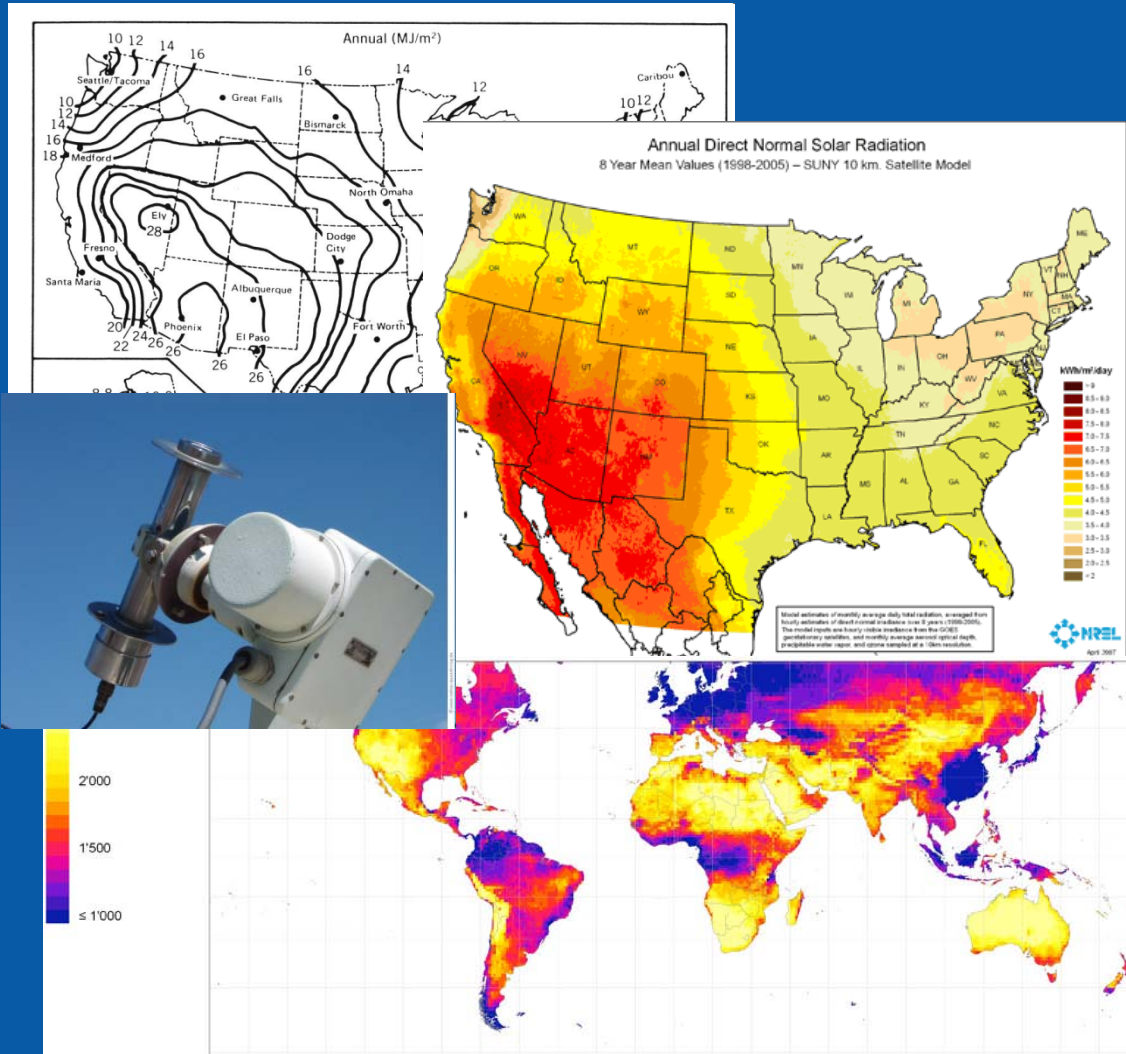




Solar Resources For Concentrating PV (CPV)



**PV Module Reliability
 Workshop
 Golden CO**

Daryl R. Myers
 National Renewable Energy Laboratory
 Electricity, Resources, and Buildings Systems
 Integration Center

daryl.myers@nrel.gov
 303-384-6768

Feb 19 2010

This presentation does not contain any
 proprietary or confidential information.

National Solar Radiation Data Base

~ 97% modeled broadband hourly data
 Collector modes: Perez Anisotropic Model
 Global ~ ±10%, DNI ~ ±15%

National Solar Radiation Data Base

Data Sets

NEW!
Announcement:

The new **Typical Meteorological Year version 3 (TMY3)** data sets are now available for download. The TMY3 data set is an update to, and expansion of, the TMY2 data sets released by NREL in 1994. The TMY3 data sets provide greater geographical coverage than previous TMY data sets with information on 1020 locations in the United States, compared with 239 locations in the TMY2 data set.

The Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors

Manual

- The Solar Radiation
- Data**
 - Averages of Solar R
 - Spreadsheet Portable
 - In alphabetical order
 - In numerical order
 - All sites in complete
 - Windows (
 - Mac (str.)
 - Unix (tar.2
 - 30-Year Average of
 - Spreadsheet Portable
 - In alphabetical order
 - In numerical order
 - All sites in complete
 - Windows (
 - Mac (str.)
 - Unix (tar.2

National Solar Radiation Database 1961-1990

The National Solar Radiation Data Base 1961-1990 (NSRDB) contains 30 years of solar radiation and supplementary meteorological data from 237 NWS sites in the U.S., plus sites in Guam and Puerto Rico.

National Solar Radiation Database 1991-2005 Update

The updated 1991-2005 National Solar Radiation Database holds solar and meteorological data for 1,454 locations in the United States and its territories.

- Hourly Solar Data
- Statistical Summaries
 - Daily Statistics Files
- Solar Radiation Data Manual for Buildings
- Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors
- Typical Meteorological Year (TMY2) Files

- Hourly Solar Data

User's Manual for TMY2s
 Typical Meteorological Years

Derived from the 1961-1990 National Solar Radiation Data Base

William Marion and Ken Hubbs

NREL

National Renewable Energy Laboratory
 1617 Cole Boulevard
 Golden, Colorado 80401-1503
 A national laboratory of the U.S. Department of Energy
 Managed by Midwest Research Institute
 for the U.S. Department of Energy
 Under Contract No. DE-AC36-83CH10093

Jan
Feb
Mar
Apr
May
June
July
Aug
Sep
Oct
Nov
Dec

June 1995

Special Data Sets: Circumsolar and Spectral

NREL's Spectral Solar Radiation Data Base

The Solar Energy Research Institute (SERI)*, Electric Power Research Institute (EPRI), Florida Solar Energy Center (FSEC), and Pacific Gas and Electric Company (PG&E) cooperated to produce a spectral solar radiation data base representing a range of atmospheric conditions (or climates) that is applicable to several different types of solar collectors. Data that are included in the data base were collected at FSEC from October 1986 to April 1988, and at PG&E from April 1987 to April 1988. FSEC operated one EPRI and one SERI spectroradiometer almost daily at Cape Canaveral, which contributed nearly 2800 spectra to the data base. PG&E operated one EPRI spectroradiometer at San Ramon, Calif., as resources permitted contributing nearly 300 spectra to the data base. SERI collected about 200 spectra in the Denver/Golden, Colo., area from November 1987 to February 1988 as part of a research project to study urban spectral solar radiation, and added these data to the data base.

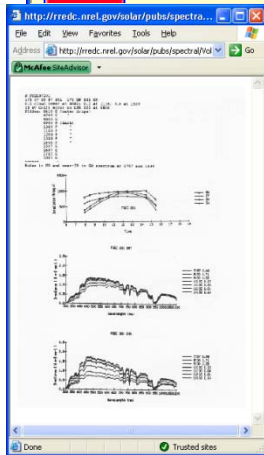
*In September 1991 the Solar Energy Research Institute became the National Renewable Energy Laboratory.



Spectral Solar Radiation Data Base Documentation, Vol. I



Spectral Solar Radiation Data Base Documentation, Vol. II



**3000 spectra
CA, FL, CO
DNI, Global
tilt, GNI, and
GHZ**

http://redc.nrel.gov/solar/old_data/spectral/ Microsoft Internet Explorer

Address: http://redc.nrel.gov/solar/old_data/spectral/

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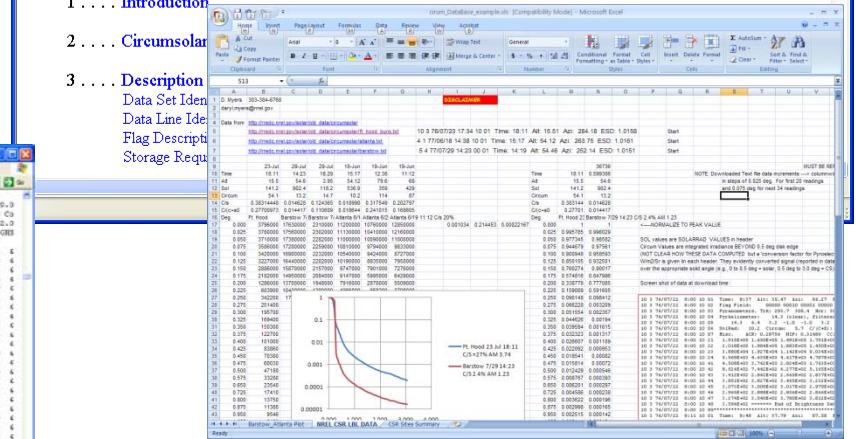
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C 15 1210.0 141.50 45.4 45.4 45.0 37.2 1.137 0.00100 9.000 0.00 0.0 0.0 2.3
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1 300 0.004 0.005 0.013 0.023 0.025 0.023 0.041 0.083 0.089 0.074 E
1 320 0.082 0.092 0.114 0.120 0.113 0.114 0.145 0.143 0.144 0.149 E
1 340 0.170 0.174 0.189 0.187 0.188 0.189 0.203 0.205 0.205 0.204 E
1 360 0.264 0.265 0.270 0.269 0.273 0.274 0.273 0.270 0.280 0.280 E
1 380 0.367 0.371 0.364 0.371 0.380 0.382 0.365 0.359 0.370 E
1 400 0.484 0.490 0.513 0.522 0.532 0.541 0.549 0.571 0.578 0.592 E
1 420 0.584 0.585 0.584 0.575 0.544 0.554 0.545 0.533 0.524 0.645 E
1 440 0.642 0.639 0.700 0.700 0.713 0.708 0.713 0.702 0.684 0.794 E
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1 500 0.813 0.818 0.831 0.838 0.844 0.844 0.813 0.822 0.807 0.801 E
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1 560 0.930 0.924 0.929 0.960 0.959 0.951 0.942 0.943 0.916 0.908 E
1 580 0.970 0.974 0.975 0.964 0.964 0.944 0.947 0.943 0.917 0.917 E
1 600 0.938 0.899 0.891 0.894 0.883 0.884 0.893 0.845 0.847 0.847 E
1 620 0.940 0.881 0.884 0.897 0.913 0.911 0.888 0.888 0.841 0.843 E
1 640 0.944 0.880 0.859 0.852 0.857 0.821 0.813 0.805 0.779 0.802 E
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1 860 0.570 0.574 0.580 0.560 0.597 0.581 0.584 0.544 0.514 0.508 E
1 880 0.554 0.554 0.551 0.550 0.547 0.539 0.524 0.500 0.472 0.441 E
1 900 0.470 0.437 0.440 0.430 0.410 0.414 0.409 0.400 0.410 0.410 E
1 920 0.421 0.411 0.420 0.420 0.420 0.419 0.419 0.419 0.420 0.424 E
1 940 0.310 0.314 0.323 0.319 0.313 0.310 0.315 0.342 0.340 0.352 E
1 960 0.374 0.374 0.383 0.383 0.380 0.385 0.412 0.413 0.414 E
1 980 0.397 0.410 0.421 0.420 0.425 0.439 0.441 0.441 0.441 0.440 E
1 1000 0.438 0.434 0.443 0.439 0.440 0.440 0.443 0.441 0.440 0.438 E
1 1020 0.428 0.421 0.428 0.425 0.424 0.421 0.423 0.418 0.417 0.415 E
1 1040 0.414 0.411 0.410 0.430 0.407 0.405 0.404 0.402 0.398 0.394 E
1 1060 0.378 0.378 0.380 0.382 0.379 0.377 0.374 0.371 0.372 0.372 E
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```

Circumsolar Data Manual - Microsoft Internet Explorer

Address: http://redc.nrel.gov/solar/pubs/circumsolar/index.html

Circumsolar Radiation Data: The Lawrence Berkeley Laboratory Reduced Data Base

- Table of Contents
- Title Page
 - Foreword
 - 1 Introduction
 - 2 Circumsolar
 - 3 Description
Data Set Ident
Data Line Ide
Flag Descript
Storage Requ



**179,000 Circumsolar
profile scans
0.025° steps
11 locations**

NREL Solar Prospector: <http://mercator.nrel.gov/csp/>

Solar Resources Classes kWhm²/day

- 2 - 3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 - 5
- 5 - 5.25
- 5.25 - 5.5
- 5.5 - 5.75
- 5.75 - 6
- 6 - 6.25
- 6.25 - 6.5
- 6.5 - 6.75
- 6.75 - 7
- 7 - 7.25
- 7.25 - 7.5
- 7.5 - 7.75
- 7.75 - 8
- Above 8

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1998	6.339	5.429	7.444	8.256	8.837	10.470	9.175	8.332	8.259	7.517	6.678	6.352	7.769
1999	6.195	6.530	8.025	6.969	8.723	9.936	8.327	8.410	7.824	7.770	6.866	6.255	7.659
2000	5.715	5.526	7.291	6.452	9.413	9.296	9.208	7.730	8.440	6.594	6.392	6.010	7.510
2001	5.096	5.583	7.305	7.686	9.190	9.414	9.071	8.544	8.707	6.897	6.655	5.565	7.485
2002	5.994	6.777	7.496	8.007	9.186	9.904	8.099	8.903	7.520	7.009	6.535	5.760	7.600
2003	5.830	5.632	7.344	8.003	8.015	9.754	8.151	7.684	8.031	7.305	5.810	5.566	7.259
2004	5.863	3.493	7.971	7.999	9.258	9.965	9.210	8.136	8.187	6.208	6.011	5.845	7.361
2005	5.130	4.437	7.450	7.884	9.088	10.001	8.604	7.964	8.338	7.132	6.390	5.029	7.301
Hourly Mean	5.771	5.426	7.541	7.927	9.064	9.843	8.839	8.248	8.164	7.057	6.415	5.799	7.517
Std. Dev.	0.42	0.99	0.27	0.42	0.23	0.34	0.4	0.38	0.35	0.46	0.33	0.4	0.16
Map Means	5.688	5.517	7.38	8.028	9.027	9.864	8.739	8.271	8.235	7.074	6.336	5.715	7.499
Hourly Mean - Map	0.083	-0.091	0.161	-0.101	0.037	-0.021	0.1	-0.023	-0.071	-0.017	0.079	0.084	0.018

Solar Resource Variability

Wh / sq. m. / day

Max
Min
Mean

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC ANNUAL

Download Window

1. Select Format:

TMJ Format
CSV Format

2. Select Years

Available: 1999, 2000, 2001, 2002, 2003, 2004, 2005, TDY

Selected: 1998

Submit Close

DNI Time Series

Perez
"SUNY"
10 km
Satellite
estimates

1998-2005 Solar data
"Average" Year
10 km Grid
DNI $\pm 15\%$

Typical GNI DNI Summary Data

(Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors)

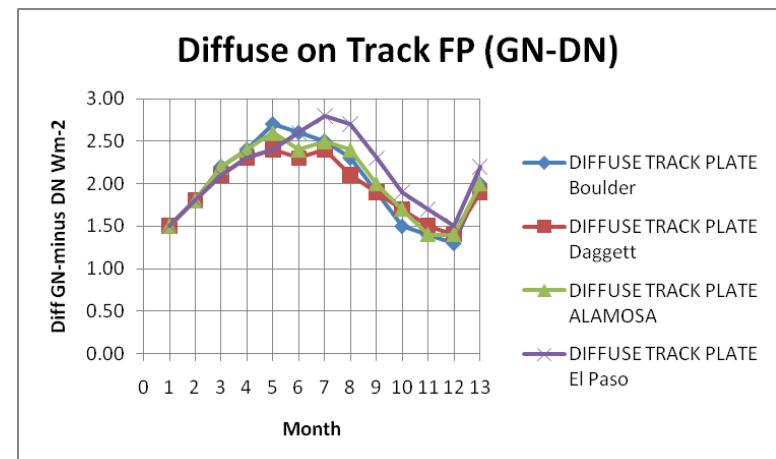
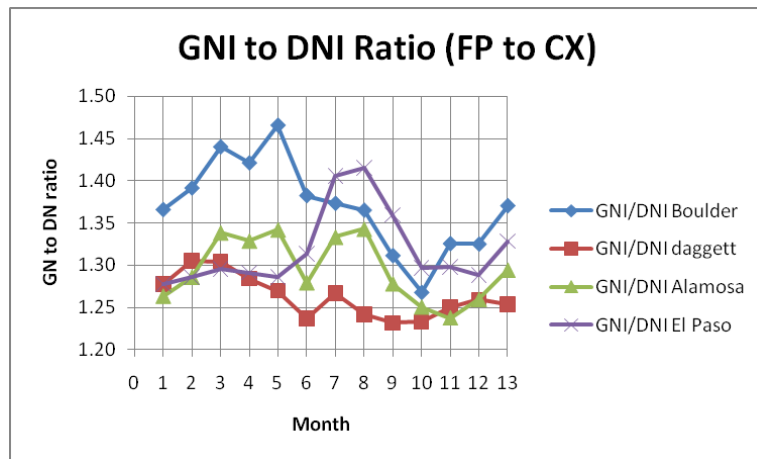
Entries for Boulder CO

SOLAR RADIATION FOR 2-AXIS TRACKING FLAT-PLATE COLLECTORS (kWh/m2/day), Percentage Uncertainty = 9														
Tracker		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2-Axis	Average	5.6	6.4	7.2	8.1	8.5	9.4	9.2	8.6	8	7.1	5.7	5.3	7.4

DIRECT BEAM SOLAR RADIATION FOR CONCENTRATING COLLECTORS (kWh/m2/day), Percentage Uncertainty = 8														
Tracker		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2-X	Average	4.1	4.6	5	5.7	5.8	6.8	6.7	6.3	6.1	5.6	4.3	4	5.4

Example Ratios GNI/DNI

GNI/DNI Boulder	1.37	1.39	1.44	1.42	1.47	1.38	1.37	1.37	1.31	1.27	1.33	1.33	1.37
GNI/DNI daggett	1.28	1.31	1.30	1.28	1.27	1.24	1.27	1.24	1.23	1.23	1.25	1.26	1.25
GNI/DNI Alamosa	1.26	1.29	1.34	1.33	1.34	1.28	1.33	1.34	1.28	1.25	1.24	1.26	1.29
GNI/DNI El Paso	1.28	1.29	1.30	1.29	1.29	1.31	1.41	1.42	1.36	1.30	1.30	1.29	1.33



Previous Analysis: Kurtz et al. 1990

Summary of data observed for all of the sites studied*

Site	PPR DNI (W/m ²)	Latitude (°)	Longitude (°)	Altitude (m)	# hours	GNI (kWh/m ²)	DNI (kWh/m ²)	DNI/GNI	Kt	PPR T (°C)	Annual T (°C)	PPR Wind (m/s)	Annual Wind (m/s)
Alamosa, CO	875	37.5	105.9	2297	13,734	8.8	6.8	0.773	0.638	16.1	5.1	3.1	3.8
Flagstaff, AZ	870	35.01	111.6	2135	10,974	8.4	6.4	0.762	0.607	16.7	7.7	4.1	2.7
Prescott, AZ	867	34.65	112.4	1531	11,980	8.7	6.8	0.782	0.627	21.8	11.7	4.1	3.6
Cheyenne, WY	865	41.15	104.8	1872	10,205	7.3	5.2	0.712	0.562	17.8	7.6	6.2	5.8
Elko, NV	863	40.83	115.8	1547	10,516	7.5	5.5	0.733	0.582	20.0	8.2	3.1	2.7
Ely, NV	861	39.28	114.9	1906	10,309	8.1	6.0	0.741	0.608	18.2	7.0	4.1	4.3
Kahului, HI	861	20.9	156.4	15	11,952	8.0	5.8	0.725	0.577	28.2	24.2	8.8	6.1
Daggett, CA	860	34.87	116.8	588	16,115	9.4	7.5	0.801	0.681	27.2	19.8	5.2	5.1
Cedar City, UT	853	37.7	113.1	1762	11,078	8.3	6.2	0.747	0.614	20.6	10.3	4.1	3.4
Winnemucca, NV	853	40.9	117.8	1323	11,205	7.7	5.6	0.727	0.596	22.2	9.5	4.1	3.7
Tonopah, NV	852	38.07	117.1	1653	12,852	8.6	6.7	0.779	0.638	20.2	10.6	4.1	4.1
Tucson, AZ	851	32.12	110.9	779	14,605	9.0	7.0	0.778	0.653	28.9	20.2	3.6	3.9
Reno, NV	849	39.5	119.8	1341	12,582	8.2	6.2	0.756	0.621	20.9	10.4	2.6	3.1
Rock Springs, WY	849	41.5	108.5	2056	10,319	7.6	5.4	0.711	0.587	18.3	5.9	5.2	4.8
Grand Junction, CO	845	39.12	108.5	1475	12,475	8.0	5.9	0.738	0.616	23.3	11.7	3.6	3.5
Lewiston, MT	843	47.05	109.5	1264	7,883	6.5	4.4	0.677	0.541	18.0	5.8	3.6	4.2
Tucumcari, NM	841	35.18	103.6	1231	12,266	8.3	6.1	0.735	0.616	24.1	14.3	5.2	4.4
Albuquerque, NM	836	35.05	106.6	1619	11,484	8.8	6.7	0.761	0.658	22.2	13.4	3.6	4.1
Anchorage, AK	836	61.7	150.0	35	2,847	4.0	2.3	0.575	0.427	14.4	2.2	2.6	3.1
Las Vegas, NV	834	36.08	115.2	664	12,804	9.1	7.1	0.780	0.675	26.7	19.5	3.6	4.4
Amarillo, TX	832	35.23	101.7	1098	11,518	7.9	5.8	0.734	0.595	24.4	13.8	6.7	6.0
Bismarck, ND	827	46.77	100.8	502	9,692	6.6	4.5	0.682	0.553	21.7	5.3	5.2	4.3
Lubbock, TX	825	33.65	101.8	988	11,191	7.9	5.7	0.722	0.594	25.8	15.6	6.2	5.6
El Paso, TX	821	31.8	106.4	1194	14,476	8.9	6.7	0.753	0.656	26.7	17.3	3.1	3.4
Abilene, TX	821	32.43	99.7	534	11,190	7.7	5.5	0.714	0.584	27.2	18.1	5.7	5.0
Wichita Falls, TX	821	33.97	98.5	314	10,973	7.4	5.2	0.703	0.572	27.4	17.2	6.2	5.2
Midland, TX	819	31.93	102.2	871	10,914	8.1	5.9	0.728	0.610	27.8	17.4	6.2	5.1
Santa Maria, CA	818	34.9	120.5	72	16,733	7.8	5.7	0.731	0.610	19.4	14.1	5.2	3.2
San Angelo, TX	817	31.37	100.5	582	11,191	7.7	5.5	0.714	0.584	28.3	18.3	5.2	4.6
Sacramento, CA	814	38.52	121.5	8	13,662	7.6	5.5	0.724	0.606	25.4	16.0	3.6	3.2
Phoenix, AZ	814	33.43	112.0	339	13,908	8.9	6.8	0.764	0.665	30.6	22.6	3.1	3.0
Bakersfield, CA	813	35.42	119.1	150	13,925	7.9	5.7	0.722	0.617	27.8	18.6	3.6	3.0
Honolulu, HI	810	21.33	157.9	5	10,966	7.7	5.2	0.675	0.569	27.8	25.1	6.2	4.9
Fresno, CA	806	36.77	119.7	100	14,548	7.8	5.6	0.718	0.622	27.2	17.4	3.1	2.9
Fort Worth, TX	806	32.83	97.05	164	11,188	7.2	4.8	0.667	0.564	27.9	18.6	5.2	4.9
Austin, TX	806	30.3	97.7	189	9,319	7.0	4.6	0.657	0.547	28.1	20.3	4.6	4.0
San Antonio, TX	789	29.53	98.47	242	9,984	7.0	4.5	0.643	0.554	28.9	20.3	4.6	4.1
Mean	836	36.17	112.8	931	11,718			0.601	0.601	23.7	14.1	4.5	4.1
Standard deviation	22	6.84	14.6	711	2405			0.047	0.047	4.4	5.9	1.4	0.9
Median	836									24.4		4.1	

*PPR DNI = median DNI for GNI between 975 and 1025 W/m²; # hours = number of data points. GNI and DNI = the average daily energy [14,15], and the DNI/GNI column shows their ratio; Kt is the global clearness index; PPR T and PPR Wind = median temperature and wind speed, respectively, for GNI between 975 and 1025 W/m². Annual T and Annual Wind = annual temperature and wind speed from the NSRDB [14,15].

What is DNI for GNI at SRC?

Mean GNI **1000 ± 25 W⁻²**

Avg *MEDIAN* DNI **836 Wm⁻²**

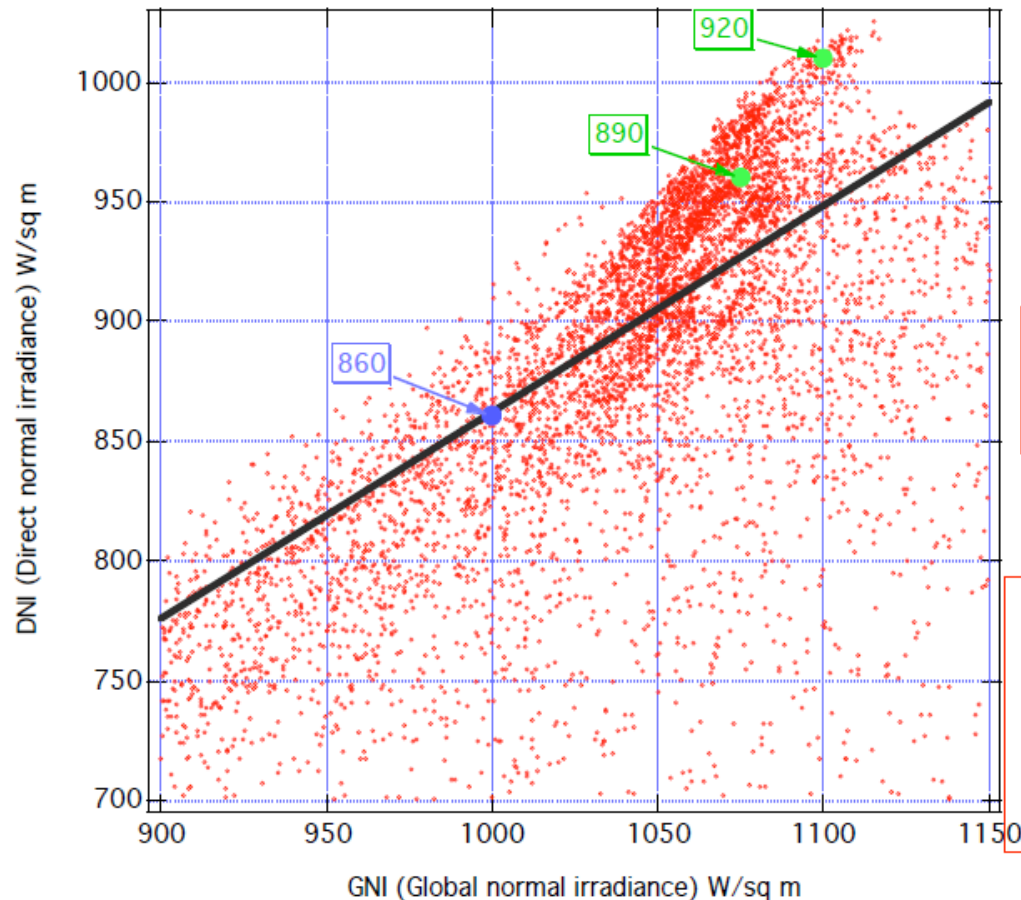
Power rating – 850 or 1000 W/m²?

Flat plate

- 1000 W/m²

CPV

- 850 W/m²



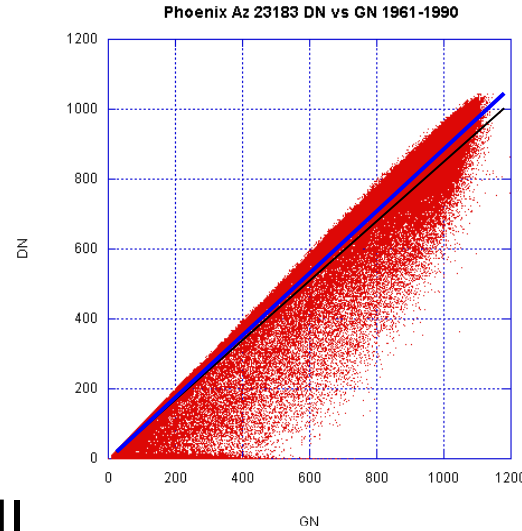
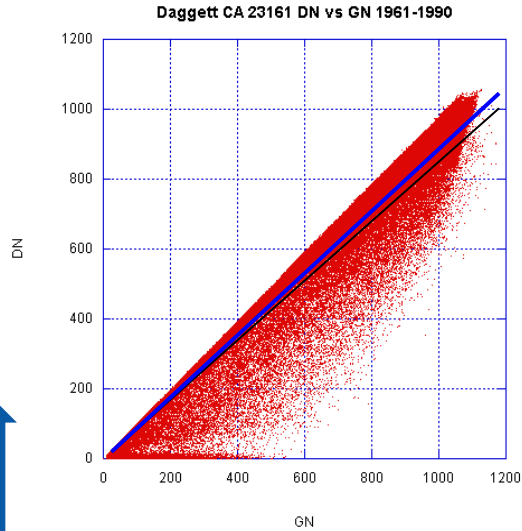
Data taken in Golden, CO

Tags give ratio of DNI/GNI normalized to 1000 W/m²

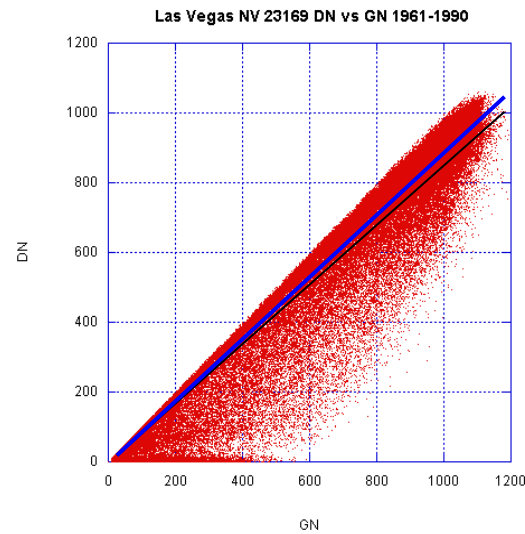
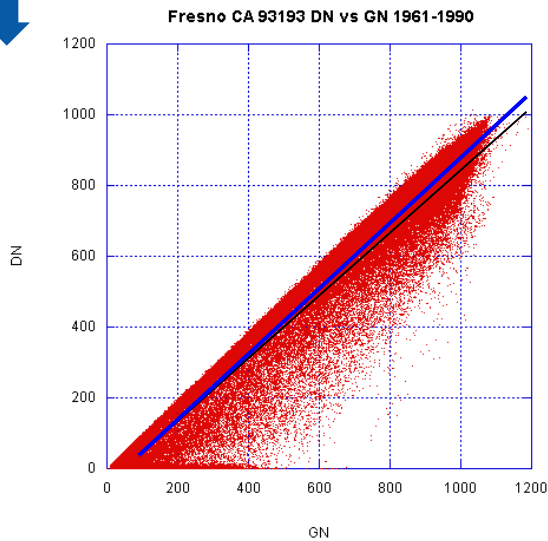
Example DNI Vs GNI ALL Hours ~ 120,000

GNI model from
NSRDB
Glo, Beam, Diff
with Perez
Anisotropic
model

DNI



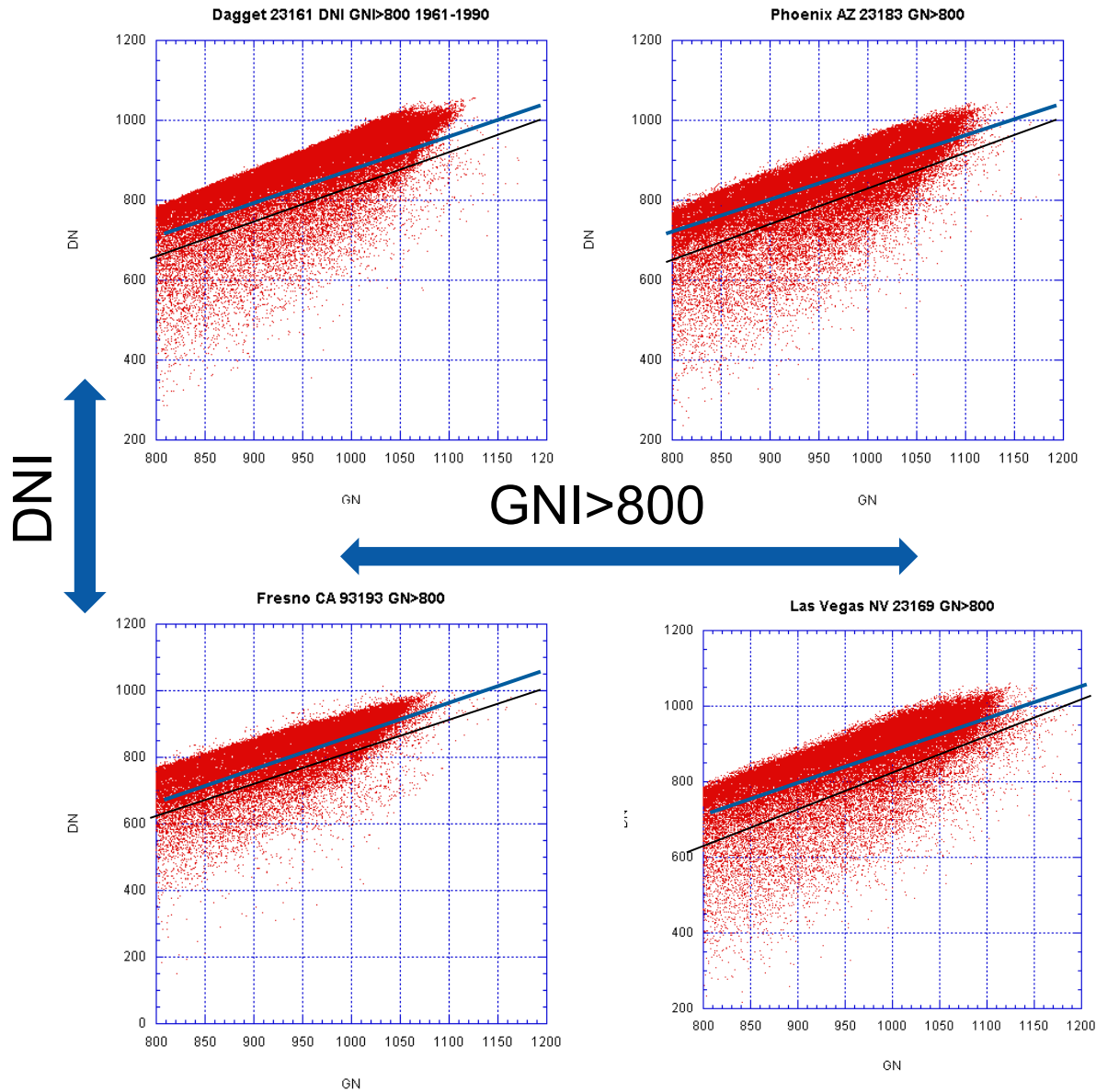
GNI



DNI/GNI
0.874

DNI/GNI
0.836

Example DNI Vs GNI>800 Wm⁻²



DNI/GNI
0.874

DNI/GNI
0.836

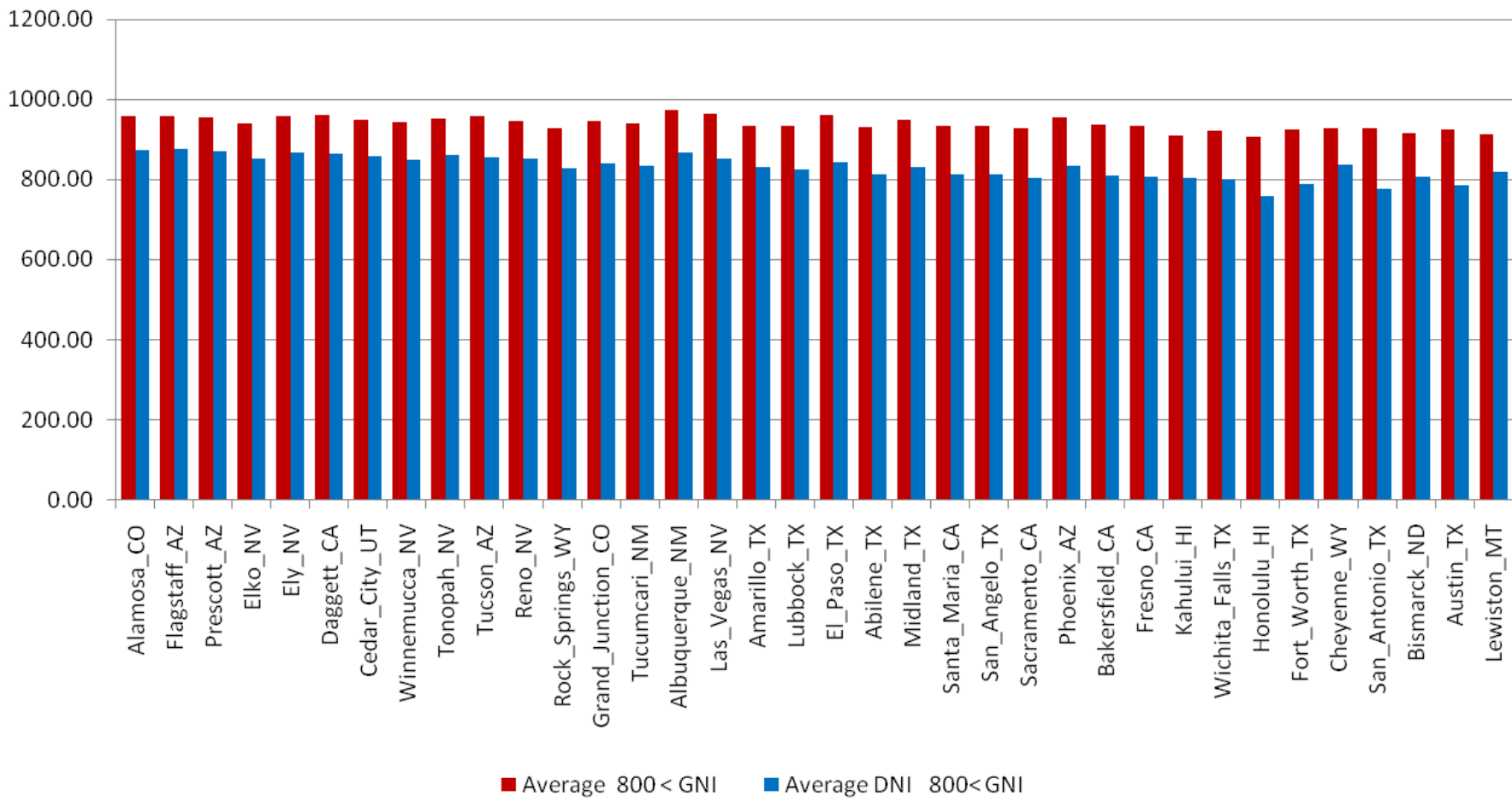
Averages 36 Sites, 30 yr hourly GNI > 800 Wm⁻²

STATION	Lat	Long	AVG GNI > 800	Stdev GNI	AVG DNI GNI >800	DNI GNI >800	GNI/DNI (GNI >800)	G/D GNI	COUNT
Alamosa_CO	37.5	-105.8	956.94	82.05	874.75	115.83	1.11	0.11	57934
Flagstaff_AZ	35.1	-111.8	956.91	83.06	876.45	108.62	1.10	0.09	50947
Prescott_AZ	34.7	-112.5	955.27	81.19	870.39	107.92	1.11	0.10	56419
Elko_NV	40.8	-115.8	940.35	75.84	853.20	101.82	1.11	0.09	42136
Ely_NV	39.3	-114.9	958.01	82.76	868.63	116.97	1.12	0.13	49065
Daggett_CA	35.4	-119	959.86	77.04	864.55	101.02	1.12	0.11	67184
Cedar_City_UT	37.7	-113	949.10	79.31	856.71	108.39	1.12	0.11	50680
Winnemucca_NV	40.9	-117.8	944.09	76.03	849.57	101.24	1.12	0.10	44429
Tonopah_NV	38	-117.1	953.04	79.93	861.53	104.64	1.12	0.10	55544
Tucson_AZ	32.1	-110.9	956.73	77.68	856.41	105.95	1.13	0.12	62831
Reno_NV	39.5	-119.8	947.04	76.40	850.84	98.45	1.12	0.10	50218
Rock_Springs_WY	41.5	-109	927.86	74.73	826.72	109.85	1.13	0.12	38236
Grand_Junction_CO	39.1	-108.5	946.55	78.10	841.33	114.10	1.14	0.15	48786
Tucumcari_NM	35.2	-103.5	939.32	75.42	833.42	109.66	1.14	0.12	47069
Albuquerque_NM	35	-106.5	972.12	83.31	866.24	117.12	1.14	0.14	61065
Las_Vegas_NV	36.1	-115.2	963.55	81.77	853.26	105.54	1.14	0.14	63730
Amarillo_TX	35.2	-101.7	934.41	72.50	829.96	105.01	1.14	0.11	47923
Lubbock_TX	33.6	-101.8	933.98	72.99	823.50	107.88	1.15	0.12	47198
El_Paso_TX	31.8	-106.5	959.59	78.95	843.60	113.65	1.15	0.16	60792
Abilene_TX	32.5	-99.8	931.70	71.50	812.27	109.19	1.16	0.13	45168
Midland_TX	31.9	-102.2	947.56	76.42	830.11	116.65	1.16	0.15	51542
Santa_Maria_CA	34.9	-120.5	935.33	68.42	814.10	91.70	1.16	0.11	50523
San_Angelo_TX	31.4	-100.5	933.04	72.03	813.77	109.71	1.16	0.13	45630
Sacramento_CA	38.5	-121.5	929.26	69.07	804.46	86.51	1.16	0.10	44286
Phoenix_AZ	33.5	-112	955.11	78.27	832.80	102.04	1.16	0.13	61909
Bakersfield_CA	35.5	-119	935.99	71.93	808.45	90.80	1.17	0.10	47259
Fresno_CA	46.6	-119.8	935.14	71.08	807.41	92.30	1.17	0.12	46850
Kahului_HI	20.9	-156.5	910.09	62.11	802.94	95.05	1.14	0.10	44970
Wichita_Falls_TX	33.9	-98.5	922.91	68.56	801.22	107.14	1.17	0.13	41522
Honolulu_HI	21.3	-157.9	905.50	63.44	758.18	105.06	1.21	0.15	36966
Fort_Worth_TX	32.8	-97.1	926.24	69.38	789.85	120.03	1.20	0.17	39765
Cheyenne_WY	41.2	-104.8	927.11	71.68	837.23	101.14	1.12	0.10	38131
San_Antonio_TX	29.5	-98.5	926.76	70.33	776.17	127.49	1.22	0.19	37249
Bismarck_ND	46.3	-100.8	914.89	65.22	806.72	96.15	1.15	0.12	31778
Austin_TX	30.3	-97.7	923.59	69.85	786.33	117.60	1.19	0.15	37194
Lewiston_MT	47	-109.5	911.32	66.28	818.68	93.57	1.12	0.09	27507
		Average	939.62		830.60				

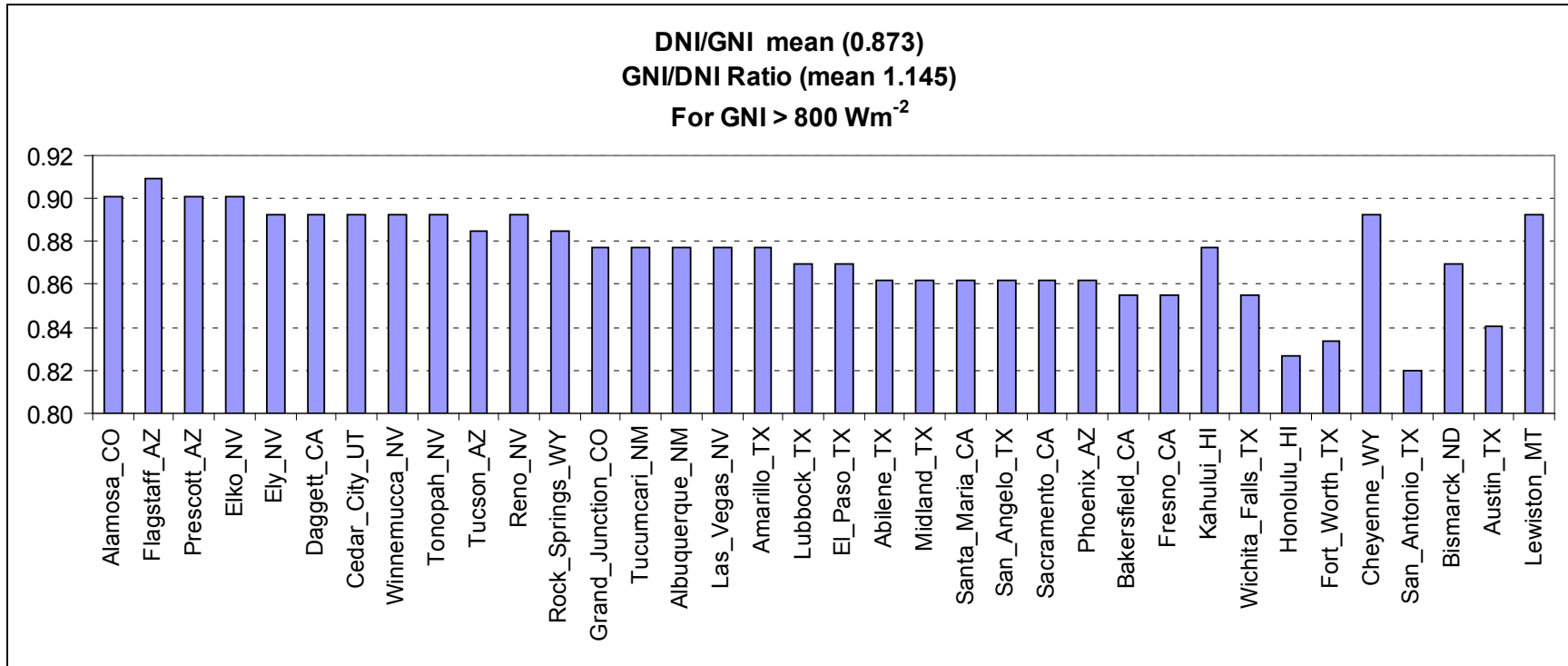
Mean GNI
939.6 ± 70

Mean DNI
830.6 ± 100

Summary GNI > 800 Wm⁻²



Summary DNI/GNI for GNI > 800

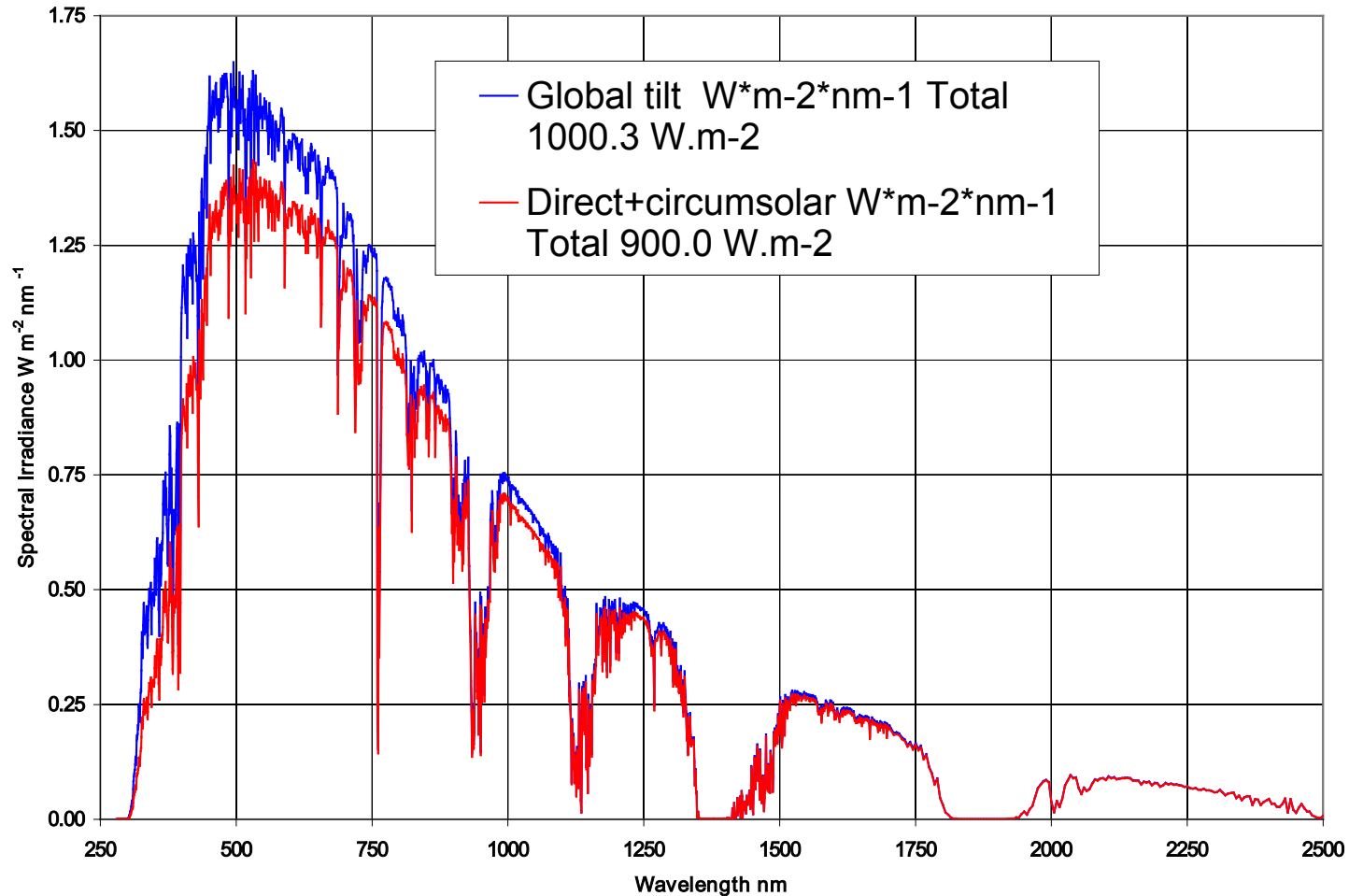


$GNI \sim 1000 \text{ Wm}^{-2} \Rightarrow DNI \sim 873 \text{ Wm}^{-2}$

ASTM G 173 AND ISO REF SPECTRAL STD :

Global "Tilt = 37°" = 1000 Wm⁻²

DNI for same conditions = 900 Wm⁻²



MEASUREMENTS

Uncertainty

MODELS

$U_{meas} (\pm\%)$

Global	Direct	Diffuse
6	5	6

$U_{mod} (\pm\%)$

Model	Glo/Dif RMS (U_{mod})	Glo/Dif MBE (U_{bias})	Dir RMS (U_{mod})	Dir MBE (U_{bias})
METSTAT	8	2	15	4
SUNY	5	0	14	1

$$U_{opt} = (U_{meas}^2 + U_{mod}^2 + U_{bias}^2)^{1/2} (\pm\%)$$

$U_{opt} (\pm\%)$

Model	Glo/Dif	Dir
METSTAT	10	16
SUNY	8	15

$U_{add} \text{ Satellite } (\pm\%)$

Condition	Additional Uncertainty
Time shifting	2
Ground snow cover	5
High latitude	10

$U_{add} \text{ METSTAT } (\pm\%)$

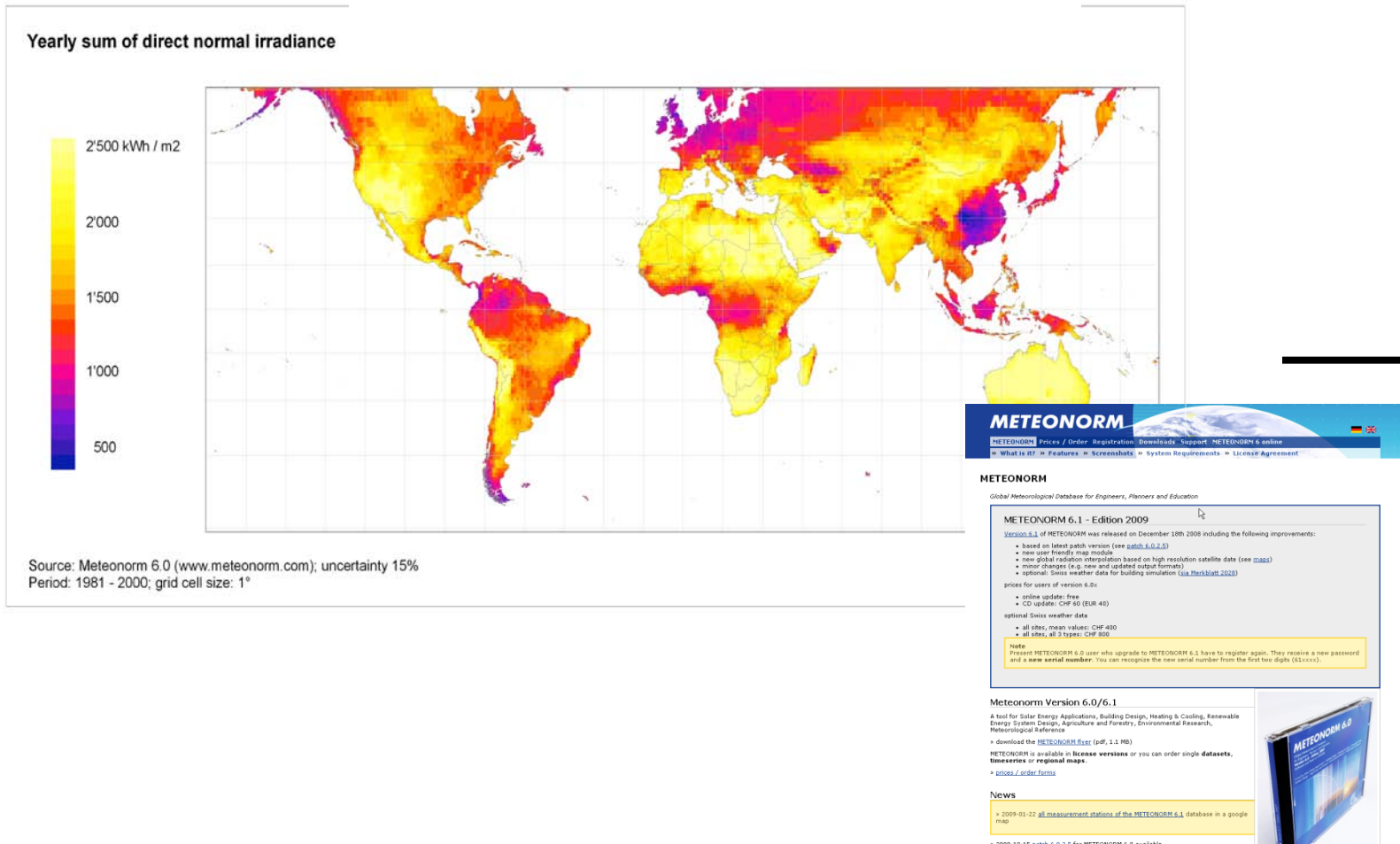
Condition	Additional Uncertainty
Short- and med-termfilling	4
Long-term filling	14
Cloud probability derivation	4
Cloud probability nearby site	4
ASOS-only	22

$$U_{95} = (U_{opt}^2 + U_{add1}^2 + U_{add2}^2 \dots)^{1/2} (\pm\%)$$

Sanity Check: Other Methods; Meteonorm

DIRECT

Source: Meteonorm 6.0 (www.meteonorm.com); uncertainty 15%
Period: 1981 - 2000; grid cell size: 1°



Analysis 6 Solar Databases Europe

Šúri1, et al., “First Steps in the Cross-Comparison of Solar Resource Spatial Products in Europe” *Proceeding of the EUROSUN 2008,*

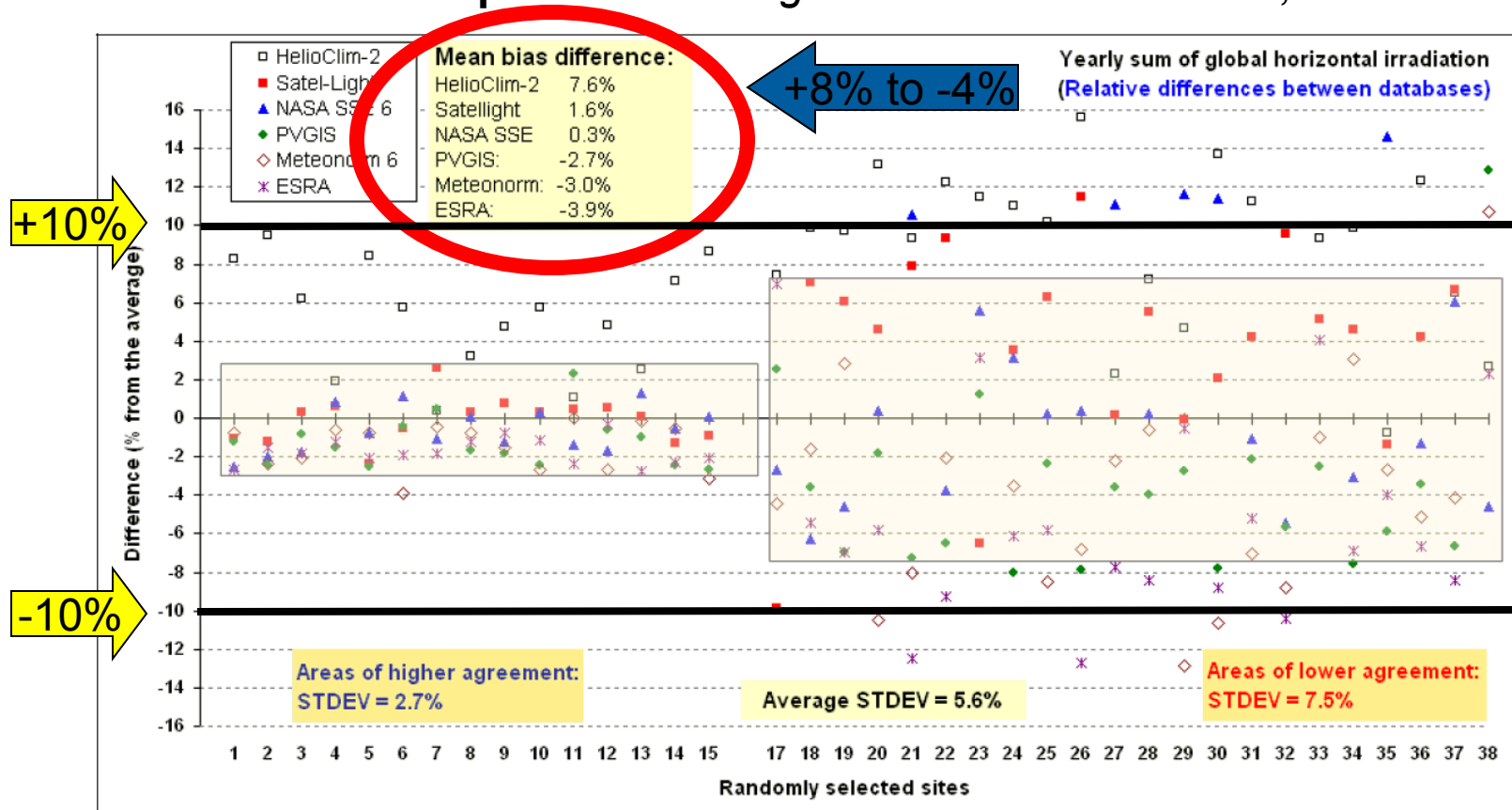
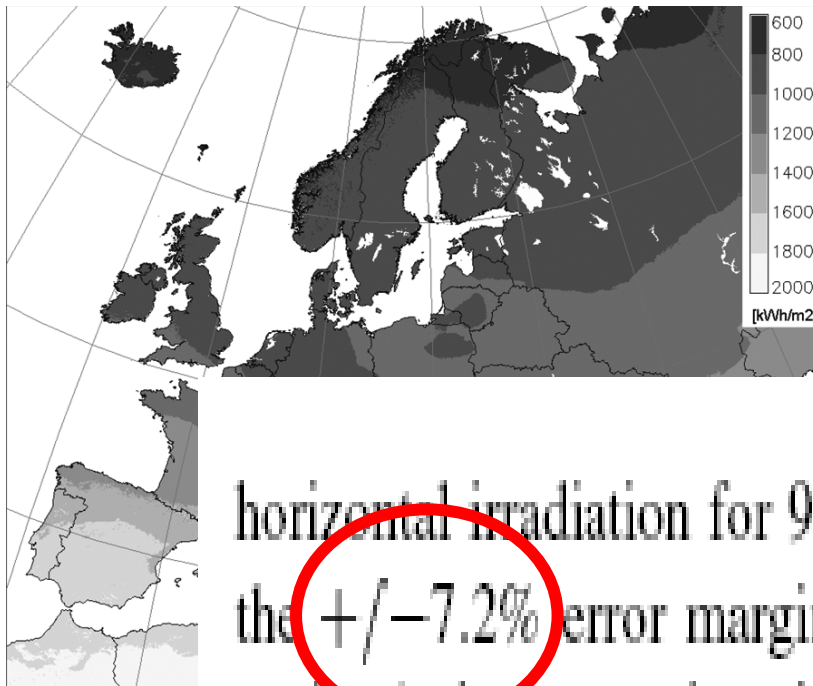


Fig. 3. Yearly sum of global horizontal irradiation – differences of the values from 6 databases relative to the overall average. First 15 points represent areas with higher agreement between databases; the other 22 points are randomly selected in areas where the difference between the databases is higher.

European PVGIS Uncertainty

Súri et al., “Geographic Aspects of Photovoltaics in Europe: Contribution of the PVGIS Website” *IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING*, VOL. 1, NO. 1, MARCH 2008



—the estimate of yearly global horizontal irradiation for 90% of station locations falls within the $\pm 7.2\%$ error margin, and in 19 locations (3.5% of all stations) the uncertainty is higher than $\pm 10\%$.

PV system monitoring vs satellite based solar maps

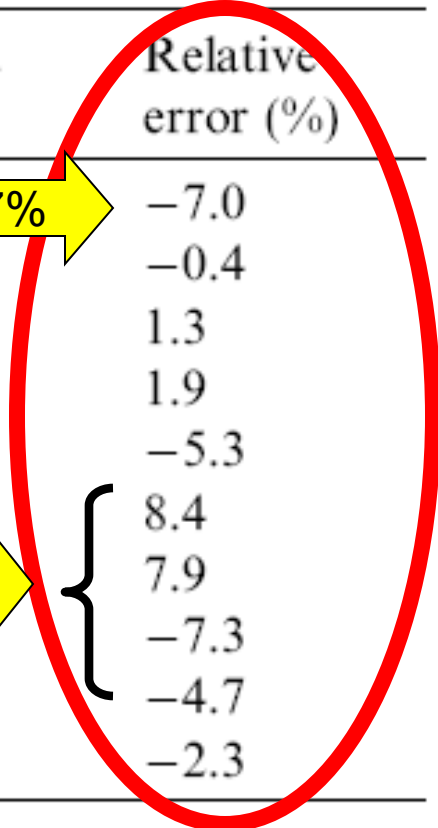
A. Drews et al., “Quality of performance assessment of PV plants based on irradiation maps”, *Solar Energy* 82 (2008) 1067–1075

Modeled and measured annual yield of the 10 systems under inspection

Location	Modeled yield (kWh/kW)	Measured yield (kWh/kW)	Relative error (%)
Borna	928	998	-7.0
Seiffenndorf	926	930	-0.4
Starbach	942	930	1.3
Hartha	976	957	1.9
Zwickau	906	957	-5.3
Plauen	921	850	8.4
Berzdorf	1040	964	7.9
Freiberg	906	977	-7.3
Mittweida	912	958	-4.7
Dresden	966	989	-2.3

-7%

-5 to +8 %



Sample Results: European Benchmarking Satellite vs Ground (IEA Task 36)

Station	GHI av [W/m ²]	nov	R ²	Bias%	RMSD%	KSI%	DNI av [W/m ²]	nov	R ²	Bias%	RMSD%	KSI%
Camborne (BSRN, 2001-2003)	238.5	10815	0.95	-1.01%	29.77%	0	262.5	7655	0.83	-0.52%	60.98%	0
Carpentras (BSRN, 2000)	345.8	5618	0.98	2.82%	18.55%	0	482.4	4779	0.9	2.66%	31.41%	0
DeAar (BSRN, 2001-2003)	501.5	9168	0.97	3.44%	16.76%	0	673.9	8469	0.9	0.89%	23.80%	0
Geneva (IDMP, 2002-2003)	309.9	6560	0.95	7.74%	29.37%	0	372.9	5384	0.84	7.52%	52.58%	0
Lerwick (BSRN, 2001-2003)	174.1	12112	0.93	-1.72%	38.64%	0	187.2	7082	0.68	-9.43%	92.72%	0
Payerne (BSRN, 2000-2003)	383.6	11139	0.96	0.66%	18.84%	0	428.3	9886	0.87	-3.33%	36.88%	0
SedeBoqer (BSRN, 2003 - 2005)	561.5	10048	0.98	4.64%	12.96%	0	607.2	9934	0.78	-2.50%	30.37%	0
SolarVillage (BSRN, 2000 - 2002)	574	11640	0.98	-0.02%	10.84%	0	578.1	11418	0.81	-0.37%	31.09%	0
all	387.3	77100	0.97	1.93%	18.79%	0	467.8	64607	0.87	-0.73%	36.83%	0

Time scale	RMSD GHI %	R ²	RMSD DNI %	R ²
hour	18.79%	0.97	36.83%	0.87
day	11.08%	0.99	23.58%	0.95
month	4.95%	0.99	9.69%	0.99
year	3.66%	0.99	4.92%	0.99

SUMMARY

- Measured data SPARSE and EPISODIC
- Specialized Measured Data available
- Measured-Model broadband difference patterns ~ 10% - 15% Typical
- Uncertainty Function of Site, INPUT data and REFERENCE DATA uncertainties
- Data Sources PROLIFERATING; benchmarking is a RESEARCH project !!
 - International Energy Agency Task 36 on Solar Radiation Knowledge Management <http://www.iea-shc.org/task36/index.html>
- U.S. Satellite (SUNY) Uncertainty comparable European Estimates (state of the art)

NOTE: MODELS CONTINUOUSLY EVOLVING !

Measurements AND models: Similar Uncertainty Limits:

5% - 10% Global Month Mean Daily Total

10%- 15% Direct Month Mean Daily Total

Statistics help, but this is essentially WEATHER data!

***Rating Conditions: DNI ~ 900 W/m² appropriate compromise with GNI,
Flat Plate ~ 1000, and DNI Reference spectrum***