The Baseline Surface Radiation Network (BSRN) station at the Cabauw observatory

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Introduction

Radiation is the primary energy source and the ultimate energy sink for the Earth's climate system. Most climate changes are directly or indirectly related to changes in radiation. It is therefore not an overstatement to say that understanding of the climate system begins with the understanding of radiation and its interactions with the atmospheric constituents such as clouds, aerosols, and greenhouse gases. Because of the important role of radiation in the climate system, radiation measurements are indispensable for climate research. They provide the best check for the theory of radiative transfer in the Earth's atmosphere and can be used for the evaluation and improvement of models designed for weather and climate prediction. Furthermore, long-term measurements of surface radiation provide an opportunity for the detection of climate change.

The importance of accurate and precise radiation measurements for climate research was the primary reason for the joint scientific committee of the World Climate Research Programme (WCRP) to establish in 1988 the international Baseline Surface Radiation Network (BSRN)1). The goal was to establish a world-wide network of radiation measurements adhering to the highest achievable standards. Currently there are 39 fully operational and 8 candidate stations (Figure 1).

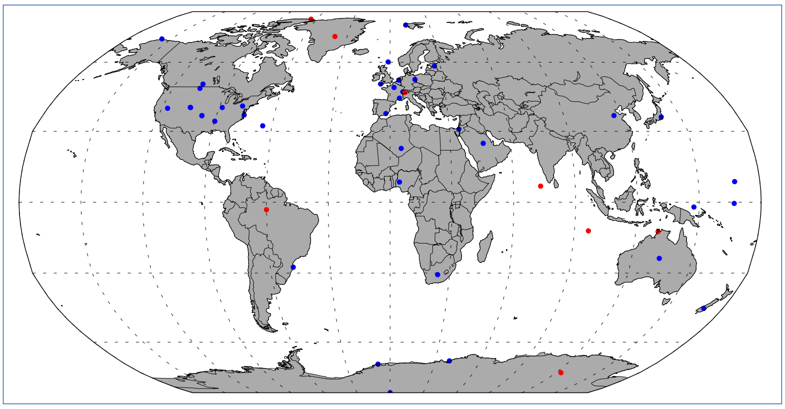

Figure 1. Global map of all stations of the Baseline Surface Radiation Network (BSRN). The blue dots indicate fully operational stations (39) whereas the red dots indicate candidate stations (8) (situation: August 2006). KNMI participates in BSRN with the radiation station at the Cabauw observatory (51.97°N, 4.93°E).

In 2004 BSRN was designated as the global baseline network for surface radiation for the Global Climate Observing System (GCOS; http://www.wmo.ch/web/gcos).

The idea for KNMI to join BSRN existed in the early 1990s but it was not until 2001 that the necessity for accurate and precise radiation measurements became urgent. A radiative closure study2) revealed that the radiation measurements were not accurate enough to draw firm conclusions on the significance of differences between model calculations and measurements of surface radiation. After an exploratory visit to the BSRN station of Payerne, Switzerland, in 2002 it was decided to initiate the construction of a radiation site in Cabauw according to the BSRN requirements.
The organization of this chapter is as follows. First, the BSRN station in Cabauw is described in terms of instruments and measured quantities. Also, an example of measurement quality control is given. Then it is shown how the calibration of the solar radiation measurements in Cabauw is linked to the world standard of irradiance. In the following two sections, two applications of the BSRN measurements in Cabauw are presented. The first is an evaluation of different methods for the determination of sunshine duration. The Cabauw measurements allowed for a thorough evaluation of a method that is used for nation-wide estimates of sunshine duration from global radiation. The second application deals with the effect of aerosols on solar radiation in relation to the origin of the air masses arriving in the measurement area. An outlook for the future is given in the last section.

BSRN Cabauw

The field constructions for the BSRN station in Cabauw were completed by the end of 2004 (Figure 2). The data acquisition system, designed to meet the stringent BSRN requirements, and a basic set of radiation instruments were operational by early 2005. The first consistent monthly dataset of basic radiation measurements (global, direct, diffuse and downward longwave radiation) was obtained in February 2005. Since then, the station has been extended with various spectral radiation measurements (both direct

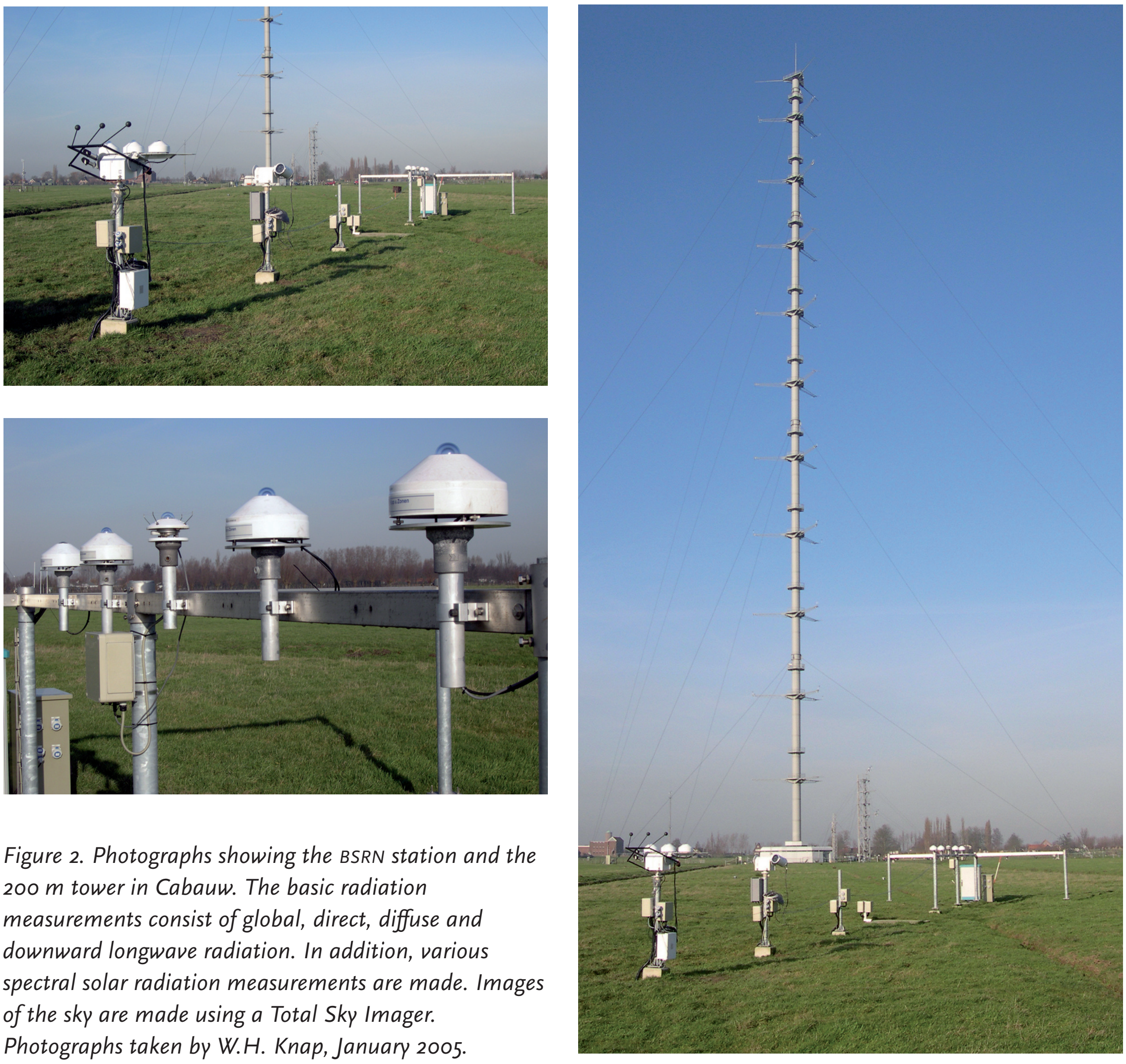

Figure 2. Photographs showing the BSRN station and the 200 m tower in Cabauw. The basic radiation measurements consist of global, direct, diffuse and downward longwave radiation. In addition, various spectral solar radiation measurements are made. Images of the sky are made using a Total Sky Imager. Photographs taken by W.H. Knap, January 2005.

and diffuse) made at different solar wavelengths. A total sky imager has been installed as well as instruments for measuring ultraviolet and photosynthetically active radiation and sunshine duration. The formal status of Cabauw as BSRN station was announced at the 9th BSRN Workshop and Scientific Review in Lindenberg, Germany, May 2006[3].

Besides the installation of constructions and instruments, considerable effort has been put into the implementation of quality control procedures and the development of a web-based system for the access to quick looks and measurements. Some of the applied quality control procedures involve the use of radiative transfer models. An example for a selection of downward longwave irradiances measured at BSRN Cabauw is shown in Figure 3. The same quantity was calculated using the radiative transfer model MODTRAN 4. The bias of $7 \pm 4\ \mathrm{W\ m^{-2}}$ between model and measurements is considered to be acceptable and gives confidence in the measurements and excludes serious instrument malfunction.

International Pyrheliometer Comparison

The World Radiometric Reference[4] is the measurement standard representing the SI unit of irradiance ($\mathrm{W\ m^{-2}}$). The WRR is realized by measurements of direct solar radiation made by a group of 15 absolute cavity radiometers – the World Standard Group (WSG) – which is situated at the Physikalisch-Meteorologisches Observatorium Davos/World Radiation Center (PMOD/WRC) in Davos, Switzerland. The WRR has been introduced to ensure worldwide homogeneity of solar radiation measurements and is in use by the meteorological community since 1981. The reference has an estimated accuracy of 0.3% and guarantees that worldwide solar radiation measurements are precise within 0.1%[4]. The dissemination of the WRR

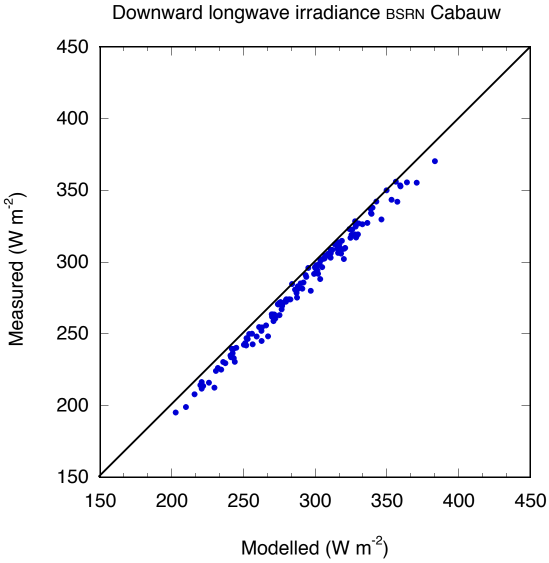

Figure 3. Scatterplot of modelled and measured clear-sky downward longwave radiation for BSRN Cabauw. The modelled values were calculated with the radiative transfer model MODTRAN (version 4). The model underestimates the measurements by an acceptable 7 ± 4 $W\ m^{-2}$.

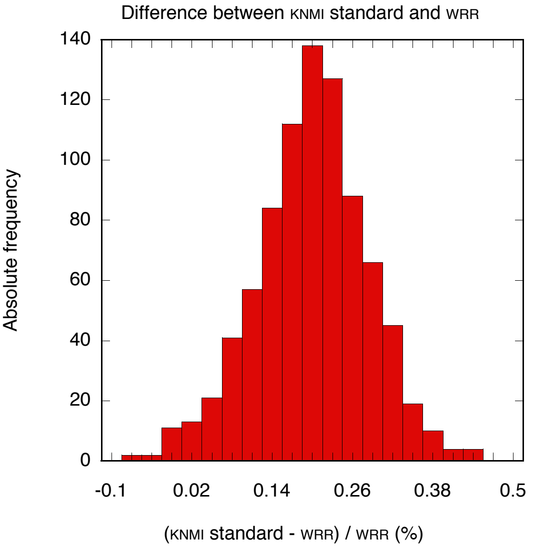

Figure 4. Left panel: KNMI instruments for the measurement of direct solar radiation present during the 10th International Pyrheliometer Comparison, Davos, Switzerland, autumn 2005. Right panel: histogram of the relative difference between the KNMI measurement standard for direct solar radiation (Eppley HF cavity radiometer) and the World Radiometric Reference (WRR).

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is realized by direct intercomparisons between pyrheliometer measurements and the WRR during the International Pyrheliometer Comparison (IPC) which is held at PMOD/WRC every five years. For BSRN stations, representing the highest standard of radiation measurements, it is essential to participate in IPCS so as to guarantee direct traceability of solar radiation measurements to the WRR.

From 26 September until 14 October 2005 KNMI participated in the 10th International Pyrheliometer Comparison (IPC-X), Davos, Switzerland[5]. It was the third time that KNMI was present in Davos; in 1990 and 1995 KNMI participated in the 7th and 8th IPC. Each time, KNMI used the same Eppley Hickey–Frieden (HF) cavity radiometer (Figure 4, left panel), which is one of the most accurate instruments for measuring direct solar irradiance. The 10th IPC was characterised by favourable weather conditions that resulted in a record number of calibration measurements. Figure 4 (right panel) shows the performance of the KNMI instrument relative to the WRR. On average the difference appeared to be as small as 0.20 ± 0.08%. The excellent agreement with the WRR will allow us to perform on site calibrations of the solar radiation instruments of the BSRN site in Cabauw, that are directly traceable to the WRR.

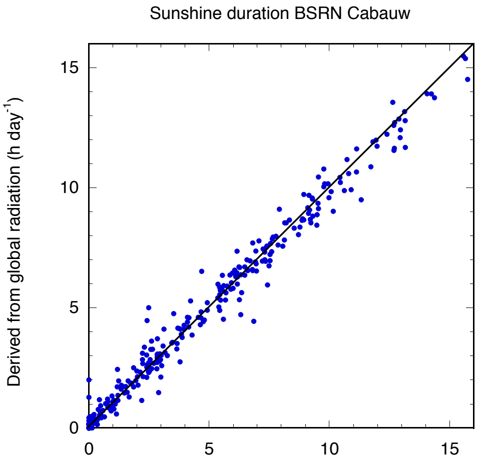

Figure 5. Scatterplot of daily sunshine durations for 2005 (in h day^{-1}) derived from measurements of global radiation (vertical axis) and direct solar radiation (horizontal axis) made at BSRN Cabauw. The first are estimates of sunshine duration based on a simple correlation algorithm and the second are values based on the WMO definition of sunshine duration.

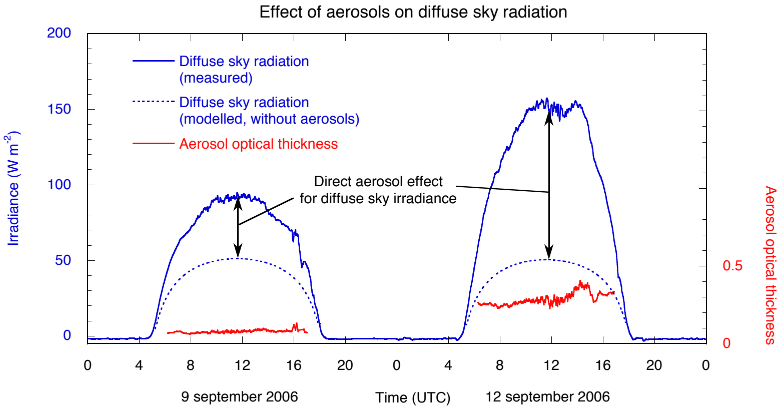

Figure 6. Measurements of diffuse sky radiation and aerosol optical thickness made at BSRN Cabauw on 9 and 12 September. Also shown are radiative transfer calculations for Rayleigh atmospheres with added water vapour. The arrows indicate the direct aerosol effect for diffuse sky irradiance.

The large variations in aerosol optical thickness that are observed in Cabauw can largely be understood by considering the origin of the air masses arriving in the measurement area

Sunshine duration

One of the first applications of the radiation measurements made in Cabauw was a detailed evaluation of different methods for the determination of sunshine duration from measurements of global radiation[6,7]. The rationale for the evaluation is the fact that sunshine duration is often estimated from global radiation instead of direct radiation because instruments for measuring direct radiation are expensive. The true sunshine duration was derived by application of the formal WMO definition of sunshine duration, which states that 'the sun shines' when the direct solar irradiance exceeds 120 W m^{-2}. The evaluation showed that relatively accurate estimates of daily sunshine duration can be made from 10-min mean observations of global irradiance, using simple correlation techniques (Figure 5). The uncertainties for daily and yearly sums appear to be typically 0.5 h day^{-1} and 0.5%, respectively.

Slob and Monna[8] developed a more complicated method for the determination of sunshine duration from global radiation, which relies on parameterized estimates of direct and diffuse radiation. An adjusted version of the method has been operational since 1992 for nation-wide estimates of sunshine duration[9]. Application of the method allows KNMI to continue the historical record of sunshine duration (dating back to 1901) as determined with the Campbell-Stokes sunshine recorder. Using the BSRN measurements for Cabauw, Hinssen and Knap[6,7] showed that the method is potentially accurate but requires extensive tuning of model parameters. They also showed that the operational algorithm significantly overestimates the sunshine duration; the cumulative number of sunshine hours for 2005 appears to be 13% too high. This is caused by the fact that the operational method is tuned to the traditional way of determining sunshine duration, which is based on the use of the Campbell-Stokes sunshine recorder (a glass sphere that burns a trace in a paper card). This instrument tends to overestimate the sunshine duration, especially during broken-cloud conditions. Hinssen[6] gives recommendations on how to improve the operational sunshine duration product.

The effect of aerosols on solar radiation

The BSRN radiation measurements made in Cabauw, together with other measurements made within the framework of the Cabauw Experimental Site for Atmospheric Research (CESAR; http://www.cesar-observatory.nl) allow us to perform detailed studies of the interaction between clouds, aerosols, and radiation. An example of the effect of aerosols on the diffuse sky radiation is shown in Figure 6, which contains cloudless measurements made in 2006 on a day with low aerosol load (9 September) and a day with high aerosol load (12 September). The aerosol optical thickness (AOT) at 500 nm, measured with the SPUV sunphotometer[10,11)], ranges from 0.06 on the first day to 0.41 on the second day, which largely spans the spectrum of AOT values occurring in the Netherlands. At noon, the diffuse sky radiation on 12 September (high AOT) is about 60 W m^{-2} higher than on 9 September (low AOT), which is caused by enhanced scattering of sunlight by aerosols. Since aerosols scatter visible sunlight without a clear preference for a certain wavelength, the human eye observes this increase in diffuse sky radiation as a change in sky colour; from deep blue to whitish.

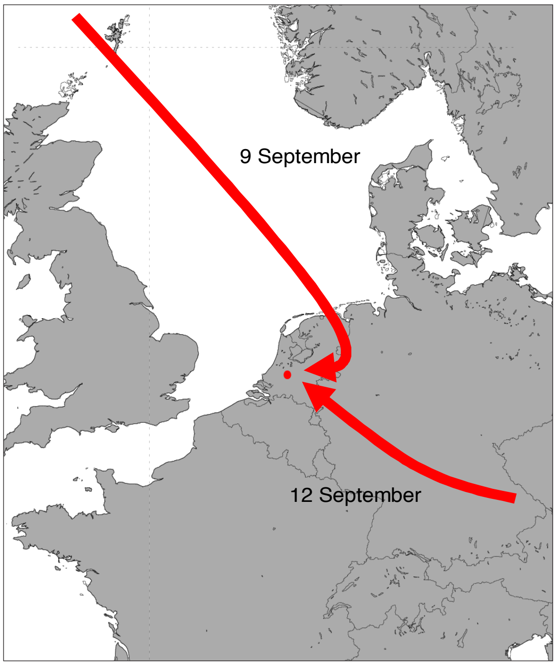

Figure 7. Schematic representation of the origin of air masses arriving in the Cabauw area on 9 and 12 September 2006, derived from trajectory analysis. The period between these days represents a transition from low to high aerosol loads.

To further analyse the relation between aerosols and radiation, radiative transfer calculations were made for a Rayleigh atmosphere (containing only the permanent atmospheric gases) with added water vapour (dotted lines in Figure 6). By substracting these calculations from the measurements of diffuse sky radiation, one is left with the direct aerosol effect for the diffuse sky radiation. On the two days mentioned above the effect appears to be at noon 40 W m^{-2} (low AOT) and as much as 100 W m^{-2} (high AOT).
The large variations in aerosol optical thickness that are observed in Cabauw can largely be understood by considering the origin of the air masses arriving in the measurement area. For 9 and 12 September, the large-scale flow was identified using a trajectory model (Figure 7). It appears that the air arriving in the Cabauw area on 9 September has travelled mainly over the Atlantic Ocean and the North Sea where several natural and most anthropogenic sources of aerosol are absent. The situation for 12 September is very different: the air was advected over land, in particular over industrialized regions in Germany, where major sources of atmospheric pollution are present. These, in combination with natural sources of aerosol, give rise to the observed high values of AOT.

Outlook

Long-term monitoring of the solar and infrared radiation components with high accuracy and precision is an indispensable activity for the climate research community. The BSRN station of Cabauw will therefore continue to be operational as the reference radiation monitoring station for the Netherlands and will make its contribution to the global network of surface radiation measurements. The station will be extended with downward facing instruments for the measurement of upward shortwave and longwave radiation. Together with the downward radiation components this addition will complete the surface radiation budget, which is one of the GCOS Essential Climate Variables.

The combination of BSRN and CESAR, the national observatory for atmospheric research, gives a unique opportunity for high-level scientific research that aims at an improved understanding of the interaction between clouds, aerosols and radiation. The construction of time series, for example of the effect of aerosols on radiation, will be an integral part of future research. These time series, which are in itself valuable for the detection of possible trends, will also be used for the evaluation of models such as KNMI's regional atmospheric model, RACMO.

Acknowledgements

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