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Polar baseline surface radiation measurements during the International Polar Year 2007–2009

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Abstract

Downwelling and upwelling shortwave and longwave radiation components from six active polar sites, taking part of the Baseline Surface Radiation Network (BSRN), were selected for the period of the last International Polar Year (March 2007 to March 2009), and included in the BSRN-IPY dataset, along with metadata and supplementary data for some of the stations. Two sites, located at Svalbard archipelago (Ny Ålesund) and Alaska (Barrow), represent Arctic sea-level conditions. Four Antarctic stations represent both sea-level (Dronning Maud Land and Cosmonaut Sea) and high-elevation conditions (South Pole and East Antarctic Plateau). The BSRN-IPY dataset content and quality are discussed. The dataset is now available at doi:10.1594/PANGAEA.737668 (to resolve a DOI name use http://dx.doi.org), and can be used for free after accepting the BSRN data release guidelines.

1 Introduction

The radiative energy budget at surface plays a fundamental role in defining the thermal conditions and drives the general circulation of the earth-atmosphere system, shaping the main characteristics of the earth climate. To provide the scientific community with a high quality surface shortwave and terrestrial radiation monitoring, the Baseline Surface Radiation Network (BSRN, http://bsrn.awi.de), was established in 1988, under the oversight of the GEWEX Radiation Panel (www.gewex.org). The BSRN provides accurate measurement of surface radiation fluxes collected at 51 sites around the world. The project provides structure and general guidance to a select group of international observing sites, whose leaders voluntarily contribute their efforts and data to a central data archive. A set of requirements and specifications (Ohmura et al., 1998; Hegner et al., 1998; McArthur, 2004) as well as the overall goals have been subject to review and revision as new needs, capabilities and technology appear. The network has grown from nine reporting sites in 1992 to 51 sites that have provided data through 2010, although three of those sites are considered no longer active. There are about 20 additional sites that have indicated an intent to participate and may be able to provide both prior and current data (Dutton and Erlich, 2010). Four high latitude sites operate since BSRN establishment (1992) in both Arctic (Ny Ålesund and Barrow) and Antarctic (Amundsen-Scott and Neumayer), while two additional Antarctic sites have archived data since 1994 (Syowa) and 2006 (Concordia).

Radiation measurements at high latitudes are specially affected by problems due to rime deposition, snow accumulation, solar tracker failures, and calibration temperature compensation. The dedicated working group "Cold Climate Issues" was established during the "Tenth BSRN Scientific Review and Workshop" 2008 in De Bilt in order to minimize the impact of these problems on the data quality of the polar BSRN stations (Dutton, 2008).

2 BSRN-IPY dataset description

The BSRN-IPY dataset contains many continuously measured top-quality broadband surface radiation fluxes, averaged over one minute, collected by BSRN polar stations from March 2007 to March 2009, coincident to IPY intensive field experiment (http://ipy.org). Description of the BSRN polar stations contributing data to this dataset are indicated in Table 1. Four of them are operating in Antarctica at both coastal (Syowa 69° S, and Neumayer 71° S) and high plateau (Amundsen-Scott 90° S and Concordia 75° S) positions. The remaining two stations, Ny Ålesund 79° N and Barrow 71° N, contribute their data representing northern polar conditions at sea level, from Svalbard archipelago and Alaska respectively. Geographic position of the operating BSRN stations included in this dataset, and of two additional stations not included in this dataset because in a pending status (Alert 83° N and Greenland Summit 73° N), are given in Fig. 1.

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The basic set of measurements to be implemented in order to keep part of the network, consists of the global, direct and diffuse components of downwelling solar radiation (shortwave, SW), and the terrestrial (longwave, LW) downwelling radiation. This is a common set of measurements for all the BSRN sites. Some of them also present an expanded set of measurement composed of the upwelling shortwave and longwave components (Ny Ålesund and Neumayer). Additionally supplementary datasets like synoptic observations, upper air soundings, ozone values and ceilometer data are given for a few stations (Ny Ålesund, Neumayer 71° S and Syowa 69° S). Other stations are known to measure upwelling components of SW and LW (Concordia and Amundsen-Scott), that were not submitted to archive when the present release of the BSRN-IPY dataset was compiled. Interested users are requested to verify updates in order to collect these additional radiation components, useful for a complete surface radiative balance knowledge.

The dataset consists of 150 monthly basic radiation data given in tab-delimited textfile (down-welling components) containing average, standard deviation, maximum and minimum reported with the time resolution of one minute. Additionally, it is completed by 50 monthly upwelling components of short-wave and long-wave radiation given with the same time resolution, 75 monthly files containing surface synoptic observations obtained from meteorological stations, 50 monthly files containing ozone soundings and 50 monthly files containing radiosonde measurements. Table 1 reports the detailed list of data available in the polar stations of BSRN.

Each textfile includes all necessary metadata. No special software is needed to access the data but it is suggested to have a look at software offered by PANGAEA to convert (Pan2Applic, doi:10.1594/PANGAEA.288115) or visualize the data (PanPlot, doi:10.1594/PANGAEA.330147). In particular, the PanPlot tool is suitable for the visualization of time patterns of data and multivariate analysis (Fig. 2).

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2.1 Data access

The dataset was composed by a subset of monthly files archived in the world Radiation monitoring Center (WRMC) – the central archive of the BSRN – hosted at Alfred Wegener Institute (see: http://bsrn.awi.de). All these independent monthly archives, were joined into a parent dataset, see http://dx.doi.org/10.1594/PANGAEA.737668.

The access to all metadata of the BSRN-IPY datasets is free, nevertheless the full access, available at doi:10.1594/PANGAEA.737668 is subject to BSRN data release guidelines (http://bsrn.awi.de). Any user who accepts them may ask, through a dedicated web section, to obtain an account to download more than 400 doi-references datasets, directly through listed links or via ftp. Alternatively the dataset could be downloaded using the dedicated PANGAEA tool BSRN Toolbox available at doi:10.1594/PANGAEA.744019.

3 Instrumentation and methods

All radiation measurements should be acquired using primary reference instruments, with a minimum logging frequency of 1 Hz and stored at least as minute averages, along with their standard deviation, maximum and minimum. Basic meteorological parameters such as air temperature T_a, relative humidity RH, and pressure p should complete the radiation file. Pyranometers and pyrgeometers should be ventilated, the body temperature T_b and whenever possible the dome temperature T_d of a shaded pyrgeometer should be collected, in order to calculate longwave component using the correction given by Philipona et al. (1995). Corrections of the pyranometers shortwave measurements should be performed for (i) the thermal offsets, (ii) the cosine response, and (iii) the temperature compensation of the calibration constant variability; these corrections should be applied following BSRN guidelines (McArthur, 2004).

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Although all measurements performed within the BSRN are expected to be as accurate as possible and all traceable with the World Radiometric Reference (WRR) standards, differences between the precision of various components should be expected. The aims of the network with respect to absolute errors, fullfilled in most cases, vary between components. The most accurate measurement implemented could be considered the diffuse shadowed pyranometer (DIF) that is expected to be affected by an error of no more than ±5 W/m^2; the direct normal component $DIR_\perp$, is expected to be associated with an absolute error of ±5 to ±10 W/m^2 at most of BSRN sites, where windowed pyrheliometer were deployed; the global unshadowed pyranometer (global 2 or G2) is expected to be affected by errors up to ±20 W/m^2 (Ohmura et al., 1998). The global measurement, performed with a ventilated and unshaded first-class pyranometer, is affected by substantial cosine error in presence of the direct SW component, while for the diffuse one this error is reduced to an averaged cosine error over all incoming hemispherical directions. Moreover, the diffuse component is weakly dependent on leveling errors with respect to the global one that is strongly affected by leveling because of the vertical component of the direct radiation. All shortwave components are referenced to the World Radiometric Reference (WRR). It is valid for both pyrheliometer and pyranometers being the latter calibrated with respect to the WRR set of pyrheliometers with the shading-unshading method (McArthur, 2004). Using the BSRN-IPY dataset the downwelling shortwave global radiation (SWD) could be obtained from the pyranometer (global 2 or G2), or calculated as sum of the diffuse DIF and the direct normal $DIR_\perp$ component, the latter weighted by the cosine of the solar zenith angle θ (McArthur, 2005; Michalsky, 1988),

$$G1 = DIF + \cos\theta DIR_\perp \quad (1)$$

Global 1, calculated using Eq. (1), is expected to be more accurate and should be preferred e.g. for intercomparisons with instantaneous data from models or satellites. On the other hand, it is better to use Global 2 for averages and trends, since it normally has less missing values than G1, which requires continuity in solar tracker

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operation and gets data from two independent instruments. Longwave downwelling measurements performed with shadowed and ventilated top class pyrgeometer are expected to be affected by an error not greater than $\pm 10\,\mathrm{W/m^2}$ (Ohmura et al., 1998), and all instruments referred to the World Infrared Standard Group (WISG) hosted at PMOD/WRC. The efforts of the BSRN community and in particular of the Physikalisch-Meteorologisches Observatorium Davos/World Radiation Center (PMOD/WRC, Davos, Switzerland) aims to the best definition of a standard measurements using black-body cavity BB1995 and BB2007 as reference, presenting emissivity near unit (0.9999 and 0.9985).

All instruments used along the BSRN-IPY are identified in each monthly file header and the WMO traceability could be always identified; a summary of the models used at 6 stations for the various radiative components is given in Table 2. It could be observed that all instruments are manufactured by Kipp and Zonen or Eppley Laboratory, Inc.: sites managed by the Japan (*syo*) and Italy (*dom*) use Kipp and Zonen radiometers for both shortwave and longwave fluxes, German sites (*gvn*, *nya*) use Kipp and Zonen radiometers for SW while use Eppley PIR for LW. In Amundsen-Scott (*spo*) and Barrow (*bar*) sites, managed by NOAA, instruments from Eppley are adopted for both longwave and shortwave measurements. Stations *gvn* and *syo* changed the set of instruments several times along the IPY period, *spo*, *nya* and *bar* replaced instruments one time, following the guidelines of the network, while *dom* used the same set of instruments for the whole period.

Figure 3 shows a monthly time series of data availability for global 2, direct, diffuse and longwave downwelling components for each station. The percentages are calculated with respect to the maximum number of minutes per month with a solar zenith angle $\theta < 90^{\circ}$for shortwave components, and for all-day minutes per month for the longwave. Hence, the fraction of shortwave available data was not reported during polar nights, although most sites report a valid number that could be used to verify the residual offset presented by pyrheliometers and pyranometers (that for BSRN requirements has to be greater than $-4\,\mathrm{W/m^2}$). Some lack of longwave affected *dom* and *bar* sites,

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while shortwave measurements presented incomplete datasets during some months for *dom* and *syo*. Problems could be related to technical failures in the data acquisition system or tracker failures, and to data quality checks.

4 Data availability and quality test

All radiation data are subjected to strongly defined quality controls (QC), not made centrally in the World Radiation Monitoring Center but recommended from the BSRN for the station managers who are responsible for the data quality of their station. They involve physically possible and climatological extremely rare limit checks, along with test of consistency between different data. Also comparison of the various components with radiative transfer calculations is indicated as a useful tool for station leaders for data interpretation. A final visual inspection of the time series of irradiances in various time resolutions and combinations with other information, is considered the most effective test when performed by experienced data owners (Ohmura et al., 1998; Long and Shi, 2008; Long and Dutton, 2002). Physically possible (*ppl*) and extremely rare limits (*erl*) adopted are given in Table 3, while comparisons tests are listed in Table 4. A subset of the QC were applied to the downwelling components of the IPY-BSRN dataset, and results reported as follows. All *ppl* and *erl* checks were applied, along with the across quantities including: (a) fraction between G1 and G2, (b) the diffuse DIF to global SWD ratio (not reported on this paper), and (c) the longwave LWD to air temperature T_a comparison.

The BSRN guidelines clearly indicate that *erl* should be defined according to a significant climatology of the site, and values valid for one station could not be applied to another. Nevertheless, in this framework, the value indicated by Long and Dutton (2002), were adopted for the definition of the extremely rare limits. Keeping in mind this fact, it was observed that the lower longwave *erl* (+60 W/m^2) was experienced by Concordia many times (12%), with the 10th percentile of 58 W/m^2 and median value of 79 W/m^2 and a 90th percentile of 98 W/m^2. The more similar station was *spo* that

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presents a 10th percentile of 82 W/m^2, a median of 108 W/m^2 and a 90th percentile of 158 W/m^2.

Direct normal component was overestimated with respect to the extremely rare limit checks by *nya* and *gvn* stations mainly during the early and late summer (although at rate always less than 5% per month); diffuse component was some times overestimated (but again less than the 5% of the time) at *spo*, *gvn* and *nya*. This is likely related to the high reflectance of the polar surfaces that, in conjunction with scattered clouds, can enhance the diffuse component with respect to locations with a lower surface albedo. These data are not necessarily to be considered as errors, because worldwide typical limits were applied. These data should be taken with care and not excluded without further investigation performed by the data users.

A comparison of G1 and G2 for all sites included in the dataset was performed and the result represented in Fig. 4. For each station, the root mean square calculated for pair with global 2 greater that +50 W/m^2, was calculated. They varied between a minimum of 0.011 for *nya* to a maximum of 0.045 for *spo*. A significant BIAS ($1/N\sum[\mathrm{G1}-\mathrm{G2}]$), was observed for *spo* (−24 W/m^2), while for the other station the BIAS was observed to be consistent with absolute error expected. The maximum values of SW global radiation were observed in sites with the lower latitude (higher solar elevation), being the southern sites reaching values up to 1300 W/m^2.

According to the failure of the diffuse *erl*, *spo* experienced some failure of the diffuse to global ratio during the last period of the IPY (Dec 2008–Mar 2009). The extreme latitude of the South Pole, where the maximum solar elevation is only 23.5 degrees, could be considered the main source of the problem, because pyranometer cosine corrections are more difficult to perform at these illumination geometries.

Figure 5 shows the downwelling longwave LWD to air temperature T_a comparison, for all stations. This test is formulated considering that an effective atmospheric emittance – defined as $\epsilon_A = \mathrm{LWD}/\sigma T_a^4$ – of no less than 0.4 should be considered valid. On the other hand a longwave component greater than a black-body emission at surface air temperature, is considered highly not probable. If this is true for mid-latitude sites, in polar regions, a combination of temperature inversion and thick cloudiness, could enhance the effective emissivity of the atmosphere inducing measurements of several W/m^2 greater than this limit (König-Langlo and Augstein, 1994). With this in mind, all the Antarctic sites *spo*, *dom*, *syo* and *gvn* overpass the upper limit at different occurrance rates, while respecting all *ppl* and *erl* tests on the longwave component. This could be exactly explained with surface temperature inversion matter in cloudy conditions.

Finally, in Fig. 6 the monthly averages are reported for downwelling global (G2) and longwave. Being latitude and cloudiness are the most significant parameters affecting it, a discussion of the global shortwave average is abandoned. At coastal sites, downwelling longwave ranges between 170 W/m^2 during clear sky late winter months to 250 W/m^2 in Antarctic summer and to 300 W/m^2 in Arctic, according to an expected greater cloud occurrences of thicker clouds in Arctic regions.

Acknowledgements. Many authors, as station leaders, are also responsible for data quality of the product submitted to the BSRN archive. Collecting data was possible because of different research projects founded by many national institutions: The Alfred Wegener Institute (*nya* and *gvn*), the National Oceanic and Atmospheric Administration (*bar* and *spo*), the Programma Nazionale di Ricerche in Antartide (*dom*), the National Institute of Polar Research and the Japan Meteorological Agency (*syo*). Special acknowledgment to all people contributing their efforts to the maintenance of the hardware and software infrastructure, as well as to the improvement of the data quality of the BSRN network.

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Table 1. List of the BSRN stations covered by the dataset, BSRN station identifier and number and abbreviation (st_n/st_id), coordinates, surface and topography type. Basic measurements of radiation (B), Expanded measurements (E), Meteorological synoptic observations (M), Ozone measurements (O), and Radiosonde measurements (R).

Site	st_n	st_id	LAT°	LON°	Alt(mt)	Surface type	Topography type	Data type
Barrow	22	*bar*	71.323	−156.607	8	Tundra	flat, rural	B
Ny Ålesund	11	*nya*	78.925	11.950	11	Tundra	Mt. valley, rural	B,E,M,O,R
Syowa	17	*syo*	−69.005	39.589	18	Sea Ice	hilly, rural	B,M,O,R
G. von Neumayer	13	*gvn*	−70.650	−8.250	42	Iceshelf	flat, rural	B,E,M,O,R
Concordia	74	*dom*	−75.100	123.383	3233	Glacier, accum.	flat rural	B
South Pole	26	*spo*	−89.983	−24.799	2800	Glacier, accum.	flat rural	B

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Table 2. Set of instruments adopted by various stations for the various components. The “Repl” column indicates how many times a set of the same type was completely or partially replaced. *gvn* replaced CM11 with CM22 on February 2009. *spo* replaced just pyrgeometer. *syo* replaced pyrheliometer many times along the IPY period. Details are given in the metadata of the datasets.

Site	SWD	DIR	DIF	LWD	SWU	LWU	Repl
bar	PSP	NIP	PSP	PIR	PSP	PIR	1
dom	CM22	CH1	CM22	CG4	–	–	0
gvn	CM11	NIP	CM11	PIR	CM11	PIR	5
gvn’	CM22	NIP	CM22	PIR	CM22	PIR	–
nya	CM11	NIP	CM11	PIR	CM11	PIR	2
spo	PSP	NIP	PSP	PIR	PSP	PIR	1
syo	CM21	CH1	CM21	CG4	CM21	CG4	10

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Table 3. Quality checks as defined in the BSRN guidelines. G2 is the downwelling global shortwave measured by the pyranometer. $S_a = 1368\,\mathrm{W/m^2}$ is the solar constant that should be scaled according to the earth-sun distance, while μ is the cosine of the solar zenith angle θ. All absolute values are in $\mathrm{W/m^2}$.

Quantity	ppl_l	erl_l	erl_u	ppl_u
G2	−4	−2	$1.20\,S\,\mu^{1.2}+50$	$1.50\,S\,\mu^{1.2}+100$
$DIR_\perp$	−4	−2	$0.95\,S\,\mu^{1.2}+10$	1368
DIF	−4	−2	$0.75\,S\,\mu^{1.2}+30$	$0.95\,S\,\mu^{1.2}+50$
LWD	40	60	500	700
SWU	−4	−2	$S\,\mu^{1.2}+50$	$1.2\,S\,\mu^{1.2}+50$
LWU	40	60	700	900

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Table 4. Across quantity as defined in the BSRN guidelines. G2 is the SWD measured by the pyranometer. G1 is the SWD obtained as sum of diffuse and direct components. S_a = 1368 W/m^2 is the solar constant that should be scaled according to the earth-sun distance, while μ is the cosine of the solar zenith angle θ. Values involving LWD are expressed in W/m^2, the others are dimensionless.

Comparison	lower limit	upper limit
G2/G1 ($\theta < 75^\circ$)	0.92	1.08
G2/G1 ($\theta > 75^\circ$)	0.85	1.15
DIF/G2	–	<1.05
DIF/G2	–	<1.10
SWU/G1(or G2)	<1.0	<1.0
LWD (to T_a)	$0.4\sigma T_a^4$	$\sigma T_a^4 + 25$
LWU (to T_a)	$\sigma(T_a - 15)^4$	$\sigma(T_a + 25)^4$
LWD-LWU	−300	+25

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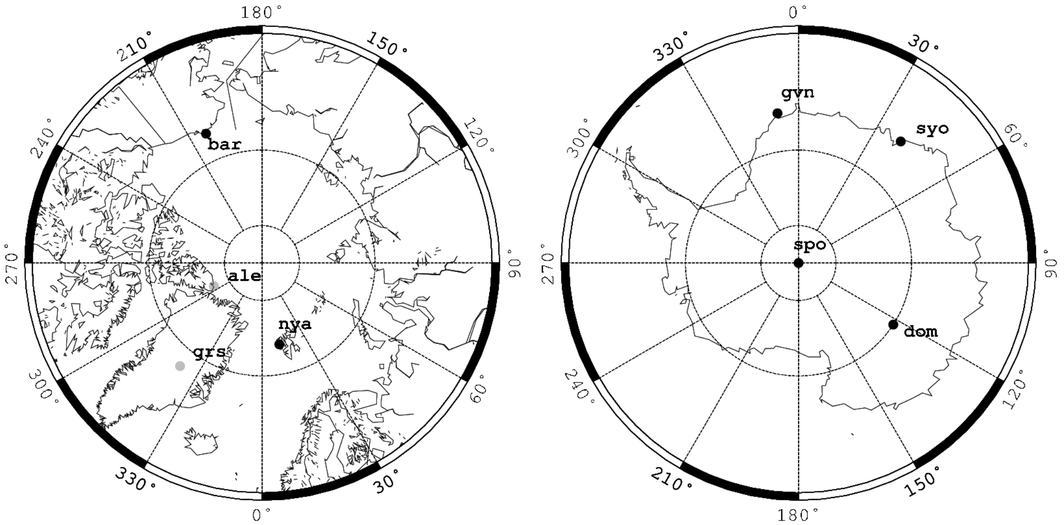

Fig. 1. Position of the BSRN-IPY polar station (black), along with BSRN stations in pending status (gray).

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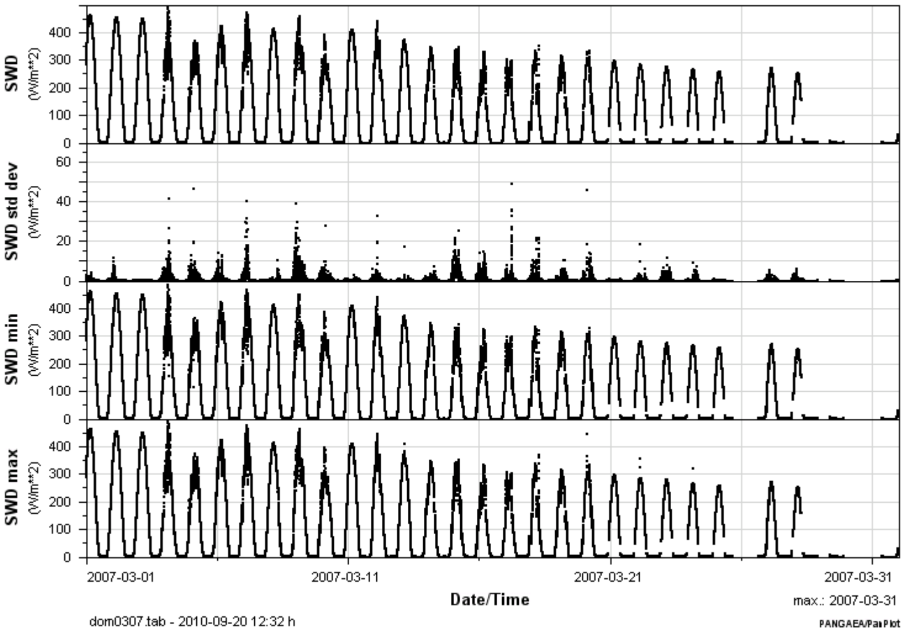

Fig. 2. Example of PanPlot at work. It is free tool developed for time series visualization of data stored in PANGAEA archive format.

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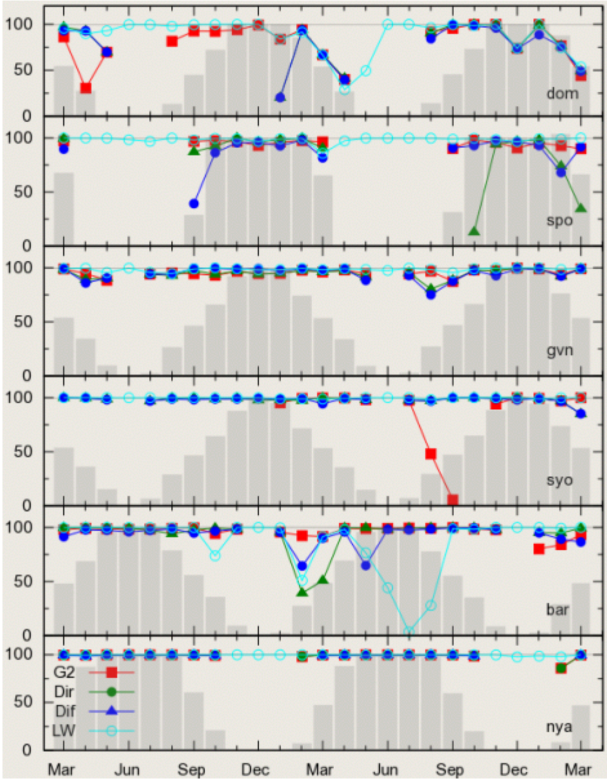

Fig. 3. Monthly availability of the BSRN data for downwelling global shortwave G2 (squares), direct (filled circles), diffuse (triangles) and longwave downwelling (open circles). Fractions for shortwave components are calculated with respect to the daylight (SZA < 90°), while for longwave with respect to all-day. Bars indicate the daylight fraction for various months of the IPY measurement period from March 2007 to March 2009.

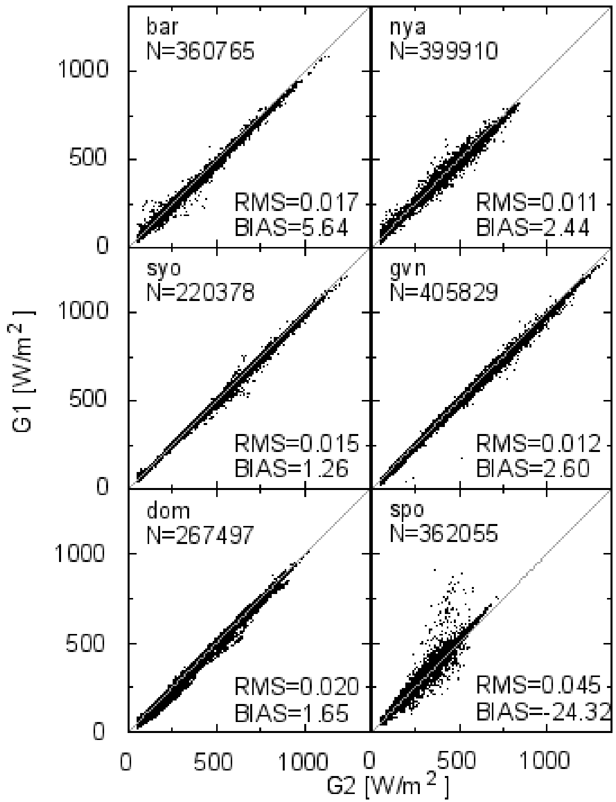

Fig. 4. (Left) Comparison between the global radiation measured by the pyranometer (G2) and the sum of direct and diffuse radiation (G1). The cloud of points for *spo* that stay away from the bisector, originate from a hundred points on the 1st Jan 2009.

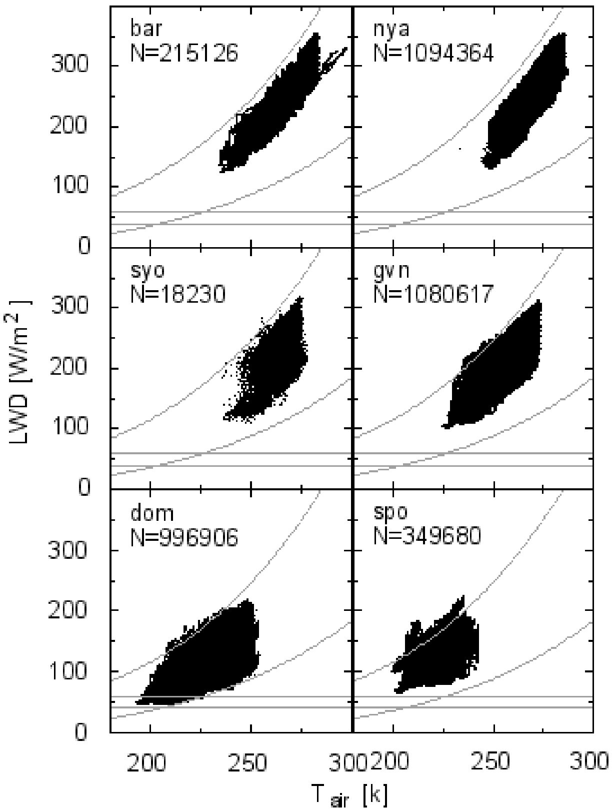

Fig. 5. Downwelling Longwave to air temperature comparison. Horizontal lines represent the erl_l (upper one) and the ppl_l. Curves represent the lower and the upper limits of LWD to T_a comparison (see Table 4).

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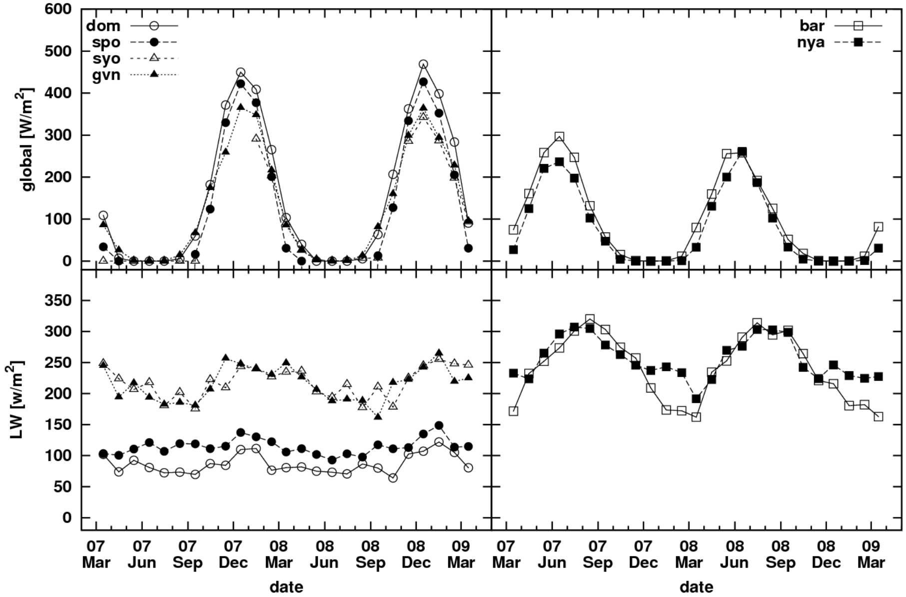

Fig. 6. Monthly means of global downwelling shortwave G2, and downwelling longwave radiation LW for the Antarctic (left) and Arctic stations (right).

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