Quality Control and Corrections of the Radiation Measurements at the BUBBLE-Surface Sites

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Radiation measurements at the urban site „Basel-Spalenring“

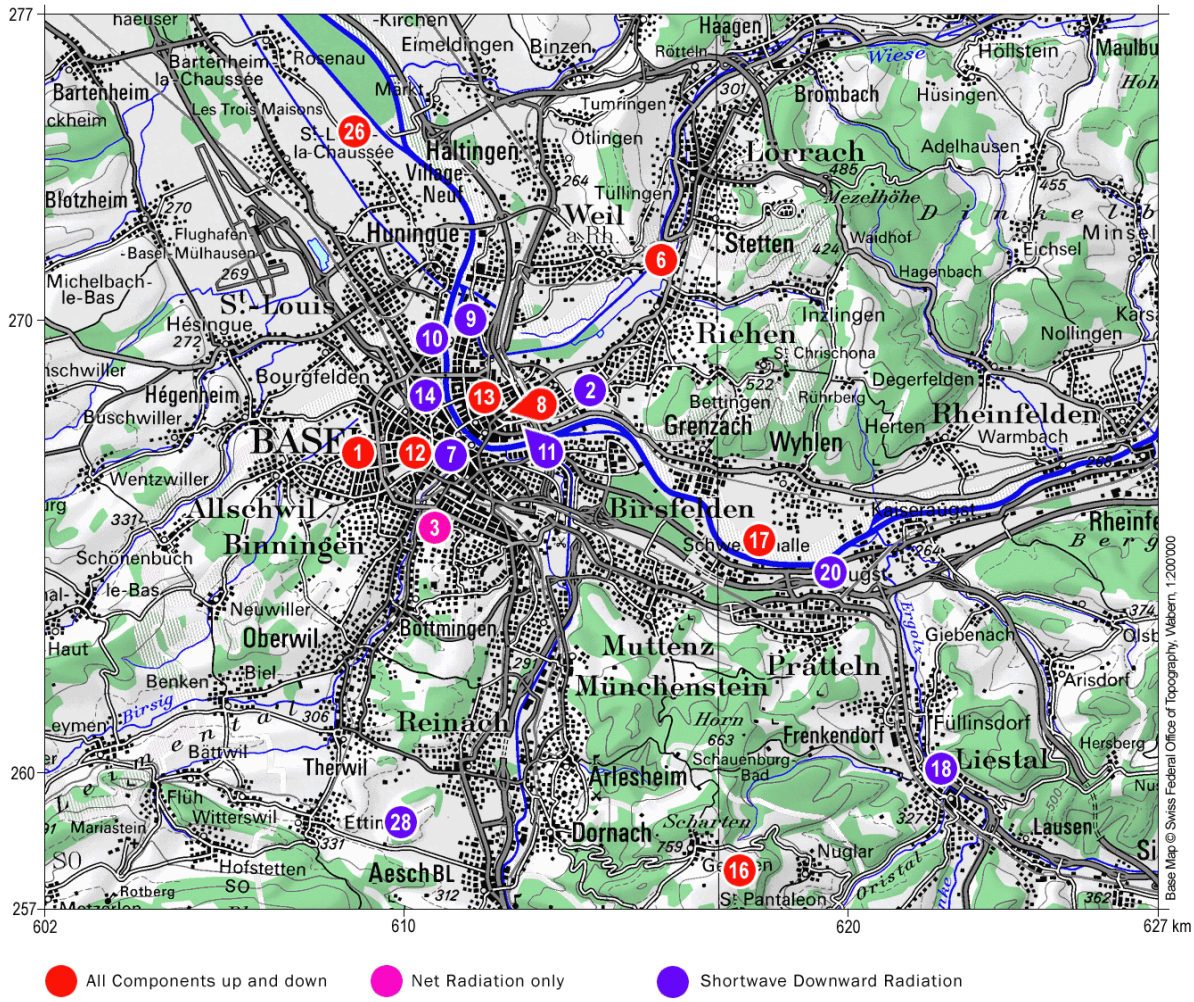
1. Motivation

During the Basel Urban Boundary Layer Experiment (BUBBLE) eight micrometeorological surface energy balance sites were operated inside and around the city of Basel. Additionally, a number of operational and experimental meteorological surface sites provided measurements of shortwave downward radiation R_{sd}. All energy balance sites were equipped with pyranometers and pyrgeometers to measure all 4 components of the radiation balance:

$$R_n = R_{sd} - R_{su} + R_{ld} - R_{lu}$$

It is of great importance to determine the instrumental errors and to have a general quality control of the radiation data. Therefore, the data-checks and the corrections are documented in this report.

Fig. 1: Map of all surface sites with at least one component of the radiation balance measured during the BUBBLE IOP (June/July 2002). See Tab. 1 for numbers. Base map: © Swiss Federal Office of Topography, Wabern.



Tab. 1: Surface sites which provided radiation measurements during the BUBBLE IOP (June/July 2002).

No	Code	Site Name	Location (SLK)	H	Data Provider(s)	Radiation Measurements
28	AESH	Aesch Schlatthof	610375 / 258775	353	LHA	R_{sd}
1	ALLS	Allschwil *	609250 / 267180	277	Uni Basel	R_{sd}, R_{su}, R_{ld}, R_{lu}
2	BBHF	Basel - Bäumlihof	614130 / 268540	289	Gymnasium Bäumlihof	R_{sd}
3	BBIN	Basel - Binningen	610850 / 265620	316	MeteoSwiss, Uni Basel	R_{sd}, R_n, UVB
6	BLER	Basel - Lange Erlen *	615835 / 271310	275	Uni Basel	R_{sd}, R_{su}, R_{ld}, R_{lu}
6	BLEO	Basel - Leonhard	611200 / 267055	273	Gymnasium Leonhard	R_{sd}
9	BKLY	Basel - Novartis Klybeck	612000 / 270125	255	Novartis	R_{sd}
8	BMES	Basel – Messe *	612200 / 268070	282	TU Dresden	R_{sd}, R_{su}, R_{ld}, R_{lu}
10	BNSJ	Basel - Novartis St. Johann	610840 / 269775	257	Novartis	R_{sd}
11	BROC	Basel - Roche	612775 / 267750	255	Roche	R_{sd}
12	BSPA	Basel - Spalenring *	610360 / 267140	294	Uni Basel	R_{sd}, R_{su}, R_{ld}, R_{lu}
13	BSPR	Basel - Sperrstrasse *	611890 / 268365	255	Uni Basel	R_{sd} (2), R_{su} (2), R_{ld} (2), R_{lu} (2)
14	BSTJ	Basel - St. Johann	610750 / 268375	260	LHA	R_{sd}
16	GEMP	Gempen *	617640 / 257965	710	Uni Basel	R_{sd}, R_{su}, R_{ld}, R_{lu}
17	GRNZ	Grenzach *	617830 / 265130	265	Uni Basel	R_{sd} (2), R_{su} (2), R_{ld}, R_{lu}
18	LIES	Liestal LHA	621800 / 259950	320	LHA	R_{sd}
20	PRAT	Pratteln Hardwasser	619625 / 264500	272	LHA	R_{sd}
26	VLNF	Village Neuf *	608940 / 274240	240	Uni Basel	R_{sd} (2), R_{su} (2), R_{ld}, R_{lu}

* Energy balance sites.

Tab. 2: The different instrument types involved in BUBBLE:

No.	Type	Manufacturer	Type	Sites (see Tab. 1)
6	CNR1	Kipp & Zonen	Net Radiometer with 4 components: 2 Pyrgeometer, 2 Pyranometer	1, 6, 8, 13 (31.7m), 16, 26
10	CM11	Kipp & Zonen	Pyranometer	7, 12, 13 (3.2m) 17, 26
1	CM6B	Kipp & Zonen	Pyranometer	2
4	PIR	Eppely	Pyrgeometer	12,17
1	CG2	Kipp & Zonen	Pyrgeometer with 2 components	13 (3.2m)
6	*Others*		Pyranometers	9, 10, 11, 14, 20, 28
1	*Others*		Net Radiometer	3

2. Shortwave Downward Radiation (R_{sd})

The intercomparison between BUBBLE-sites that is shown in this section is based on the assumption that - in a "climatological" mean - all sites measure the same R_{sd}, regardless of topographic height (Range 240-353 m a. s. l.) and regardless of shading due to buildings and structures. The site „Gempen" was excluded from the intercomparison because it is situated on a mountain plateau (710 m a. s. l.).

The intercomparison of R_{sd} includes 10min-data between April 15 and July 15 2002. However, at some sites there are only data available in the period from June 1 to July 15 2002 and at "Basel-Messe" even less (June 24 to July 10 2002). The measurement at „Basel – Spalenring" was selected as reference for R_{sd} (instrument CM11 923942). All data from all situations were compared, including rainy and overcast days. This leads to a higher scatter between the sites than by just taking clear sky days into account, particularly during situations with scattered clouds, but should not have a significant impact on climatological mean and median values on this small domain (20 x 20 km).

2.1. Kipp & Zonen CNR1

Fig. 2: Field calibration of the BUBBLE instruments in Southern Italy ("Bari 02")

The CNR1 instruments operated at the energy balance sites were intercompared side-by-side during a field experiment in July 2002 in Southern Italy („Bari 02"), just after the BUBBLE experiment ended. There, the CNR1 were compared to a high-end Kipp & Zonen CM21 (Pyranometer) and an Eppley PIR (Pyrgeometer) which were both recently calibrated by the World Radiation Centre (WRC), Davos, Switzerland. The resulting calibration factors derived from this weeklong intercomparison / calibration confirmed that R_{sd} measured by CNR1 is generally underestimated by 2%. The instruments from the sites „Basel - Lange Erlen" and „Gempen" were not involved in this field calibration, nevertheless the number of four CNR1 indicate that the underestimation by 2% is an instrumental problem. The underestimation was observed systematically and significantly with all four CNR1. The two sites that were not involved in the "Bari 02"- calibration were therefore corrected with so called "generic factors". Generic factors represent the manufacturer a_1 multiplied by 1.0195, which is a mean value of the four other instruments.

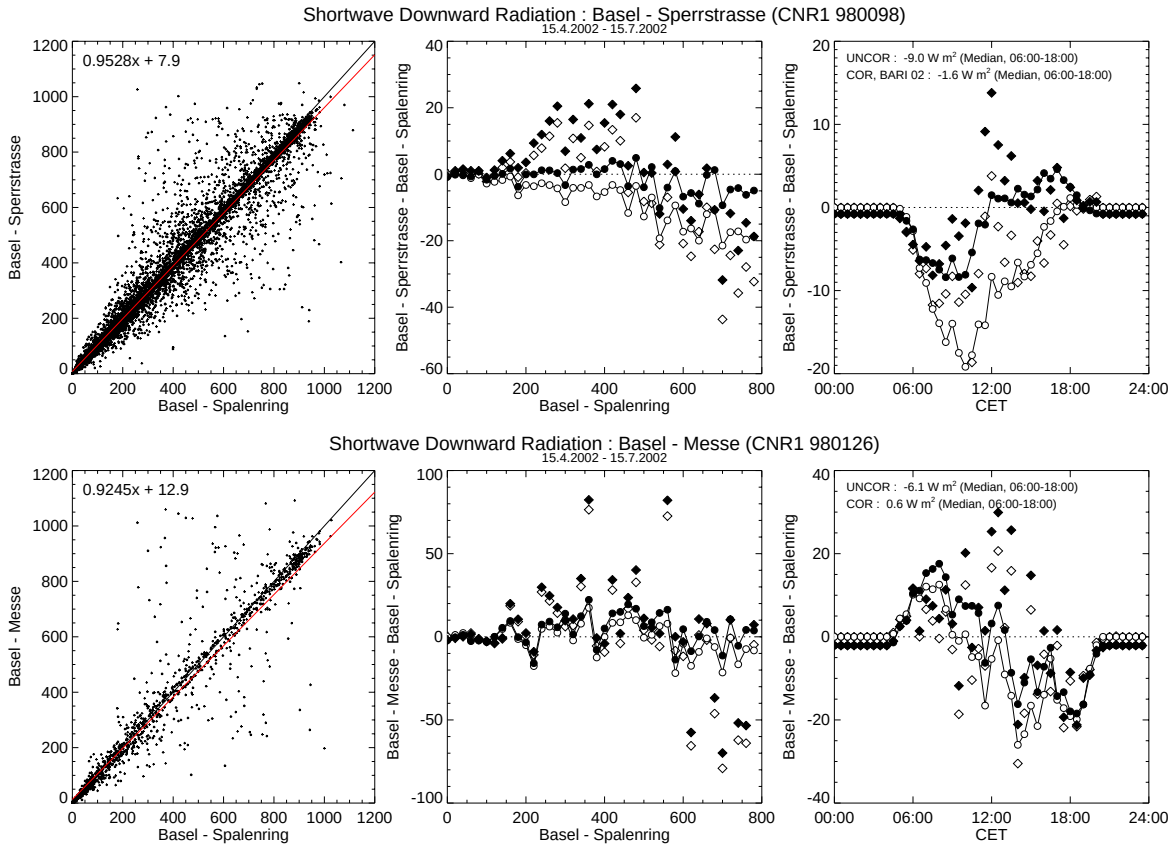
The CNR1-calibration for R_{sd} is linear:

R_{sd} (W m^{-2}) = $a_0 + a_1 \cdot$ *Signal* (mV)

Tab. 3: Calibration factors for R_{sd} of the CNR1:

Site	**Instrument**	**Manufact. Calibration**	**„Bari 02" -Calibration**
Basel – Sperrstrasse (31m)	CNR1 980098	a_1 = 112.74	a_1 = 114.88, a_0 = -0.8
Basel - Messe	CNR1 980126	a_1 = 85.47	a_1 = 87.01, a_0 = -2.1
Allschwil - Rämelstrasse	CNR1 010285	a_1 = 103.84	a_1 = 105.82, a_0 = -1.9
Village Neuf	CNR1 020419	a_1 = 133.33	a_1 = 136.27, a_0 = -1.4
Basel - Lange Erlen	CNR1 980080	a_1 = 102.56	a_1 = 104.56, a_0 = 0 *
Gempen	CNR1 980142	a_1 = 91.66	a_1 = 93.45, a_0 = 0 *

* Generic corrections were applied: a_1(corrected) = a_1(manufacturer) · 1.0195, a_0 = 0



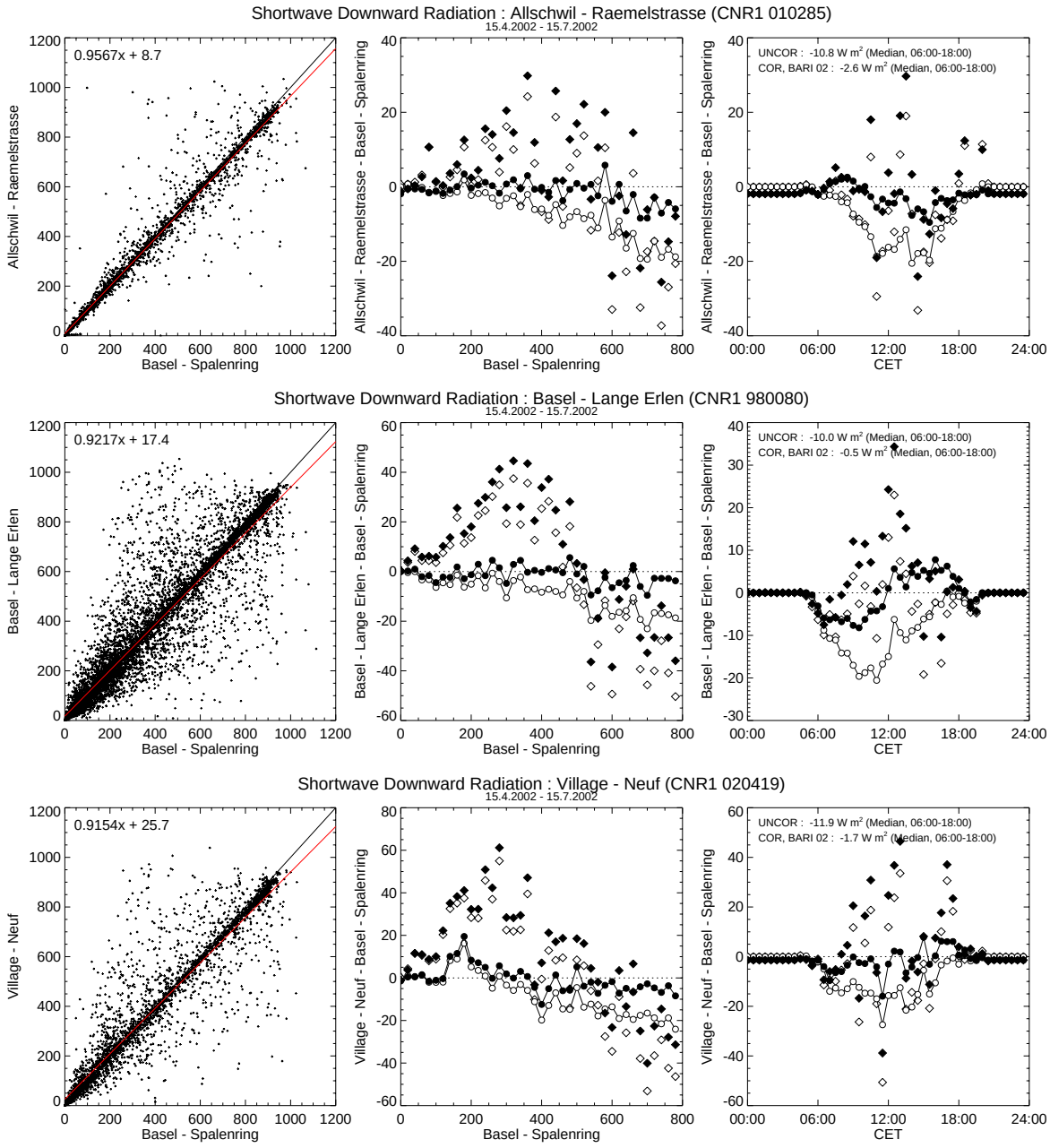


Fig 4: Left plots: R_{sd} at "Basel-Spalenring" compared to R_{sd} at the selected site with manufacturer calibrated sensors (includes all data). **Central** plots: Difference between the values measured at the selected site and the reference vs. magnitude of R_{sd} in 20 W m^{-2} classes. Circles show the median of the 20 W m^{-2} classes, diamonds indicate the mean values. **Right** plots: Diurnal course of the difference, in 30 min classes. Analogous circles show the median and the diamonds the mean. In the central and right plot the manufacturer calibrations are drawn with open (white) symbols, the values with the "Bari 02" calibration are drawn with filled (black) symbols.

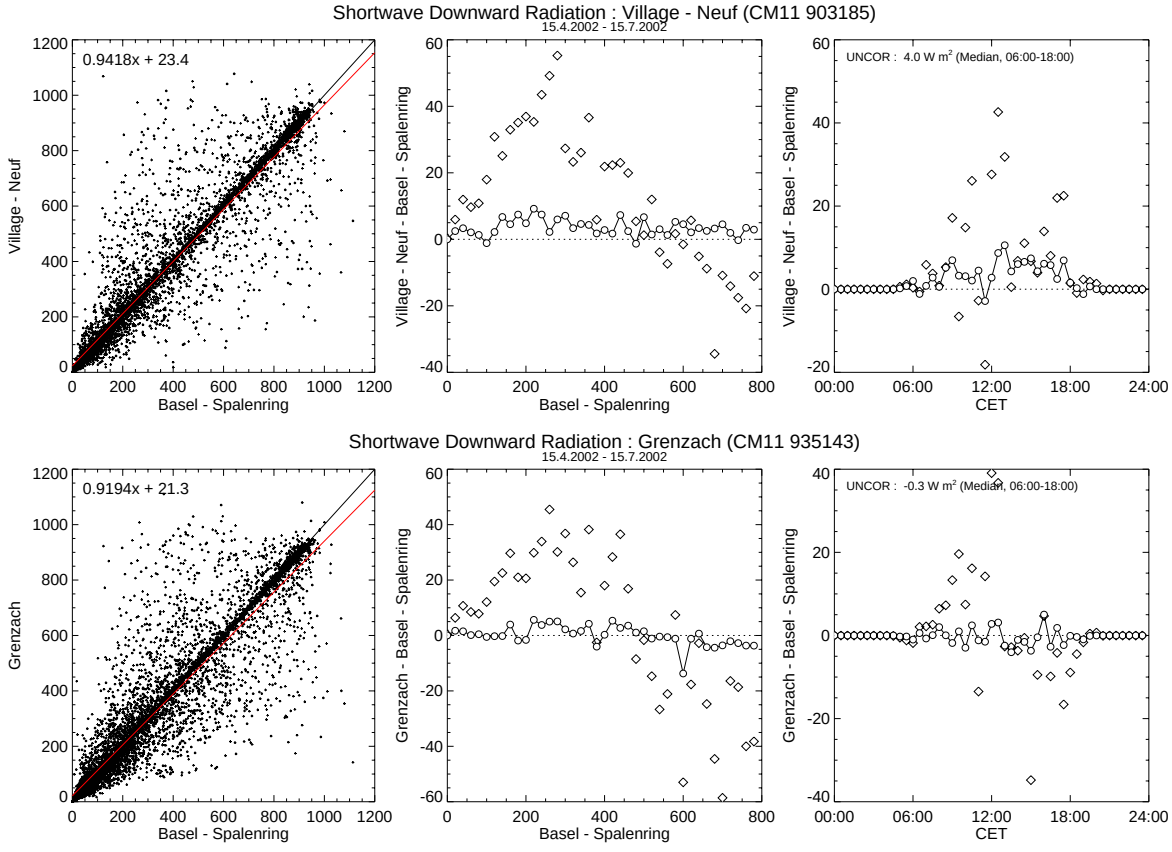
Tab. 4: Effects of the „Bari 02"-calibration on daytime median-values of the difference "Site minus Basel - Spalenring" (not corrected) for 06:00 to 18:00 CET.

Site	**Instrument**	Median Difference with **Manufact. Calibration**	Median Difference with **„Bari 02" Calibration**
Basel – Sperrstrasse (31m)	CNR1 980098	-9.0 W m^{-2}	-1.6 W m^{-2}
Basel - Messe	CNR1 980126	-6.1 W m^{-2}	+0.6 W m^{-2}
Allschwil - Rämelstrasse	CNR1 010285	-10.8 W m^{-2}	-2.6 W m^{-2}
Village Neuf	CNR1 020419	-11.9 W m^{-2}	-1.7 W m^{-2}
Basel - Lange Erlen	CNR1 980080	-10.0 W m^{-2}	-0.5 W m^{-2}

Conclusion: Applying the manufacturer calibration to the CNR1 leads to an underestimation of R_{sd} by 2% relative to the reference (CM11 / CM21). The „Bari 02"-factors lead to a better correlation between the sites and to the reference, i.e. the „Bari 02" correction improves the values. Therefore, the "Bari 02"-correction was applied to all CNR1 in the BUBBLE-database.

The instruments at „Basel-Sperrstrasse" and at "Basel-Messe" show both a diurnal course. That implies that the sensor was not mounted exactly horizontal.

2.2. CM11 und CM6B



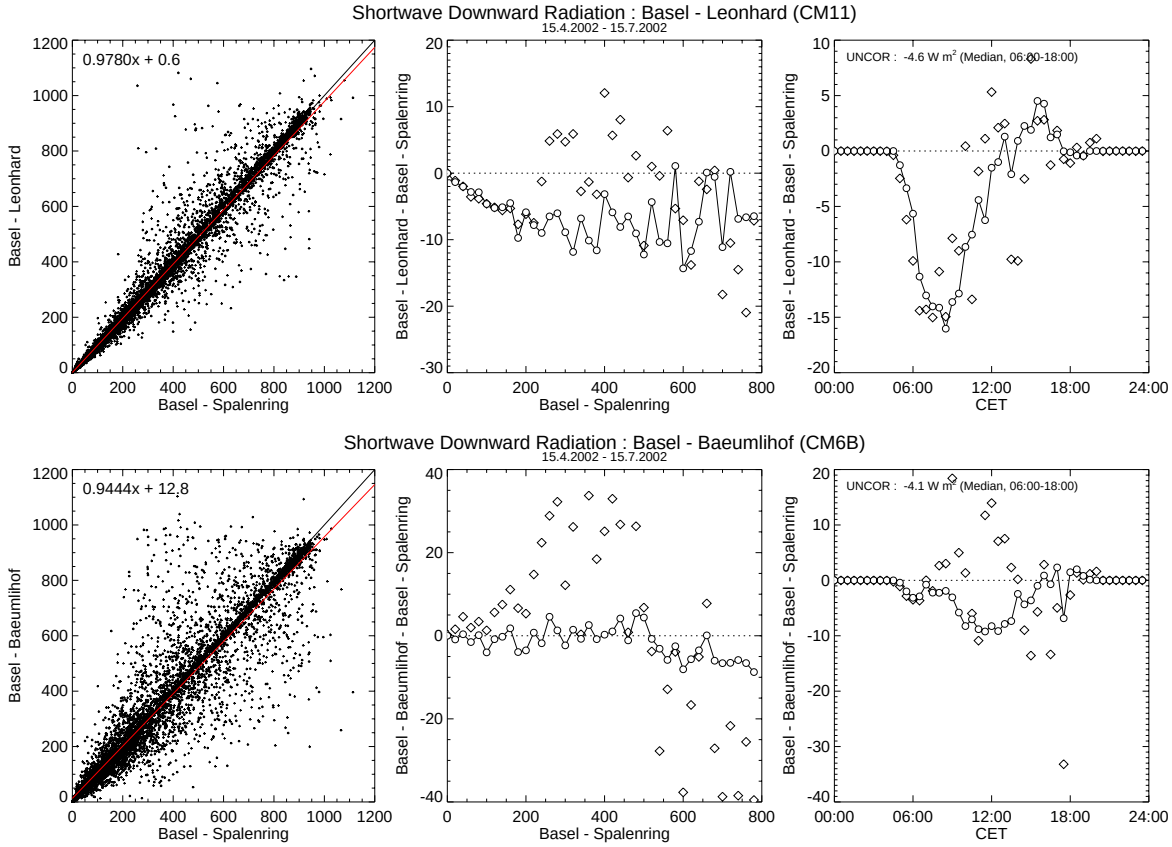
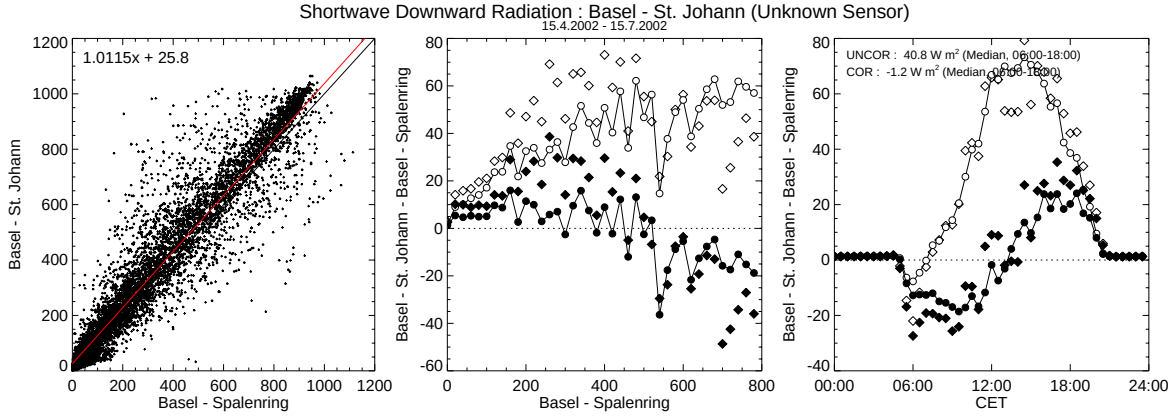


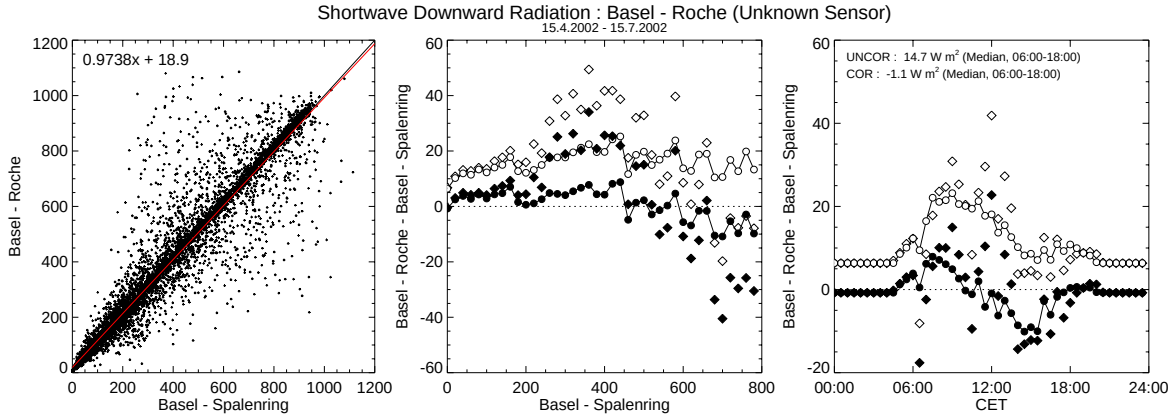
Fig 5: Left plots: R_{sd} at "Basel-Spalenring" compared to R_{sd} at the selected site with manufacturer calibrated sensors (includes all data). **Central** plots: Difference between the values measured at the selected site and the reference vs. magnitude of R_{sd} in 20 W m^{-2} classes. **Right** plots: Diurnal course of the difference, in 30 min classes. Circles show the median and the diamonds the mean.

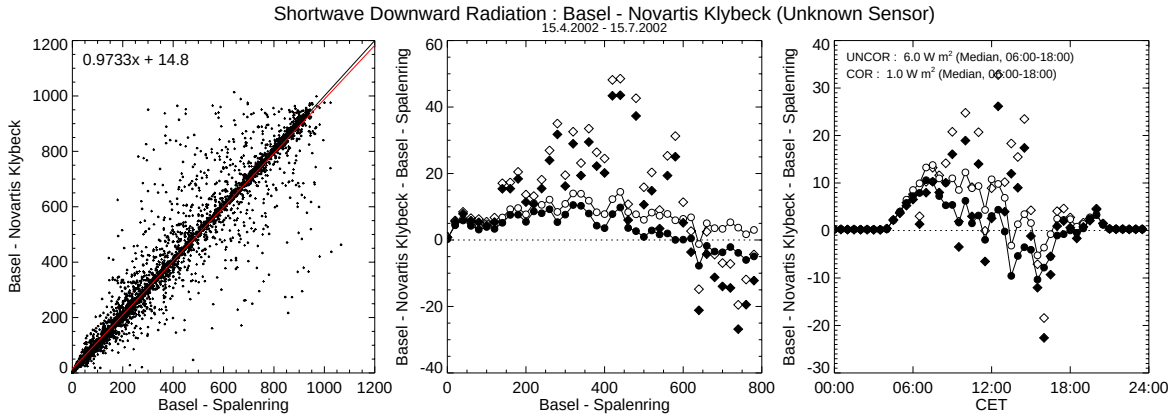
Conclusion: CM11 and CM6B-Instruments agree reasonably by just using the manufacturer calibration (e.g. „Grenzach" vs. „Basel-Spalenring"), so no additional calibration was applied.

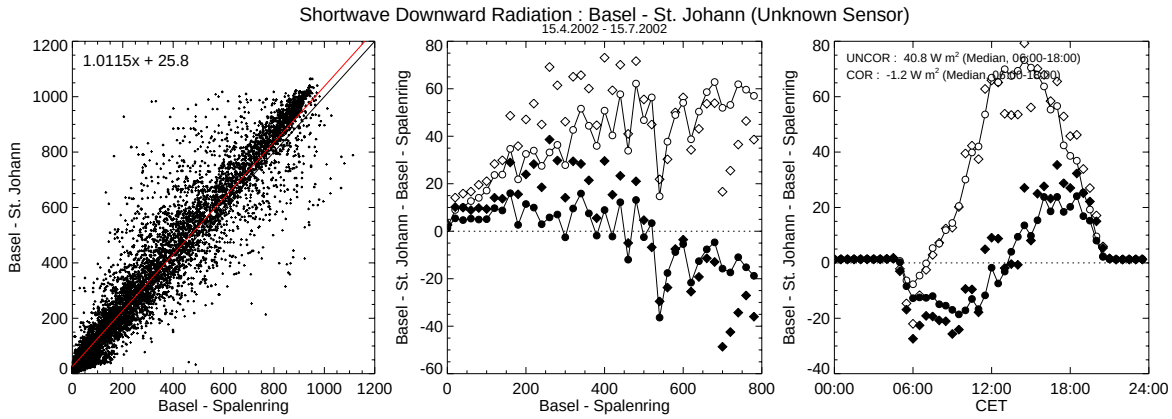
2.3. External Surface Sites

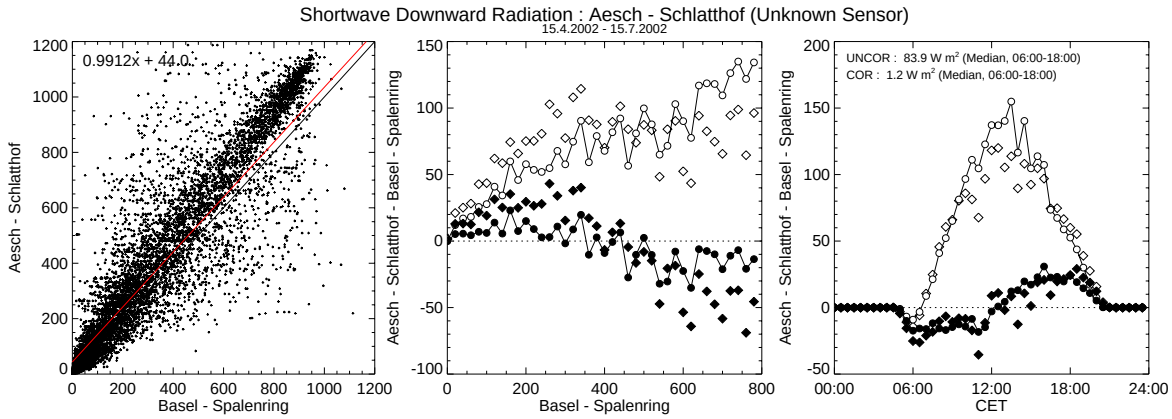
These sites are operated and provided by the chemical industry (Roche, Novartis) and LHA.




Shortwave Downward Radiation : Basel - Roche (Unknown Sensor)
15.4.2002 - 15.7.2002
0.9738x + 18.9
Basel - Roche
Basel - Spalenring
Basel - Roche - Basel - Spalenring
UNCOR : 14.7 W m² (Median, 06:00-18:00)
COR : -1.1 W m² (Median, 06:00-18:00)
CET


Shortwave Downward Radiation : Basel - Novartis Klybeck (Unknown Sensor)
15.4.2002 - 15.7.2002
0.9733x + 14.8
Basel - Novartis Klybeck
Basel - Spalenring
Basel - Novartis Klybeck - Basel - Spalenring
UNCOR : 6.0 W m² (Median, 06:00-18:00)
COR : 1.0 W m² (Median, 06:00-18:00)
CET


Shortwave Downward Radiation : Basel - St. Johann (Unknown Sensor)
15.4.2002 - 15.7.2002
1.0115x + 25.8
Basel - St. Johann
Basel - Spalenring
Basel - St. Johann - Basel - Spalenring
UNCOR : 40.8 W m² (Median, 06:00-18:00)
COR : -1.2 W m² (Median, 06:00-18:00)
CET


Shortwave Downward Radiation : Aesch - Schlatthof (Unknown Sensor)
15.4.2002 - 15.7.2002
0.9912x + 44.0
Aesch - Schlatthof
Basel - Spalenring
Aesch - Schlatthof - Basel - Spalenring
UNCOR : 83.9 W m² (Median, 06:00-18:00)
COR : 1.2 W m² (Median, 06:00-18:00)
CET

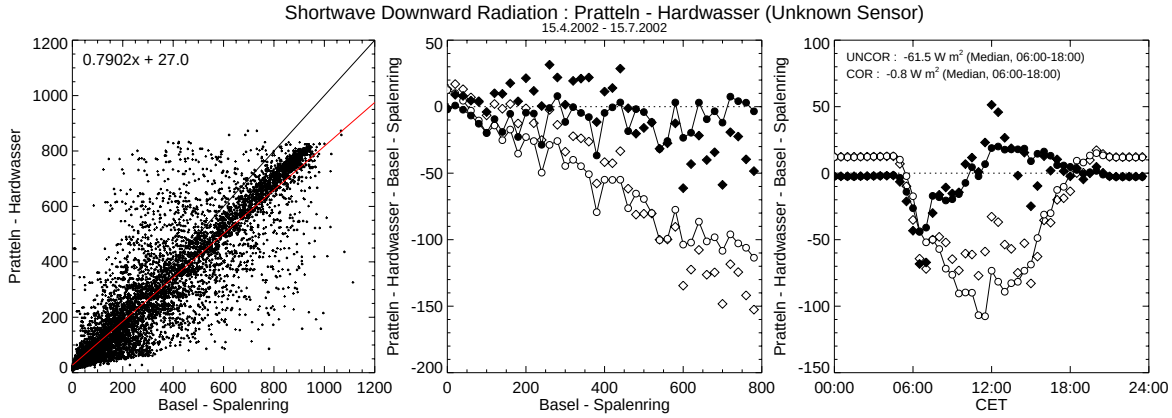


Fig 6: Left plots: R_{sd} at "Basel-Spalenring" compared to R_{sd} at the selected site with the provided data. **Central** plots: Difference between the values measured at the selected site and the reference vs. magnitude of R_{sd} in 20 W m^{-2} classes. **Right** plots: Diurnal course of the difference, in 30 min classes. Circles show the median and the diamonds the mean. In the central and right plot the provided data are drawn with open (white) symbols, the corrected data with empirical factors from Tab 5. are drawn with filled (black) symbols.

Tab. 5: Correction of R_{sd} at the external sites.

Site	**Correction factors** applied to the already calibrated and provided data.	**Median-difference** to the reference with correction factors
Basel - St. Johann	$a1$ = 0.91, $a0$ = 0	-1.2 W m^{-2}
Basel – Roche	$a1$ = 0.98, $a0$ = -7	-1.1 W m^{-2}
Basel – Novartis Klybeck	$a1$ = 0.99, $a0$ = 0	1.0 W m^{-2}
Basel – Novartis St. Johann	$a1$ = 0.97, $a0$ = -8	-0.5 W m^{-2}
Aesch - Schlatthof	$a1$ = 0.84, $a0$ = 0	1.2 W m^{-2}
Pratteln - Hardwasser	$a1$ = 1.19, $a0$ = -17	-0.8 W m^{-2}

Conlusions: The external data show larger under- and overestimations e.g. „Basel - St. Johann" overestimates by 10%, „Aesch-Schlatthof" by 15%. „Pratteln - Hardwasser" underestimates by 15%. The measurements in the BUBBLE database were corrected to fit the reference.

Most of the instruments from the external sites show asymmetric diurnal courses, again an indication, that the instruments are not aligned to the horizontal plane: „Basel-Roche", „Basel – Novartis Klybeck" and also slightly „Basel –St. Johann". At the site „Basel - Novartis St. Johann" shading effects due to the nearby buildings affect the data during morning and afternoon hours. Data from the external sites are not suited for energy balance and micrometeorological measurement, they are more indicators for irradiance. Note that only R_{sd} was measured at the external sites.

3. Shortwave Upward Radiation (R_{su})

Because of the different surface properties at the sites, R_{su} cannot be checked by using the BUBBLE-data itself. Even in the field calibration it was difficult to get a homogeneous surface. No additional correction was applied to R_{su} and the manufacturer calibration factors were used for the database. However, due to the low albedo values, the calibration of R_{su} has not a significant influence on the radiation balance.

Tab. 6: Mean albedo at the energy balance sites.

Site	**Surface**	**Mean Albedo** (April 15 –July 15 2002)
Basel – Sperrstrasse (31m)	Urban	11.0%
Basel - Spalenring	Urban	11.2%
Allschwil - Rämelstrasse	Suburban	13.2%
Basel – Messe	Urban, parking lot (concrete)	32.7%
Village Neuf	Rural, bare soil	19.2%
Basel - Lange Erlen	Rural, grassland	21.4%
Grenzach	Rural, grassland	22.2%
Gempen	Rural, agriculture	18.6%

4. Longwave Downward Radiation (R_{ld})

The intercomparison of R_{ld} shown here is based upon the assumption that – again in the climatological mean- at all sites the same R_{ld} is measured, regardless of real temperature anomalies (i.e. urban heat island, fog, height above sea level).

The following plots are analogous to the ones presented in chapter 1. An Eppley PIR (#31207F3, WRC Modification, with 4 thermistors) at the site „Grenzach“ was chosen as reference instrument.

4.1. CNR1

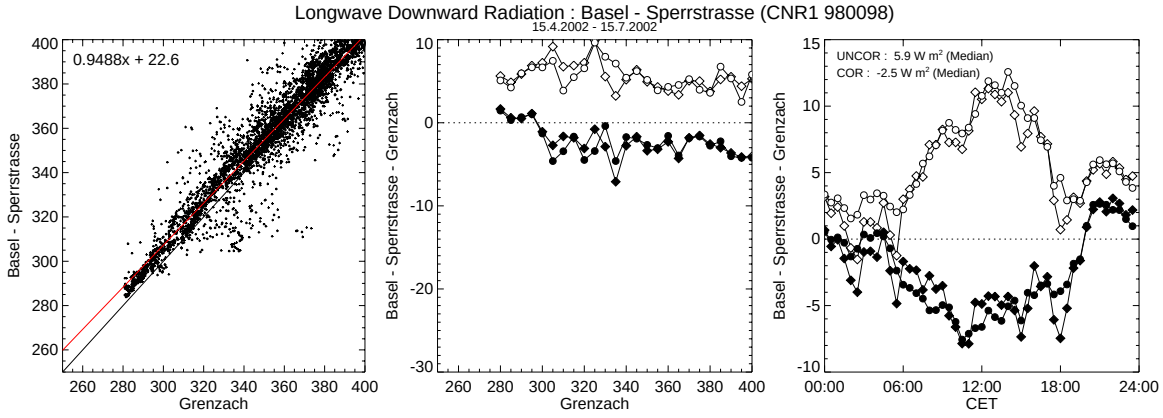
The field calibration in Southern Italy („Bari 02“), as well as older studies at the Institute of Meteorology, Climatology and Remote Sensing of the University of Basel have shown that the R_{ld} measured by CNR1 instruments show a significant dependence from R_{sd}. As a first result from the „Bari 02“-calibration the following Correction was proposed for the CNR1 (for more details see also an upcoming publication by R. Vogt):

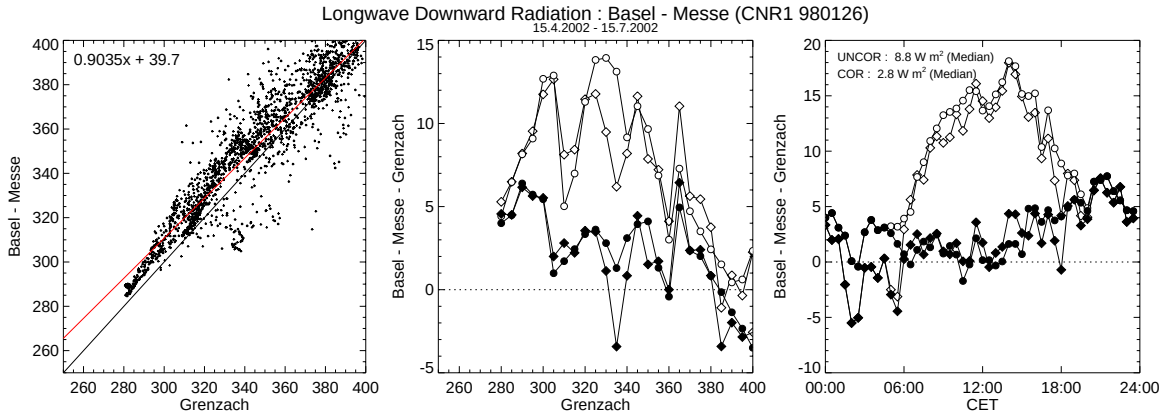
R_{ld} (W m^{-2}) = $a_1 \cdot Signal$ (mV) + σ T^4 + $f_k \cdot R_{sd}$ (W m^{-2})

Tab. 7: Experimental factors for f_k and a_1 obtained during the „Bari 02"-calibration compared to the manufacturer calibration factors.

Site	**Instrument**	**Manufact. Calibration**	**„Bari 02"-Calibration**
Basel – Sperrstrasse (31m)	CNR1 980098	a_1 = 112.74	f_k = -0.018, a_1 = 117.60
Basel - Messe	CNR1 980126	a_1 = 85.47	f_k = -0.021, a_1 = 85.47
Allschwil - Rämelstrasse	CNR1 010285	a_1 = 103.84	f_k = -0.018, a_1 = 103.84
Village Neuf	CNR1 020419	a_1 = 133.33	f_k = -0.023, a_1 = 90.90
Basel - Lange Erlen	CNR1 980080	a_1 = 102.56	f_k = -0.019, a_1 = 102.56 *
Gempen	CNR1 980142	a_1 = 91.66	f_k = -0.019, a_1 = 91.66 *

* = These instruments were not involved in the „Bari-02"-calibration. A generic value of f_k = 0.019 was applied. The a_1 values were not changed.





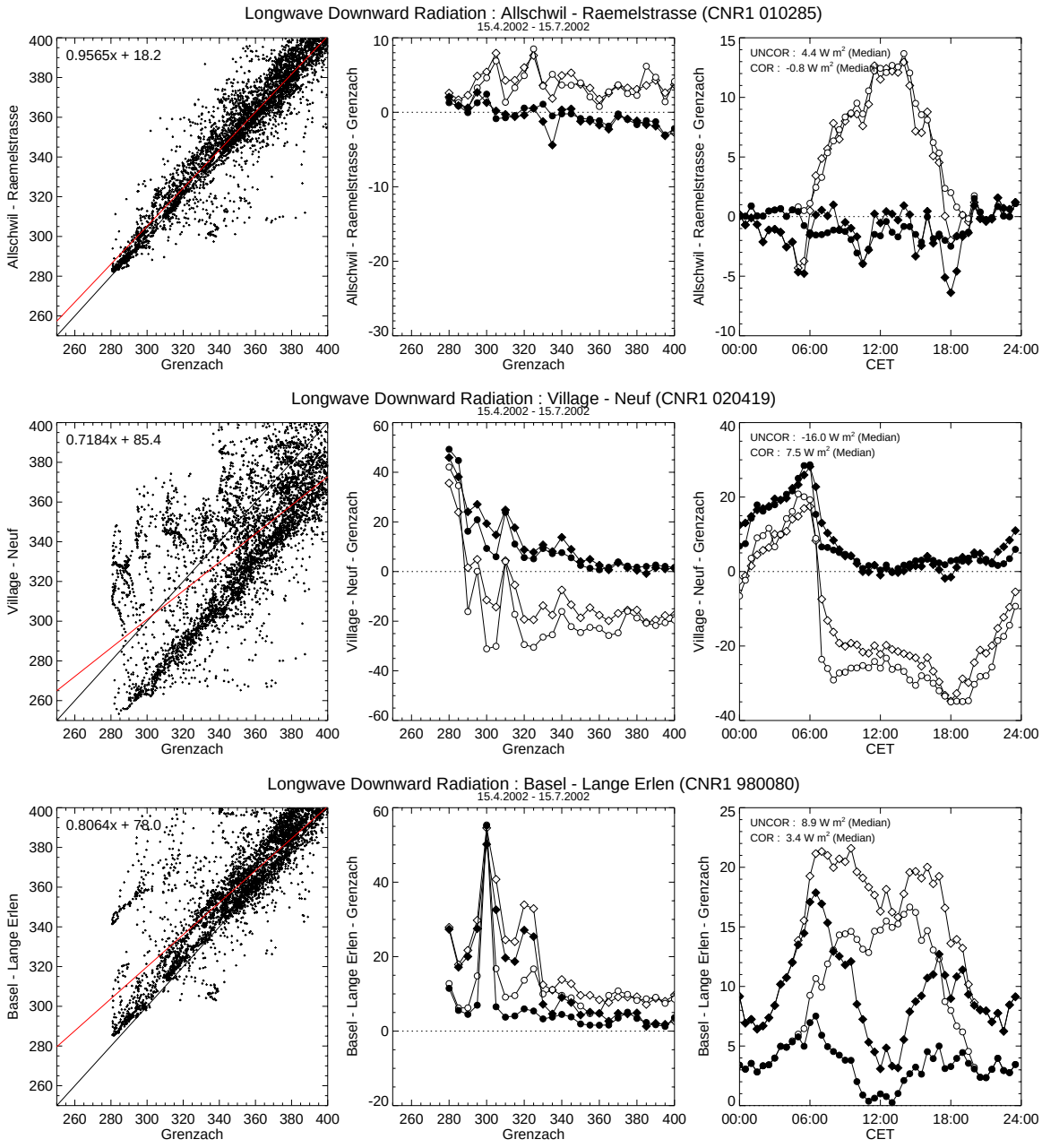


Fig 7: Left plots: R_{ld} at "Basel-Spalenring" compared to R_{ld} at the selected site with manufacturer calibrated sensors (includes all data). **Central** plots: Difference between the values measured at the selected site and the reference vs. magnitude of R_{ld} in 20 W m^{-2} classes. Circles show the median of the 20 W m^{-2} classes, diamonds indicate the mean values. **Right** plots: Diurnal course of the difference, in 30 min classes. Analogous circles show the median and the diamonds the mean. In the central and right plot the manufacturer calibrations are drawn with open (white) symbols, the values corrected with the "Bari 02" factors and the f_k-correction applied are drawn with filled (black) symbols.

Tab. 8: Effects of the „Bari 02"-calibration on median-values of the difference "Site minus Grenzach".

Site	**Instrument**	Median Difference with **Manufact. Calibration**	Median Difference with **„Bari 02" Calibration and f_k-Correction**
Basel – Sperrstrasse (31m)	CNR1 980098	+9.1 W m^{-2}	+0.9 W m^{-2}
Basel - Messe	CNR1 980126	+8.8 W m^{-2}	+2.8 W m^{-2}
Allschwil - Rämelstrasse	CNR1 010285	+4.4 W m^{-2}	-0.8 W m^{-2}
Village Neuf	CNR1 020419	-16.5 W m^{-2}	+7.5 W m^{-2}
Basel - Lange Erlen	CNR1 980080	+8.9 W m^{-2}	+3.4 W m^{-2}

Conclusion: With the „Bari 02" calibration, data are improved especially during daytime as an effect of applying the f_k-correction. Median and mean values are inside a range -1 to +8 W m^{-2} (approx. 2%) relatively to the reference instrument at „Grenzach". Note that real-world differences are included in this intercomparison.

The rural sites „Basel - Lange Erlen", „Grenzach" and „Village - Neuf" show a relative maximum in the differences during night and in the early morning hours. This is an effect of dew on the sensors. Dew is very rarely observed in the city itself, but much more present at the rural sites.

4.2. Eppley PIR

Tab. 9: Calibration factors from WRC-Davos for the Eppley-PIR pyrgeometers operated during BUBBLE.

Site	**Instrument**	**Dome Thermistors**	**Calibration Factors**	**Date of Calibration**
Basel – Spalenring (R_{ld})	Eppley PIR / WRC 30323F3	*3*	C = 0.00424 k_1 = 0.1561 k_2 = 1.0096 k_3 = 3.46	3.6.1998
Basel – Spalenring (R_{lu})	Eppley PIR / WRC 28961F3	*1*	C = 0.004640 k_1 = 0.1394 k_2 = 1.0012 k_3 = 2.377	24.1.1997
Grenzach (R_{ld})	Eppley PIR / WRC 31207F3	*3*	C = 0.00366 k_1 = 0.1077 k_2 = 1.0013 k_3 = 3.22	28.05.1998
Grenzach (R_{lu})	Eppley PIR / WRC 28962F3	*1*	C = 0.0043 k_1 = 0.1344 k_2 = 1.0018 k_3 = 2.394	10.01.2002

Calibration Function (WRC):

R_l (W m^{-2}) = *Signal* (mV) / C $(1 + k_1 \sigma T_{body}^3) + (k_2 \sigma T_{body}^4) - k_3 \sigma (T_{dome}^4 - T_{body}^4)$

T_{dome} is either a mean of 3 dome thermistors or the value of the only one dome thermistor.

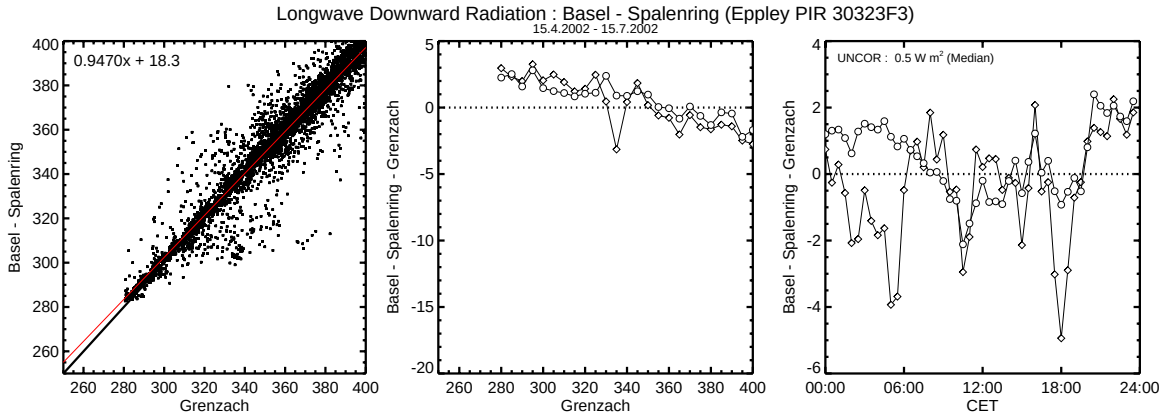


Fig 8: Analogous to Fig. 7 for the Eppley PIR at "Basel Spalenring".

Note that both instruments are high-end instruments with an agreement of 0.5 W m^{-2} in the median. Both Eppley PIR at „Basel-Spalenring" and "Grenzach" are now calibrated taking all 4 thermistors into account (before summer 2003, the data from "basel-Spalenring" in the BUBBLE database was only with 2 thermistors and another calibration, this problem is now fixed). The post-intercomparison in summer 2003 between all 4 Eppley PIR's resulted in a very good agreement between all 4 the instruments (± 2 Wm^{-2}).

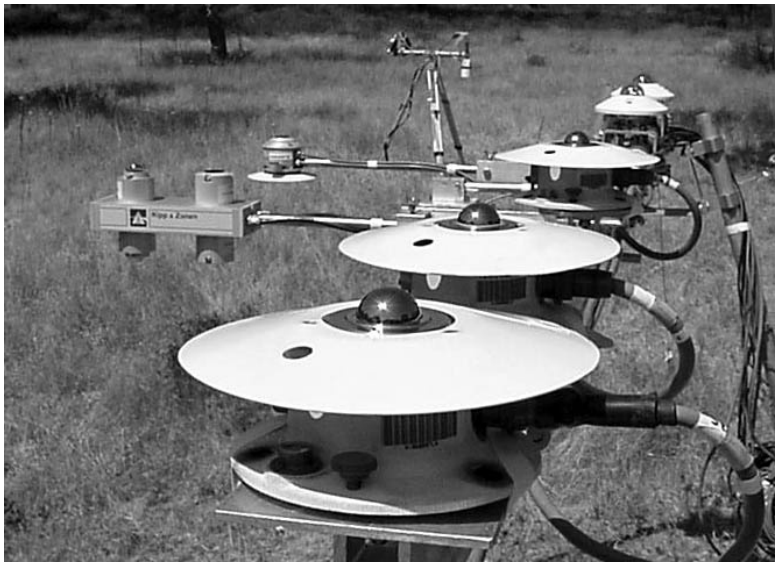


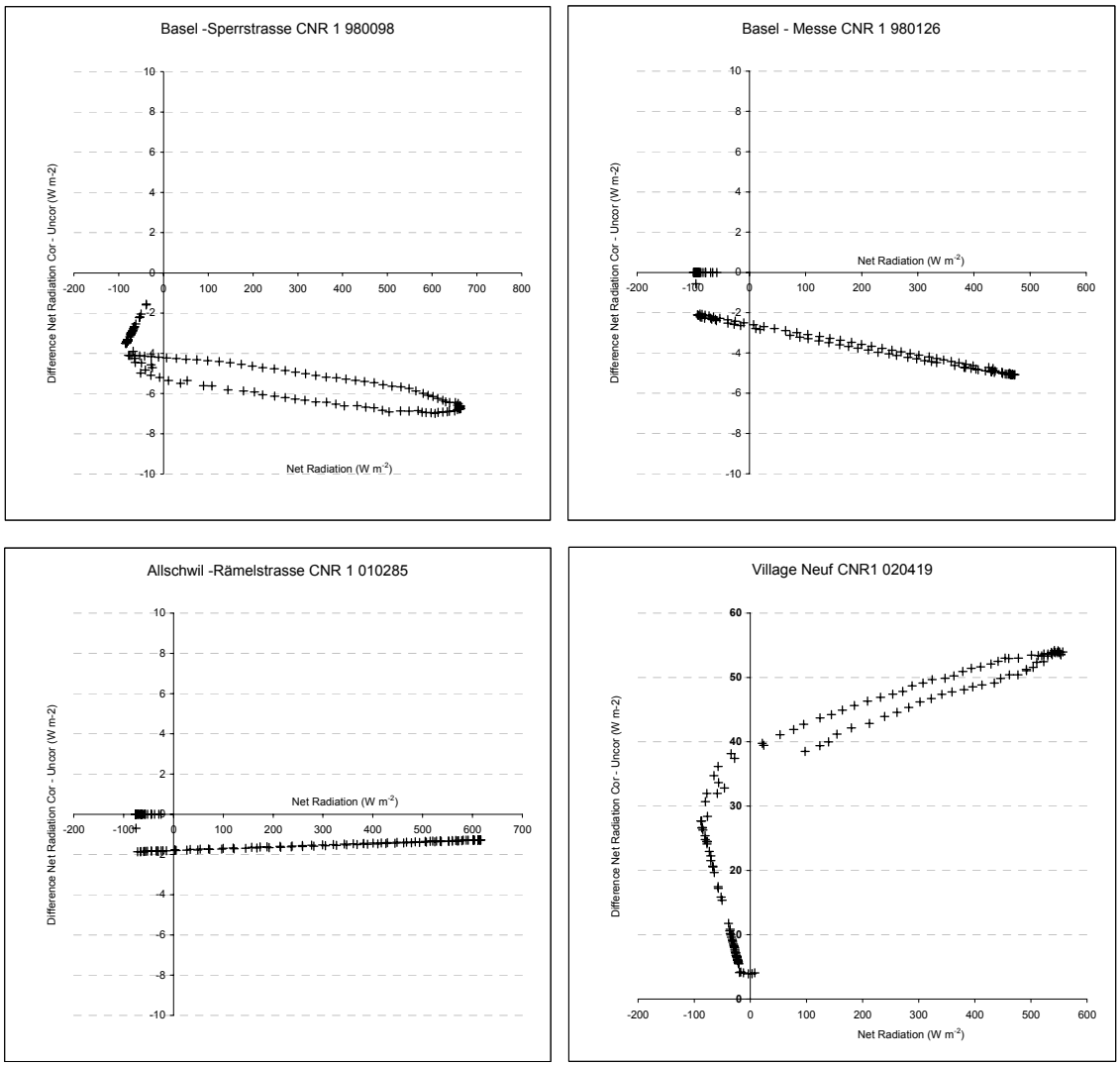
Fig. 9: Field intercomparison of the Eppley-PIR / WRC at Rio Frio experimental site (Portugal, June/July 2003)

5. Longwave Upward Radiation (R_{lu})

The R_{lu} measured at „Basel-Sperrstrasse“ and „Village Neuf“ were corrected with the same a_1 factors derived for R_{ld} during the “Bari 02” calibration (Tab. 7). But no f_k-correction was applied to the CNR1. To the Eppeley PIR the WRC-Calibrations were applied (Tab. 9).

6. Impact on Net Radiation (R_n)

To test the impact of the corrections on R_n an example clear-sky day was chosen (July 5, 2002). For this particular day R_n was calculated twice, once with the uncorrected, manufacturer calibration („uncor“) and once with the new „Bari-02“-calibrations and improvements. The plots illustrate the effects of the new calibrations on R_n including the 2% rise of R_{sd} (Tab. 3), the f_k-correction of R_{lu} as well as the new factors for the longwave radiation (Tab. 7).



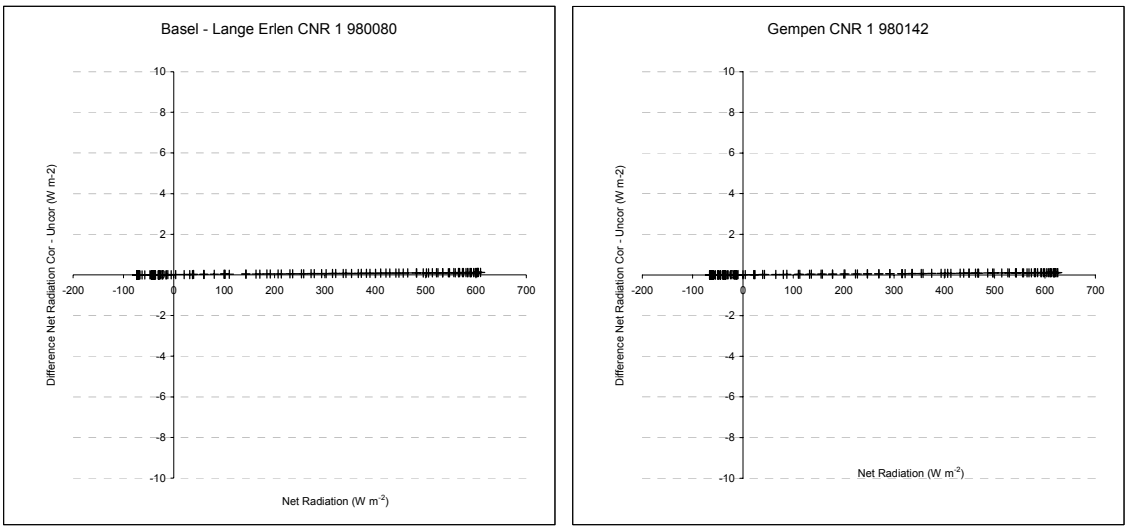


Fig 10: Difference of corrected minus uncorrected R_n-values in function of absolute values of R_n.

Conclusion: As we can expect, in general we do not observe a significant difference between the corrected and the uncorrected values. This is because the 2% rise of R_{sd} (Tab. 3) is counterbalanced by the f_k-correction of R_{ld}. The measurements at the site „Village Neuf" show higher changes. Here the manufacturer calibration was probably wrong or drifted.

Tab. 10: Effects of the corrections on R_n measurements of CNR1-instruments based on a linear regression between the "uncor" and the "cor" data from July 5 2002.

Site	**Instrument**	**Mean Offset**
Basel - Sperrstrasse	CNR1 980098	-5 Wm^{-2}
Basel - Messe	CNR1 980126	-4 Wm^{-2}
Allschwil - Rämelstrasse	CNR1 010285	-2 Wm^{-2}
Village Neuf	CNR1 020419	+45 Wm^{-2}
Basel - Lange Erlen	CNR1 980080	0 Wm^{-2}
Gempen	CNR1 980142	0 Wm^{-2}

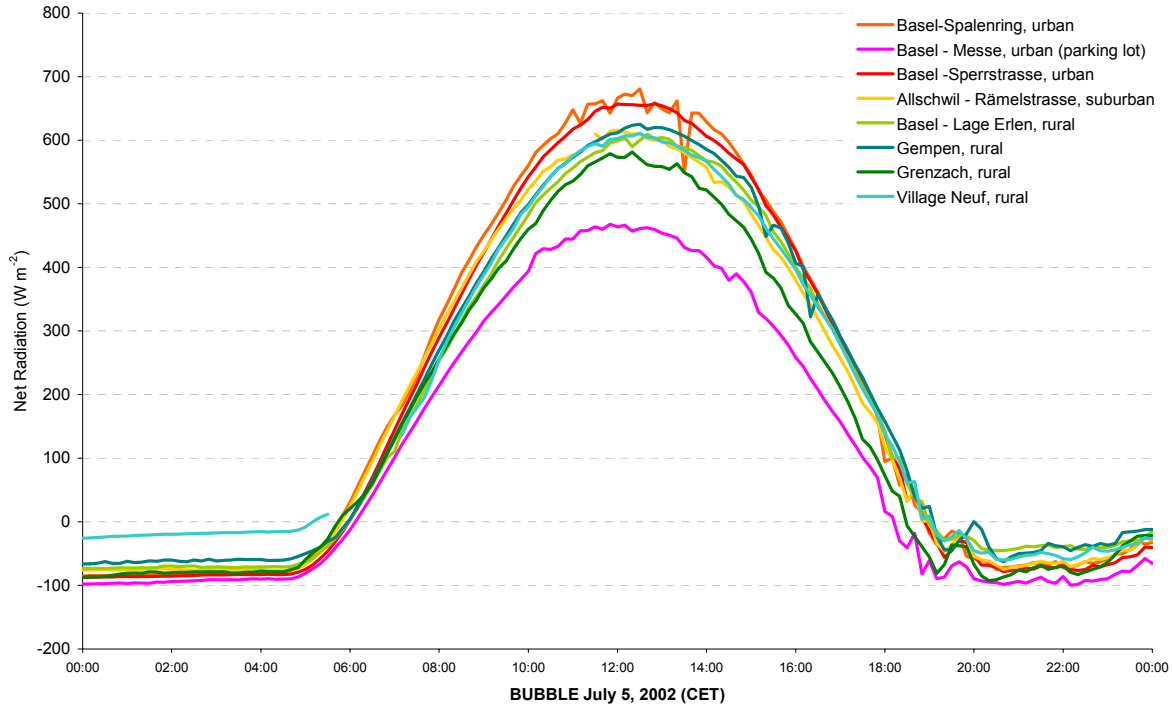


Fig. 11: Diurnal course of the R_n for a selected clear sky day (July 5, 2002) using all corrected components.

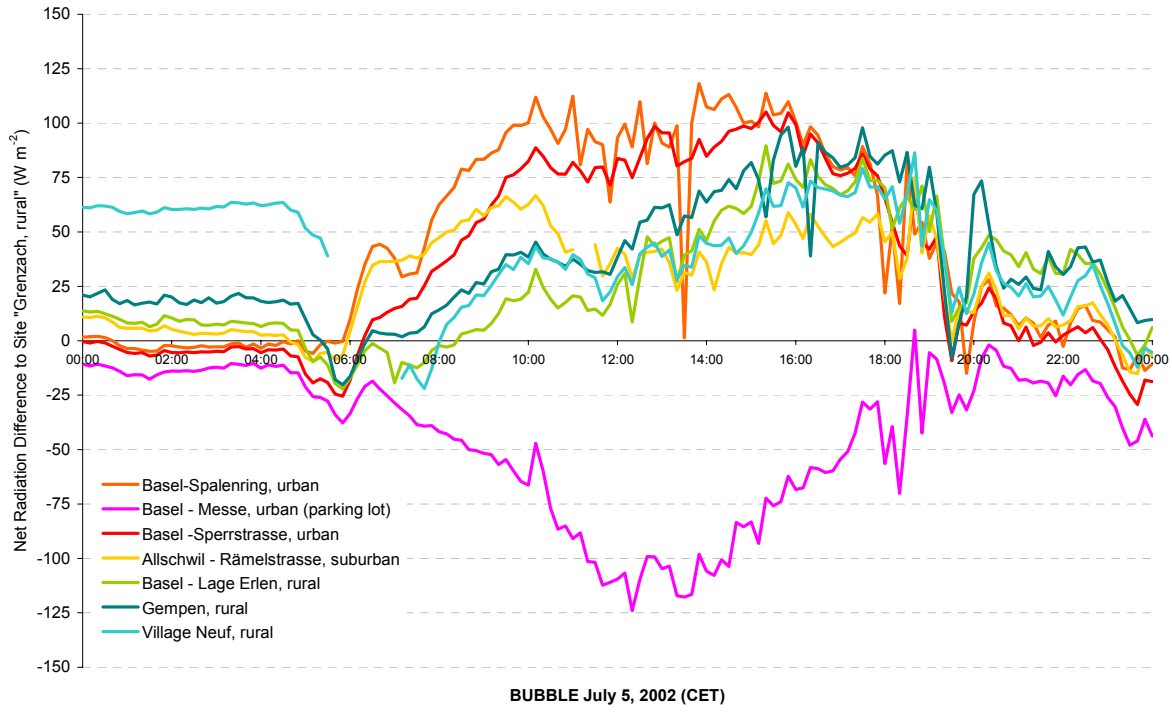


Fig. 12: R_n difference to the measurement at the site „Grenzach“ (Reference, rural). Shown is the selected clear sky day (July 5, 2002) using all corrected components.