureole, and 5 filter measurements, allows the absolute sensitivity of the CCDs to be obtained. The highest component of the uncertainty in the relationship is the relative sensitivity of the CCD arrays, as this still requires a stable and known relative irradiance source to be available; currently this is provide by a 1000 W FEL lamp. Initial results from measurements at two field locations in Australia suggest that a reference with 1% uncertainty (95%) between 400 and 900 nm for band-passes of the order of 3 nm is achievable with the ASR.

4.3.2 Interannual Variations of Aerosol Optical Depths at Ilorin (T. Aro)

Measurements of atmospheric aerosol optical depth (AOD) have been taken continuously at Ilorin since 1987, with gaps in the record only for periods of calibration of the equipment away from the site. Three types of instruments have been used to date: EKO, CIMEL and Micro-Top. The EKO instrument is a four-channel hand-held filter sunphotometer used to produce AOD values for the periods 1987-1990, 1996-1998 and 1998-1999. The

CIMEL is an automated 8-channel scanning sunphotometer and has been in operation at Ilorin as part of the NASA-led AERONET network since May 1998. The Micro-Top instrument is a portable, 4-channel sunphotometer that measures both AOD and total ozone and which came into operation in August 1999.

Since measurement of AOD is necessarily limited to periods when the view of the solar disc is free of clouds, data at Ilorin have been obtained primarily during the dry season between October and March, when the dry and dust-laden Harmattan wind blows from the Sahara Desert southwards to the Gulf of Guinea. Measurements are also possible for short periods in May and June when the sun shines through occasional clear gaps occurring between batches of cumulus clouds. Results have demonstrated significant minute-to-minute variations as well as variations in the daily, monthly and annual means. It has been found that monthly mean AOD is at a minimum in May, with a value at 500 nm of about 0.3, and maximum in January, when its value may be greater than 1.5. Instantaneous values greater than 3 have been observed during severe Harmattan periods.

Inter-comparison of results from the three instruments are being carried out in order to ensure consistency. Measurements of AOD are also being taken at various locations along the north-south transect from Kano-to-Ilorin-to-Lagos using the Micro-Top instrument and the GPS, in order to determine the spatial variations along the NE-SW path of the Harmattan. The objective is to obtain a thorough knowledge of both temporal and spatial variations of AOD in this sub-sahel region.

4.3.3 CIMEL Measurements of AOD in the Australian Desert (R. Mitchell)

Dr. Mitchell presented some results of AOD measurements from the CSIRO Aerosol Ground Station Network (AGSnet), which had been established to pursue the characterization of significant natural aerosol types on the Australian continent through a combination of surface measurements and satellite retrievals. The AGSnet currently comprised 3 operational surface stations (Tinga Tingana in the Strzelecki Desert of SA, Lake Argyle in the Kimberly district of WA and Alice Springs, NT), with a fourth to be established at Jabiru, NT in mid-2000. The instrument complement at each site includes a CIMEL sunphotometer, a Radiance Research nephelometer, an aerosol filter sampler and other environmental sensors. The sites are solar-powered and operate automatically, with data communications effected via commercial satellite telephone. The sunphotometer data are contributed to the NASA-led AERONET network for aerosol measurements.

During the period from April to July 1998, two CIMEL sunphotometers were operated side-by-side at the Tinga Tingana site for purposes of direct intercomparison. Correlations between them showed rms errors in AOD of 0.0018 at 440nm and less than 0.001 at longer wavelengths over the 100-day study period. This degree of precision allowed investigation of weak molecular absorption contaminating the 1020 nm channel, which could be attributed to a combination of water vapour and a broad absorption feature of the O2-O2 collisional complex. Results showed the Tinga Tingana site to be exceptionally good for purposes of sunphotometer calibration.

4.3.4 Multi-Year Measurements of AOD (J. Michalsky)

Aerosol Optical Depth (AOD) have been made using the Multi-Filter Rotating Shadowband Radiometer (MFRSR) since 1991 at nine sites in the eastern US, and at the US DOE ARM/CART SGP site in Oklahoma since 1992. Accuracies of 0.01 to 0.02 are achieved through a procedure involving constant calibration the instruments using a 'robustification' technique.

Dr. Michalsky described some results using daily averages of retrieved optical depth to examine the seasonal and interannual behaviour at three sites in the central, north-eastern and mid-Atlantic US. All are continental sites showing summer peaks and winter minima in AOD. The winter aerosols were observed to be consistently larger than the summer ones. All three sites showed evidence of the Mt. Pinatubo eruption at the beginning of their records, both in optical depth and wavelength dependence, with the larger particles of the stratospheric residual of the eruption giving rise to larger average particles in the column. This was particularly evident in the winter when aerosol optical depths are lower. All three sites indicated a mean Angstrom alpha coefficient near 1.3 after the Pinatubo aerosol epoch.

A draft of this work can be found via anonymous ftp to: hazy.asrc.cestm.albany.edu; cd pub/papers; get techniques.pdf or .ps. Data are at the URL: hog.asrc.cestm.albany.edu.

4.3.5 BSRN Specification for AOD Measurements

Dr. Forgan reviewed the work done by the Aerosol Optical Depth Working Group formed at the previous BSRN workshop in Budapest, and in particular the draft specification that had been developed for measurement and archiving of AOD in the BSRN. The draft specification was accepted in its entirety by the group at this meeting, and is presented as Annex IV to this report. **[8,9]**

4.3.6 User-Friendly Software for AOD Measurements (A. Heimo)

Dr. Heimo demonstrated the use of new software that had been developed collaboratively between SwissMeteo and the Institute of Applied Physics of the University of Bern. The software provides a user-friendly tool for the evaluation of narrow-band spectral measurements needed for determining AOD. The graphic software is compatible with both the UNIX and Windows operating environments supporting the MATLAB software package (Version 5.3) and allows the user to:

- display the raw data;
- select the period for Langley plots either manually or with an automatic objective algorithm;
- select periods for long-term evaluation;
- perform different Langley plot algorithms;
- take into account the characteristics and possible degradation of the radiometer filters;
- perform analysis of AOD, water vapour and ozone amounts;
- store the results in daily files; and
- compute means or other statistical values.

The software has a modular structure which allows for easy upgrading and extension. Additional refinement was planned during the remainder of 2000, following which it would be posted for free access via the BSRN Web site.

UV Measurements

4.3.7 Report of the BSRN Sub-Group on UV-B Measurements (A. Manes)

Dr. Alex Manes reported on the main findings of the BSRN Sub-group on UV-B Measurements, which had been established at the previous workshop to monitor this issue in behalf of the BSRN. It had been agreed at that meeting that UV-B measurements should eventually be included in the BSRN suite of measurements, but that other groups (e.g. GAW) were currently engaged in such activities and close liaison and assessment would be required before taking any decisions.

The UV-B sub-group had reviewed the measurement activities being undertaken by a number of agencies, as well as the current status of instrumentation in use. Also, Dr. Manes had attended the European Conference on Atmospheric UV Radiation, held in Helsinki, Finland from 29 June to 2 July 1998, on behalf of the group. The results of this work can be found in the sub-group report, which is presented as Annex V of the current report. Of particular note was the fact that there still remains a wide discrepancy in the results obtained from differing instruments, and that it is certainly premature to consider adding UV-B measurements to the BSRN suite at this point in time.

Following discussion of this issue, it was agreed that the BSRN Sub-group on UV-B Measurements would continue to monitor the activities of various relevant groups and would seek the cooperation of individuals, agencies and manufacturers of precision UV radiometers in its activities. The sub-group was asked to prepare specifications and technical requirements for UV radiometers suitable for measurements at BSRN stations and to report these to the next BSRN workshop in 2002. Membership of the sub-group was agreed as A. Manes (Chairman), B. Forgan, I. Galindo, A. Heimo, B. McArthur, R. McKenzie, J. Olivieri and R. Philipona. **[10]**

4.3.8 UV-B Measurements at Carpentras (J. Olivieri)

Dr. Olivieri updated the group on UV calibration activities at the Carpentras BSRN station using the Yankee Environmental Systems (YES) Model UVB-1 ultraviolet pyranometer that had been installed there since 1994.

4.3.9 Spectral UV Measurements Using Precision Filter Radiometers (R. Philipona)

Spectrally-resolved information on natural UV-radiation is important for many biological, chemical and medical UV-related investigations. Measurements are usually performed with delicate spectroradiometers which are difficult to calibrate and not very cost-effective in network operation. An easier approach to obtaining UV-spectra is to measure narrow-band spectral radiation at a small number of selected wavelengths and use these measurements to adjust calculated spectra from radiation transfer models.

Dr. Philipona described the results of some experiments in which spectral direct sun irradiance was measured with UV-precision filter radiometers (UV-PFRs) using filters with FWHM of 1 to 2 nm and centre wavelengths at 305, 311, 318 and 332 nm, and also with precision filter radiometers (PFRs) using filters with FWHM of about 5 nm and center wavelength at 368, 412, 500 and 862 nm. The PFRs had been laboratory-calibrated using standard lamps and trap detectors which guarantee high absolute accuracy and traceable long-term stability. The PFR measurements were compared with direct UV-spectra from three Bentham DM-300 UV-spectroradiometers. Intercomparisons were also made with instruments of the Fraunhofer Institute für Umweltforschung (IFU) at the Garmisch-Partenkirchen and Zugspitze sites in southern Germany and with the Bentham DM-300 of the University of Innsbruck on the Jungfraujoch in Switzerland. UV-spectra measured at Air Masses (AM) between 1.1 and 5 were compared among the respective instruments. To compare filter instruments with high-resolution spectroradiometers, the spectroradiometer results were convoluted with PFR filter functions. Up to AM 2, all filter measurements were within 5% of the spectroradiometric measurements. At AM 2.8, the 305 nm channel of the UV-PFR began to deviate and at AM 5 and high turbidity, the signal level was too low to allow a comparison to be made. It was therefore concluded that using PFR measurements and radiation transfer model calculations allowed the determination of UV-spectra which compare very well with those measured by spectroradiometers.

In addition to UV-spectra, PFR measurements also allow total ozone content and aerosol optical depth to be determined. PFRs have the advantages of measuring all channels simultaneously in a one-minute interval and yet produce much less data than spectroradiometers. They are also easy to use and need little manpower.

4.3.10 Comparison of UV Indices Derived from Measurements and from the AMEX Regional Model (L. Lemus-Deschamps)

Dr. Lemus-Deschamps presented some results of a collaborative research project between the Australian Bureau of Meteorology (BoM) and the University of Colima (CUICA) in Mexico in which UV indices derived from measurements at CUICA were compared with those obtained from a new clear-sky diagnostic regional radiative transfer model (Australia-Mexico, or 'AMEX'). Comparisons for 1999 showed generally very good agreement between the measured values and the model during clear-sky conditions. Deviations in the measured results were observed (as expected) during conditions of cloud, aerosols from biomass burning and transient periods of very low atmospheric total ozone. Future work is planned to include cloud and aerosol effects in more detail.

4.3.11 UV-B and Radiation Measurement Programmes at NIWA Lauder (R. McKenzie)

Irradiance measurements in the UV spectral region have larger uncertainties than those for pyranometer measurements in general. Calibrations are generally referred to 1000W quartz-halogen lamps which are far from ideal in terms of output and stability in the UV region. Difficulties with wavelength alignment, dynamic range, and cosine response also limit the ultimate accuracies. It is difficult to achieve absolute accuracies of better than ±5%, and agreement between instruments is usually significantly poorer than this, especially for larger solar zenith angles (SZA).

Attempts to quantify the expected increases in UV in response to ozone reductions have met with limited success, due in part to these calibration issues along with other factors such as a lack of suitable instrumentation and the confounding influence of factors other than ozone (e.g. clouds, aerosols, albedo changes, SZA changes). For example, it has been shown that cloud variability would mask any attempts to detect long term trends in UV doses due to ozone depletion at mid latitudes for several decades[6].

Measurements of spectral UV irradiances (~1 nm resolution, 290-450 nm) have been available from the NIWA atmospheric research site at Lauder Central Otago, New Zealand (45.04ºS, 169.68ºE, 370 m a.s.l.) since late 1989. These data are supported by a wide range of complementary measurements of broad-band radiation (including diffuse, direct and global pyranometer data, sunburning UV), trace gases (including ozone), aerosols, and cloud cover.

Spectrometer measurements of peak summertime UV irradiances (which are less sensitive to clouds, aerosols, and albedo changes) at Lauder have been used to demonstrate the expected long-term anti-correlation between ozone and UV, and have demonstrated UV increases of about 10 to12% through the 1990s[7] (McKenzie et al., 1999). Over the same period changes in UV-A radiation, which is insensitive to ozone, were insignificant. Although 1999 had the lowest annually averaged ozone on record at Lauder, the UV data from the most recent summer (1999/2000) show lower UV amounts in response to the slightly larger ozone in those months compared with the previous years, as well as cloudier weather. Several more years of measurements will be needed to establish any turnaround in ozone depletion.

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[6] Lubin, D. and Jensen, E.H. (1995): Effects of clouds and stratospheric ozone depletion on ultraviolet radiation trends. *Nature 377*: 710-713.

[7] McKenzie, R.L., Connor, B.J. and Bodeker, G.E. (1999): Increased summertime UV observed in New Zealand in response to ozone loss. *Science 285 (10 September)*: 1709-1711.

Similar spectrally-resolved UV measurements are also available from the Mauna Loa Observatory Hawaii and from Boulder Colorado, in collaboration with NOAA/CMDL. Beginning in summer 2001, measurements will also be available at two sites in Australia in collaboration with the Bureau of Meteorology.

Photosynthetically Active Radiation (PAR)

4.3.12 Report of BSRN *Ad-hoc* Working Group on PAR

Dr. Pinker reported on some findings of the ad-hoc Working Group on PAR, which had been established at the previous workshop to assess the requirements for PAR measurements which could be made at BSRN stations and to identify instruments and techniques which could be used for such measurements. She noted that the climate community had shown increasing interest in PAR measurements in recent years in view of the importance of net primary productivity for the carbon cycle issue. There is a strong need for high-quality surface measurements to validate the global-scale information being obtained from satellites. Several groups are now measuring PAR on a regular basis using a relatively limited range of instruments, namely:

- the Li-Cor quantum sensor;
- the Kipp and Zonen Par Lite sensor;
- coloured hemispheres (Schott filters) on pyranometers;
- spectrometers.

There has been no systematic evaluation of the performance of these instruments to date, and only factory-based estimates of accuracy are available.

Dr. Pinker noted several activities that had been identified in the past two years involving an evaluation of PAR observations, including: comparisons between Li-Cor and Par Lite instruments at the Tartu Observatory in Estonia; evaluation of the Li-Cor instrument for the NASA Langley Research Center (see below); PAR measurements at the Bratt's Lake BSRN station; and comparisons between Li-Cor and Par Lite results at the University of Maryland.

Following discussion of the PAR issue, it was agreed that the activities of the Ad-hoc Working Group on PAR (R. Pinker, Chairperson, with A. Kallis, K. Larman, B. McArthur and K. Rutledge) should be continued until at least the next BSRN Workshop. The main responsibility for the group would be to explore the possibility of organizing an intercomparison of PAR instruments over a one-week period prior to, or perhaps during, the next workshop. The group will also prepare a document precisely defining the key PAR issues for presentation to the next workshop. **[11]**

4.3.13 Calibration of Quantum Flux Sensors at Mauna Loa (K. Larman)

Dr. Kevin Larman reported on the results of calibration studies involving eight Li-Cor LI-190 Quantum Sensors carried out at the Mauna Loa Observatory in Hawaii, USA during January 2000. This work was performed in support of the Radiation and aerosols Branch at for the NASA Langley Research Center. The LI-190 hemispherical sensor is sensitive to PAR in the range from 400 to 700 nanometers. The so-called 'Alternate Method', developed for BSRN pyranometer calibration, was used to determine instrument sensitivity values by: 1) measuring coincident global, diffuse and direct normal radiation as a function of solar zenith angle (Z) over two independent temporal periods; and 2) determining diffuse and global instrument calibration values by solving linear equations in Z. For this application, the direct normal component measurement was made by a collimated spectroradiometer with an uncertainty of +/- 5% (99% confidence level, U)).

The mean value of the manufacturer calibration was 5.00 micromole per meter-squared second with a mean uncertainty of +/-5%. The mean quantum sensor sensitivity value determined by the application of the Alternate Method was 6.51 micromole per meter-squared second with mean uncertainty of 6.06% (U95), a difference of 30.2%. The preliminary uncertainty analysis indicated a maximum anticipated error of 7.7%. Detailed examination of the data and results indicates a need to repeat the measurements and analysis.

5. SCIENTIFIC APPLICATIONS AND USE OF BSRN DATA

5.1 BSRN and the User Community

5.1.1 Applications and Challenges for BSRN Data (E. Dutton)

Dr. Dutton presented an overview of the results from a number of studies involving the use of BSRN data. In one case, it was demonstrated that the analysis of radiation data can be carried out on different time-scales and thereby reveal various features of the data. Physical process that can be investigated range from minute-to-minute variations induced by clouds to long-term fluctuations over several decades. A number of publications over the last decade, listed by Dr. Dutton, have suggested a long-term downward trend in total solar irradiance at the surface. He noted that both the climate-modelling and satellite-observation communities are using BSRN data to verify and/or to help interpret their results, and presented some comparisons of BSRN data with GEWEX/SRB (Surface Radiation Budget) and ECMWF products. He also discussed the consequences of the level of agreement and disagreement between observations and modelled surface irradiances with reference to several recent publications. A major ongoing project making extensive use of BSRN data is the NASA Clouds and Earth's Radiant Energy System (CERES) project. This is expected to continue for several years, as are the GEWEX/SRB project and other satellite-based surface radiation estimation programmes and many global climate modelling efforts, all of which will be able to utilize existing and future BSRN data.

5.1.2 Perspectives of the GEWEX Radiation Panel (G. Stephens)

Dr. Graeme Stephens, Chairman of the GEWEX Radiation Panel (GRP), reviewed the objectives and status of the GRP and the manner in which the BSRN contributed to achieving those objectives. The GRP oversees a number of projects that seek to provide global information on radiative fluxes and the constituents of the atmosphere that affect these fluxes. These projects are largely based on the use of global satellite data and are interconnected with one another, as exemplified by the Surface Radiation Budget project (SRB) which uses the ISCCP DX cloud data, global aerosol data to be provided by the Global Aerosol Climatology Project (GACP), and archived data from the BSRN for ultimate validation.

The individual projects of the GRP, when taken collectively, represent the strategic approach towards the goal of determining the spatial distribution and time variation of long- and short-wave radiation fluxes and understanding the factors that determine these distributions. The plan is to develop a quantitative understanding of the links between the radiation budget at the surface, in the atmosphere and at the top of the atmosphere (TOA) and the properties of the atmosphere and surface that define this budget. The objective is to determine the net radiative fluxes in the atmosphere and at the surface of the earth and the variation of these fluxes to the following increasingly stringent accuracies:

- ~20 W/m^2 by the year 2000 to support improved weather forecasting (i.e. 1 day, mesoscale resolution);
- ~15 W/m^2 by the year 2005 to support prediction of climate anomalies like ENSO (i.e. 5 day, 200 km resolution);
- ~5 W/m^2 by the year 2010 to support prediction of climate change (i.e. monthly, 200 km resolution).

These objectives are intimately linked to the issues of climate forcing and climate feedback. The need to identify gaps and reduce the uncertainties associated with these phenomena is critical to making significant progress toward improved climate predictions. The strategy for undertaking this work is being developed along two tracks: the first is by way of applying integrated observations from all available sources to define the state of the atmosphere and to determine the fluxes; the second is to improve the appropriate formulations in models (radiative transfer and related parameterizations in process models, enhancement of Cloud Resolving Models and better representations in NWP and GCMs). The integration of the improved models with the best available observations should reduce the uncertainties in the results required to meet the stated goals.

The GRP is currently involved in a re-assessment of these goals and the strategy adopted to this point, and a related assessment of the progress being made toward the achievement of the goals. This is being approached by systematically assessing the current best measurements of TOA fluxes, surface fluxes and in-atmosphere profiles of fluxes. This includes a review of current abilities to measure these fluxes and to derive them through the parameterizations used in global models. The BSRN experience is central to the measurement portion of this assessment study.

5.1.3 Global Atmosphere Watch (GAW) Aerosol Programme (J. Gras)

Dr. John Gras briefed the meeting on the aerosol measurement programme within the WMO Global Atmosphere Watch (GAW). Measurement of aerosols and AOD, which have been carried out by the WMO since the early 1970’s, were consolidated in the GAW programme in 1997 under the scientific direction of a Scientific Advisory Group (SAG) for Aerosols, of which Dr. Gras is a member. The current GAW aerosol programme includes measurement of the following 12 components at each of the 22 GAW Global Stations:

1) aerosol optical depth (AOD)
2) mass in two size fractions
3) major chemical components in two size fractions
4) light scattering and hemispheric backscattering coefficient at various wavelengths
5) light absorption coefficient
6) aerosol number concentration
7) cloud condensation nuclei number concentration at 0.5% supersaturation
8) diffuse, global and direct solar radiation
9) aerosol size distribution
10) detailed size fractionated chemical composition
11) dependence on relative humidity
12) vertical distribution of aerosol properties.

The first four of these components are also to be measured at the over 300 GAW Regional Stations. It is intended that routine aerosol measurements eventually be collected in a full range of climatic regimes.

For obtaining AOD measurements, GAW is focussing on the Precision Filter Radiometer (PFR) instrument developed at the World Optical Depth Research and

Calibration Centre (WORCC) in Davos, Switzerland. Twelve PFRs will be installed at GAW sites, some of which will also be BSRN sites. Three sites have been selected, with the other nine currently under review. The aerosol SAG has recommended that BSRN standards and protocols should be used for surface radiation and AOD measurements at all GAW Global Stations. Dr. Gras emphasized the view of the SAG that increased interaction and possible convergence of observational programmes in air chemistry, aerosols and radiation will need to occur in the future to better advance the science of air chemistry and its impacts on climate. A significant overlap among the GAW network, BSRN and the AERONET network is seen as essential in this regard.

5.2 Australian Programmes on Satellite Validation

5.2.1 Aerosol, Biomass Burning and Clouds in Tropical Australia (R. Boers)

Through land-management practice and wild fires, the entire Northern Territory (NT) of the Australian continent is burned every two years. The onset of the fire season in the tropical savannah region north of 20°S is soon after the end of the monsoon period (early April), while it ends in late October-early November. Australian flora are highly resistant to fires and in some cases have developed adaptation in the form of heat or smoke requirements in the germination of tree species. Many tree species have a corky bark, which resists the penetration of heat, and in case the tree is destroyed, many species have special lignotubers from which new shoots can rapidly develop. The ground cover in the savannah region is dominated by leaf litter and annual grass, which grows during the wet season and rapidly cures near the onset of the dry season. Consequently, biomass burning in the NT is mostly grass burning.

The CSIRO has embarked on a project to estimate the atmospheric effects of aerosol and to validate satellite observations of aerosol and cloud properties in the NT environment. The primary objectives of the project, which is also supported by the Australian Greenhouse Office, are as follows:

- Estimation of the amount of aerosol injected into the atmosphere by biomass burning and the aerosol optical depth using a combination of satellite observations of burned ground cover, together with a nested grid model that simulates the horizontal and vertical dispersion of the aerosol;

- Measurement of the AOD and surface scattering properties at several remote locations, including one where a more comprehensive set of radiation and remote sensing equipment will be located, including a BSRN station;

- Estimation of the aerosol optical properties from satellite remote sensors to obtain regional coverage that can be used to monitor the seasonal patterns of biomass burning.

Jabiru, located in Kakadu National Park, NT, has been selected as the station for extended measurements of aerosol and cloud properties. Jabiru has several attractive features for this purpose:

- It provides a grey site for aerosol retrievals, supplementing and completing the Lake Argyle (black) and Tinga Tingana (white) aerosol retrieval sites already in existence;
- It is homogeneous on a 50 - 50 km scale;
- It has sealed road access year around;
- There is a small airfield near the observation site;
- There are large seasonal variations in aerosol content and cloudiness;

- There is a large seasonal variation in water vapour (ranging from 10 to 20 g kg^{-1} at the surface);
- It provides excellent infrastructure.

Instruments to be located at the site include a CIMEL sun photometer, an all-sky camera, a lidar, a microwave radiometer and the basic suite of BSRN instruments. A GPS receiver to be used for water vapor retrievals is currently operational.

On the basis of the information and proposals presented by Dr. Boers, the meeting endorsed Jabiru as a candidate site for a formal BSRN station.

5.2.2 CIGSN: Validation Measurements for the Surface Radiation Budget (F. Prata)

Dr. Fred Prata of the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) presented an overview of the Continental Integrated Ground-truth Site Network (CIGSN). The CIGSN had been established by CSIRO in 1992 to measure short-wave and long-wave radiation flux densities (upward and downward) at several sites in Australia. Sites had been carefully selected for the uniformity and representativeness of their surface characteristics, such that radiation budget measurements made at scales of several metres could be up-scaled to represent areas as large as 1-10 km^2 and, in one case, 100-200 km^2 . This facilitates direct validation of satellite-based products which in turn can be used for comparisons with climate model simulations. The three sites currently in operation are:

- Uardry, NSW at 34.39°S, 145.30°E and 110 m a.s.l. in grassland used for sheep and cattle grazing;
- Amburla, NT at 23.39°S, 133.12°E and 626 m a.s.l. on bare, quartz-rich soil in a semi-arid climate region;
- Thangoo, WA at 18.18°S, 122.35°E and 30m a.s.l. in acacia woodland (tropical savannah) in a monsoon climate.

Each site is equipped with pyrgeometers and pyranometers that have unobstructed views of the sky and surface. At Thangoo, because of the height of the vegetation, downward-looking measurements are made up to four times per year from a small aircraft. A unique feature of all sites is the use of radio-frequency communication which allows measurements to be made at several widely-separated locations. For example, at Uardry, upward short-wave flux density is measured at four locations up to 500 m from a central tower where the data are logged to a computer and downloaded at monthly intervals. There are eight such ‘satellite’ sites in total at Uardry and Amburla and four at Thangoo. This approach allows an estimation of the uniformity in each case and direct comparison with 1 km^2 data from satellite-borne sensors.

To date, data from the CIGSN have been used for calibration and validation of a number of satellite sensors, including the ATSR, ATSR-2, ADEOS and MODIS/ASTER, as well as for intercomparisons with GCM outputs. Dr. Prata reviewed several specific applications of the data.

5.3 <u>General Scientific Applications and Studies</u>

5.3.1 Identifying Clear Skies and Calculating SW Cloud Effect from Broadband SW Measurements (C. Long)

Dr. Long presented an overview of an automated technique for identifying clear-sky periods at a site from measurements of downward short-wave global, direct, and diffuse irradiance. The technique is based on an algorithm developed by scientists at the Pacific Northwest Laboratory and the NOAA/ARL/SRRB and can also be used to determine clear-sky SW functions, downwelling SW cloud effect, and fractional sky cover. It requires no additional ancillary data, such as those inputs required for model calculations, and can be applied to a full year of typical BSRN data in about 20 minutes on a desktop PC. The technique has been shown to be a valuable analysis tool, not only for climatological study of the data, but also for operational data quality monitoring. Dr. Long made copies of the algorithm package, complete with documentation and instructions on usage, available to workshop participants via floppy disks distributed at the meeting. Further details can be found in the reference below[8] or via the Web site http://playground.arm.gov/~clong/. **[12]**

5.3.2 Radiation Measurements from a Tethersonde (B. McArthur)

Dr. McArthur presented details of a small radiation payload that had been designed for flight on a tethered balloon to provide solar and terrestrial radiation measurements, as well as temperature, pressure and humidity, to altitudes of up to 1.6 km. The objective of developing such a payload was to allow measurement of radiation and surface properties over a large, site-representative field of view without the complexity and expense of utilizing instrumented aircraft, while still overcoming the limitations of moderate-height guyed towers. For example, the 90% field of view at 1.6 km has a diameter of about 10 km compared with that of a 30m tower of under 0.2 km. The package developed had been flown in separate campaigns over a three-year period at the Bratt's Lake BSRN site, and comparisons made between albedo measurements from the tethersonde package and two levels on a 30 m tower. Clear differences were observed in the measurements obtained, due primarily to local surface effects at the tower and also for the tethersonde package at low altitudes. The results generally confirmed the difficulty in determining representative values of albedo for a site with even modest variations in surface characteristics, and the advantages of increasing the height of the measurement when comparisons with model results or satellite measurements are to be made. **[13]**

5.3.3 Influence of Irradiance Variations on the Albedo Measured at a Uniform Grassland Site (I. Grant)

The short-wave (SW) albedo (ratio of up-welling to down-welling SW flux density) of land surfaces is not an intrinsic property of the surface but depends on the angular and spectral distribution of the illumination. Dr. Ian Grant of CSIRO described the results of investigations into the influence of sun angle and cloudiness on albedo measurements at a specific location. The site in question is Uardry, located about 400 km north of Melbourne, Australia, in a flat, grazed paddock. Albedo was measured at three locations within about one km of each other by dividing the up-welling SW flux at each location by the down-welling flux obtained from a single unshaded pyranometer. Time-averaged results and diurnal variations were obtained over a period of several months. The differences between the albedos at the three locations varied over time from 0 to 15% (e.g. 0.03 out of an albedo of 0.20), consistent with a spatial variation about 6% over the site as observed from airborne imagery. Despite these differences, some features of the diurnal variation were common to two or all three locations, and so are expected to be evident at the 1-km scale that is characteristic of the pixel size of many satellite sensors. The albedo showed a noon minimum, and a simple model of the dependence of the albedo on the solar zenith angle, with a single parameter to control the strength of the dependence, captured much of the variation. These and related findings had been discussed in a journal paper that had recently appeared (J. Appl. Meteorol., 39, 231-244, 2000). Dr. Grant also showed an example of

[8] Long, C. N. and T. P. Ackerman, (2000): Identification of Clear Skies from Broadband Pyranometer Measurements and Calculation of Downwelling Shortwave Cloud Effects, JGR, 105, No. D12, 15609-15626.

differences in albedo of 20% or more between the same measurements taken on overcast and clear days closely spaced in time.

5.3.4 Surface Radiation, Cloud Forcing and the Greenhouse Effect (R. Philipona)

The Swiss Alpine Surface Radiation Budget (ASRB) network comprises eleven stations located between 370 m and 3580 m a.s.l. throughout the Swiss Alps. It was initiated in 1994 to investigate the surface radiation budget, cloud forcing and the green-house effect in the Alps. The surface radiation budget strongly depends on the nature of the surface (albedo) and altitude. The altitude dependence stems from the important contribution of the water vapour content to the overall greenhouse effect of the atmosphere. Water vapour decreases with decreasing air temperature and thus with increasing height. Annual mean net radiation goes from about 50 Wm^{-2} at the lower stations to almost zero (but still positive) at high altitude stations.

Clouds affect Earth's climate in two major ways: by reflecting short-wave (solar) radiation back to space, and by reducing the loss of long-wave (infra-red) radiation to space. The reflection of short-wave radiation (SW) tends to cool the earth, while the trapping of the long-wave (LW) radiation tends to warm it. These effects are quantified by defining the cloud forcing (CF):

$$CF_{net} = CF_{SW} + CF_{LW} = (SWnet_{AS} - SWnet_{CS}) + (LWnet_{AS} - LWnet_{CS})$$

The subscripts *AS* and *CS* designate All-Sky and Clear-Sky conditions. The importance of the two competing effects of the SW and LW cloud forcing ($CF_{SW\ and}$ CF_{LW}) raise questions such as whether clouds on average have a positive or negative effect on the radiation balance. Measurements show a slight cooling effect (-5 to -10 Wm^{-2}) on the annual mean at low altitudes. In the Alps, clouds have a warming effect (max. 30 Wm^{-2}), with winter months being especially affected.

In addition to very accurate measurements of the altitude-dependent radiation budget, a major goal of ASRB is to measure a possible change in the LW downward radiation due to an increase of greenhouse gases. The current impact of clouds in the Alps is large in comparison to the expected change resulting from the greenhouse effect. An increasing greenhouse effect induces a change in climate by direct radiative forcing. Thus, if ΔCF_{net} has the same magnitude as the direct forcing, so that the cloud feedback is positive (as in the Alps), the warming is amplified by a factor of two.

The greenhouse effect G is commonly referred to as the energy trapped in the atmosphere. It can be defined as the difference between the thermal radiation emitted by the Earth's surface ($LW\uparrow_{Surface}$) and that escaping to space ($LW\uparrow_{ToA}$):

$$G = LW\uparrow_{Surface} - LW\uparrow_{ToA}$$

The greenhouse effect is not directly measurable from the surface, but there is a strong linear correlation with the LW downward flux. Downward LW measurements from the ASRB have indicated that the greenhouse effect at the lower stations is 158 Wm^{-2} and decreases with altitude, showing a gradient of -1.1 Wm^{-2} /100 m for annual mean values.

A detectable increase in the LW downward radiation will precede those of other climatological elements in identifying climate warming. The air temperature increase will be significantly delayed due to heating of the ocean, and the precipitation change will be difficult to detect because of large annual variations. The very accurate measurements of LW downward radiation in the ASRB, and the small year to year variation, make this one of the most promising parameters for greenhouse effect monitoring.

5.3.5 Changes in LW Downward Radiation at BSRN Sites as Projected in Transient Climate Change Simulations (A. Ohmura, M. Wild)

Prof. Ohmura presented some results of LW downward radiation estimates from a number of leading GCMs, including ECHAM4, LMD, UKMO, GISS, ECHAM3, GFDL, CCC and NCAR. It was found that the best agreement with the most recent estimate based on BSRN data (close to 345 Wm^{-2} global annual mean) was produced by the ECHAM4 model (344 Wm^{-2}) while the poorest model result was about 311 Wm^{-2}. Global radiation budgets at the top-of-the-atmosphere, atmosphere and the earth’s surface were computed using 5 European GCMs (ARPEGE, ECHAM3, HadAM2b, HadAM3 NA and HadAM3). The best performance was HadAM3 while HadAM2b was the poorest, with differences in the computed and observed values ranging from 5 to 25 Wm^{-2}.

The ECHAM4/OPYC coupled 240-year transient experiment (1860-2100) shows that greenhouse gases play a more dominant role than aerosols on climate change during the next 100 years, and that an increase of about 12 Wm^{-2} can be expected in LW downward radiation by 2100. The ratio of long-term change to year-to-year variation is 4, while the same ratio for global mean air temperature is 2, demonstrating the better suitability of LW downward radiation for detecting climate change as opposed to air temperature. In view of the recent advances in absolute accuracy of BSRN LW measurements, it may be possible to detect this change by 2020. The most sensitive geographic areas for this purpose are those with small precipitable water vapour and cloud amount - that is, desert and polar regions.

5.3.6 Estimation of Absorption in Stratus Clouds Using BSRN and Satellite Data (A. Ohmura)

Many atmospheric models produce significant overestimates of the short-wave irradiance at the earth’s surface. Uncertainties exist in model absorption both by clouds and by the atmosphere in clear-sky conditions. Dr. Ohmura described some studies into the absorptive characteristics of different cloud types as part of investigations into this problem. The characteristics of sheet-type clouds of type stratus (St) and stratocumulus (St) were investigated using the collocated solar radiation measurements from METEOSAT and BSRN. The effects of the atmosphere between the TOA and the cloud top and between the earth's surface and the cloud bottom were taken into account in the model computation. The mean characteristics for 5 cases of Sc were: Total cloud albedo 0.52, Absorptance 0.57 km^{-1}; and for 28 cases with St: Total cloud albedo 0.53, Absorptance 0.65 km^{-1}. On average, the absorbed radiation by clouds during the experiment was 86 Wm^{-2}. These values help to close the gap between the computation and observation of the global solar radiation absorption, but still leaves about 50% of the missing absorption to be attributed to underestimation of clear-sky absorption in the models.

5.3.7 Homogeneity of the WRDC Time Series in Comparison with BSRN Data (A. Tsvetkov)

Dr. Anatoly Tsvetkov described some of the work being undertaken at the WMO World Radiation Data Centre (WRDC) in addressing the problems of non-homogeneity in time series of radiation data. The WRDC was established at the Voeikov Main Geophysical Observatory in St. Petersburg in 1964 and has since been centrally archiving solar radiation data (e.g. daily totals of global, diffuse and direct radiation, hourly totals of radiation balance and daily-monthly totals of sunshine duration). The WRDC archive catalogue has a list of 1286 stations for which data are available. A number of GAW stations have also submitted data to the WRDC for archival.

The problems of non-homogeneity include those arising from instrument types, calibration methods, raw data recording, data processing, site characteristics, etc. Dr. Tsvetkov presented some examples of homogeneity breaks in specific sets of radiation data and some of the procedures currently in use to eliminate or minimize them.

6. OTHER ISSUES

6.1 BSRN Operations Manual

Dr. McArthur lead a discussion of the latest status of the BSRN Operations Manual, which had been published (V1.0) in early 1998. The corrigendum pages that were to have been added to that document had not yet been included. There had been, and still was, significant demand from users for copies of the manual, and it was clear that it was serving a very useful purpose. Following general discussion, it was agreed that minor updates (Annex modifications, previous corrigendum additions) to the current version would be prepared for discussion during the IPC experiments in Davos in September 2000 (Action: B. McArthur). More substantial changes to the document would be incorporated into a new version (V2.0) which would make changes from V1.0 obvious to the reader (e.g. modification list at front, or pages specially marked). The current version would be made available on the BSRN Web site immediately (Action B. McArthur, O. Albrecht). **[14]**

6.2 Literature Search and Compilation

Ken Rutledge reported on the progress made to date by the ad-hoc group which had been established at the previous workshop to carry out a literature search for published papers, in any language, on the performance and/or characteristics of thermopile-based radiometers used for solar and terrestrial radiation measurements. Although the task was not yet completed, initial literature searches and manual collation of citations had begun. English and Japanese literature had been the focus of attention to date and approximately 150 citations were presently in the compendium established by the group. Action was underway to implement a Web-based software access system to allow BSRN participants easy access to the database being developed from this compendium. Participants would be able to access/query this initial database for retrieval of citations and also for inserting additional new and old citations, thereby assisting in keeping the information up to date. The software system was being developed at NASA Langley Research Center (LaRC) and implemented using LaRC computing resources. A web pointer from the BSRN main web pages would point to this capability. Completion of the software access system was planned by January 2001, followed by a six-month period to allow for the entry of the initial citation database. This schedule was designed to allow BSRN members to use the system prior to the next BSRN meeting in 2002 and hence for comments on its utility to be made at that meeting.

The meeting expressed thanks to Mr. Rutledge and the other ad-hoc group members for their efforts to date and looked forward to the capability to access the database via the Web in due course. **[15]**

6.3 Site Audits, Accuracy Specifications

The issue of site audits of BSRN stations was discussed with a view to the feasibility of continuing such audits in the future. It was agreed that that the carrying out of site audits to assess the operation of BSRN sites and assist in overcoming any problems or difficulties was a very useful practice (four such visits had been carried out by the BSRN International Programme Manager (IPM) during the preceding biennium). In view of the fact that it was not feasible for one person to carry out all such visits in the future due to time limitations, it was agreed that the IPM would develop a strategy for distributing the burden of such a process, including specifics of the procedures that should be followed for any particular visit. **[16]**

The issue of accuracy specifications was considered further in light of the earlier presentations on formal concepts of uncertainty analysis and ISO standards. It was agreed to the establishment of an Ad-hoc Working Group on Accuracy Specifications. That group was charged with the establishment of a methodology for assessing uncertainty in BSRN measurements, which will be included in future versions of the BSRN Operations Manual. A draft methodology for uncertainty assessments was to be prepared for discussion at the next International Pyrheliometer Comparison (IPC) experiments to be held in Davos, Switzerland in September/October 2000. Membership of the working group was agreed as B. Forgan (Chairman), E. Dutton, N. Hyett, K. Larman, C. Long, R. Philipona and A. Tsvetkov. **[17]**

6.4 Review of Station Lists

The meeting endorsed the stations marked with an asterisk below as additions to the formal list of BSRN stations. **[18]** Thus the current complete set of BSRN stations comprises:

- **19 Operational** stations as listed in Table 1 of Section 3.1;

- **9 Pending** stations:

    - Budapest/Lorincz, Hungary
    - De Aar, South Africa
    - Sedeh Boqer, Israel
    - Balbina, Brazil
    - Riyadh, Saudi Arabia
    - Lauder*, New Zealand
    - Manus*, Papua New Guinea
    - Nauru*
    - Tamanrasset*, Algeria

- **13 Candidate** stations:

    - Fort Peck, USA
    - Boulder/Surfrad, USA
    - Bondville, USA
    - Goodwin Creek, USA
    - Camborne, UK
    - Lerwick, UK
    - Albany*, USA
    - Cocos (Keeling) Islands*, Australia
    - Desert Rock*, USA
    - Jabiru*, Australia
    - Kiritimati* (Christmas Island), Kiribati
    - Penn State*, USA
    - Zvenigorod*, Russian Federation

6.3 Next Workshop

The next BSRN workshop was tentatively scheduled for the April-May 2002 time period, with Israel and Canada as two potential sites. Final choice of dates and location would be made in due course and transmitted to all potential participants.

It was agreed that the use of poster presentations to present the bulk of the status reporting information on BSRN stations was an efficient mechanism and would be repeated at future workshops.

7. CLOSURE OF WORKSHOP

The Sixth BSRN Science and Review Workshop was closed at 12:30 p.m. on Friday 5 May 2000. The participants reiterated their thanks to Dr. Forgan, his organizing team and the Australian Bureau of Meteorology for the excellent arrangements and kind hospitality in hosting the meeting.

Annex I: List of Participants

BSRN Sixth Science and Review Workshop

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Annex II: Workshop Agenda

BASELINE SURFACE RADIATION NETWORK

6th SCIENCE AND REVIEW WORKSHOP

Bureau of Meteorology
150 Lonsdale Street, 5th Floor
Melbourne, Australia
1-5 May, 2000

DRAFT AGENDA

MONDAY, 1 MAY

0830 Registration

1. INTRODUCTION AND OBJECTIVES OF MEETING

0900 Welcome and Opening Remarks
- Ellsworth Dutton (BSRN Manager)
- Hans Teunissen (WCRP Joint Planning Staff)
- Geoff Love (Deputy Director Bureau of Meteorology)

0920 Orientation and safety briefing (*B. Forgan*)
0925 Review of Agenda
0930 Action Items from BSRN Workshop #5 (Budapest) *(H. Teunissen)*
0940 Overview of the state of the BSRN *(E. Dutton)*
1000 Activities at the World Radiation Monitoring Center *(O. Albrecht)*

1020 BREAK

2. STATUS REPORTS FROM EXISTING BSRN STATIONS

Short talks/poster session 1030-1200:

Switzerland *(A. Heimo)*
Canada *(B. McArthur)*
Hungary *(G. Major)*
Nigeria *(T. Aro)*
US/CMDL *(E. Dutton)*
Japan *(Y. Hirose)*
Germany *(K. Behrens)*
Israel *(A. Manes)*
Estonia *(A. Kallis)*
De Aar, South Africa *(D. Esterhuyse)*
Billings, ARM/CART *(C. Long)*

12:00 LUNCH

3. NEW AND PROPOSED STATIONS

1330 Balbina, Brazil *(S. Colle)*
1350 Cocos Is and Jabiru, Australia *(B. Forgan)*
1400 Tropical West Pacific (TWP/ARM) (*C. Long*)

4. BSRN AND THE USER COMMUNITY

1430 Applications and challenges for BSRN data *(E. Dutton)*

1500 BREAK

1520 Perspectives from the GEWEX Radiation Panel *(G. Stephens)*
1540 GAW and the Aerosol SAG (*J. Gras*)

5. AUSTRALIAN PROGRAMMES ON SATELLITE VALIDATION

1600 Satellite verification studies in the Australian Region *(D. O'Brien/R. Boers)*
1620 The Continental Integrated Ground-truth Site Network – CSIGN: Validation measurements for the Surface Radiation Budget *(F. Prata)*

<u>TUESDAY, 2 MAY</u>

6. SOLAR RADIATION INSTRUMENTATION AND TECHNICAL ISSUES

0845 Surface Radiation, Cloud Forcing and the Greenhouse Effect in the Alps *(R. Philipona) (part of Item 10)*
0900 The effect of diffusometer shading geometry *(G. Major)*
0915 Determination of uncertainty in solar irradiance measurements *(N. Hyett)*
0930 The stability of the Australian/ WMO Region V solar and terrestrial irradiance standards *(P. Novotny)*
0945 Experiments with windowed cavity radiometers *(D. Nelson)*

1000 BREAK

1020 Pyranometer offsets *(E. Dutton)*
1035 Investigations of night-time zero offset effects at short-wave measurements *(K. Behrens)*
1050 Algorithms and methods for dealing with pyranometer zeros *(B. Forgan)*
1105 Experiences at Payerne related to BSRN measurements (*A. Heimo*)
1130 Discussion on outstanding issues in solar irradiance measurements

<u>1200 LUNCH</u>

7. AEROSOL OPTICAL DEPTH

1330 Combining the WRR with spectral irradiance in a travelling standard *(B. Forgan)*
1350 Interannual variations of aerosol optical depths at Ilorin *(T. Aro)*
1410 CIMEL AOD measurements in the Australian desert *(R. Mitchell)*
1430 Multi-year measurements of aerosol optical depth *(J. Michalsky)*

1500 BREAK

1520 BSRN specification related to AOD *(B. Forgan)*
1535 Open discussion on AOD and other issues

WEDNESDAY, 3 MAY

8. THERMAL INFRARED IRRADIANCE INSTRUMENTATION AND TECHNICAL ISSUES

0840 Calibration of PIR pyrgeometer with improved conical cavity blackbody in JMA *(Y. Hirose)*
0900 A comparison between measured and calculated long-wave radiation *(K. Behrens)*
0920 IPASRC-I Pyrgeometer calibration and characterisation *(R. Philipona)*

1000 BREAK

1020 Report of the BSRN Sub-Group on UV-B Measurements *(A. Manes)*
1040 UV-B measurements at Carpentras *(J. Olivieri)*
1100 Spectral UV measurements using filter radiometers *(R. Philipona)*
1120 Comparison of UV indices derived from measurements and from AMEX (Australia-Mexico) regional models *(Lemus-Deschamps)*
1140 UV-B and Radiation Measurement Programmes at NIWA Lauder, New Zealand *(R. McKenzie)*
1200 Open Discussion on IR and UV-B issues

1210 Short break before excursion

1220 **Excursion to the Bureau's Training Annex and Melbourne Airport meteorological station and region.**

THURSDAY, 4 MAY

9. DATA MANAGEMENT AND ARCHIVE

0840 Status of BSRN data archive *(O. Albrecht)*
0900 BSRN data processing software *(Y. Hirose)*
0920 Homogeneity of the WRDC time series in comparison with BSRN *(A. Tsvetkov)*
0940 Discussion on BSRN data management and archive issues

1000 BREAK

10. SCIENTIFIC APPLICATIONS

1020 Identifying clear skies and calculating SW cloud effects and sky cover from broadband SW measurements *(C. Long)*
1040 Research site and programme at Zvenigorod *(B. Koprov)*
1100 Radiation measurements from a tethersonde *(B. McArthur)*
1120 CERES and surface validation *(K. Rutledge)*
1140 The influence of irradiance variations on the albedo measured at a uniform grassland site *(I. Grant)*

1205 LUNCH

10. SCIENTIFIC APPLICATIONS (continued)

1330 Changes in downward long-wave radiation at BSRN sites as projected in transient climate change simulations *(A. Ohmura for M. Wild)*
1350 Estimation of absorption in stratus clouds using BSRN and satellite data *(A. Ohmura)*
1410 Diffuse Errors due to shade disk geometry *(A. Ohmura)*
1425 PAR Issues *(R. Pinker)*
1435 Instrument characterization *(K. Hoogendijk)*
1445 General discussion

1500 BREAK

1540 Review of BSRN Operations Manual and current specifications *(B. McArthur et al.)*
1600 Open discussion of unsettled issues; adjustments to Friday's agenda

<u>FRIDAY, 5 MAY</u>

11. BSRN RECOMMENDATIONS AND SPECIFICATIONS

0845 Overview of status and future of BSRN
0915 Recommendations for improved/strengthened BSRN operation and performance

1000 BREAK

1030 Final review of current and future BSRN measurement programs, specifications and modifications to recommendations
1200 Adjournment pending unfinished business

<u>Annex III: BSRN Diffuse Pyranometer Thermal Offset Investigation</u>

(recommended by offset working group at Melbourne BSRN 2000 meeting)

Purpose:

Investigate the extent of daytime thermal offsets in diffuse pyranometers used at all BSRN sites.

Conditions for experiment

1. Use IR reflective white cap distributed at BSRN 2000 meeting in Melbourne.
2. Tracking shade disk must be on pyranometer and pyrgeometer.
3. Collect data between about 2 PM and 3 PM LST.
4. Wind < about 3 m/s.
5. Select clear, drier day, for the particular site.
6. Data rate 1 per 10 seconds; 1 per second would be preferred
7. Record:
    (i) date and time of observation;
    (ii) solar diffuse thermopile signal (to report irradiances);
    (iii) pyrgeometer thermopile;
    (iv) pyrgeometer case temperature;
    (v) dome temperature.
8. Use ventilation (if any) typical for your BSRN site.

Procedure:

Using continuous recording over the period of the experiment during the day (1 hour):

1. Record data for five minutes undisturbed.
2. Place cap on diffuse pyranometer for 2 minutes only. Place weight (0.5 kg) on cap to ensure a good seal.
3. Remove cap for 10 minutes.
4. Repeat steps 2 -3 three times on one day.
5. Repeat steps 1- 4 on three or four different days.

Please do not deviate from above instructions, in order that all sites will be able to report data using the identical sampling procedure.

Verify and confirm voltmeter zero readings (short-out cable connector at instrument end). Either correct data for voltmeter offsets or indicate voltmeter offsets in data submission.

Simultaneous measurements with B&W solar diffuse instrument, and checking of night values, are optional.

Send results (via e-mail), with no thermal offset corrections applied, in ASCII format (delimited by space, tab or comma) to Ells Dutton (edutton@cmdl.noaa.gov). Include information on pyranometer, pyrgeometer, ventilator type, and data structure. If possible, add this information to the header of the ASCII data file. Identify any modifications to instruments or special local conditions.

If you have any questions contact Ells Dutton.

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Annex IV: BSRN Specification Related to Aerosol Optical Depth

BSRN Specification related to Aerosol Optical Depth

(Accepted 5 May 2000)

Bruce W Forgan

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Summary

The BSRN Archive related to aerosol optical depth will be made up of spectral transmission data from radiometers that measure direct and diffuse irradiance signals at wavelengths that are only subject to molecular (Rayleigh) scattering, ozone absorption and aerosol extinction. Sampling will be at 1 minute intervals. With these and station ancillary data indicating wavelength characteristics, and other extinction parameters, the BSRN Archive will reduce these data using a fixed quantitative algorithm into estimates of aerosol optical depth for clear sun conditions.

Background

Historically, monitoring of aerosol optical depth is problematic from instrumental, analytical and environmental factors. Instrument stability and calibration have been issues since the first hand-held sun photometers were used to estimate aerosol optical depth, and still remain as the significant issues with the solar monitoring spectral radiometers that are available today.

Similarly the consistent reduction of aerosol optical depth from spectral radiometers signals is difficult when there are many different models of molecular, ozone and water vapour extinction. Aerosol extinction using the sun as a source can only be reduced by removing all the other components of extinction, and there is poor certainty that this remainder is aerosol optical depth and not cloud effects or other extinction components.

The problems associated with the BAPMoN Turbidity archive are well documented. However, the basic principle of the archive was founded on good metrological practice. What failed the BAPMoN Turbidity archive was the infancy of the technology, the sampling strategy, the inconsistency of the way in which various data could be supplied to the archive and, the limited quality assurance cycle. For the BSRN Archive to include parameters related to aerosol optical depth it needs to learn from the problems of the BAPMoN turbidity archive and not duplicate those same problems.

The aim of the BSRN is to provide high quality irradiance (and associated) measurements to the global scientific community. The BSRN Archive accepts irradiance and ancillary data from stations on the conditions that the data are collected and processed using proven methods that achieve a low level of uncertainty. In all cases the radiometric data is a relatively simple proportional conversion of signal to irradiance with little if any need for modelling of the atmospheric impact on the signal. Deriving aerosol optical depth data is almost the inverse of this process.

Most importantly the solar irradiance data in the current archive have a practical hierarchy of traceability that allows the conversion of signal to irradiance. For terrestrial (longwave) irradiance a source-based traceability hierarchy is being established through the BSRN longwave working group. Unfortunately no such practical hierarchy exists for optical depth; it still requires the development of detector-based spectral irradiance standards and knowledge of the spectral irradiance at the top of the atmosphere. The default practice at the moment is to use extrapolation to the top of the atmosphere (that is, variant applications of the Bouger-Lambert-Beer transmission law); this method is not independent of the atmospheric condition.

In essence, while the instrumental and sampling problems have lessened a great deal, the current situation is still very similar to those existing when the BAPMoN turbidity archive was established.

This specification aims to provide the user community with a database that has a useful future, by:

(1) collecting data that are consistent with the current archive;
(2) providing aerosol optical depth data in clear sun conditions based on the a BSRN assured objective algorithm; and
(3) provide a data source to advance the methods of deriving optical depth.

The specification outlined below was based on the experience and knowledge gained by the optical depth community and its instrumental specifications and is based to some extent on the recommendations of the WORCC/PMOD.

Definition of parameters

t = time representing the irradiance measurement , and described by the second of the day;

δt = time period centred on t that encompasses all observation set measurement for time t, in seconds;

λ = representative wavelength of spectral irradiance;

$\delta\lambda$ = full width at half maximum transmission for the representative wavelength of spectral irradiance

$S_o(t, \lambda)$ = instrument signal at time t due to top of the atmosphere spectral irradiance;

$S(t,\lambda)$ = instrument signal at time t due to direct beam spectral irradiance;

$T(t,\lambda)$ = direct beam spectral transmission at time t, that is
= $S(t,\lambda)/So(t,\lambda)$;

$Sd(t,\lambda)$ = instrument signal at time t due to diffuse spectral irradiance;
$\theta(t)$ = observed solar zenith distance at time t;

$Dt(t,\lambda)$ = diffuse spectral transmission at time t
= $Sd(t,\lambda)/(So(t,\lambda) * \cos(\theta(t)))$.

P(t) = atmospheric pressure at instrument at time t;

Oz = ozone atmospheric column amount above the instrument in atmospheric centimetres (atm. cm) that represents the amount at time t;

FOV = field of view;

An *observation set* consists of all measurements (and calculated parameters) for a set of wavelengths at t, and provides one record of data. For example, say four wavelength values of T and Dt from an MFRSR at time t, δt in this case representing the time between the two global irradiance signal measurements that encompass the global->subglobal->diffuse->subglobal->global measurement sequence, P(t) and $\theta(t)$, and t.

Data transmitted to the Archive

The final format of the data for submission to the archive will be determined once this specification is accepted, but the basic data records would be expected to be in a similar form as the irradiance records. However, utilising minute statistics (such as the minute mean, maximum, minimum and standard deviation) would increase the uncertainty in any derived optical depth. Instead each observation set will only represent a fraction of each minute. Most importantly two new time parameters (t and δt) will be required for each observation set.

Like the instrument parameters, instrument characteristics would be transmitted and any changes recorded using methods almost identical to the current protocol.

The current archive storage mechanisms for ozone and atmospheric pressure would also use current protocols in data submissions but with one important caveat, namely no spectral transmission data will be accepted unless ozone and atmospheric pressure data are supplied for time periods covered by the observation sets.

Parameters required to define the measurements

To utilise the transmittance measurements it is essential that the instruments are described both quantitatively and qualitatively. The parameters isolate the methodology of measurement and the instrument limitations hence enable definition of uncertainty limits.

Note that the magnitude of the calibration value is not a parameter required in the submitted data, only the date and the methodology of calibration. However, the uncertainty parameters are required as these can be used as part of the BSRN Archive quality assurance process.

The required parameters are listed in Table 1.

Table 1: Parameters to define type of measurements

Parameter	Description	Why?
Number of instruments	Numeric value of instruments supplying the transmittance data	As with the irradiance data set, multiple instruments may be used for the measurements
Instrument 1 Type	Numeric key to indicate type of device	Is it an cosine or solar tracking device
Description of Instrument 1	Text description of instrument 1	General information
Number of wavelengths data supplied by instrument 1	Numeric value of instruments supplying the transmittance data	Multiple wavelengths possible from each instrument
Calibration method	Numeric key to indicate type of calibration	Langley, instrument comparison, solar or lamp irradiances, trap detector?
Calibration description	Text description of calibration method	General information
Calibration date	Numeric parameters to described date of last calibration	General information
Optics type	Numeric key to describe the instrument optics	Describes the optics
FOV parameters	Numeric parameters based on type of optics	Determines the relationship between solar disk, aureole for quality assurance
Wavelength 1 from instrument 1	Numeric value for λ	Stored 1st wavelength
Bandpass wavelength 1	Numeric value of $\delta\lambda$	Stored 1st bandpass
Calibration uncertainty	Numeric parameters that describe the uncertainty in the calibration parameters	Would include the combined uncertainty and the coverage factor.
Description of wavelength 1 bandpass	Text description of the type of mechanism used for wavelength limitation	General information: is it data from an interference filter, light emitting diode, CCD array?
Repeat last three inputs for all remaining instrument 1 wavelengths	…….	…….
……	……….	……..
Description of wavelength n bandpass of instrument 1	Text description of the type of mechanism used for wavelength limitation	General information: is it data from an interference filter, light emitting diode, CCD array?
Repeat inputs as for instrument 1 for other instruments	…….	

Parameters required for each Observation Set (or measurement record)

Table 2 below describes the parameters that can be recorded for each observation set.

Note the transmission data from the site includes ALL observation sets available when the sun is above the observed horizon. Observation sets should not be subjected to post-collection clear sun criteria and should include *all* measurements when the instrument is operational and sensing direct (and diffuse) spectral irradiance. This adds to the value of the data set in monitoring total atmospheric (and hence cloud transmission) and ultimately conversion of the transmittance data to spectral irradiances.

The sampling strategy used in spectral radiometry by the various instruments available at this time means that it would be inappropriate for this data set to prescribe a fixed sampling time. However, it maybe necessary for easy of import of the data into the archive that a 'missing' record is added for each minute period when no observation set (or record) was taken.

Table 2: Parameter requirements fro each observation set.

Parameter	**Description**	**Mandatory?**	**Comment**
t	Time of measurement in seconds of the day	Yes	In seconds of the day of measurement (range 1-86400)
δt	Period in seconds to collect observation set	Yes	In seconds and centred on t.
$\theta(t)$	Observed solar zenith distance in radians	Yes	Can be used in calculations and a quality assurance check on t
P(t)	Atmospheric pressure (hPa)	No	Pressure data must exist in the other monthly submitted data if not included
Radiometer Temperature	Numeric in °C	No	Ambient air temperature must exist in the other monthly submitted data if not included
T(t, wavelength 1)	Direct transmission	Yes	
Dt(T, wavelength 1)	Diffuse transmission	No	
T(t, wavelength 2)	Direct transmission	Yes	
Dt(T, wavelength 2)	Diffuse transmission	No	
……	…….		Repeat for the total number of wavelengths
T(t, wavelength n)	Direct transmission	Yes	
Dt(T, wavelength n)	Diffuse transmission	No	

Location Requirements

Time measurement accuracy and location information are as per the current BSRN irradiance specification. It is essential that these time and location specifications be maintained as poor calculation of the sun position from the location and time has a significant impact on the conversion of transmission data to optical depth.

Data sampling frequency

As with the current irradiance protocol the required frequency is 1 observation set per minute, however, until 2004 a less frequent observation set can be submitted. As indicate above, current instrumentation that produces data adequate for the BSRN Archive (see Appendix A) have a variety of sampling mechanisms, for example, some on a fixed time interval and others on fixed zenith distances or both.

One important restriction is that data from manually operated spectral radiometers will not be submitted to the BSRN Archive. Any acceptance of this poor frequency of observation data from manual devices would require significant and unacceptable resource requirements for data quality assurance. Furthermore, manual observations are qualitatively biased to the observers perception of conditions.

In the case where a number of radiometers are operating in parallel to make up one observation set, the sampling should be synchronised so that the same t value applies to both radiometers. The δt value should be the maximum value within the ensemble of radiometers.

Maintenance requirements

The optical surfaces should be cleaned to ensure that the window material does not impact on the sensitivity. Normally, windows should be cleaned at least once per day as per the pyranometer and pyrradiometer domes and preferably after sunrise but before the sun is more than 8 degrees above the horizon. In the case of devices using diffusers, the surface and aperture limits should be checked daily and if any foreign material is observed it should be removed by the manufacturer’s or preferred methods.

Wavelength Specification

This follows to a large extent the recommendation of the WORCC and is described in Table 3.

The difference between the BSRN and WORCC specification is that the latter allows for wavelengths centred on water vapour and NO_2 absorption bands. Such wavelengths are *not included* within the BSRN data system related to aerosol optical depth. To include such wavelengths in the BSRN transmission specification would imply that there is readily available information about aerosol extinction at these wavelengths. It would require a complete definition of filter transmission and the specification would have to be redefined to accommodate all forms of optical depth rather than just aerosol optical depth.

Ideally these wavelengths chosen are centred on relatively flat areas of the solar spectrum, away from water vapour bands. The proximity to the influence of water vapour (and oxygen) absorption forces restrictions on the allowed displacement from the nominal wavelength, and the half width at full maximum (or band width).

The actual wavelength λ should be determined to the nearest 0.3 nm.

Out of band rejection should be at least 10^{-4} at wavelengths 40 nm from λ.

The wavelengths are ranked in order of priority with highest priority designated by 1, and least by 7. That priority is determined by the degree of uncertainty in the observation as related to aerosol extinction. Four wavelengths are designated as mandatory, but like the sampling requirements are only to be required by 2004.

Table 3: Wavelength specification

Nominal Wavelength (λo) (nm)	Allowed wavelength displacement $\|\lambda-\lambda o\|$ (nm)	Maximum $\delta\lambda$ (nm)	Priority	Mandatory?
412	2	6	1	Yes
862	4	6	2	Yes
500*	3	6	3	Yes
368	2	6	4	Yes
778	2	11	5	
675*	3	11	6	
610+	2	11	7	

* Subject to ozone absorption, which can be a significant source of uncertainty if ozone is not well known.

\+ Moderate ozone absorption

Calibration

As indicated above, unlike broadband irradiance, the calibration of spectral radiometers for suitable derivation of transmission, and hence optical depth is an unresolved issue. It was an issue in the 1970s and remains contentious. Until there is some practical traceable hierarchy in place, the reliability calibration of the spectral radiometers for transmission will likely remain the sole preserve of the BSRN station manager.

It is recommended that for a group of stations under the control of one BSRN member, the station radiometers are calibrated by comparison to a travelling standard with identical wavelengths to the station radiometer(s) using the ratio-Langley methodology.

In the interim until a detector based calibration hierarchy is established, the group standard radiometer(s) calibration can be determined by:
(1) an independent detector based standard; or
(2) a series of 20 or more 'Langley' type calibrations at a high transmission site over a period of 3 months or less; or
(3) a set of lamps with a traceability hierarchy.

Once data from more than one group is submitted into the archive, the BSRN should organise a round robin calibration process similar to that used for the terrestrial (longwave) standarization process. It is recommended that the WORCC be involved in such a round-robin.

Orientation accuracy

Two main types of spectral radiometers are in use and can be considered for this specification: direct beam and 2π (horizontal) radiometers. Each has their specific requirements related to pointing accuracy.

Direct beam radiometers should be mounted on tracking systems as specified for direct beam pyrheliometry within BSRN. The FOV of the devices should be less than 2° in the case of systems using lens to focus the sun's image, and in other cases the slope angle should be less that 1° and the opening angle less than 2.5°.

In the case of 2π (horizontal) radiometers, they must be able to measure the global and diffuse components of the spectral irradiance for every observation set. Most importantly,
(1) their cosine response must be known to within 1% for all zenith angles between 0° and 82° and specified independently for all wavelengths being reported; and
(2) their optical level must be maintained to within 0.1°.

It will be required that by 2004 any station using a 2π (horizontal) radiometer for data submission must have a direct beam radiometer monitoring spectral transmission operating in parallel at 2 duplicate wavelengths to the 2π (horizontal) radiometer. This requirement is to ensure that a suitable on-site cosine response check can be completed to reduce orientation uncertainties.

Data acquisition

In order to reduce the impact of the data acquisition system on the transmission data, the data system must be able to resolve 5000:1 for the direct beam (or global) irradiance signal at the lowest airmass available at the station for all wavelengths reported. In high turbidity environments (that is aerosol optical depths at 500 nm > 0.750 occur on a regular basis) the data system must be increased to resolve 12000:1.

Attempts should be made to monitor the zero irradiance signal on all instruments. If the zero signals can be monitored they should be measured as part of the routine data collected during the collection of signals that will ultimately make up part of the of each observation set submitted to the archive

In the case of MFRSR devices, periodic checks of the zero signal at night and its relationship to the global and diffuse signals should be checked. While having an insignificant impact on the derivation of the direct transmission, lack of zero information is a significant source of uncertainty for the calculation of diffuse transmission in clear sky conditions, particularly at near infrared wavelengths.

Acceptable radiometers

Given close and careful management of the measurements, a number of commercially available radiometers can satisfy this BSRN specification. They are listed in alphabetical order by tracking requirement and type in the Appendix A.

Radiometers that utilized interference filters to sense direct beam irradiance on a solar tracker and either concentrate or do not reduce the solar energy reflected, absorbed or transmitted through the filter need special consideration. High solar exposure has been shown to degrade interference transmission. The likelihood of filter degradation can be reduced by:
(1) sealing the radiometers from to the ambient environment;
(2) ensuring the filters are not exposed to solar irradiance for more than 10% of the time between sunrise and sunset (by using a shutter or similar device);
(3) using large 25 mm diameter filters; and
(4) using filters manufactured by ion deposition process.
Historical evidence suggests that the first three methods reduce the rate of filter degradation by a significant amount. Long-term measurements have yet to show that the use of ion deposition filters is a significant improvement on non-ion deposition filters but the initial evidence is encouraging. Direct beam or 2π (horizontal) spectral radiometers using interference filters and a diffuser tend not to have high filter transmission degradation rates, if they are sealed against the environment.

The long term stability of devices that use silicon CCD arrays with diffraction gratings or prisms to isolate wavelengths is unknown at this stage, but for wavelengths > 400 nm the results are encouraging.

While measurements with a direct beam radiometer will satisfy the BSRN requirements, it is recommended that a 2π (horizontal) spectral radiometer (measuring both global and diffuse) be added to the measurement program if the site has at least 40 totally clear sky days per year. The addition of diffuse transmission to the observation set will enhance the aerosol extinction information and is likely to help characterise the spectral surface reflectance on clear sky days.

Uncertainty Targets

At the 5th BSRN Workshop the AOD WG was asked to:

- Identify one or more reference measurement instruments capable of providing AOD to an accuracy of 0.01 under near-ideal conditions for selected wavelengths in the range 360 to 1100 nm;
- Identify one or more instruments suitable for field use which are capable of providing AOD to an accuracy of 0.02 for multiple wavelengths in the range from 360 to 1100 nm for 95% of the time when water clouds do not affect the observations;
- Specify calibration procedures required to achieve above accuracies;
- Define data acquisition and processing procedures for obtaining routine field data within the above specifications.

On the assumption that the ‘accuracies’ were in fact combined uncertainties at the 95% confidence level, the measurement process was subjected to an uncertainty analysis as per the ISO Guide to the Uncertainty of Measurement, by modelling the following three measurands:

(1) Radiometer signal or counts due to irradiance on the sensor, given by

$\text{Counts} = E \,.\, \alpha / \delta Q + C_n$ where E is the irradiance, α the non-linearity (and variable window transmission), δQ the irradiance for 1 count, and C_n the digitisation noise.

(2) Transmission, given by

$$T = r^2\,(\text{Counts} - \text{Zero} - \text{Aureole})/\text{Cal}$$

where T is the transmission, r is the earth-sun distance in A.U., Zero the zero counts, Aureole the sky counts and Cal the top of atmosphere counts. This model was extended for 2π radiometers by adding a cosine-solar-zenith angle term.And

(3) aerosol optical depth, given by,

$$\delta_a = -(\ln(T) + m_r\delta_r + m_o\delta_o)/m_a ,$$

where m_r is the molecular airmass, m_o is the ozone airmass, m_a is the aerosol airmass, δ_a is the aerosol optical depth, δ_r the molecular (Rayleigh) optical depth, and δ_o the ozone optical depth.

The uncertainties were then calculated for a number of wavelengths and parameters listed in table 4 below in the airmass range 1 to 6. The analysis showed that the dominant uncertainties were those related to calibration, non-linearity and in the case of ozone affected wavelengths, the uncertainty of the ozone extinction. In the case of cosine reduced radiometers the non-linearity and cosine response error were treated as the one condition and no estimate was made of the variation in uncertainty with zenith angle; cosine calculation was assumed to be perfect and not an error contributor. No uncertainty analysis was performed for the diffuse transmission.

Table 4: Uncertainty parameters

Parameter	*Ranges*	*Type*
'Langley or detector calibration':	σ = 2%	A
Digitisation	1:5000	B
Non-linearity in detector	0.2%, 1%, 2%	B
Zero	.0003	B
Aureole:	.0005	B
Earth-Sun	0.001	B
Airmass	0.002	B
Ozone extinction	30%, 10%, 5%	B
Molecular (Rayleigh	0.7%	B
Wavelengths	368, 412, 500, 675, 862 nm	
Extra (or aerosol) optical depth	0.060	

The results indicate that provided the 'calibration' is based on at least 30 observations, the linearity is less than 1% and for ozone wavelengths the ozone extinction is known within 10%, the uncertainty of measurement is of the order or less than 0.010 for all wavelengths, and the transmission would be known to 0.01 for all wavelengths. This satisfies the Hungary requirements to a certain extent.

However, without a detector based hierarchy and the measurement of the top of the atmosphere signal, this analysis only applies to a group of instruments using the same 'calibration' and data reduction process. These measurands do not resolve the difficulty of comparing the measurements of two instruments using different calibration processes.

Given that at this stage the global community (and hence BSRN) do not have a practical calibration hierarchy it is essential that at least the derivation of aerosol optical depth uses the identical reduction mechanism, and the transmission data can be subjected to quality assurance that is consistent for the entire network.

The rejection of cloud affected data is also problematic. If each submitter of data were allowed to apply their own selection criteria (as occurs explicitly in most manual radiometer measurements), the uncertainties in the success of comparing aerosol extinction statistics would escalate even further.

Therefore while the majority of current automatic instruments appear suitable to the task it is essential that until the application of a reduction model does not contribute significantly to the uncertainty, only signal related data should be submitted to the BSRN archive. Given the potential for a variety of units for the variety of instruments, transmission is the obvious candidate for data submission.

Conclusion

Provided the measurement protocols as indicated above are utilised the likely success of a BSRN Archive related to aerosol optical depth is high. However, it is essential that to properly reduce transmission data to aerosol optical depth statistics, the BSRN must cooperate in the development of a calibration methodology for transmission that is independent of atmospheric transmission. It is therefore recommended that BSRN have a close collaboration with the WORCC in the development of a practical calibration methodology.

Appendix A: A list of known spectral radiometers

Table A1: Commercially available radiometers.

Tracking Requirements	*Type*	*Radiometer (Manufacturer)*
Require a solar tracker	Direct	ASR (Carter-Scott Design)
	Direct	PFR (PMOD)
	Direct	SP1 (Dr Schulz and Partners)
	Direct	SPO1/A (Carter-Scott Design)
	Direct	SPO2 (Carter-Scott Design)
	Direct	SPUV (Yankee Environment Sys)
Self-Tracking*	Direct	CIMEL (CIMEL)
	Direct	EKO (Eko Trading Co.)
	2π	MFRSR (Yankee Environmental Sys.)
	2π	RSS (Yankee Environmental Sys.)
	Direct	SP1 (Prede/Kipp & Zonen)

* May not conform to BSRN tracking and sampling requirements.

This table is not exhaustive, but represents a group of well known instruments.

Appendix B: Implementation of the specification

Once the basic elements of this specification are accepted by the BSRN community, and the WRMC deems it possible to accept the new data streams, the WRMC must be prepare for data distribution. Furthermore, the WRMC (or an associate group) must derive the aerosol optical depth estimates from the transmission database, a significant addition to the role of the WRMC.

Below is a methodology to overcome these changes.

Firstly, the format of the transmission archive (as related to Tables 1 and 2) must be determined and distributed by the WRMC. (The conversion of the data received into aerosol optical depth need not be implemented at/with the WRMC until after data have been received.)

Then data from the various stations with spectral transmission data can be submitted. The BSRN community's experience with the irradiance database suggest that the conformity to the exacting requirements from the disparate station data streams was a significant obstacle to the timeliness of data submission. However, extended delays in submission need not be repeated for the transmission data.

The recent experience of the Bureau of Meteorology (BoM) and the Swiss Meteorological Institute (SMI) in code for aerosol optical depth analysis indicates that a uniform objective data preparation and analysis code can be readily adapted to the different input streams used by BSRN stations. In essence, these codes are based on an independent set of routines that produce identical output streams regardless of the data source. Most importantly, provided the input streams remain in a constant format for each particular station setup, the basic data required from the WRMC would be independent of any improvements in interpretation of transmission data.

Once the WRMC format for the transmission database is completed, each data supplier would provide example data streams to a group capable and willing to adapt the code set to generate the required BSRN transmission data. The responding group would prepare the input routines and code for the specific data sets and then provide source code and executables for the data supplier. In the case of the BoM the turn around for receipt of data to code distribution was less than a week. If a similar willingness for modifying and distribution of code applies to transmission data for the WRMC, and given the initial small numbers of potential data suppliers, the time between implementation of measurement and data submission could be quite short.

Given the BoM and SMI experience, it is also likely that the same code would provide a side benefit, namely a method to assist in determining So.

The current lack of a traceable spectral irradiance standard and associated top of atmosphere irradiances together with the inconsistency of use in the models required to interpret transmission data, mean that a consistent and objective algorithm must be used to interpret for cloudiness, and ultimately clear sun aerosol optical depth. To do otherwise would increase the uncertainties in any aerosol optical archive with multiple group submissions.

The BAPMoN turbidity archive could provide archive-derived aerosol optical depth, (if the data submissions contained the relevant data). However, a review of that turbidity archive suggests algorithm development and quality assurance was not given sufficient impetus. The development of the BSRN Archive aerosol optical depth objective analysis scheme cannot afford to suffer the same resource problems.

It is recommended that either the development of the algorithm be given to the BSRN AOD Working Group in close association with the WRMC staff, or the processing of the BSRN Archive transmission data be outsourced to a BSRN-associated (and certified) group with the responsibility of providing the derived aerosol optical depth product to the WRMC/BSRN Archive. As in the case of all other BSRN radiometric parameters, the continuing improvement and development of the aerosol optical depth algorithm could proceed under BSRN AOD Working Group direction as the knowledge of the measurement and retrieval process increases.

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Annex V: Report of the BSRN UV-B Sub-Group

REPORT
OF THE BSRN UV-B SUB-GROUP SUBMITTED TO THE 6TH BSRN SCIENTIFIC AND REVIEW WORKSHOP, MELBOURNE, AUSTRALIA, 1- 5 MAY 2000

Members of the SG: A. Manes (Chair), K. Dehne, C. Froelich, I. Galindo, A. Heimo, B. McArthur, J. Olivieri, R. Philipona and A. Shalamyansky.

1. Terms of Reference

At the 5th BSRN Science and Review Workshop held in Budapest, Hungary, 18-22 May 1998, it was recommended that *precision UV-B measurements should eventually be included in the BSRN suite of observations. While the need to identify, characterize and standardize suitable UV-B pyranometers was recognized, it was also noted that this problem is being addressed by other groups (e.g. GAW).* It was therefore agreed to establish a standing BSRN Sub-Group on UV-B measurements to follow up on these issues and in particular to monitor the work of other relevant groups.

2. UVR Measurements at Active BSRN Stations and Submission of UV Data to the Archive

Measurements of UV radiation are carried in a number of active BSRN stations, e.g. Carpentras, France; Payerne, Switzerland; Georg von Neumayer, Antarctica, Syova, Japan, and others plan to do so in the near future (i.e. Rachel Pinker - BSRN station of Ilorin, Nigeria; A. Kallis, Toravere, Estonia and I. Galindo, Mexico). Practically, however, only one station is submitting UVR data to the Archive since 1998. It is the Payerne station in Switzerland. According to Alain Heimo, *they have been sending UV data from 1998 onward to the WRMC. The format has been defined preliminarily, and tested, together with H. Gilgen and H. Hegner of the WRMC.*

At Payerne, the following UV parameters are measured:

- *UVB global irradiance*
- *UVB diffuse irradiance*
- *UVB direct irradiance (in a tubus placed on the sun-tracker)*
- *UVB reflected irradiance*
- *UVA global irradiance*

All instruments are from Solar Light, Biometers, model 501A. The UV data submitted are converted to W/m2 (approx. CIE).
*The QA/QC is made on a daily basis by computing one parameter with the other two (for example Global = Direct*cos(ZA) + Diffuse) for the 3 first components, and by turning over the "reflected" instrument and comparing it to the global Biometer.*

All instruments are regularly compared with travelling standards, to guarantee at least the relative uniformity of the Swiss network.

According to Alain Heimo, this procedure may be valid only within a rather broad error margin (typically 2-3%), as each UV-B instrument has its own spectral characteristics and action curve (corresponding only approximately to the CIE action curve), depending on ozone amount, SZA, AOD and cosine response characteristics. A PMOD/WRC Biometer, which has been already participating to many International Interomparisons, is used as a reference instrument.

The reasons for not measuring UV-B radiation, or not submitting data to the Archive by other stations, are rather common, stemming from uncertainties in spectral response of the commercially available broadband radiometers, their dependence on atmospheric conditions, cosine response, lack of viable calibration hierarchy, calibration instability, and problems with formatting of the data.

3. The Present Situation with UV Measurements Addressed by Other Agencies

According to the terms of reference of the UV-B SG our main task was to follow up and monitor the activities and progress made by other groups in UV measurement and calibration procedures (i.e. GAW). We will now focus on this issue, and review the progress made by a number of "activity centers" during the last decade, i.e. EC and STUK, WMO GAW and CUCF in the USA.

3.1 EC Sponsored Activities at the European Arena

In a recent Web document published by Georgios T. Amanatidis of the European Commission EC DG XII Research (http://europa.eu.int/search/s97.vts), a brief review is given of the research policy of the European Commission during the last decade on UV radiation. The EC activities were presented also by Georgious T. Amanatidis at the European Conference on Atmospheric UV Radiation (ECUV) held in Helsinki in July 1998.

According to G. T. Amanatidis: *the research policy of the European Commission during the last decade on the atmospheric UV radiation subsequent to the stratospheric ozone depletion is to determine accurately the UV radiation field in Europe. In the framework of STEP 1989-92 and Environment 1991-94 Programmes the specific objective was to produce practical recommendations for the* ***deployment of an integrated UV network throughout Europe****. These recommendations should be based on comparison of different methods of measurements both between, and within, instrument categories (spectroradiometers, biological dosimeters, broadband and multi-band radiometers, etc.). Suitability of instruments, and the criteria of a network, were judged by their ability to meet the requirements of the potential users of the data such as atmospheric modellers, photobiologists and photochemists. Several intercomparison campaigns of UV spectroradiometers were funded and aimed at assessing the compatibility among instruments and thus the establishment of an informal network for measuring the UV radiation field and its temporal and spatial variability in Europe.*

The EC support to atmospheric UV radiation research was reinforced under the Environment and Climate Programme 1994-98. It includes instrument development and intercomparison studies, past data interpretation and management, regional process studies estimates of UV irradiance from satellites etc. A novel UV detector for UV-B radiation measurements is under development (ALDUV project). The twobiggest intercomparisons of

UV spectroradiometers (SUSPEN project) and of biological UV dosimeters (BIODOS project) were organised in 1997. Scientific interpretation of the existing ground based spectral and broad-band UV measurements in Europe has been initiated in Europe on the basis of improved understanding of the radiative transfer processes (e.g. SUVDAMA and UVRAPPF projects). Field experiments have been organized to study the UV induced changes in the tropospheric chemical composition in the Mediterranean (PAUR and ATOP projects) and the characteristics of UV radiation field in the Alps (CUVRA project). Research efforts to calculate the UV radiation field derived from satellite data have been also initiated (MAUVE and STREAMER projects).

The EC will continue supporting research in the coming years within the Fifth Framework Programme . Research on atmospheric UV radiation will be carried out in the "Global Change, Climate and Biodiversity" key action. Emphasis will be given to understand the relative contribution of all factors (cloud cover, solar elevation, atmospheric aerosol, altitude and albedo) which influence the UVradiation fluxes, as a prerequisite to define the climatology of UV radiation in Europe.

The present situation, however, with the deployment of an **Integrated UV-B Network in Europe**, which was planned for the last decade of the 20th Century, remains unclear. This is also the case with regard to the establishment of an **European Central Calibration and Characterization Facility**.

3.1.1 UV Spectroradiometers

The main effort in Europe seems to have been concentrated on intercomparison of UV spectroradiometers. An Intercomparison of UV Spectroradiometers was held in August 1997 in Garmisch-Partenkirchen (Germany), and was reported by G. Bernhard, B. Mayer and G. Seckmayer. The results of the SUSPEN intercomparison campaign of UV spectroradiometers conducted at Nea Michaniona in Greece during 1-13 July 1997 were reported by A.F. Bais et al.

The general impression from the results of these European intercomparisons is that every time the UV spectral instruments get closer together, and that the "main force" seems to be the Thessaloniki group led by Alkis Bais with the active participation of a number of leading institutes, i.e. G. Seckmayer (Germany), Ann Webb (UK), Kuik (Netherlands) and Wardle (Canada), and others.

Especially encouraging are the results of the SUSPEN intercomparison campaign held in 1997. The 19 instruments which have participated in this intercomparison were capable of producing consistent and repeatable responses to incident radiation. With the exception of three instruments the others agree to within about +/-10% in their slit-function standardized spectral measurements. Most important, *a core of instruments could be delineated, showing the best agreement with the Reference and high stability.* It is believed that with proper maintenance and calibration protocols they can provide reliable and quality controlled spectral measurements of solar UV irradiance.

Alkis Bais seems to be quite satisfied with the results of this last UV spectroradiometer intercomparison (he was kind enough to email an informal copy of the paper summarizing the SUSPEN Intercomparison, to be published in JGR).

3.1.2 Broadband UV-B Radiometers

It seems, however, that no similar, real progress was made with the characterization, standardization, calibration and stability of broadband UV-B radiometers, at least at the European UV networks, during the last 5 years. The two main intercomparisons of broadband radiometers carried out in Europe, the WMO/STUK in Helsinki (1995) and the WMO - UMAP Workshop in Garmisch-Partenkirchen (Germany) in 1996 (WMO/GAW Reports 112 and 120, respectively) did show considerable differences between the characteristics of the various types and brands of the UV-B pyranometers, as well as lack of stability of their calibration characteristics.

If we focus on the most widely used UV-B pyranometers, the SL-501 and YES UVB-1, we find considerable difference between them, and between both and spectral UV radiometers. A. Manes found about 13% difference between YES UVB-1 and SL 501, both exposed side by side at the Dead Sea area (clear sky conditions with heavy desert-borne aerosol load, typical for this region during summer), with the YES UVB-1 showing the higher values. Similar discrepancies were reported by others, i.e. Craig S. Long, Bruce McArthur, Canada - about 12% difference, etc. The last intercomparison of UV-B wideband radiometers held in Greece only a couple of months ago did not lead to more encouraging results. According to Alkis Bais the data are still being analyzed, however, a very preliminary analysis shows that some units have drifted away as far as by 25%, while others show a higher stability.

What seems to be most disturbing is not just the bias, but rather lack of calibration stability, depending probably on a variety of atmospheric conditions, solar zenith angle, ambient temperature and the characteristics of the filter used in this instruments to mimic the erythemal action spectrum.

A. Manes has corresponded recently with Saul Berger, President of Solar Light, and Arthur Beaubien of YES Company, to have their response to the above claims and problems. It should not be difficult to imagine that each one has pointed to the deficiencies of his competitor. Saul Berger claims that the reason for the positive bias of the YES UVB-1 stems from the high temperature of thermostating which shifts the spectral response of YES by 3 to 4 nm toward the UV-A, when heated. Arthur Beaubien claims that the problem stems from differences in clibration source used by both manufacturers. He claims that while the Yankee UVB-1 instrument is referenced to a broadband UVB reference pool of like-pyranometers which have been calibrated with a co-located calibrated spectroradiometer, SLC applies a calibrated lamp laboratory calibration and not atmospheric co-located spectroradiometer. Although, they both might be right, these are probably not all the problems. The problem is how could both manufacturers be “brought together” to reach some unification of calibration and referencing procedures for the sake of acceptable comparability of both types of instruments.

3.2 European Conference on Atmospheric UV Radiation (ECUV)

The European Conference on Atmospheric UV Radiation (ECUV) held in Helsinki, Finland, from June 29 to July 2, 1998, was organized by the European Commission/DG XII, COST, the Academy of Finland and the Finnish Meteorological Institute.

Although a considerable number of non-European countries have taken part in this conference, i.e. USA, Japan, Canada, Australia, New Zeland and Taiwan, the main effort at this conference was to reflect the "state-of-the-art" in UV radiation research at the European arena. The large number of participants at this conference (160 scientists) representing numerous research institutes, universities and governmental bodies involved in various aspects of atmospheric UV radiation research, 47 oral presentations and a poster session (as much as 123 posters!) - all were indicative of the importance and weight assigned by the European Community to the possible impacts of stratospheric ozone depletion and increased exposure of the biosphere to UV radiation.

Nevertheless, the ECUV revealed also that the UV measurement and instrumentation issue, especially with regard to the broadband UV radiometry, is still far from being resolved, and the efforts in this direction are highly dispersed.

A quick look into the excellent web pages compiled by Betsy Weatherhead of NOAA (www.srrb.noaagov/UV/ssc/betsy.html) on the Global UV Monitoring Network may reveal that, though all countries of the European Union run networks of UV monitoring stations, a large variety of UV instruments, spectral and wideband, is used (a list of UV instruments of various manufacture and brand is given in the above web site).

The differences in characterization of these instruments, their spectral response, lack of central calibration facility and recognized calibration hierarchy, differences in cosine response, and not the least, instability of calibration, and response characteristics to atmospheric parameters (e.g. total ozone and AOD) - all are conducive to large instrument induced differences in surface observed UV fluxes, as high as by 20-30 percent. This is certainly a far cry from the objectives of EC funded projects to deploy an **Integrated UV Network** throughout Europe. The negative consequences of such rather dispersed effort were brought up during the ECUV, though implicitly.

A certain level of coordination, however, is provided by the WMO Scientific Steering Committee (SSC) on UV Monitoring comprised of the following members:

Paul Simon	-	Chairman of SSC
Betsy Weatherhead	-	Coordinator of international efforts
Peetri Taalas	-	Head of UV data analysis group
Gunther Seckmayer	-	In charge of instrument characterization
Ann Web	-	Heading issues of QA
Sasha Medronich	-	Coordinator of UV modeling
David Wardle	-	In charge of WMO ozone and UV data center
Anne Kricker	-	Representing users of UV data
Christos Zerefos	-	Delegate of WMO EC Panel

John Miller - WMO representative
J.M. Libre - UMAP representative
Georgios Amanatidis - EC representative
Osamu Uchino - JMA representative, observer to SSC

3.3 WMO Global Atmosphere Watch (GAW) - UV Programs and Activities

The programs and activities of WMO Global Atmosphere Watch (GAW) in UV measurements were reviewed at the Plenary Session of ECUV by Liisa Jalkanen of the WMO Environment Division/AREP. GAW currently consists of 20 global stations in pristine areas, and about 300 regional stations located closer to source areas, with the goal to ensure long-term measurements. The suite of measurements at GAW stations include, among others, also UV radiation measurements. The WMO Scientific Advisory Group (SAG) on UV radiation was formed in 1995 with the aim to define requirements for measurement, organization of data and archiving at the World UV Data Center (WUDC), and to set QA/QC requirements. The necessity for setting guidelines to be followed in the global program was recognized to reach the required uniformity of measurement techniques and procedures. Liisa Jalkanen has noted that a QC document "Guidelines for site Quality Control of UV Monitoring", and a guide for data submission to the global UV data base at the Atmospheric Environment Service, Canada, "Guide to WMO/GAW World UV Radiation Center", are in press. In addition, two instrument documents will be published in the near future: "Instruments to measure Solar UV Radiation - Spectral Instruments" and "Instruments to Measure Solar UV radiation - Erythemally Weighted Broadband Instruments", respectively.

GAW's plans with regard to UV measurements are outlined in more detail in the "Global Atmosphere Watch (GAW) Strategic Plan" published in July 1997. Since the main task of the BSRN UVB SG was defined to follow-up plans and activities of other agencies involved in UV instrumentation and measurements, primarily GAW, it seems important to bring up some items in this document relevant to the UV issue.

The GAW's Strategic Plan with regard to UV radiation is outlined in section 3.2.3.5, entitled ***Radiation (ultraviolet and other).***

Current status
Lead responsibility for UV: *GAW's Scientific Steering Committee (SSC) on UV Monitoring, to be renamed "Scientific Advisory Group (SAG) for UV", responsible for all types of GAW radiation measurements in the future and for cooperation with WWW and WCRP/BSRN.*

Quality Assurance/Science Activity Center (QA/SAC): *not yet defined*

Calibration Centers: *not yet defined for* ***UV World Radiation Center***

Quality Assurance Project Plan (QAPjP): *not yet established*

Data Centers*: World Ozone and UV Data Center (WOUDC), Atmospheric Environment Service (AES), Downsview, Canada.*

Goals

- *To develop and implement the Global UV Radiation Monitoring Network , and build up operational structures for GAW's UV quality assurance, data archiving, and data analysis. To establish relationships with other agencies, user communities, and scientific programmes dealing with UV.*

- *To refine statements of the need within GAW for solar radiation data relating to the infrared and visible spectrum and, in particular,* ***to identify the interfaces with the BSRN and WWW programmes****.*

Implementation Strategy *- Task 4 states explicitly "****To establish a UV World Calibration Centre in order to initiate regular instrument calibrations and intercomparisons*** *(OSG - Operation Support Group, July 1998).*

The need for a **UV World Calibration Centre** equipped with the necessary reference instruments and calibration hierarchy is, thus, clearly recognized in the GAW's Strategic Plan.

Worthwhile noting also is the intention expressed in GAW's Strategic Plan (under **Implementation Strategy),** ***to combine the existing UV Scientific Steering Committee (UV SSC) with expert groups from BSRN and WWW.***

3.4 U.S. Interagency Central UV Calibration Facility (CUCF)

The most consolidated effort for UV radiometers characterization, calibration and maintenance seems to have taken place during the last decade in the USA. In the United States there are several UV monitoring networks operated by a number of federal agencies, i.e. NOAA, EPA, NSF, USDA, and others. One should admit, thus, that unlike the European arena, the necessity for unification of the networks, of a central calibration facility and the need for calibration hierarchy was recognized in the USA at an earlier stage. This has resulted in the *establishment of the U.S. Interagency UV-Monitoring Network Plan which has mandated the establishment of a Central UV Calibration Facility (CUCF). This facility is aimed to insure the uniformity of the measurements made by the various UV monitoring networks in North America. The primary mission of the CUCF is to assemble a complement of laboratory radiometric equipment and qualified personnel that are capable of characterizing and calibrating a variety of different UV, as well as other types of, monitoring instruments. Techniques used must meet the high quality standards established by the National Institute of Standards and Technology (NIST).*

The sole purpose of CUCF is to provide long term, NIST traceable instrument calibrations and characterizations for the U.S. UV-B monitoring Networks. The use of a common calibration facility and standards will provide quality assurance of data for the participating networks. In order to detect trends in UV-B radiation, the measurement base must be stable over the decades of the monitoring effort. The U.S. agencies will, in all probability, be deploying instruments of different designs and in different locations to achieve the individual goals of the agencies. The calibration facility will provide as services:

- *Irradiance calibrations and slit scattering/stray light measurements for spectral instruments.*
- *Absolute irradiance calibration.*
- *Angular response measurements.*
- *Linearity measurements for broadband and multi-filter instruments.*

In addition, field audits will be conducted with a field calibrator for the spectral instruments. These measurements will be conducted on an annual or semi-annual basis as needed, determined by the stability of each instrument.

One of the important functions of the CUCF is to host intercomparisons of network instruments. Thus far it has hosted four successful spectroradiometer intercomparisons in 1994, 1995, 1996, and 1997 at its outdoor test facility at Table Mountain, located on a mesa 10 miles north of Boulder. These campaigns produce a baseline reference for comparability among the networks' data. However, the gathering of experts and exchange of information that inevitably results also leads to valuable improvements to existing instruments, ideas for new instrumentation, and the development of new and more accurate monitoring methods. Each year's gathering has produced a plethora of knowledge and experience in UV monitoring.

The indoor laboratory facility of the CUCF performs measurements of a radiometer's transfer function, wavelength accuracy, and cosine response. This information, in conjunction with well-calibrated standard lamps, produces an absolute radiometric calibration. Calibrations of the networks' various types of UV spectroradiometers are performed at the location of the instrument by a field calibrator that was developed by scientists at SRRB and NIST. The field calibrator is taken to the monitoring station, thus precluding lost data and potential damage that could be incurred if the monitoring instrument was transported to the CUCF.

4. UV-B Precision Measurements - Summary

While UV spectroradiometers, as well as UV narrow band precision filter radiometers (e.g. YES MFRSR or Kipp&Zonen narrow band instrument) may have a more stable spectral response, and may give a better approximation to the CIE action curve, the spectral devices need much more care, and many of them suffer from drift which, if inadequately maintained and corrected, make them unsuitable for trend detection. Nevertheless, it should be mentioned that some BSRN scientists believe that, at least at this stage, broadband UVB measurements should not be recommended at BSRN stations, but rather UV narrow band precision filter radiometers.

One should also mention that versus the rather discouraging results with using UV-B radiometers at the European arena, as shown above, we have the more encouraging results of using broadband UV-B radiometers at the US UV-B networks, with the Interagency Central UV Calibration Facility (UCFC) playing a major role in characterization and calibration of broadband UV-B radiometers of various manufacture and brand.

According to John DeLuisi, head of the CUCF, *the performance of the CUCF seems to be quite satisfactory, including the characterization and calibration of UV-B pyranometers. The broadband radiometers used by the US UV networks are either Yankee (YES UVB-1) or Solar Light (SL 501) instruments, possessing different spectral response functions and cosine responses as well. However, if they are carefully characterized and calibrated, they can be made to agree more closely. The results of the North American Spectroradiometer Intercomparisons are used also to calibrate broadband instruments.*
These views of John DeLuisi are endorsed also by Bruce Hicks of NOAA (private communication). The broadband devices tend to drift, but probably not as much, and in any case they are simpler to maintain. Consequently, broadband instruments are used in the US networks as a common measurement, regardless of what other device is used to satisfy the individual network needs.

If it is the goal to monitor so that trends in air chemistry can be detected, then clearly spectral devices of some sort are required. If it is the intent to look for trends in the irradiance itself (and to relate these trends to physical causes), then broadband devices might well suffice. If the goal is to look at the role of UV in human and ecological health, then both broadband and spectral information seem desirable.

***The whole assembly of networks in the US is held together by the sharing of the Central UV Calibration Facility in Boulder. The CUCF is the glue that holds the US networks together. I recommend that a necessary first step, before deciding on what instruments to deploy, is to ensure that such a shared calibration capability exists and is securely in place for the future**. This capability must be recognized and endorsed by all. It is not appropriate for this "service" to be provided by instrument manufacturers. (I have the intriguing thought of sending YES instruments to Solar Light for "calibration.").* This thinking seems to be in line with the overall philosophies of the Global Atmosphere Watch, and seems especially important for measurement programs such as UV for which the measurement technology is still evolving.

The necessity of establishing a **UV World Calibration Center, as outlined also in the GAW Strategic Plan, seems to be widely accepted.**

In this context, the initiative taken by Alain Heimo to submit UV data to the Archive, despite all difficulties and shortcomings, should be regarded as a positive step in the right direction, to be followed by other BSRN station managers. For the time being there may be no better way of doing it. Probably, only by a concerted effort involving all interested agencies, including the BSRN, things will improve gradually.

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Annex VI: Consolidated List of Decisions, Recommendations and Action Items

Short Wave Measurements:

1. The meeting agreed to the continuation of studies by an Ad-hoc Working Group on Solar Diffuse Shading Geometry, comprised of A. Ohmura (Chairman) and G. Major. The group is to report back on the magnitude of potential errors in diffuse and direct solar irradiance observations due to the actual fields of view used in typical BSRN instrumentation. This assessment is to include the effect of various levels of spectral aerosol optical depth in the atmosphere.

2. The group agreed that investigations into the identification of an optimum window for Absolute Cavity Radiometers should be actively pursued, since no ideal solution has as yet been determined.

3. In response to the proposals of the Ad-hoc Working Group on Pyranometer Offsets, the meeting agreed that a ‘capping experiment’ should be conducted at each BSRN station to investigate the extent of daytime thermal offsets in the shaded pyranometers in use at the site. This experiment is to be performed during the second half of 2000 according to specified procedures (see Annex III) and the individual results provided to Dr. Dutton in order that he can report the consolidated results to the entire BSRN community by 31 January 2001.

4. The group reiterated that night-time offsets are not in general adequate for correcting daytime measurements of diffuse solar radiation using shaded pyranometers.

5. The meeting agreed to the continuation of the Ad-hoc Working Group on Pyranometer Offsets until at least the next BSRN Workshop. Its main objective is to continue analysis of the offset problem, leading eventually to an ideal approach to be used at all BSRN sites. Membership of the WG was agreed as B. Forgan (Chairman), K. Behrens, E. Dutton, R. Philipona, J. Michalsky and K. Rutledge.

Long Wave Measurements:

6. The meeting agreed that the Ad-hoc Working Group on Pyrgeometer Calibration should continue its activities until at least the next BSRN Workshop. Membership was agreed as R. Philipona (Chairman), K. Behrens, E. Dutton and T. Stoffel. Activities will include addressing the problem of development of a reference standard for calibration of LW instruments. Such a reference standard could be based on the sky-scanning radiometer currently being developed at the PMOD, Davos, or on similar instruments which may be developed. The meeting encouraged BSRN participants to carry out comparisons between different pyrgeometer models and report results to the WG Chairman for consolidation and presentation to the next BSRN Workshop.

7. The meeting agreed that a second International Pyrgeometer and Absolute Sky-Scanning Radiometer Comparison (IPARSC-2) should be carried out to investigate long-wave radiation measurement issues and intercomparisons under Arctic winter conditions. The ARM site in Barrow Alaska was proposed as a tentative site, and early 2001 as a tentative time.

Spectral Measurements:

8. The meeting endorsed the BSRN specification for AOD measurements proposed by the Ad-hoc Working Group on AOD (see Annex IV), and the objective of establishing a BSRN AOD based on this specification. The AOD archive will include spectral transmission and ancillary data to be provided by the relevant BSRN stations to the BSRN archive, where computations of AOD will be performed using an agreed quantitative algorithm to estimate AOD for clear sun conditions.

9. It was agreed that the Ad-hoc Working Group on AOD should continue until at least the next BSRN Workshop. Membership was established as B. Forgan (Chairman), A. Heimo, J. Michalsky, T. Nakajima and R. Philipona. One of the first tasks of the group will be to oversee establishment of the format for inputting transmission data into the BSRN archive, in consultation with the BSRN archive manager.

10. It was agreed that the BSRN Sub-group on UV-B Measurements will continue to monitor the activities of various relevant groups and will seek the cooperation of individuals, agencies and manufacturers of precision UV radiometers in its activities. The sub-group was asked to prepare specifications and technical requirements for UV radiometers suitable for measurements at BSRN stations and to report these to the next BSRN workshop in 2002. Membership of the sub-group was agreed as A. Manes (Chairman), B. Forgan, I. Galindo, A. Heimo, B. McArthur, R. McKenzie, J. Olivieri and R. Philipona.

11. It was agreed that the activities of the Ad-hoc Working Group on PAR (R. Pinker, Chairperson, with A. Kallis, K. Larman, B. McArthur and K. Rutledge) should be continued until at least the next BSRN Workshop. The main responsibility for the group would be to explore the possibility of organizing an intercomparison of PAR instruments over a one-week period prior to, or perhaps during, the next workshop. The group will also prepare a document precisely defining the key PAR issues for presentation to the next workshop.

Other:

12. The group agreed to the establishment of an Ad-hoc Working Group on Cloud Parameters to investigate the possibility of extracting cloud information for BSRN stations from current measurements. The working group is to provide a written status report on this issue to the next BSRN Workshop. Membership was agreed as C. Long (Chairman), R. Boers, B. Forgan, A. Heimo and R. Philipona.

13. The meeting agreed to the continuation of the Ad-hoc Working Group on Albedo and Surface Properties until at least the next BSRN Workshop. The main objective of the group will be to develop a reliable and consistent method for measuring surface reflectance at BSRN sites. The ad-hoc group will present a written report on its findings to the next BSRN Workshop. Membership was agreed as B. McArthur (Chairman), K. Behrens, I. Grant, R. Pinker and R. Stone.

14. It was agreed that minor updates (Annex modifications, previous corrigendum additions) to the BSRN Operations Manual (Version 1.0) will be prepared for discussion during the IPC experiments in Davos. More substantial changes to the document will be incorporated into a new version (V2.0) which will make changes from V1.0 obvious to the reader (e.g. modification list at front, or pages specially marked). The current version will be made available on the BSRN Web site immediately (Action B. McArthur, O. Albrecht).

15. The group agreed that the ad-hoc working group established at the previous workshop to review the literature on thermopile-based radiometers for solar and terrestrial radiation

measurements should continue its activities and looked forward to the eventual capability to access the database via the World Wide Web.

16. The meeting agreed that the carrying out of site audits to assess the operation of BSRN sites and assist in overcoming any problems or difficulties was a very useful practice (four such visits had been carried out by the BSRN International Programme Manager (IPM) during the preceding biennium). In view of the fact that it was not feasible for one person to carry out all such visits in the future due to time limitations, it was agreed that the IPM would develop a strategy for distributing the burden of such a process, including specifics of the procedures that should be followed for any particular visit.

17. The meeting agreed to the establishment of an Ad-hoc Working Group on Accuracy Specifications. That group was charged with the establishment of a methodology for assessing uncertainty in BSRN measurements, which will be included in future versions of the BSRN Operations Manual. A draft methodology for uncertainty assessments was to be prepared for discussion at the next International Pyrheliometer Comparison (IPC) experiments to be held in Davos, Switzerland in September/October 2000. Membership of the working group was agreed as B. Forgan (Chairman), E. Dutton, N. Hyett, K. Larman, C. Long, R. Philipona and A. Tsvetkov.

18. The meeting endorsed the following sites as additions to the formal list of BSRN stations:

Pending:

- Lauder, New Zealand;
- Manus, Papua New Guinea;
- Nauru;
- Tamanrasset, Algeria.

Candidate:

- Albany, USA
- Cocos (Keeling) Islands, Australia;
- Desert Rock, USA;
- Jabiru, Australia;
- Kiritimati (Christmas Island), Kiribati;
- Penn State, USA;
- Zvenigorod, Russian Federation.