CHAPTER 1

BACKGROUND

1.1 INTRODUCTION

1.1.1 Global need for accurate radiation measurements

Solar radiation energy is the fundamental driving force behind the formation of all weather and climate systems on Earth (Van den Bos, 1997; Persson, 2000). It has a significant influence on both atmosphere and ocean circulation patterns (Di Pasquale and Whitlock, 1993; Whitlock, 1993). Complex interactions between the atmosphere and ocean involving turbulent fluxes of momentum, mass and heat (latent and sensible heat) in the marine atmosphere boundary layer, as well as the subsequent exchange of energy to the higher atmosphere where clouds may form, are not yet fully understood (Morel, 1990; IUCC, 1993). Terrestrial heat fluxes may lead to convection, turbulence, cloud formation and eventually rainfall, thereby shaping the continental climate. Although solar energy is obviously regarded as an important driving force, there are still many uncertainties about the particular role of solar energy in these processes.

With respect to future scenarios, there is also considerable disagreement amongst experts about the magnitude of climate change, or more specifically, global warming that might occur during the next decades (IPCC, 2001).

The determination of a global climatology, based upon the natural terrestrial radiation budget, is therefore fundamental (Mc Arthur, 1998) in order to facilitate research towards creating a better understanding of the already recognized role that radiation plays in climate processes (Gilgen *et al.*, 1993). A conventional network of surface solar radiometry, to a great extent operated independently in individual countries as part of a meteorological measurement programme. Thus it was admittedly unable to serve as an accurate source of information to understand and explain the global radiation budget (Ohmura *et al.,* 1998). As a matter of fact, it is described as “meagre at best” (Long and Ackerman, 1994).

Hence, the need arose for a denser international network of ground-based radiometers with the necessary accuracy and data integrity. Such a network, if in existence, will have to set new global standards in surface radiometric measurement.

1.1.2 The establishment of a new radiometric network

During a meeting of the joint scientific committee for the World Climate Research Programme (WCRP) of the World Meteorological Organisation's International Council of Scientific Unions (WMO ICSU) in Geneva (19 to 21 October 1988) an urgent need was expressed for establishing a global baseline network of stations that are capable to accurately measure surface solar and terrestrial radiative fluxes. This network will contribute to meet requirements set for long-term data collection of global surface radiation balance components (Gilgen *et al.*, 1995).

The network was initially meant to serve as support for research projects of the WCRP and other scientific programs (Schiffer, 1990). According to Gilgen (1991) and Mc Arthur (1998) its main missions were identified as follows:

- Monitor the background (least influenced by human activities) shortwave (SW) and longwave (LW) radiative components and their changes with the best methods available (accurate enough to reveal any long-term trends).
- Provide verification data for the calibration of satellite-based estimates of the surface radiation budget.
- Produce high-quality observational data to be used for validating the theoretical calculation of radiative fluxes by various mathematical models.

The word "*surface*" was particularly important in the naming of such a network, since the Earth's surface transforms about 60% of the incident solar energy absorbed by the Earth (Ohmura *et al.*, 1998). Therefore, surface measurements are likely to contain the best information concerning global radiative fluxes. It was also important to locate individual network sites in contrasting climate zones (Morel, 1990) in order to extract as much information as possible from "climate change hotspots".

1.1.2.1 Launching the project *(Würzburg, Germany, 30 October to 3 November 1989)*

During a special workshop of WCRP and the Committee on Space Research (COSPAR) on the global surface radiation budget for climate change, an announcement for the establishment of a new radiation network was officially made (DeLuisi, 1989). It was then called the Global Baseline Surface Radiation Network (GBSRN). However, the qualification "Global" (G) was soon omitted from the acronym GBSRN and was never used since. The most important outcome of the Würzburg meeting was the drafting of a scientific measurement plan for the newly established network (expanded in Chapter 2 of this dissertation).

1.1.2.2 South Africa's first involvement

The late Cal Archer (1925 -2000) from the South African Weather Service (SAWS) attended the Würzburg conference (Schiffer, 1990) but in an unofficial capacity, since sanctions against the domestic policy of the South African government of that time prevented formal participation. However, this contact later proved to be vital, because South Africa's willingness to establish a Baseline Surface Radiation Network (BSRN) station within the borders of the country, had already been shown clearly at this early stage. An interesting fact is, that Namibia, and not South Africa, had initially been mentioned as the candidate country to represent the southern African region (De Luisi, 1989).

1.1.3 How the project unfolded

1.1.3.1 First workshop *(Washington DC, USA, 3 to 5 December 1990)*

Following the Würzburg meeting, this workshop was the first of a tradition of regular steering meetings, and attended by various stakeholders in the BSRN programme, to discuss issues of mutual importance, to share ideas and expertise, and to resolve issues of importance. The following points were addressed (WCRP-54, 1991):

- Measurements based on the 1989 recommendations, must commence as soon as possible, utilizing a "pilot" group of stations. Notwithstanding the fact that BSRN operational procedures still needed to be formalized, practical avenues (instrument standardization, objective assessment of instrument characteristics and local operational procedures) were also in need to be established. The first "pilot" group consisted of the following six stations: (1) Payerne in Switzerland, (2) Cape Grim in Australia, (3) Boulder in the USA, (4) Schleswig in Germany, (5) a

"Canadian site" and (6) a "USSR site".

- Resolution needed to be sought on pyrheliometer errors, calibration uncertainties surrounding diffuse and reflected SW pyranometers, downwelling LW instrumentation and the influence of domes and observation height on long wave measurements.
- Analysis of the measurement uncertainty and estimation of the effect of random and systematic errors on the final results, also needed quantification.
- Furthermore, a scheme for instrument calibration (compliance to World Radiometric Reference (WRR) standards) needed to be established as well.

Individuals, as well as groups, that had been formed, were addressing these issues. Feedback and recommendations were expected at the following workshop.

At the first workshop it was also decided that:

- Personnel involved in instrument calibration should be encouraged to visit various other sites in order to exchange knowledge and expertise. This approach should widen technical expertise in radiation measurements in relation to the measurements of other land-based meteorological parameters.
- Special assistance should be given to developing countries to enable them to establish a local BSRN site where needed. (South Africa later benefited from this decision).
- Close collaboration between the BSRN and Global Atmosphere Watch (GAW) programmes of the WMO was regarded as beneficial in the light of mutual exchange of high-quality data, optimal usage of measurement sites, in order to attract more scientific expertise to the programme.
- A detailed BSRN operations manual (on instrumentation, installation, calibration and maintenance) needs to be compiled as a matter of urgency. This enormous task was assigned to Dr Bruce Mc Arthur (Canada), which he completed seven years later in the form of a 255-page document.
- A central BSRN data archive centre needs to be identified. It was initially decided to host this at the National Aeronautic Space Agency's (NASA) Langley Research Centre (designated as the Surface Radiation Budget (SRB) Satellite Data Analysis Centre).
- Atmospheric Radiation Measurement (ARM) sites in the USA, sharing BSRN ideals, can successfully complement the BSRN. Some of these sites were eventually amongst the first to deliver BSRN data.

A circular letter (Whitlock, 1990) containing draft plans for the data format and archiving plan was circulated immediately after the first workshop (before the end of 1990). Later reference to this draft indicated that is was indeed "excellent" (WCRP-64, 1991). As a matter of fact, it was adopted to be the official BSRN plan with only a few alterations (Gilgen *et al.*, 1991).

1.1.3.2 **Second workshop** *(Davos, Switzerland, 6 to 8 August 1991)*

The World Radiation Centre (WRC-PMOD) was host for the second workshop, which was characterized by the following highlights (WCRP-64,1991):

- The draft data format and management plan was finalized and adopted.
- The basic set of BSRN measurement parameters were finalized, being:
    1. Direct solar radiation
    2. Diffuse solar radiation
    3. Global solar radiation
    4. Downward LW radiation
    5. Upward LW and SW radiation (optional)
    6. Surface three-hourly SYNOP measurements, where possible
    7. Twice-daily radiosonde soundings at a nearby facility, where possible
    8. Measurement of screen temperature, atmospheric pressure and relative humidity, as co-located meteorological data, where possible
- No decision was yet made on the reporting and sampling frequency on the above parameters.
- A proposition for the World Radiation Monitoring Centre (WRMC) in Zürich, Switzerland as official international database, was made and accepted.
- The data must be collected and submitted to the database in one-month batches with a maximum delay of three months, to allow for local quality control, transfer to magnetic media, etc (no File Transfer Protocol (FTP) facility existed as yet).
- The target date for first BSRN data to enter the database was set at between September 1991 and March 1992. The final date was 1 January 1992.

Other outcomes of the second workshop were:

- The Scientific Evaluation Panel, who was to be an integral part of the BSRN management system, was established, and responsibilities were defined.

- Feedback from a workshop on pyrgeometer errors, that took place five months earlier in Toronto, Canada, were presented. Unlike the World Radiometric Reference (WRR) for SW measurements, no absolute reference existed for LW radiation. In fact, it was recognized that it is not yet well understood.

Investigations were made on the following technical issues:

- Quantification of uncertainties related to circumsolar radiation in measuring global/direct/diffuse radiation and other pyranometer errors.
- Calibration of a pyrheliometer taking turbidity into account.
- The characterization and calibration of LW radiometers.

Meanwhile, the first data received as BSRN data, were the January 1992 sets from the four USA stations of Barrow, Bermuda, Boulder and the South Pole. Of the 27 proposed sites at that time, five more became archiving (submitted data) during the same year. They were Ny Alesund-Spitzbergen (Norway), Payerne (Switzerland), Kwajalein (Marshall Islands, USA), Ilorin (Nigeria) and Georg von Neumayer (Germany / Antarctica) (Gilgen *et al.*, 1993). Figure 1.1 shows the geographical location of this “pioneer” group of BSRN stations in 1992/1993, together with provisional (planned) BSRN sites.

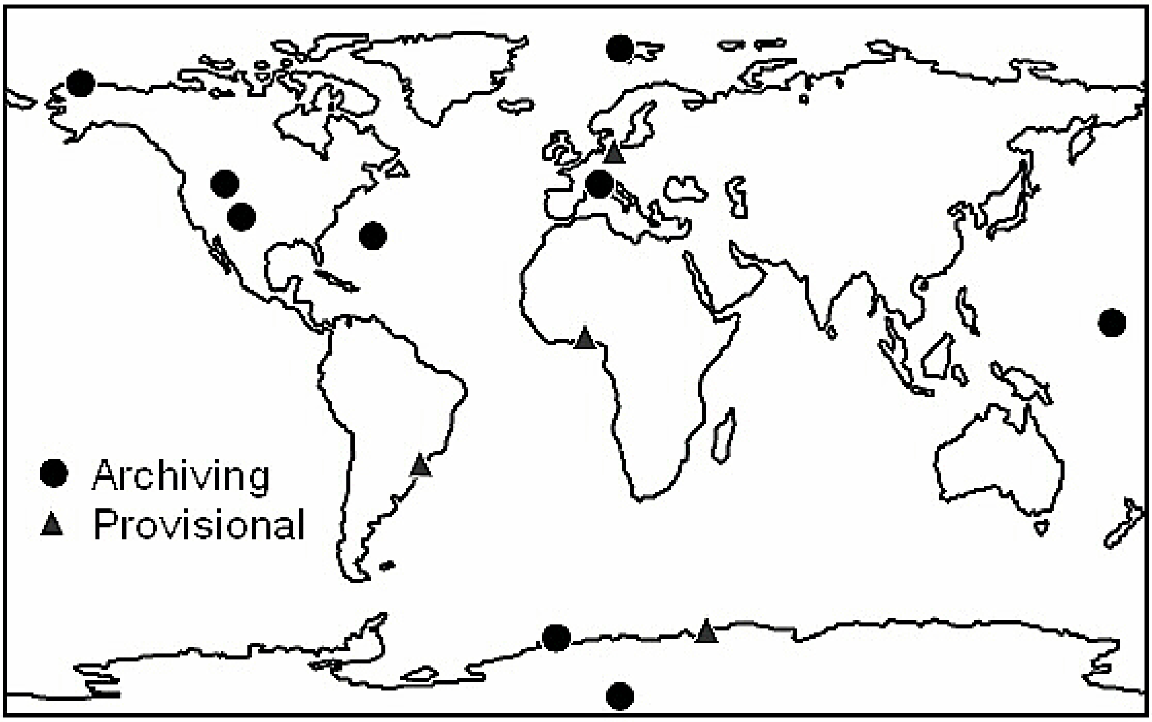

Figure 1.1 *The first group of archiving "pioneer" BSRN stations for 1992/1993, together with the provisional sites at that time*

1.1.3.3 Third workshop *(Zürich, Switzerland, 12 to 16 September 1994)*

The premises for the third workshop was the *Eidgenössische Technische Hochschule Zürich* (ETHZ), translated as the Swiss Federal Institute of Technology, which had previously been decided to be the central location of the BSRN database.

Key points addressed at this meeting (WCRP, 1995) were:

- Establishment of the database at ETHZ was completed with the purchasing of suitable computer equipment and the assignment of a full-time position for a data manager (Dr Hermann Hegner). The database was designed by Dr. Hans Gilgen, also from ETHZ, who based it upon the database of the Global Energy Balance Archive (GEBA) that was in existence since 1988 (Gilgen *et al.*, 1997). Data files were already received from the pioneer stations, and would be processed in due course.
- The ideal for BSRN data sampling and reporting frequency was set at one-minute average, standard deviation, minimum and maximum of one-second samples. It was appreciated that not all stations could comply immediately, hence records at longer intervals were also acceptable up to the end of 1997.
- The importance of co-located meteorological data (surface and upper-air) was again emphasized, but no final format of such observations was decided upon.
- Data to the database needed to be dispatched to the archive in one-month batches within a period of six months of the time of observation.
- Spectral optical depth measurements needed to be included as part of the extended BSRN observations programme, wherever possible.
- Co-operation with the ARM project was encouraged.

The BSRN Manual was in preparation, although not completed yet. The completion of this manual was set as a priority.

Working groups were formed to investigate:

- The need for continuously using an all-weather cavity radiometer (with a window) as reference for an operational pyrherliometer.
- The possibility of standardizing LW calibration procedures and measurements.

- Solutions for BSRN stations operated in extreme cold conditions.
- The communication between BSRN stations to exchange expertise (Email-list).

Following the annual BSRN report to the Working Group on Radiative Fluxes on 23 July 1996, Pierre Morel, former Director of the WCRP, described the BSRN as ***"a major success story of the WCRP".***

1.1.3.4 Fourth workshop *(Boulder, CO, USA, 12 to 16 August 1996)*

At this stage, 351 monthly files were generated by 11 BSRN stations and submitted to the database, but only 177 of them passed the stringent consistency checks (WCRP,1997). These sites were situated over a wide selection of oceanic, polar, subtropical, equatorial and high-altitude locations. There were also 17 other stations pending at that stage.

The fourth workshop was set to make decisions on the future of the network, and which additional sites, if any, were needed to complete the first phase of the network.

- Additional measurements at stations were to be in order of priority: (a) Aerosol Optical Depth (AOD), (b) Cloud base height, (c) Ultraviolet-B (UVB) and (d) Photosynthetically Active Radiation (PAR).
- A shaded, ventilated pyrgeometer was accepted to be suitable for LW measurements in BSRN.

The first draft of the operations manual was presented to the group and advice was given on a few unclear issues. Sub-groups were formed to report back to Dr Mc Arthur, and a final target date for completion of the first version of the manual (version 1.0) was set for December 1996.

An internet BSRN homepage (*http://bsrn.ethz.ch*) was introduced. This was envisaged to serve as a public platform from where detailed information about the WRMC, particulars of existing and planned stations, as well as general news could be displayed and obtained. An additional FTP site was also regarded as an important facility that could make data submission to clients much easier. Finally, an Internet-based retrieval interface for clients was also in the process of being established.

Some technical issues surfaced and as a consequence working groups were assigned to investigate the following:

- Outstanding pyrheliometric questions and the sensible use of a cavity radiometer.
- The thermal offset that occurs in pyranometers (how accurately can "nothing" be measured?)
- Establishment of a LW radiation measurement standard similar to the WRR in SW measurements. As a first attempt, pyrgeometer round-robin calibrating experiments were organized.

Amidst all this activity, the Southern Hemisphere (SH) was still poorly represented with only a few stations (Figure 1.2), compared to the populated Northern Hemisphere (NH). The large African continent was specifically poorly represented with only one station, namely Ilorin in Nigeria.

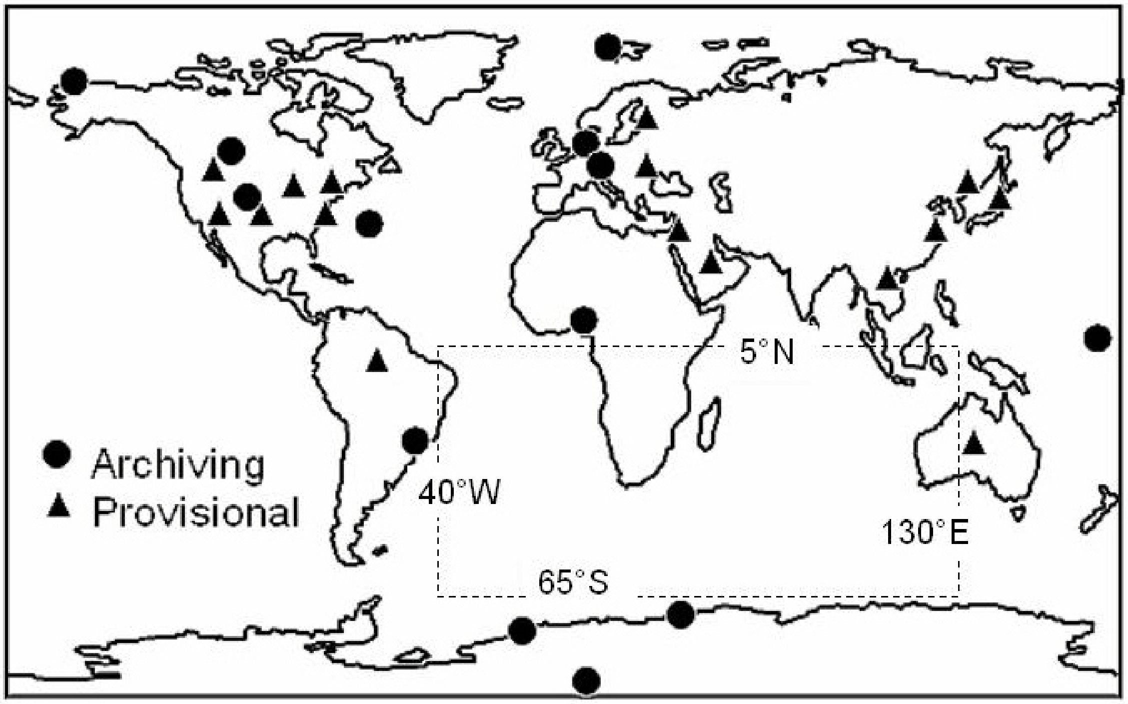

Figure 1.2 *BSRN locations (archiving and provisional) at the time South Africa was considered to join the network. The observational gap is shown in dashed lines.*

1.2 SOUTH AFRICA'S INVOLVEMENT

1.2.1 Strategic importance of South Africa in a global network

Figure 1.2 depicts the existing operational and proposed BSRN stations towards the end of 1995 (at the time South Africa re-considered its position since the 1989 proposal). An observation gap in the SH (including the southern oceans) is indicated, spanning from approximately 5°N to 65°S (70° interval in latitude) and 40°W to 130°E (170° interval in longitude), which needed urgent representation. This observation gap accounts for about 18% of the Earth's total surface. From Figure 1.2 it is also evident that the SH was poorly represented with only 3 operational stations versus 20 of the NH. South Africa was strategically well placed to fulfil the need for representation at that time.

Another important factor is the much smaller ratio of land versus ocean in the SH versus the NH. This makes it difficult to deploy a sufficiently dense and reliable ground network for measuring meteorological parameters among which are surface fluxes of radiation. The use of remote sensing as a medium for weather observations is therefore much more popular in the SH than in the NH, where large surface areas are covered by continents. The presence of adequate satellite verification points for "ground truthing" in the form of reliable ground-based stations, which do not exist in the SH. This emphasises the fact that South Africa, as a result of its strategic location, could make a significant contribution.

1.2.2 South Africa's unique contribution

As mentioned before, South Africa was represented at the 1989 Würzburg conference and showed interest in offering a location to be developed as a BSRN site. At that time, the three most possible ground locations were the following (Archer 1989):

1. The Mossgas oil-drill platform just offshore the town of Mosselbaai as a possible marine ground truth site for satellite verification.
2. Since the ozone monitoring programme of the SAWS was re-instated at the Irene Weather Office, just south of Pretoria, possible co-location of land-based ozone measurements by the Dobson spectrophotometer and BSRN measurements were considered.
3. The weather office at Upington as a land-based, non-urban observation site, that is representative of a southern African semi-arid Savannah climate.

At that time the last option (option 3) emerged as more favourable, seen in the light that Namibia was the initial candidate country to represent southern Africa in the GBSRN and Upington was the closest location to Namibia. For various reasons (not outlined here) the development of a BSRN site was not followed up in the years thereafter, and thus, the initial offer to South Africa eventually lapsed (Archer,1997).

Six years later, during November 1995 at the Eighth International Pyrheliometric comparisons (IPC-VIII) in Davos, Switzerland, South Africa was again represented. The offer to South Africa was re-opened, and a new proposal was made.

This offer was provisionally accepted, by virtue of a better outlook towards the future which was the result of an open door to WMO and associated assistance since the first democratic elections of April 1994 and the associated stability in terms of a political future. Without international involvement and co-operation, a South African BSRN site would have had very little chance of success.

However, the previous suggestion to make the Weather Office of Upington a BSRN site was no longer supported (Archer, 1997), and a new suitable location had to be found.

1.2.3 Selection of the most suitable site

Since the 1989 inception, the BSRN management gathered a lot of new site location information and experience and subsequently, had a clearer picture of particular site requirements. Hence the new offer for South Africa's participation also included a new set of criteria for selecting a suitable site. These criteria were clearly outlined in a letter received from the BSRN Project Manager after South Africa's 1995 indication of intent to participate.

Automatic weather stations were not part of the equation, since the presence of staff for the best part of 24 hours a day is essential at all prospective BSRN sites. This meant in essence, that only Weather Offices would be considered, of which there were not a large number in operation in South Africa. A Weather Office with a stable future would obviously be strongly recommended. In 1995 the SAWS had Weather Offices at the following locations:

1. Pretoria : SAWS Headquarters
2. Johannesburg International Airport
3. Cape Town International Airport
4. Durban International Airport
5. Port Elizabeth Airport
6. Bloemfontein Airport
7. Kimberley Airport
8. Upington Airport

9. George Airport
10. Pietersburg (now Polokwane) Airport
11. Bethlehem
12. Springbok
13. Calvinia
14. Irene
15. De Aar

Specific requirements and implications for selecting a candidate site for South Africa are listed below:

(i) *The site must be well away from coastal locations. None of the BSRN marine applications were envisaged for the proposed South African site.*

This severely narrowed the possible candidate sites, since a number of Weather Offices (3, 4, 5 and 9) are coastal sites located at major airports.

(ii) *The site must be located in a non-urban environment, as far as possible from urban influences, although it must be accessible to at least one trained person once a day.*

This eliminated all of the larger Weather Offices located in or around major metropolitan areas, namely 1, 2, 6, 7, 10 and 14.

(iii) *At the proposed site a first-order climate station with top-quality equipment manned by dedicated staff is required.*

All of the weather offices are indeed staffed first-order stations and at the time most of them operated 24 hours per day. Remaining were Weather Offices 8, 11, 12, 13 and 15.

(iv) *The quantities of direct radiation, diffuse radiation, long wave down welling radiation and desirably global radiation, must be measured continuously, with backup and calibration facilities also being available.*

These criteria implied that n fact, none of the existing SAWS radiation instrumentation could be used, and therefore, an entirely new facility had to be built altogether. However, the WMO offered a complete set of basic instrumentation to initiate the programme. This option, therefore, did not favour or eliminate any existing Weather Offices.

(v) *It is desirable to have surrounding land of uniform character in surface and land-use for a radius of at least 50 km from the site to yield a representative satellite*

impression.

The following sites were disqualified: Weather Office 13 (situated alongside a major river (The Orange) and resulting lush surrounding vegetation not representative of the area) and Weather Offices 11 and 12 (mountainous area that is not regularly representative, more in the case of Bethlehem than Springbok)

(vi) *Upper-air measurement facilities and possibly weather radar must exist within 100 km from the site.*

Weather Office 13 does not have radar or upper-air measurement facilities available.

By means of elimination, Weather Office number 15 (De Aar) stood out as the best remaining site that met the necessary criteria and had all the required facilities on the premises. The Weather Office of De Aar in the Bo-Karoo region of the Northern Cape Province of South Africa (Figure 1.3), was therefore chosen to be the location for the South African BSRN station.

1.2.4 The best location : De Aar

Although the process described in section 1.2.3, that led to De Aar, looks like an elimination process, the following aspects counted strongly in its favour and re-affirmed that the best choice had indeed been made :

- The small town, having a mere 30 500 inhabitants[1] had very little metropolitan growth over the last five decades, and not significantly more is planned. Therefore, the existing population and activities are not envisaged to have any significant impact (“urban heat island”) on the radiation regime.
- Development of the area around the proposed site was also not envisaged in the near future (Van den Berg, Town Clerk of De Aar, pers. comm), and as a result, the site has a pristine atmosphere that is amongst the cleanest in South Africa, and representative of the surroundings.
- It is located in a semi-arid region with relatively low rainfall, i.e. a relatively low occurrence of clouds.
- The aerial appearance of the land is uniform in the sense that no major deviations from the land appearance, such as large water bodies or associated green

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[1] United Nations Population Information: http://www.world-gazetteer.com/c/c_za.htm

vegetation, exist. In fact, the famous "Karoo-Koppies" of that region (Figure 1.4) are known to be "*if you've seen one, you have seen them all".*

- The likelihood of snow falling is 1 out of 450, or it can be expressed as 0.8 snow-days per year (SAWB, 1986). Monthly average maximum and minimum temperatures vary from 0°C during the austral winter to 33°C during the austral summer (Figure 1.5). The long-term minimum rainfall for every month is zero since there was always a calendar month in history where no rain fell (Figure 1.6).
- Rainfall can be regarded as sporadic, since the maximum values are several times the magnitude of the mean values. Maximum rain occurs in March, endemic of the summer rainfall region that comprises the entire eastern interior of the Southern African plateau.
- The site is also centrally located in the country (Figure 1.3).

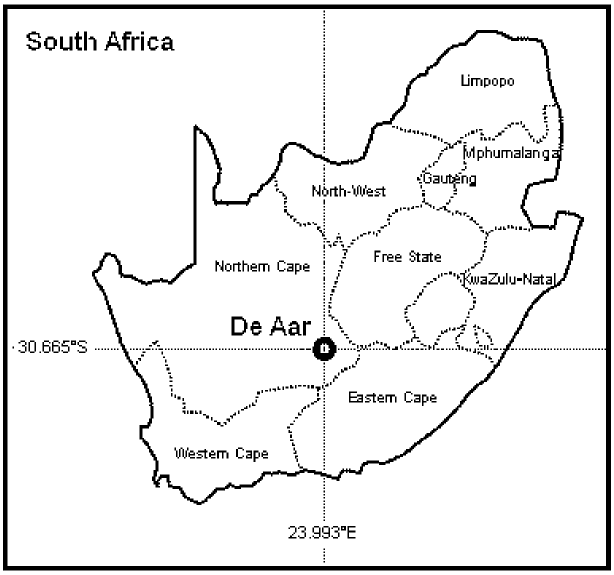

Figure 1.3 *Provincial map of South Africa depicting the central position of De Aar*

As listed in Table 1.1, the De Aar Weather Office has the following references:

Table 1.1 *Essential references for De Aar Weather Office*

Latitude	*30.665°S*
Longitude	*23.993°E*
Altitude above mean sea level	*1287 m*
Local time zone	*GMT + 2 hours*
SYNOP number	*68538*
Civil aviation METAR code	FADY

Figure 1.4 *The instrument camp at De Aar Weather Office, where the BSRN site is located. Note the semi-arid landscape and uniform"Karoo-koppies" in the background*

In the following sections, climate statistics (SAWB, 1986) applicable to De Aar are discussed:

1.2.4.1 Temperature

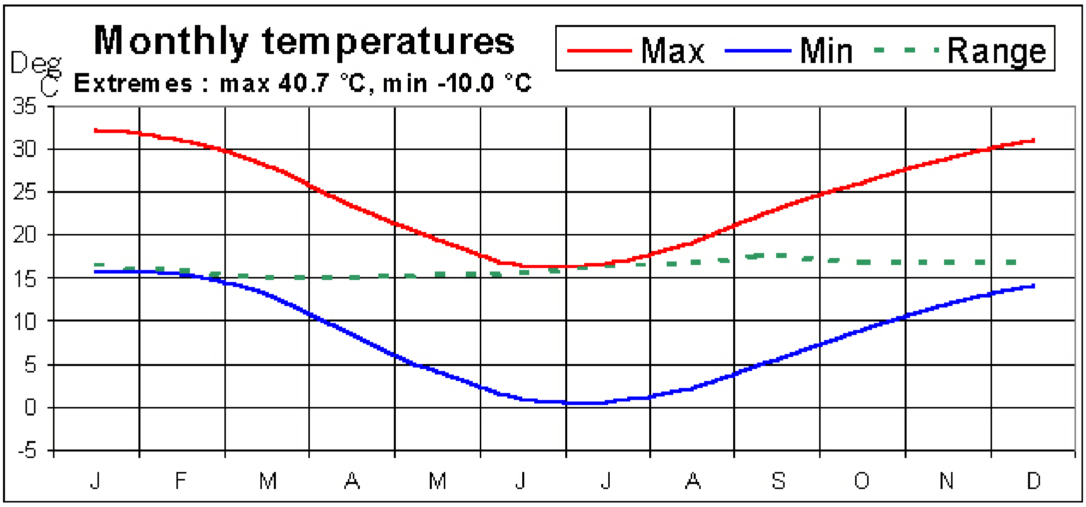

Figure 1.5 *Monthly average maximum and minimum temperature as well as temperature range, measured in ^{o}C at the De Aar Weather Office*

Monthly average temperatures at De Aar (Figure 1.5) have a very small range – even though there are significant fluctuations during the course of a year, the range (monthly maximum minus monthly minimum) is consistently 16 degrees with a deviation of only one degree. Extreme temperatures recorded in De Aar's history were -10.0°C and 40.7°C, respectively.

1.2.4.2 Precipitation

Monthly precipitation at De Aar (Figure 1.6) shows the following characteristics of episodic occurrence

- The long-term extreme per month is several times the mean (ca. 4 to 7 times).
- The annual mean (305 mm) is substantially (22%) lower than the means of the annual maxima and minima (391 mm).
- The corresponding monthly minumum is zero for all the months of the year. Hence, for this record, no rain fell at least once in each calendar month in history, even during the rain season. That is why "minimum" does not feature in Figure 1.6.

The annual average rainfall maximum occurs in March, typical of the summer rainfall region which dominates the central interior of the Southern African plateau. The peaks for extreme rainfall, however, occur in January and February.

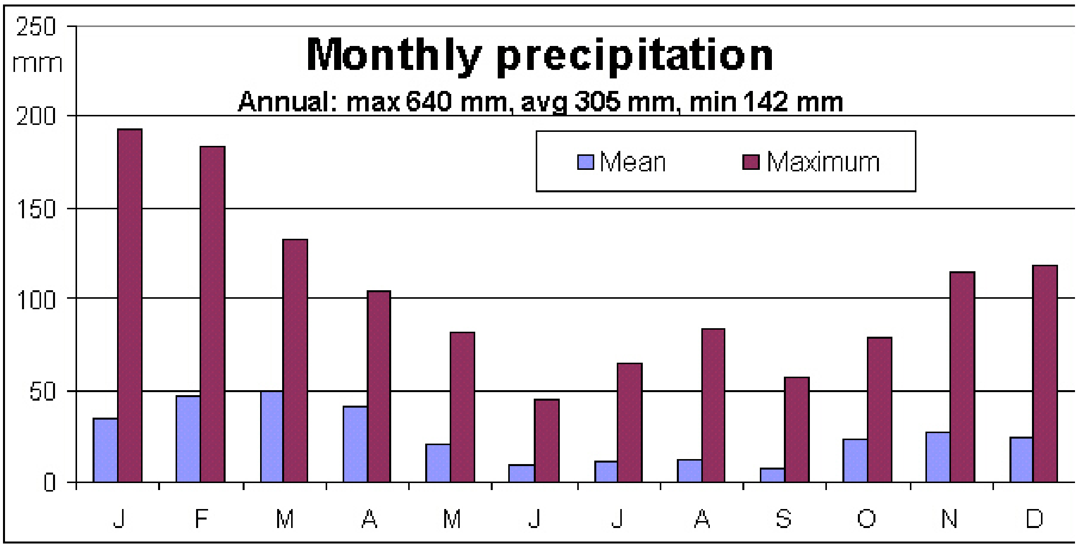

Figure 1.6 *Monthly mean precipitation (light shaded bars) and maximum precipitation (dark shaded bars) for De Aar Weather Office in mm. Note that the minimum precipitation per month is zero.*

1.3 SITE DEVELOPMENT AT DE AAR

During October 1996 a four-man delegation made the first contact with Mr George Wolfaardt (Officer in charge of the De Aar Weather Office), as well as with Mr Johan van den Berg (Town Clerk of De Aar). In turn for the publicity De Aar was to enjoy as a result of this unique development, the Town Council offered their support in principle by assisting with the establishment of infrastructure (Archer, 1997).

In February 1997, the BSRN international project leader has approved the site. Overseas training of local scientists on station management followed in October the same year in order to establish the South African BSRN station. The training included:

- A visit to the Kipp & Zonen factory in Delft, Netherlands, where the manufacturing process (largely by hand) of the various types of radiometers was observed. Having witnessed the rigorous process, the high prices of Kipp and Zonen radiometers are appreciated.
- A visit to the BSRN data centre in Zürich, Switzerland, where personal consultation took place between the visiting local scientists and the BSRN data manager, quality control specialist and other staff members. They are the very people to whom the station scientist is accountable to for data delivery and a personal contact was vital in the process of establishing a good working relationship.
- A visit to the BSRN site and station scientist in Payerne, Switzerland, regarded as a site with the best technological development and serves as an example of what can be achieved (Heimo, 1993). This station was originally selected as one of the “pilot” sites in 1991, and remained on the leading edge of development ever since.
- A visit to the World Radiation Centre (PMOD-WRC) in Davos, Switzerland, where regular calibration, such as the five-yearly International Pyrheliometric Comparisons (IPC), as well as world-leading development in instruments and measurement techniques in radiation and calibration are performed. The famous “group of seven” WRR pyrheliometers, discussed in Section 2.5.2. are housed and operated here.
- A visit to Boulder, Colorado, USA, where the BSRN project leader and associates are stationed. Useful discussions with station scientists, instrument engineers and

data technologists were held. The well-known 300 meter high monitoring tower at the BSRN Station in Boulder was visited.

The WMO-sponsored instruments for the South African station, as well as a cavity reference pyrheliometer with an automated control box, solar tracker, uninterrupted power supply, and main accessories for the initial installation, such as data loggers and field enclosures, were received in Pretoria between December 1997 and January 1998.

The complete set of hardware was erected on the rooftop of SAWS headquarters in Pretoria. The system was wired to function in full operation as it would on-site. This included uninterrupted operation of the solar tracker with all the radiometers, ventilators and data loggers for more than one year (WCRP,1998), whilst Wide Area Network (WAN) computer links between Pretoria and De Aar were developed and installed by the SAWB's Information Technology (IT) group.

This development also allowed for time to test numerous configurations in order to establish the best working system. Fine adjustments to the system were also undertaken and developed. Finally, the entire communication system between De Aar and Pretoria was simulated and tested several times. The advice, practical ideas and eventual unique solutions in this respect, provide by Cal Archer, must be emphasized.

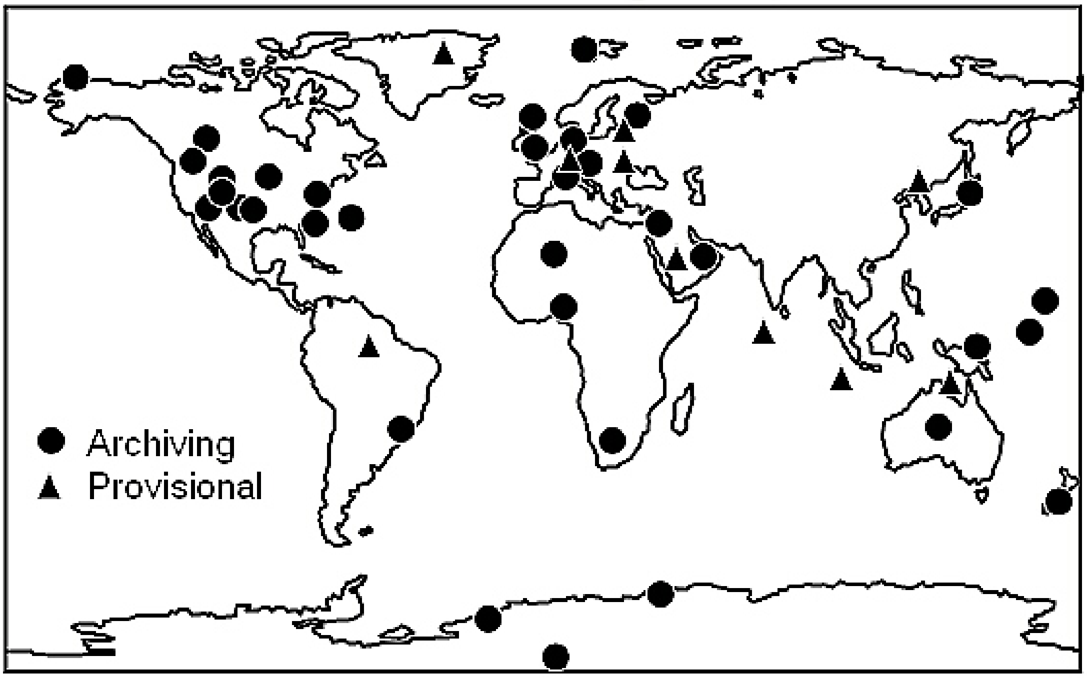

Figure 1.7 *BSRN sites, both archiving and provisional, in 2003*

At the same time, plans to prepare the site at De Aar for final installation were introduced. One trip to survey the site and surroundings, and to liase with the Town Council, was undertaken in February 1998. This was followed by the delivery and installation of the uninterrupted power supply, power cabling, communication facilities as well as foot-mounting brackets for the radiometers in December 1998.

The Town Council unfortunately had to withdraw their offer to erect a security fence, but instead installed a certified 220 Volt power point on the site. In June 1999, a barbed-wire security fence with a lockable pedestrian gate was erected by a local service provider around the perimeter of the site hillock, taking special precaution to make as little impact on the environment and projected measurement plan as possible. By 2000 the De Aar station was in full operation (WCRP, 2001; WCRP, 2002), and since then is making a significant contribution to the global BSRN as in 2003 (Figure 1.7).

1.4 OBJECTIVES OF THIS RESEARCH

The objectives of this research focus on the establishment of the De Aar BSRN station and the subsequent quality control of recorded data.

The primary objective of this research is to document the technical and other means by which the De Aar BSRN station, which embodies the application of international standards of radiation measurement to South Africa, was established.

This objective has been achieved by means of a thorough study of BSRN data requirements, as well as practical experience incurred by the author. The author was both instrumental towards and actively involved in the management and application of the many procedures that preceded the final installation. As official station scientist he visits the De Aar site on a regular basis, ideally twice annually, to perform major maintenance on the site, including radiometer calibration. To keep abreast with the latest developments in technology and maintain sound international relations, several workshops were attended and institutions in countries such as Switzerland, Holland, Hungary, Australia, Canada and the USA visited.

The secondary objective of this research is to develop, evaluate and introduce quality assurance procedures (according to BSRN requirements) in such a way that it can be applied on a routine basis to measured data before submission to the WRMC archive.

This has been achieved by detailed analysis of the available BSRN data spanning three years since inception of the site, as well as study of relevant literature. For this purpose, software (FORTRAN code and Microsoft Excel spreadsheets) has been developed by the author.

The methods applied in this research are:

- Thorough literature study of the background to the BSRN programme and how South Africa became involved
- An explanation of the scientific measurement plan, and how the design and testing of the South African system led towards realising the measurement plan in South Africa
- Detailed analysis of the available data of the BSRN station since inception, and application of the various quality assurance techniques.

Apart from the academic content, the author wishes to compile a useful document as reference tool with respect to South Africa's involvement in the BSRN programme and a guideline for future generations, embarking on future developments. This could include either upgrading of the existing facility, or the establishment, should the need arise, of new BSRN sites in the Southern African Development Community (SADC) region.

1.5 ORGANISATION OF THIS DISSERTATION

Following this Chapter (introduction to the BSRN programme and South Africa's involvement), the following topics per chapter were studied:

Chapter 2: Scientific plan

The logical next step after the introduction is the definition of a sound scientific measurement plan for the South African BSRN site and the elucidation of numerous aspects surrounding it. These aspects include basics of radiation measurement in the atmosphere, associated measurement techniques and instrumentation.

Chapter 3: System design

Forthcoming from the measurement plan, is the design of a useful measurement system to materialize the plan. In this case, some site operational issues encountered during the initial phases of the project are investigated. This is brought in context with radiometer calibration and data management.

Chapter 4: Quality control

After a system has been designed and installed, the resultant data needs to be quality controlled. This Chapter explains the different terminology involved, elucidates the various WRMC quality control procedures and presents an analysis of three complete years of BSRN data to which the said procedures have been applied.

Chapter 5: Case studies

Special and very unique measurement opportunities presented themselves when two total solar eclipses traversed Southern Africa in 2001 and 2002. In both cases, a significant amount of the partial phases were visible over De Aar, in pristine measurement conditions, that delivered data lending itself to various forms of comparisons.

Chapter 6: Conclusions and recommendations

A summary on the position of the South African BSRN site in all its contexts is presented, along with the most important findings and subsequent conclusions forthcoming from this study.

References:

A standard and exhaustive listing of all sources that were consulted in this research.

Appendices:

Appendix A.	Photo pages
Appendix B.	Station-to-archive file format
Appendix C.	Specific data for a typical year at De Aar
Appendix D.	The Köppen climate zone classification
Appendix E.	Connection and operation of a pyrgeometer