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CHARACTERIZATION OF METEOROLOGICAL PARAMETERS, SOLAR RADIATION AND EFFECT OF CLOUDS AT TWO ANTARCTIC SITES, AND COMPARISON WITH SATELLITE ESTIMATES

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ABSTRACT

The analysis of measurements of daily mean temperature, daily mean relative humidity and daily total solar irradiation for the period 1979-1985, at the Antarctic stations Almirante Brown (64.9ºS, 62.9ºW, 10m a.s.l., West of Antarctic Peninsula), and BelgranoII (77.9ºS, 34.6ºW, 250m a.s.l., East of Antarctic Peninsula) is presented. A short-term characterization of monthly averages was established. Typical temperatures for summer and winter were 2ºC and –7ºC respectively at Brown, and –2ºC and –20ºC at BelgranoII. Relative humidity was always above 60% at both stations. Both measured parameters enter also as input variables in model calculations of the equivalent clear-sky daily total irradiation for each day, to determine the effective cloud transmittance of solar radiation. The effect of cloudiness was stronger at Brown, where an average cloud transmittance of 49% was determined, while it was of 71% at BelgranoII. Average daily irradiation of 27.4MJ/m^2 in December at BelgranoII is within the highest reported world-wide. Also, some days show increases in the daily irradiation over 20% than that expected for clear-sky conditions. Antarctic solar irradiation levels are considerably higher than in the Arctic. Ground-based data are compared with the satellite database from NASA Surface Meteorology and Solar Energy Data Set.
Key words: climatology; Antarctic Peninsula; solar radiation; meteorology; clouds

CARACTERIZACIÓN DE PARÁMETROS METEOROLÓGICOS, RADIACIÓN SOLAR Y EFECTO DE LAS NUBES EN DOS SITIOS ANTÁRTICOS, Y COMPARACIÓN CON ESTIMACIONES SATELITALES

RESUMEN

Se presenta el análisis de mediciones de temperatura media diaria, humedad relativa media diaria e irradiación solar total diaria, realizadas en el periodo 1979-1985 en las

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Bases Antárticas Almirante Brown (64.9ºS, 62.9ºO, 10m s.n.m., Oeste de Península Antártica) y BelgranoII (77.9ºS, 34.6ºO, 250m s.n.m., Este de Península Antártica). Se estableció una caracterización de corto plazo sobre medias mensuales. Las temperaturas típicas en verano e invierno fueron 2ºC y –7ºC respectivamente en Brown, y –2ºC y -20ºC en BelgranoII. La humedad relativa fue siempre sobre 60% en ambas estaciones. Estos dos parámetros entran como variables en cálculos de la irradiación solar diaria equivalente a cielo despejado, para determinar la transmitancia efectiva de radiación solar por nubes. El efecto de nubes fue mayor en Brown, con transmitancia efectiva media de 49%, respecto del 71% en BelgranoII. La irradiación media de 27.4MJ/m^2 en diciembre en BelgranoII es de las más altas registradas en el mundo. Asimismo, algunos días muestran incrementos de irradiación por sobre un 20% de la esperada para cielo despejado. La irradiación solar media en Antártida es considerablemente mayor que la registrada en el Ártico. Se comparan las mediciones con datos satelitales del Surface Meteorology and Solar Energy Data Set/NASA.
Palabras clave: climatología; Península Antártica; radiación solar; meteorología; nubes.

1. INTRODUCTION

The clean environment of the Antarctic is considered a reference for the study of atmospheric changes. Surface temperature and air composition have been analyzed from long-term data series (Wendler 2000; Braun et al. 2001; Marshall et al. 2002), and the evolution of the ice fields monitored (Nicholls 1997; Conrad and Hager 1997; Liu et al. 2002) as they depend on temperature changes resulting from the greenhouse gases increase. Solar radiation drives many geophysical and biological processes in Antarctica, such as photosynthetic processes of phytoplanckton in the marine environment (e.g. Whitmarsh and Govindjee 1999; De Mora et al. 2000), the radiative budget and polar ice melting (e.g. Bintanja and van den Broeke 1996; Bintanja 2000). Also, the stratospheric ozone depletion registered in the last two decades has its more critical contribution in the springtime Antarctic "ozone hole" (e.g. WMO 2003), and its analysis led to many studies on characterization of solar ultraviolet radiation in Antarctica (e.g. Frederick and Alberts 1991; Nunez et al. 1997; Frederick et al. 1998).

The access difficulties and the adverse weather conditions in Antarctica reduce the possibilities of collecting extensive databases. At the same time, knowledge of Antarctic meteorology is important not only for its scientific value, but also to plan logistic tasks. Every reliable set of measurements thus becomes very significant. In the beginning of the 1980s two Antarctic stations, Almirante Brown (Paradise Bay, West of Antarctic Peninsula) and BelgranoII (South coast of Weddell Sea, East of Antarctic Peninsula), were integrated into the Argentine Solarimetric Network with daily measurements of daily total solar irradiation on a horizontal surface (daily sum of total irradiance, 300-3000nm) and meteorological parameters. Data were collected from 1979 to 1985. Brown and BelgranoII stations are located in different climates on both sides of the Antarctic Peninsula (e.g. Birnbaum 2003), allowing for the investigation of climatic differences in terms of simultaneously measured parameters.

Satellite measurements have the advantage of a daily broad spatial coverage of the Earth, but they need to be calibrated and validated against local ground measurements. This is even far more relevant at high latitudes, where conditions make difficult satellite measurements and less ground-truth data are available. In particular, the NASA Surface Meteorology and Solar Energy Data Set (SSE) is a new satellite 10-year global database of monthly-averaged solar irradiation and meteorology data on a 1º by 1º grid system, whose present version (release 5.1) was launched on January 2005. Data are considered to represent the average of each parameter over the entire area of the pixel, so as to provide an estimate of the renewable energy resource potential at any place (Whitlock et al. 2000). SSE total irradiation at surface is calculated with an upgraded Staylor algorithm (Darnell et al. 1992), using as major inputs the cloud, radiation, and precipitable water data from the Version D1 International Satellite and Cloud Climatology Program (ISCCP-D1), and other meteorological inputs from the Version 1 Goddard Earth Observation System (GEOS-1) data, on a 3-hourly basis, for 280km equal-area pixels within the period July 1983 through June 1993. Final calculated values are then bi-linearly interpolated to the conventional 1º x 1º grid system over the globe. The SSE data have been tested against ground-based measurements from a selected high-quality set of about 1000 sites from the Global Energy Budget Archive (GEBA, World Radiation Data Center), which does not include stations from polar regions (Whitlock et al. 2000). Thus, comparison with the measurements at stations Almirante Brown and BelgranoII gives a first insight on the uncertainties involved over the poles.

In the present work, the revised measurements of daily total solar irradiation, temperature and relative humidity from Brown and BelgranoII databases are analyzed. Temperature and relative humidity measurements are also important as they are used in the radiative transfer A-model (Iqbal 1983) to calculate the day-to-day equivalent clear-sky daily irradiation at surface, from which the effect of cloudiness on the solar total radiation is studied. Even though the time span of available data does not reach the required 30 years to determine a climatology (IPCC 2001), a short-term characterization of monthly averages is determined on the several years of measurements, which is compared with the SSE satellite database of the same parameters and with other reports on polar regions.

2. INSTRUMENTS AND DATA

The analyzed database consists of daily mean temperature, daily mean relative humidity and daily total solar irradiation measured at two Argentine Antarctic stations: Almirante Brown (64.9ºS, 62.9ºW, 10m a.s.l.) and BelgranoII (77.9ºS, 34.6ºW, 250m a.s.l.). The geographic location of both stations is shown in figure 1. Brown is surrounded by mountains with a mean elevation approximately 10º above the horizon, whereas the area surrounding BelgranoII is flatter. Terrain on both places was always almost completely snow-covered. Brown data include the period February 1979-March 1984. BelgranoII data cover the periods March 1980-June 1981 and March 1983-June 1985.

Daily averaged temperature and relative humidity were obtained from manual registers following meteorological standards of procedure and calibration (WMO 1983). Figure 2 shows the measured daily mean temperature and relative humidity for the complete period at Brown and BelgranoII, respectively. Their importance also lies, as mentioned above, in that they are input parameters in the day-to-day calculation of the equivalent clear-sky daily irradiation.

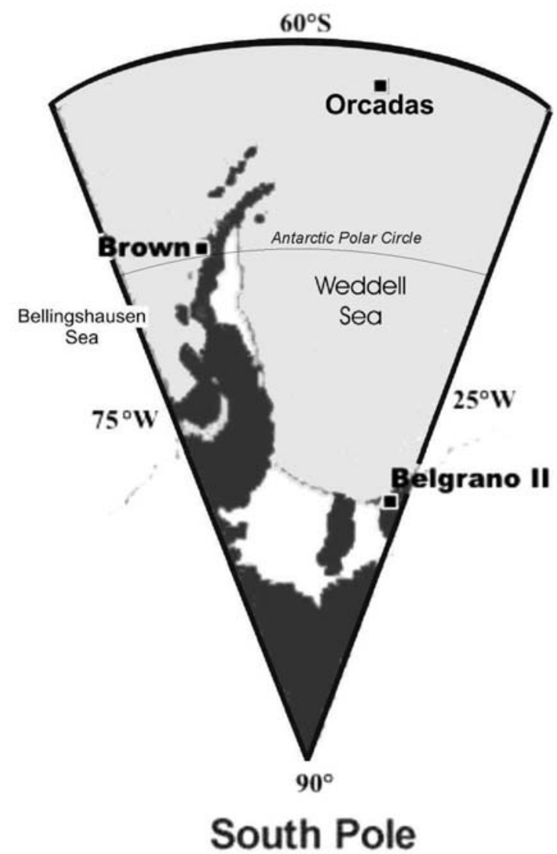

Figure 1. Geographic location of Almirante Brown and BelgranoII Antarctic stations.

Solar total irradiance was measured with silicon photovoltaic instruments of verified linearity and stability over a wide range of temperatures (Grossi Gallegos et al. 1982). The spectral response of such instruments ranges typically from 400nm to 1500nm, i.e., reduced with respect to the conventional 300-3000nm range of the thermoelectric pyranometers. Thus, they were calibrated in-field against a reference thermoelectric instrument of the Argentine Solarimetric Network to measure the total irradiance in the range 300-3000nm. Photovoltaic instruments, which have a very quick time response to changes in the solar irradiance, were connected to a temperature-stabilized pulse integrator to obtain the sum along the day, i.e. the daily total irradiation. Each system instrument-integrator, to be allocated to a station, was calibrated together in order to minimize the total uncertainty in daily values, which is lower than 6% (all uncertainties in the work are referred to one standard deviation). It can be observed that a part of the wavelength range of measurement, approximately 300-330nm, is affected by the ozone content in the atmosphere. In-field, the instruments were calibrated under typical southern mid-latitude ozone layer conditions. However, calculations show that even a change of 100 DU in the atmospheric ozone column causes a variation of less than 0.2% in the total irradiance for solar zenith angle (SZA) of 45º. Thus, the uncertainty by changes in the ozone column is largely included in the range of uncertainty of the instruments. Level control and cleaning of the dome of the instruments were carried out frequently during the field measurements at both stations.

Clear-sky daily total irradiation at surface was estimated through time-integrated irradiance calculations at 5-minutes intervals with the one-layer parametric A-model (Iqbal 1983). This model determines first the direct component of the irradiance as a function of the transmittances due to absorption by ozone, water vapor and other gases, Rayleigh scattering and attenuation by aerosols. To calculate the diffuse component, it assumes that one-half of the Rayleigh-scattered radiation reaches the ground, and the single scattering albedo and asymmetry factor are included in the formula for aerosols contribution. An additional factor due to the multiple reflections between the ground and the atmosphere completes the calculation. It has shown its reliability in other similar work at Brown station (Luccini et al. 2003). Solar constant of $1367 W/m^2$ was taken from the homogenized satellite data series of the World Radiation Center (available at http://www.pmodwrc.ch/solar_const/solar_const.html). Input parameters for the calculations are the daily mean temperature, relative humidity and ozone column, aerosol parameters and surface albedo. Ozone measured by NASA TOMS/Nimbus-7 satellite instrument (available at http://toms.gsfc.nasa.gov/n7toms/nim7toms.html) for both locations was used. Data near winter, when the TOMS instrument cannot measure, were taken from the closest available pixel at each station, a few degrees at north. For Brown, this period is from May 10 through July 31, and maximum departure is in June 21 when ozone is taken from latitude 60.5ºS. For BelgranoII, periods are from April 5 through April 22 and from August 21 through September 7, and maximum departure is in April 22 and August 21 when ozone is taken from latitude 71.5ºS. The Angström's aerosol optical depth formula $AOD(\lambda)=\beta\lambda^{-\alpha}$ with fixed $\alpha=0.34$ and $\beta=0.02$, single scattering albedo $\omega_0=1$ and asymmetry factor $g=0.784$ were taken from typical Antarctic background aerosols (Shaw 1982; Hess et al. 1998). An effective surface albedo of 0.7 determined by Luccini et al. (2003), fitting the irradiance measurements in summer clear-sky days at Brown with calculations made with the same model, was used as a good approximation throughout the year at both sites, to calculate the clear-sky daily irradiation at surface. A change from 0.5 to 0.9 in the effective surface albedo causes variations below 2% with respect to the values for albedo 0.7 in the calculated daily surface irradiation during the year. Even though the albedo in both regions increases towards the winter due to the accumulation of fresh snow and formation of extended sea-ice areas, this period is excluded in the analysis of effects of cloudiness (see section 3.3) as large relative differences between measured and clear-sky modeled values correspond to very small irradiation levels. The use of an effective albedo determined for summer remains a good approximation for autumn and spring. Figure 3 shows the measured and clear-sky modeled daily total irradiation at surface for the whole available data at Brown and BelgranoII, respectively. It can be noted that at both sites the calculations fit very well as an envelope curve to the measurements all along the year, corresponding to clear-sky conditions, fact that is crucial for the study of cloud effective transmittance to be detailed in section 3.3. As an independent test, monthly means of calculated clear-sky daily total irradiation closely agree with those of SSE database, within relative differences of only (2±3)% at Brown and (1±1)% at BelgranoII.

Results of the present analysis for each parameter are compared with the SSE release 5.1 database at both locations (available at http://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi), which has been obtained from 10-years (1983-1993) satellite data which partially overlap the period of measurements at the stations.

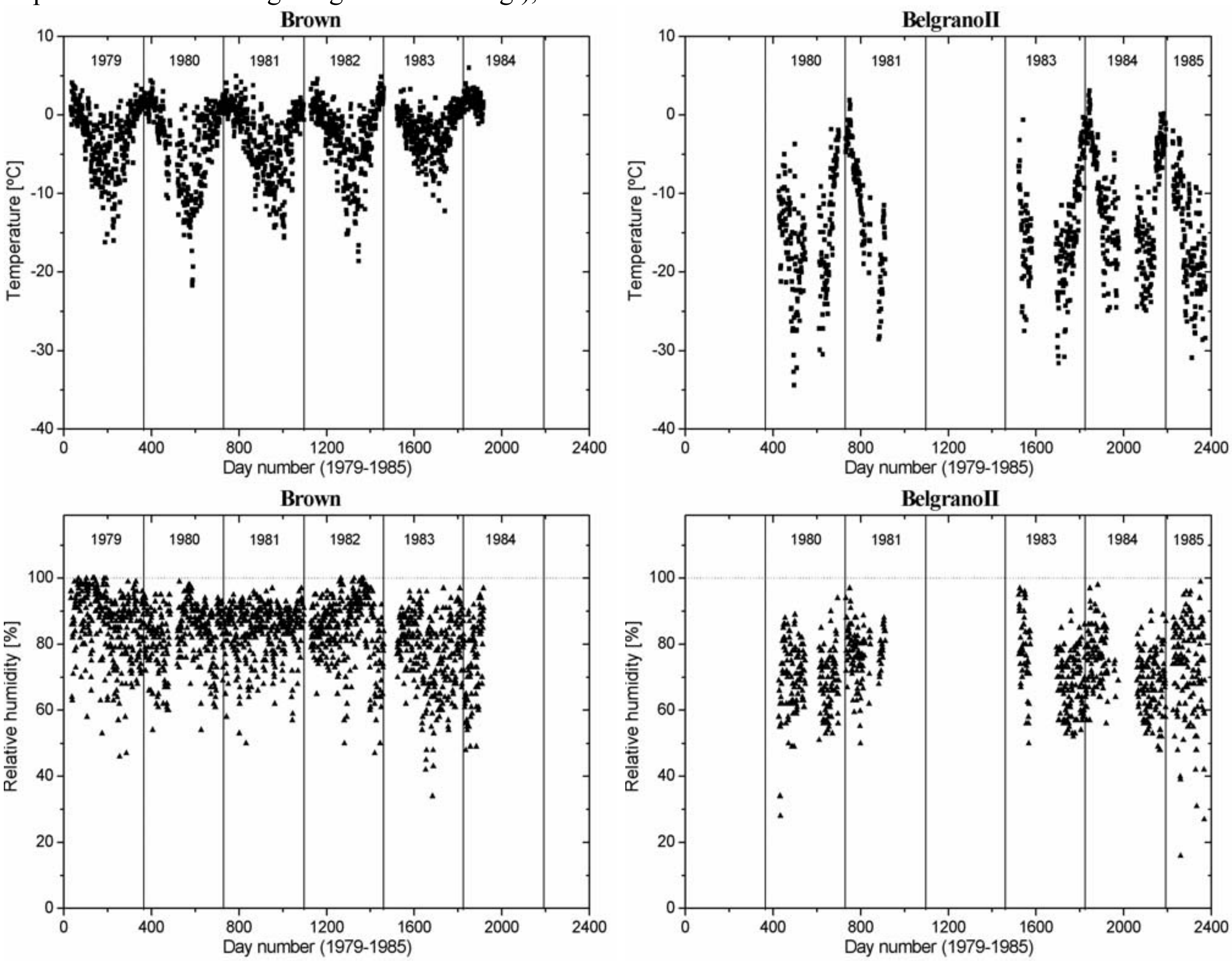

Figure 2. Daily mean temperature (top) and relative humidity (bottom) measured at Almirante Brown (left) and BelgranoII (right) stations within the period 1979-1985.

3. DATA ANALYSIS

3.1 Characterization of measured parameters at the stations

From the measurements shown in figures 2 and 3 the short-term characterization of temperature, relative humidity and daily total irradiation were calculated on monthly means of daily averages during the year for Brown and BelgranoII. They are shown in figure 4, with the uncertainty bars representing the parameter's variability, together with the SSE data. Months with a total of less than 15 measurements available were excluded from the analysis.

Maximum monthly mean temperature around 2ºC on December-January and minimum mean close to –7ºC on August were registered at Brown. At BelgranoII, the maximum monthly mean temperature was approximately –2ºC on December and the minimum mean close to –20ºC during June-August (following the behavior of SSE data, as there are no measurements during July). As a comparison, the measured winter mean temperatures during the subsequent period 1991-1998 at Halley (75.52ºS, 26.75ºW) and Neumayer

(70.62ºS, 8.37ºW) stations, on the southern coast of Weddell Sea near BelgranoII, were –28.4ºC and –23.4ºC, respectively (Birnbaum 2003). Surface temperature inversions are frequent in polar regions due to its cold surface temperatures, particularly in winter (Connolley 1996; Liu et al. 1998; Hudson and Brandt 2005), giving higher variability to the temperatures as can be observed in the larger dispersion of winter temperatures from figure 4 at both sites. Annually averaged temperatures from figure 2 data at Brown correlate qualitatively with the long-term database at Orcadas station (60.7ºS, 44.7ºW, see figure 1) for the same years (Wendler 2000). At BelgranoII, however, there are not enough observations to make an analysis of annual averages. Mean relative humidity was rather high and homogeneous at both sites, around approximately 80% at Brown and 70% at BelgranoII throughout the year. Brown station is located very close to the Antarctic Polar Circle and, as can be observed in figure 4, the daily irradiation is practically zero in June when the noon SZA reaches almost 90º. At BelgranoII, noon SZA larger than 90º produce zero daily irradiation levels in May, June and July. Absolute maximum daily irradiation of 35.4MJ/m^2 at both sites was registered, on December 6 1979 at Brown and on December 28 1983 at BelgranoII.

Figure 4 shows a maximum monthly mean daily irradiation almost constant at ~17MJ/m^2 during November, December and January at Brown. At BelgranoII, the maximum monthly mean daily irradiation is 27.4±5.4MJ/m^2 in December. A simple model calculation shows that the maximum of monthly mean clear-sky daily total irradiation at horizontal plane on the Earth's surface would be of the order of 35MJ/m^2 near summer solstice, with rather homogeneous values from the Tropic to the Pole in the summer hemisphere. In consequence it is interesting to note that, including the relatively large cloudiness percentage of the region (see the analysis of section 3.3), the measured mean daily irradiation in December at BelgranoII (27.4MJ/m^2) is within the highest world-wide reported values, as can be seen in the comparative table I. For practical applications of the summer solar radiation in the Weddell Sea zone, simple calculations based on an anisotropic sky diffuse radiation and Lambertian ground reflection model (Iqbal 1983) show that, for vertical plane collector, the daily irradiation following the sun with a suntracker device may be above twice the horizontal daily irradiation. So, irradiations above 50MJ/m^2 may be expected to collect in this case.

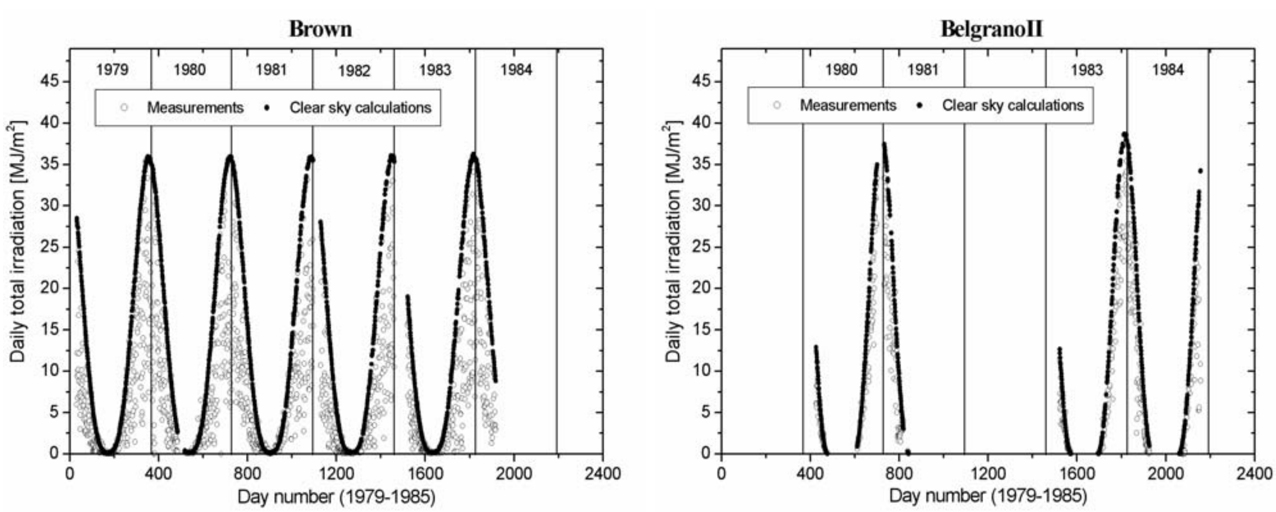

Figure 3. Measured and clear-sky modeled daily total irradiation at Almirante Brown (left) and BelgranoII (right) stations within the period 1979-1985.

In order to compare with other high-latitude sites, it is interesting to analyze as well the radiative environment of both stations in terms of the monthly mean total irradiance, calculated as the monthly mean daily irradiation over the monthly mean daylight time. Table II shows the monthly mean total irradiance on a horizontal plane during the year determined at Brown and BelgranoII from the present work, and at the South Pole for the period 1976-1987 (Dutton et al. 1991), for comparison. The monthly mean total irradiance for summer at the South Pole is even over 35% higher than at BelgranoII station. The main causes for this difference are the much higher altitude of South Pole station (2800m a.s.l.), the higher surface albedo at the South Pole which is completely surrounded by snow-covered surface, while Brown and BelgranoII are coastal stations, and the significantly less cloud cover percentage at the South Pole.

For example, SSE 10-year data indicate that at the South Pole there are, on average, 14 clear-sky days in December (cloud cover percentage <10%), against 0 days at Brown and BelgranoII. In comparison with Northern Hemisphere high latitudes, maximum average irradiance at all sites in Alaska from 54ºN to 71ºN is 285.55W/m^2 at Kotzebue station in June (Dissing and Wendler 1998). In turn, throughout the Arctic, only the high altitude Plateau in Greenland over 2800m a.s.l. presents extreme average irradiance of 340W/m^2 in June (Serreze et al. 1998). Then, comparison with values of table II indicate that summer irradiation levels over Antarctica are between 15 and 25% higher than the Arctic levels. Of course, part of this systematic difference is inherent to the approximately 7% higher extraterrestrial solar irradiance during the Southern Hemisphere summer solstice with respect to the Northern Hemisphere summer solstice, due to the eccentricity of the Earth's orbit (e.g. Liou 2002). In terms of the atmospheric conditions, an important asymmetry is found in the aerosols content, given the frequent incursions of polluted air reaching the Arctic from the industrial regions of the Northern Hemisphere, against the very low concentration of aerosols and pollutants in Antarctica (see Stanhill and Cohen 1997, and references therein). Calculations with the A-model show that, during the high pollution months with average AOD(500nm)~0.2 in the Arctic (Shahgedanova and Lamakin 2005), aerosols attenuate the total irradiance by about 5% with respect to the clean Antarctic values. This imply that a difference between 5 and 15%, depending on the place, higher irradiation levels in Antarctica with respect to the Arctic must be attributed to the sum of other factors like cloud cover and surface albedo.

3.2 Comparison with SSE database

Following the guidelines of Whitlock et al. (2000), the comparison between SSE database and ground measurements is referred to the differences in the monthly mean values. For this purpose, SSE grid points closest to the geographic position of the stations were used. Furthermore, the comparison takes into account three important aspects: a) SSE and ground data are not simultaneous and have a different extension, b) the SSE pixel resolution of 1º by 1º represents a spatial average against the locality of ground measurements (as an example, surface elevation at Brown station is 10m while average elevation of the corresponding SSE pixel is 500 m. On the other hand, elevation at BelgranoII station is 250m while average elevation of the SSE pixel is 124 m), and c) when the uncertainty in SSE data is also considered, their values in general overlap the measurements at Brown and BelgranoII.

From figure 4, it can be seen that SSE temperature generally underestimates the measured values at both places, in coincidence with general results (Whitlock et al. 2000). Mean bias in temperature are (–4.1±1.9)ºC at Brown and (–4.8±3.6)ºC at BelgranoII. Note that smaller differences were observed in spring, with excellent agreement at BelgranoII. Surface temperature inversions, and the high surface albedo, make difficult the estimate of shortwave and longwave radiation on the surface

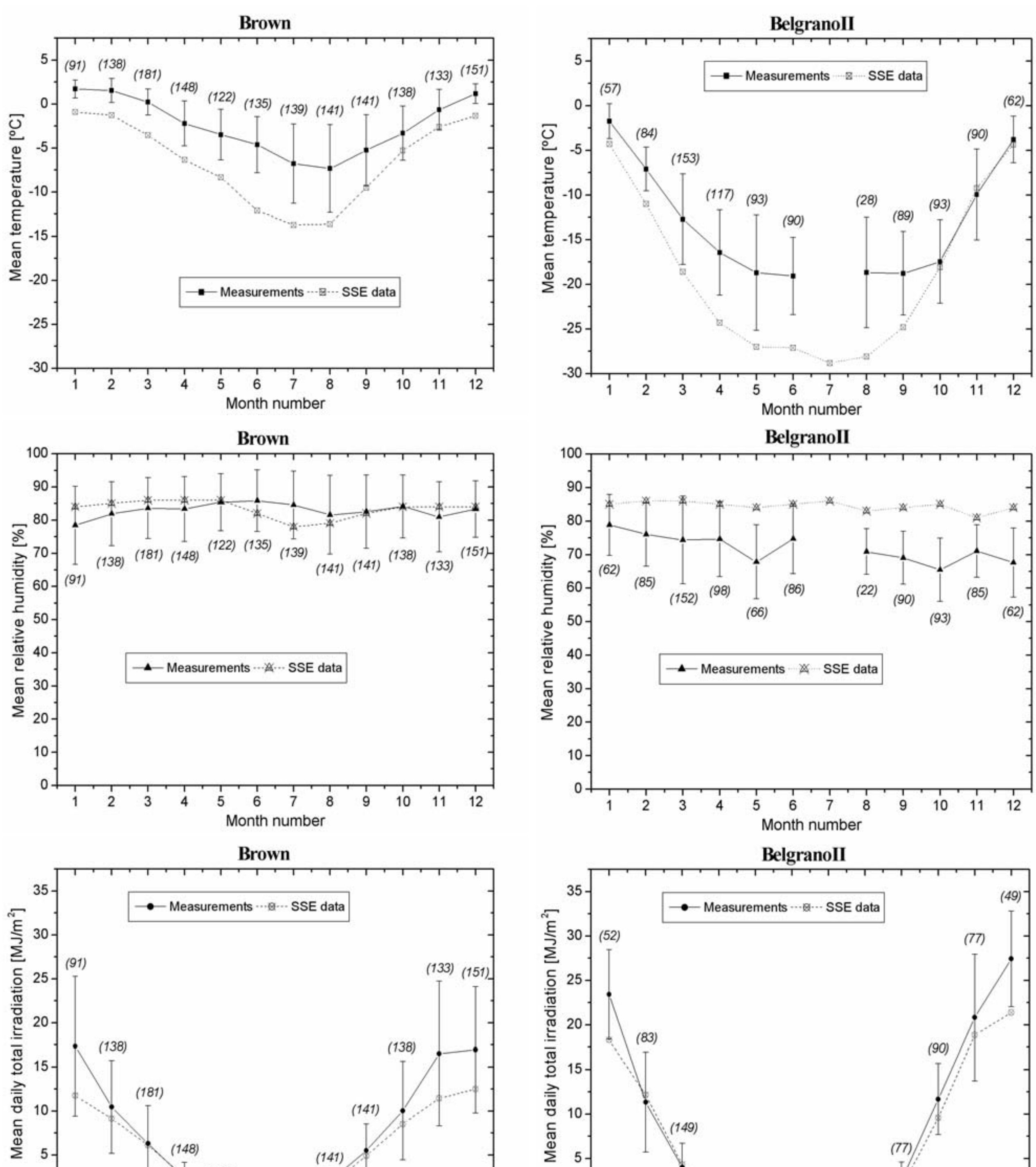

Figure 4. Monthly means of daily temperature (top), relative humidity (middle), and daily total irradiation (bottom) from local measurements and SSE database at Almirante Brown (left) and BelgranoII (right) stations. Bars indicate the variability of ground-measured parameters at one standard deviation level. In parenthesis, the number of available data used for the average on each month is detailed.

Table I. Comparison of average daily irradiation in December at BelgranoII with the maximum monthly average irradiation reported world-wide.

Location	Maximum monthly average daily irradiation [MJ/m^2]	Reference
South Pole	~37.5	Dutton et al. 1991
Jordan network	~31	Durisch et al. 1995
Egypt network	27.6	Omran 2000
BelgranoII	27.4	This work
Argentine Andean Plateau	~27	Grossi Gallegos 1998
Oman network	26.8	Al-Hinai and Al-Alawi 1995
Carpentras (France, 44ºN)	26.7	Iqbal 1983
Turkey network	26.6	Sen and Sahin 2001
Resolute (Canada, 75ºN)	25.1	Iqbal 1983
Brasil network	~25	Tiba et al. 2000
Montreal (Canada, 45ºN)	21.2	Iqbal 1983
Trappes (France, 49ºN)	20	Iqbal 1983
Bergen (Norway, 60ºN)	17	Iqbal 1983

Table II. Monthly mean total irradiance at Almirante Brown and BelgranoII stations during the year, for the period 1979-1985. Mean values at South Pole (2800m a.s.l.) for the period 1976-1987 are also presented for comparison.

	Mean total irradiance [W/m^2]		
Month	Brown	BelgranoII	South Pole [(a)]
1	257	271	373
2	188	144	203
3	146	88	40
4	76	28	0
5	39	0	0
6	19	0	0
7	34	0	0
8	75	9	0
9	143	72	19
10	197	177	132
11	261	241	335
12	234	317	434

[(a)] From Dutton et al. (1991)

from satellite measurements (see e.g. Liu et al. 1998), increasing the uncertainty in the estimated surface temperature. Then, it must be taken into account that SSE temperature uncertainty ranges from about 1.1% above –10ºC to 3.2% near –30ºC (Whitlock et al. 2000). SSE relative humidity values, whose global relative uncertainty is about 15% (Whitlock et al. 2000), agree quite well with the measurements at Brown, showing an absolute bias of only (0.4±3.4)%, although at BelgranoII SSE overestimates the measurements by an absolute bias of (12.5±3.8)%, i.e., somewhat larger than general results given by Whitlock et al. (2000). A rough correction of SSE temperature and relative humidity due to the altitude effect mentioned in point (b) can be made if, for example, the Antarctic summer vertical profiles for 75ºS measured by Tomasi et al. (2004) are considered valid for both stations. Then, SSE summer temperatures at Brown must be increased by about 3ºC giving a better agreement with ground measurements. In turn, SSE summer temperatures at BelgranoII must be diminished by about 1ºC and differences with ground measurements increases slightly. Correction of relative humidity with the altitude is less evident, due to its larger variability.

Monthly mean of daily total irradiation was rather well represented by SSE from February to April for both sites, within relative differences of ~10%, but for the rest of the year it underestimates the measured values by about 20%, on average. This may be due to an overestimation of the cloud cover percentage at polar regions as determined by the satellite instrument (like in the ultraviolet range, see e.g. Herman et al. 1999), to an overestimation of the clouds optical depth, or even to an underestimation of the multiple reflection of the irradiance between the high-albedo surface and the clouds base. This result seems also to be restricted to polar regions. Indeed, validation against measurements primarily made at low and mid-latitudes sites yield, on the contrary, a typical overestimation of SSE daily total irradiation with respect to the ground truth (Whitlock et al. 2000). It is important to note that the relative uncertainty in the SSE-estimated irradiation from non-polar sites is of about 14%, with an additional factor of uncertainty for coastal sites (as is the case of Brown and BelgranoII stations) where the cloud detection is more difficult from space (Whitlock et al. 2000).

3.3 Effect of clouds on total radiation

From the daily data shown in figure 3, the ratio of measured over clear-sky modeled daily irradiation, i.e. the effective cloud transmittance t at both stations for the whole period was determined. It is shown in figure 5. Monthly means of t together with the SSE cloud cover percentage data (expressed as a fraction) at both stations are also shown in figure 5. Days with noon SZA<75º were selected to make the results comparable, avoiding data which may be completely affected by the shadows of surrounding mountains, and the less efficient cosine response of the instruments at large SZA. Values different from t=1 can be attributed essentially to the effects of clouds and, eventually, fog which is also frequent in Antarctica. Mean values of t are 0.49±0.25 at Brown and 0.71±0.20 at BelgranoII.

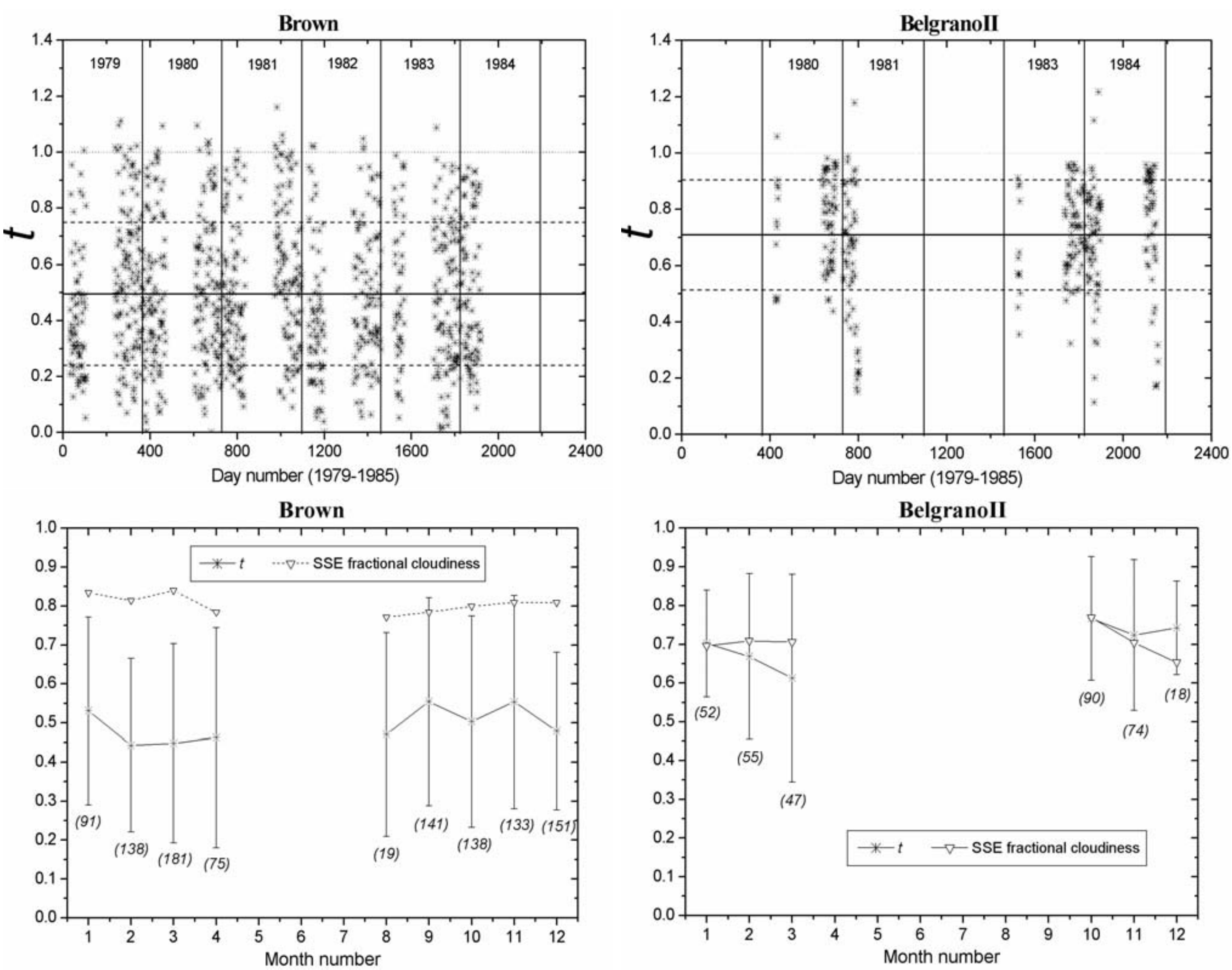

Figure 5. Effective cloud transmittance (t) at Almirante Brown (left) and BelgranoII (right) stations, for days with noon SZA<75º within the period 1979-1985 (top), and monthly means of t together with the SSE data of cloud cover percentage, expressed as fraction (bottom). Bars indicate the variability at one standard deviation level. In parenthesis, the number of available data used for the average on each month is detailed.

While the database is more extensive at Brown (1067 points) than at BelgranoII (336 points), monthly means of *t* nevertheless show no substantial dependence on the season at both stations, showing that cloudiness attenuates around 22% more the solar radiation at Brown than at BelgranoII, during the year. As pointed out by Birnbaum (2003), the Antarctic Peninsula acts as a pronounced topographic barrier for the cyclones moving north-eastwards from the Bellingshausen Sea, favoring the formation of cloudiness with high precipitation rate on the West of Antarctic Peninsula where Brown station is located. On the other hand, the reduced cyclonic activity in the southern Weddell Sea and the smooth topographic transition from the ocean to the land result in less cloud formation and precipitation in the region where BelgranoII is placed (Birnbaum 2003). Furthermore, the higher precipitation rate over the West of Antarctic Peninsula indicates that cloudiness is optically thicker at Brown. Parameters from SSE database agree with the analysis above: the larger cloud cover percentage at Brown than at BelgranoII (figure 5, bottom) and the annual average total column of precipitable water which is 0.63 cm at Brown and 0.33 cm at BelgranoII. The larger cloud cover percentage and its higher optical thickness result in the stronger attenuation of solar radiation at Brown with respect to BelgranoII. Stanhill and Cohen (1997) found a linear trend of $-0.28 W/m^2/yr$ in the total radiation in Antarctica from a complete study at 12 stations in the period 1956-1994, which is not possible to analyze in this case due to the much shorter databases of our sites. Some days presented a marked increase in the daily irradiation, over 20% than that expected for clear-sky conditions. Such days correspond generally to conditions of broken cloud fields, amplifying the irradiance at ground by direct reflections from the clouds and multiple reflections between clouds and ground, a phenomenon which becomes particularly intense in conditions of large SZA and high surface albedo, typical of polar regions (Liu et al. 1998). This confirms the fact that the enhancing of irradiance under those conditions can span large time intervals, even up to hours (e.g. Cede et al. 2002).

4. CONCLUSIONS

The analysis of measured temperature, relative humidity and daily total solar irradiation within the period 1979-1985 at the Antarctic stations Almirante Brown and BelgranoII has been presented.

Conclusions from the short-term monthly characterization of parameters at both stations are:

- The first comparison of SSE/NASA satellite database with Antarctic measurements was made. SSE generally underestimates temperature at both places, with differences increasing from summer to winter and a mean bias of about –4ºC. SSE relative humidity agreed with measured values at Brown, while it overestimates the measurements at BelgranoII by a mean absolute bias of 12.5%. SSE data of daily total irradiation underestimates in general the measured values by about 20%, with smaller differences in autumn when the agreement is reasonable. Differences indicate that validation against other reliable measurements at polar regions is essential to improve the precision of the SSE satellite-derived parameters.
- The monthly mean daily irradiation of $27.4 MJ/m^2$ in December at BelgranoII is within the highest reported world-wide. The use of flat vertical collectors on suntracker devices may increase the received irradiation in the Weddell Sea region to above $50 MJ/m^2$.
- Summer average daily irradiation at the South Pole (from Dutton et al. 1991) is even over 35% higher than at BelgranoII, so that potential for practical applications is still much important. Main causes are the elevated altitude, high surface albedo and less cloud percentage at the South Pole.
- Summer average daily irradiation at Brown, BelgranoII and at the South Pole is between 15 and 25% higher than at equivalent regions in the Arctic. 7% of this difference is due to the Earth-Sun distance, and about 5% to the polluted aerosol incursions over the Arctic. Clouds and surface albedo are the main factors to explain the remaining difference.

A parametric radiative transfer model, where temperature and relative humidity enter as input variables, was used to estimate the equivalent clear-sky daily irradiation for each day in the sample. The effect of clouds was studied through the ratio of measured over clear-sky modeled daily irradiation, i.e. the effective cloud percentage transmittance *t*. We conclude that:

- In accordance with the very different climate conditions on both sides of Antarctic Peninsula, the attenuation by clouds was stronger at Brown, where *t*=0.49, while *t*=0.71 was registered at BelgranoII. No substantial dependence on the season was noted, at both sites.
- Summer monthly mean daily irradiation of only 17MJ/m^2 registered at Brown, in contrast with the 27.4MJ/m^2 at BelgranoII, is a consequence of the mentioned smaller cloud transmittance.
- Enhancing of daily irradiation over 20% of the expected clear-sky value was observed at both stations, associated to the effect of broken cloud fields. This is an important result, as there are very few reports of this effect lasting long time intervals.

Results of the present study extend the knowledge of the Antarctic radiative and meteorological environments. They give new insights to calibrate and validate satellite databases at polar regions and they also encourage evaluation of the possible practical applications of solar energy in view of the high daily irradiation values reached in some Antarctic regions in summer.

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