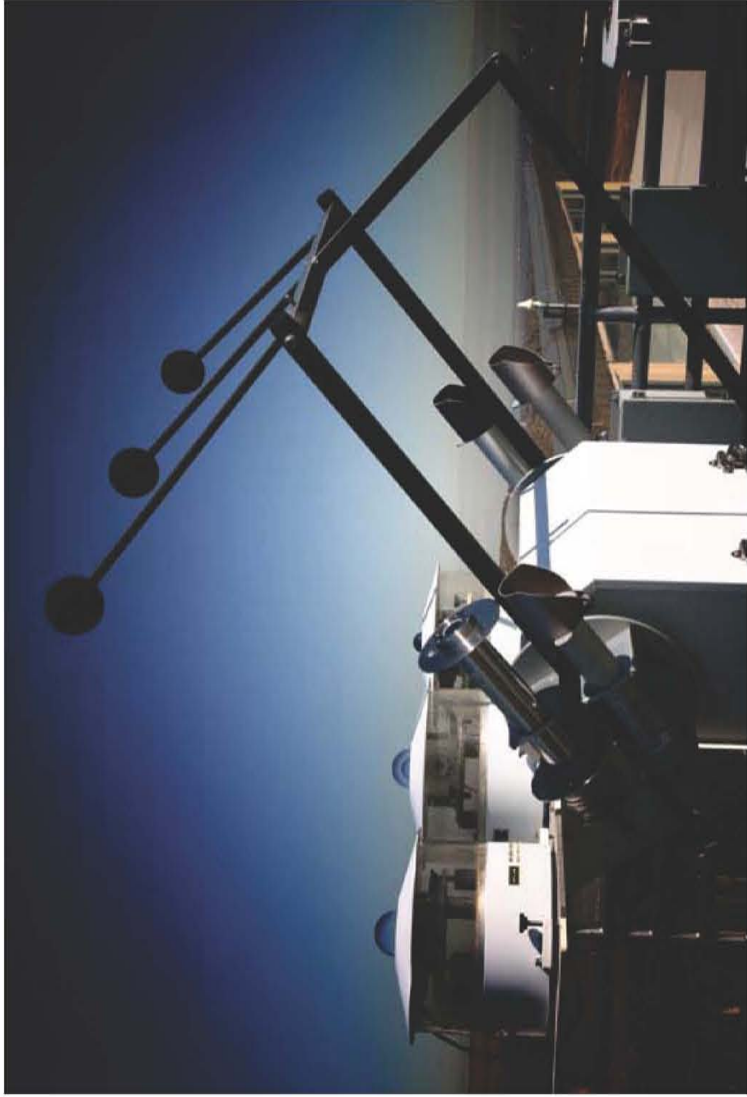




National Renewable Energy Laboratory
Innovation for Our Energy Future



Overview of Solar Resource Data

- National Solar Radiation Database (NSRDB)
- State University of New York at Albany 10 km Gridded Data (“Perez”)
- Data Uncertainty
- Typical Meteorological Year Data Sets
- Measured Site Specific or Network Data

National Solar Radiation Database

Original NSRDB (1961-1990)

- 239 sites based on NWS stations with a 30-year period of record
- Developed as an update to the SOLMET/ERSATZ data set
- Serially complete sunup data set (some met data filled)
- 93% of solar data modeled
- Used widely by solar designers, building architects, and engineers
- Foundation for value added products (TMY2, data manuals)

NSRDB *Features of the 91-05 Update*

- 10-km SUNYA modeled gridded hourly global, direct, and diffuse data set derived from GOES satellite data for 1998-2005 (100,000+ pixels)
- 800+ sites for 1991-2005 with complete period of record (compared with 239 for old NSRDB).
- Another 650 sites with some useful resource data
- All 1961-1990 sites represented in updated data set
- Almost all solar data modeled (some measured data exist for about 40 sites, but represents < 1% of all data)

NSRDB *Why So Much Modeled Data?*

- Ground measurements are expensive
 - Equipment (radiometers, trackers)
 - Infrastructure (communications, power, venue)
 - Manpower (ongoing cleaning and maintenance)
 - Not foolproof (data must be carefully examined)
- Often inconsistent from site to site
 - Different level of funding and commitment
 - Measurements with differing purpose or goals
 - Instrumentation (varying quality)
 - Quality of Staff
- Modeled data provides solar estimates from other data sets, funded and maintained by other agencies
 - National Weather Service surface observations
 - Satellite data (a tremendous windfall offering high spatial resolution)

NSRDB Addressing Update Issues

- NWS no longer making manual cloud observations (total and opaque) required for METSTAT model and have been replaced by the Automated Surface Observing System (ASOS)
- Addressed by combining ASOS ground data (low clouds) with NCDC Supplemental Cloud Product (high clouds) for total and opaque cloud estimates
- Where supplement cloud product not available (about half of the sites, including all of Alaska), statistical derived cloud values were used to match climate norms
- These methods produced data sets with varying levels of uncertainty.

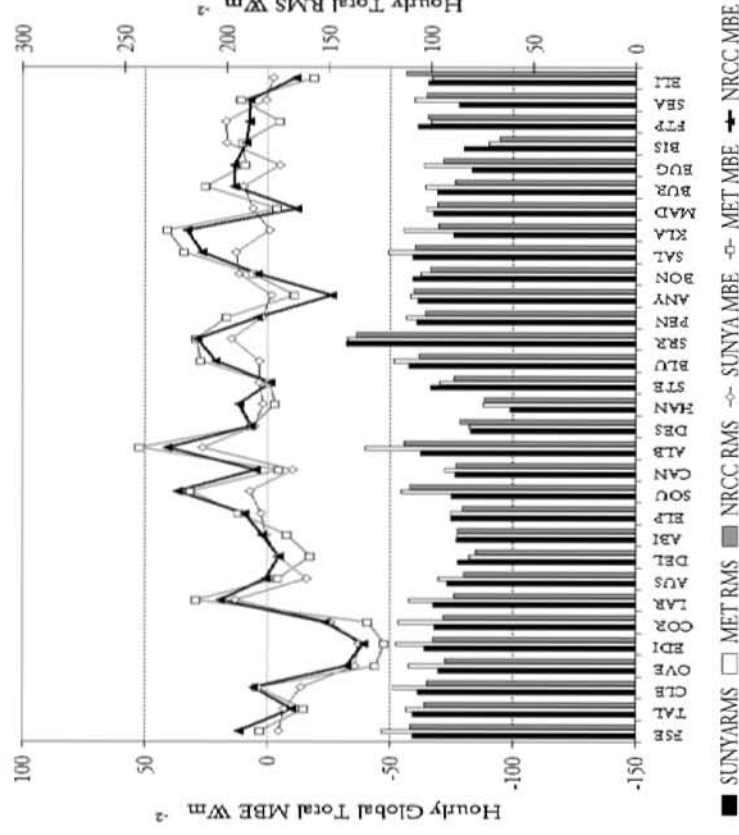
NSRDB Model Selection

Three Models Evaluated for NSRDB

1. Northeast Regional Climate Center (NRCC) developed ASOS-specific model (enhanced with satellite cloud estimates)
2. NREL METSTAT Model (used for original 1961-1990 NSRDB)
3. SUNYA satellite model
 - All models performed comparably in evaluation
 - METSTAT chosen because of its NSRDB legacy and convenience for processing
 - SUNYA Model chosen for its consistency, high resolution coverage, and potential for future (but only available 1998-2005)

NSRDB Model Evaluation

- All models performed similarly, although the satellite model had consistently smaller errors.
- Variations between sites is larger than variations among models at each site.
- Model selection based on convenience and ease of use.



NSRDB *Satellite-derived Data Sets*

- Data (Global, Direct, Diffuse) from SUNYA Satellite model included for subset of years
- Provides enhanced spatial resolution (10-km grid)
- Required time-shifting of data to conform with the top-of-the hour, hourly integrated realm of the NSRDB
- Undoubtedly represents the future of solar resource assessment data sets

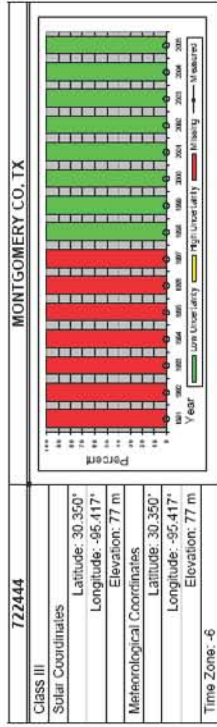
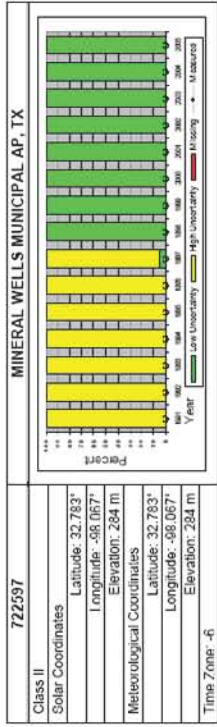
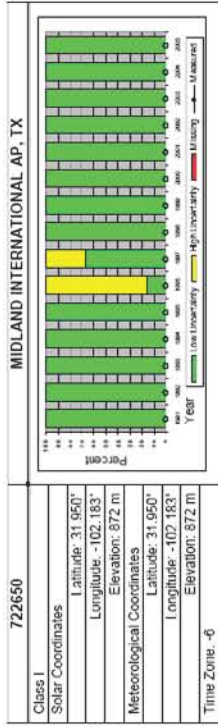
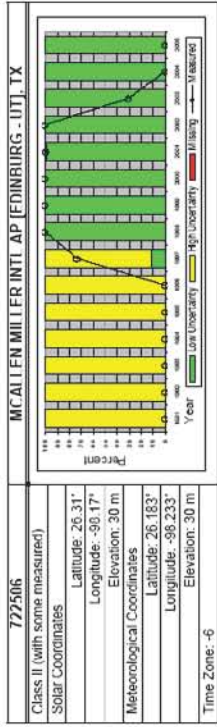
NSRDB Aerosols, Water Vapor, Ozone

- 10-km gridded data set for aerosols, water vapor, and ozone.
- Aerosols derived from NASA MISR and MODIS satellite data, surface AERONET (sun photometry), and legacy NSRDB DNI broadband estimates. **Data formed as climatological means**
- Water vapor derived from NASA Water Vapor Project (NVAP) or North American Regional Reanalysis (NARR) ($1^\circ \times 1^\circ$, $0.5^\circ \times 0.5^\circ$, or 32-km cells interpolated to 10-km cells)
- Ozone from Total Ozone Mapping Scanner (TOMS) ($1^\circ \times 1\frac{1}{4}^\circ$ cells interpolated to 10-km cells)
- For the ground stations, GIS used to select nearest cell

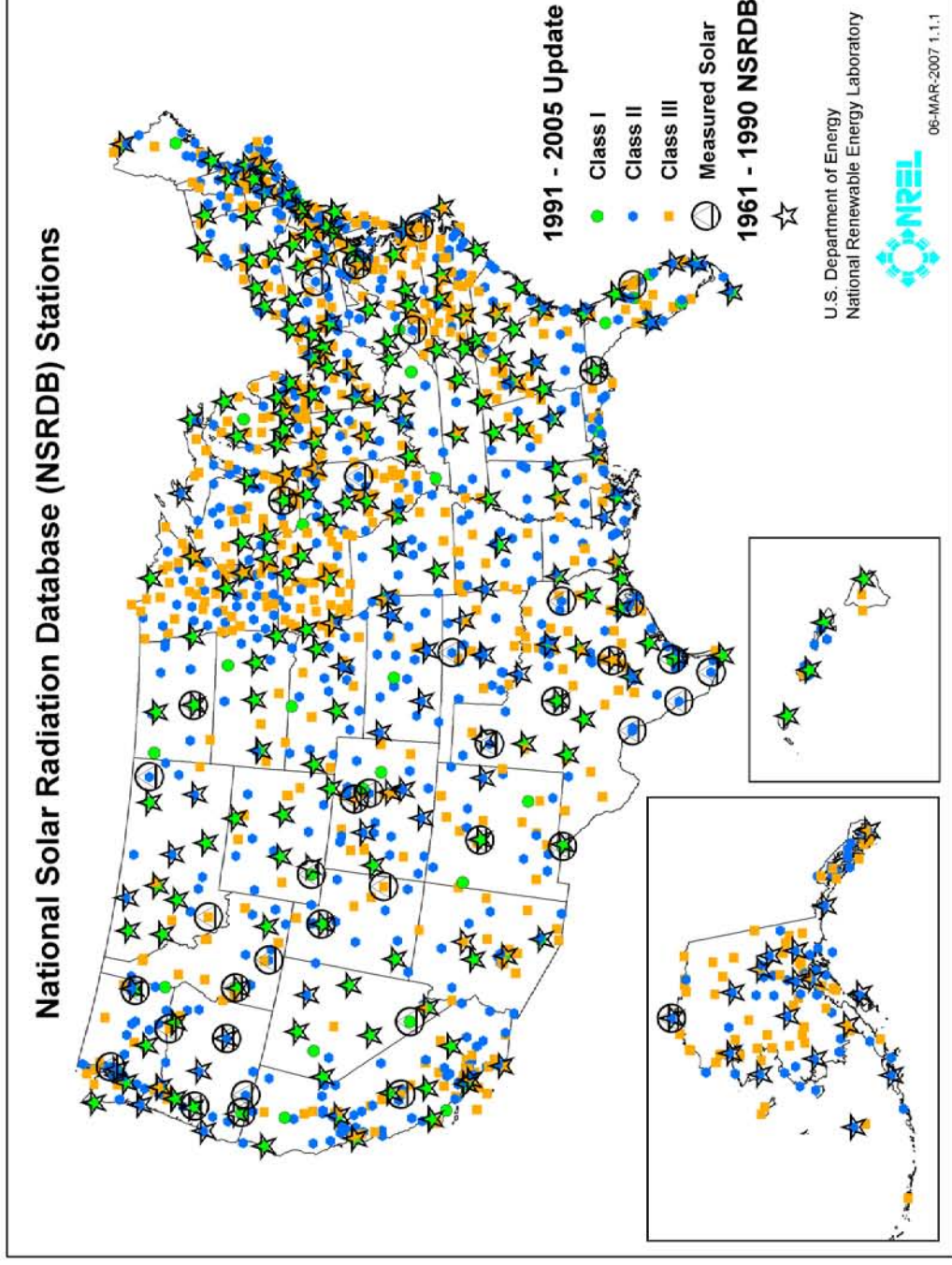
NSRDB Site Classifications

- Sites are segregated based on availability, quality, and completeness of data
 - **Class I** sites (221) have complete period of record for all parameters for 1991-2005 and have data with the lowest uncertainty ($\pm 10\text{-}15\%$)
 - **Class II** sites (637) have a complete period of record, but data are of higher uncertainty ($\pm 15\text{-}25\%$)
 - **Class III** sites (596) are not serially complete, but have at least three years of solar and pertinent meteorological data from 1991-2005
- This classification scheme helps optimize the quality and quantity of data available for a wide range of applications.

NSRDB User's Manual



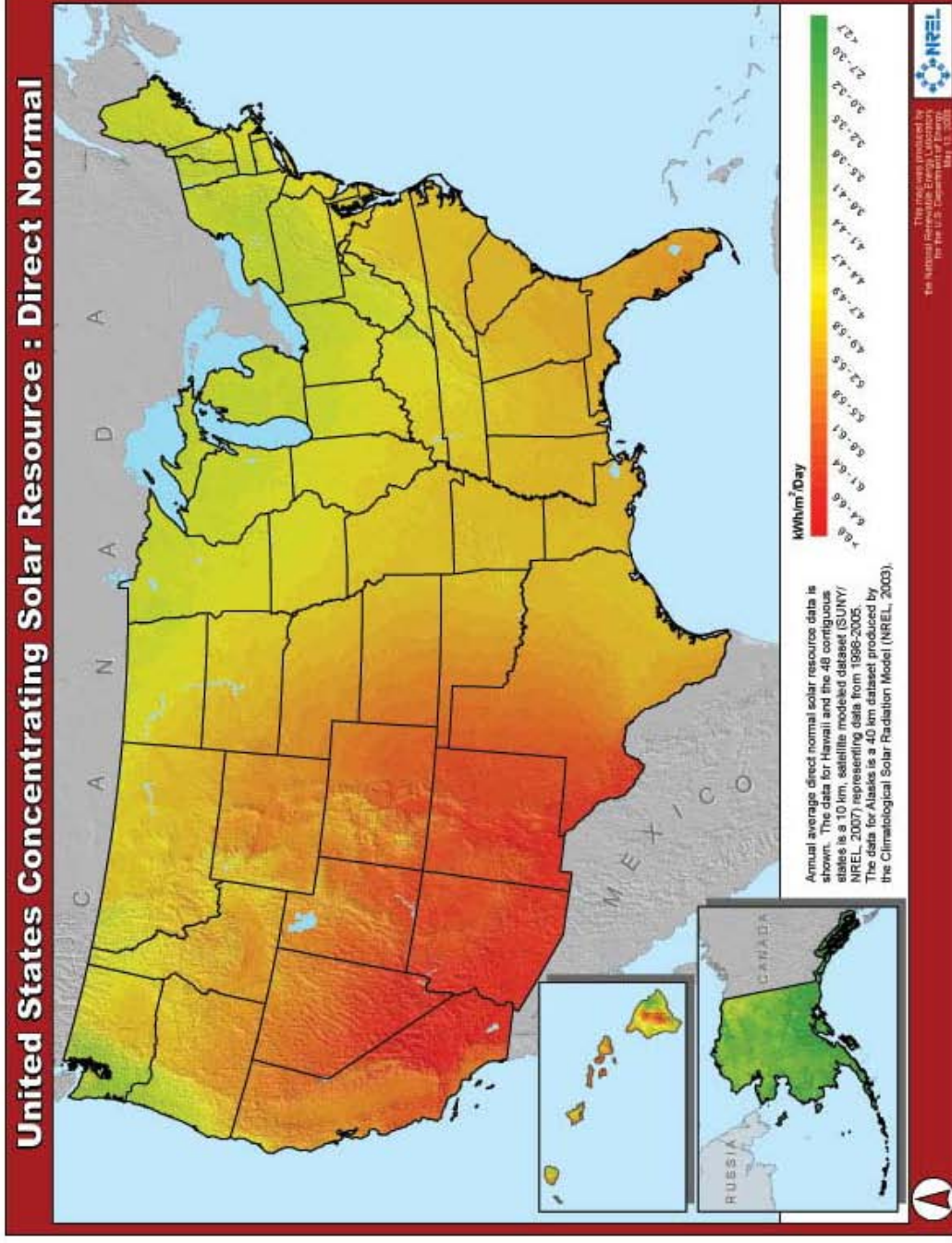
NSRDB Site Map



NSRDB Data Products

- Solar Radiation
 - Global, Direct, Diffuse (measured, modeled, modeled clear-sky).
 - Measured data are not merged with modeled data (separate fields)
- Meteorological
 - Cloud cover (total and opaque)
 - Temperature (dry bulb, dew point), humidity
 - Wind direction and speed
 - Barometric pressure, visibility
 - Aerosols, water vapor, ozone

NSRDB Solar Maps



NSRDB Hourly Statistics Files

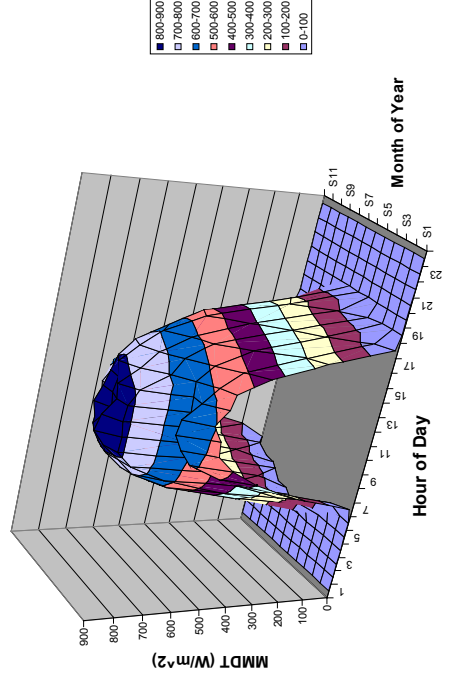
DIRECT MEANS

1	I	6	0	0	0	0	0	0	0	14	247	400	502	563	570	606	565	556	445	252	9	0	0	0	0	0	0
2	I	6	0	0	0	0	0	0	0	53	305	506	625	668	699	691	633	585	512	295	55	0	0	0	0	0	0
3	I	6	0	0	0	0	0	0	12	228	405	499	607	621	605	631	632	637	586	460	208	2	0	0	0	0	0
4	I	6	0	0	0	0	0	0	100	420	634	764	819	816	823	818	789	693	661	572	304	22	0	0	0	0	0
5	I	6	0	0	0	0	0	19	314	585	721	782	842	884	870	828	837	771	720	620	421	105	0	0	0	0	0
6	I	6	0	0	0	0	0	51	398	623	736	797	819	861	809	818	809	821	760	691	553	256	2	0	0	0	0
7	I	6	0	0	0	0	0	22	317	594	730	789	823	830	844	826	811	795	749	645	534	219	1	0	0	0	0
8	I	6	0	0	0	0	0	0	131	446	626	739	758	746	762	741	679	664	568	506	293	49	0	0	0	0	0
9	I	6	0	0	0	0	0	0	30	326	546	661	717	730	740	674	617	540	449	346	93	0	0	0	0	0	0
10	I	6	0	0	0	0	0	0	3	174	467	627	681	732	740	711	681	584	452	199	8	0	0	0	0	0	0
11	I	6	0	0	0	0	0	0	0	43	320	510	633	660	683	689	606	509	343	57	0	0	0	0	0	0	0
12	I	6	0	0	0	0	0	0	0	2	93	282	380	428	445	447	405	298	169	14	0	0	0	0	0	0	0
13	I	6	0	0	0	0	0	8	109	292	486	613	684	712	716	707	672	621	535	388	207	54	0	0	0	0	0

DIRECT STANDARD DEVIATIONS

1	I	6	0	0	0	0	0	0	0	17	201	323	354	359	367	355	342	297	304	174	17	0	0	0	0	0	0
2	I	6	0	0	0	0	0	0	0	63	238	300	305	338	343	349	357	336	303	236	59	0	0	0	0	0	0
3	I	6	0	0	0	0	0	0	27	195	310	358	349	383	413	393	379	344	327	275	139	6	0	0	0	0	0
4	I	6	0	0	0	0	0	0	79	180	176	123	143	167	166	189	174	214	182	175	150	23	0	0	0	0	0
5	I	6	0	0	0	0	0	22	147	159	151	189	145	97	127	157	126	198	18	175	150	23	0	0	0	0	0
6	I	6	0	0	0	0	0	34	156	194	199	193	183	155	237	226	207	177	21	175	150	23	0	0	0	0	0
7	I	6	0	0	0	0	0	22	156	174	191	192	208	223	225	200	218	179	20	175	150	23	0	0	0	0	0
8	I	6	0	0	0	0	0	0	102	182	200	142	201	245	214	220	252	217	23	175	150	23	0	0	0	0	0
9	I	6	0	0	0	0	0	0	27	154	191	208	197	226	224	241	249	287	25	175	150	23	0	0	0	0	0
10	I	6	0	0	0	0	0	0	6	123	167	172	188	155	182	183	200	233	19	175	150	23	0	0	0	0	0
11	I	6	0	0	0	0	0	0	0	40	146	167	167	173	170	153	194	191	15	175	150	23	0	0	0	0	0
12	I	6	0	0	0	0	0	0	0	3	91	187	224	258	238	236	226	213	13	175	150	23	0	0	0	0	0
13	I	6	0	0	0	0	0	16	149	239	213	172	143	133	125	113	125	145	17	175	150	23	0	0	0	0	0

Monthly Diurnal Profiles - Daggett, CA



NSRDB Daily Statistics Files

723815 DAGGETT BARSTOW-DAGGETT CA -8 N34 51 W116 48 586 945 1991-2005																							
MO	AVGLO	FL	SDGLO	AVDTR	FL	SDDIR	AVDIF	FL	SDDIF	AVETR	ATRN	TOT	OPQ	H2O	TAU	MAX_T	MIN_T	AVG_T	AVGDT	RH	HTDD	CLDD	AWWS
1	2955	K5	314	4674	K6	1030	997	K5	112	5183	14241	4.2	3.1	1.02	0.06	16.08	3.41	9.22	11.71	51	266	0	3.6
2	3792	K5	316	5075	K6	908	1299	K5	156	6596	15276	4.4	3.3	1.02	0.06	17.96	5.23	11.24	13.81	49	191	0	4.2
3	5306	K5	436	6570	K6	1069	1503	K5	172	8409	16501	3.2	2.4	1.03	0.08	22.10	8.13	14.90	17.54	42	112	12	5.1
4	6753	K5	276	7335	K6	696	1904	K5	222	10065	17695	2.6	1.6	1.07	0.12	25.73	10.86	18.17	20.80	34	53	52	6.2
5	7681	K5	305	8326	K6	883	1969	K5	283	11144	18648	2.3	1.4	1.37	0.10	31.60	15.81	23.75	25.92	30	8	175	6.4
6	8217	K5	174	9349	K6	603	1707	K5	232	11551	19079	1.1	0.7	1.47	0.09	36.54	19.76	28.29	30.60	25	1	296	6.1
7	7637	K5	296	8618	K6	754	1719	K5	226	11286	18749	1.6	1.2	2.03	0.08	40.04	23.36	31.81	34.00	25	0	414	5.3
8	6936	K5	206	8032	K6	467	1617	K5	138	10365	17824	1.6	1.3	2.17	0.09	39.57	23.15	31.36	34.14	26	0	404	4.9
9	6034	K5	213	7840	K6	668	1292	K5	178	8894	16671	1.4	1.0	1.73	0.07	35.31	19.15	27.12	29.97	29	0	267	4.5
10	4700	K5	174	6779	K6	540	1139	K5	126	7104	15470	1.8	1.3	1.29	0.07	28.39	13.17	20.39	23.44	32	25	101	4.3
11	3473	K5	128	5845	K6	481	940	K5	83	5505	14395	2.7	1.8	1.08	0.06	20.28	5.99	12.59	15.87	38	159	3	4.8
12	2786	K5	231	4915	K6	884	880	K5	114	4737	13854	3.4	2.5	0.98	0.06	15.61	2.35	8.42	11.24	45	290	0	3.4
13	5523	K5	128	6946	K6	449	1414	K5	117	8403	16534	2.5	1.8	1.36	0.08	27.43	12.53	19.77	22.42	36	1105	1725	4.8
1991																							
1	2857	I5	965	4730	I6	2736	886	I5	310	5177	14236	4.3	3.0	1.05	0.04	14.35	1.65	7.36	9.74	54	320	0	3.4
2	3951	I5	990	5627	I6	2828	1151	I5	480	6578	15262	4.4	2.6	1.03	0.05	22.10	6.70	13.78	17.06	32	110	0	3.8
3	4985	I5	1515	6134	I6	3424	1449	I5	638	8382	16481	3.9	3.0	1.00	0.06	17.59	5.02	11.14	13.27	50	218	0	6.3
4	7061	I5	609	8236	I6	1708	1631	I5	551	10044	17677	2.0	0.9	1.10	0.10	24.66	9.70	17.10	19.68	36	50	15	6.9
5	8044	I5	606	9319	I6	1685	1600	I5	514	11133	18635	2.0	1.0	1.28	0.09	28.25	13.15	20.79	22.76	31	22	95	7.2
6	8260	I5	877	9806	I6	2251	1530	I5	646	11549	19078	1.7	1.0	1.52	0.08	34.93	18.55	26.73	28.96	28	0	252	6.2
7	7974	I5	1054	9529	I6	2399	1428	I5	585	11295	18760	1.7	1.2	2.11	0.08	39.61	22.80	31.32	33.48	28	0	399	4.9
8	6964	I5	962	7708	I6	2134	1747	I5	569	10384	17837	1.9	1.5	2.33	0.12	38.31	22.13	29.98	32.72	30	0	369	5.1
9	5726	I5	860	6469	I6	2077	1664	I5	506	8919	16690	2.6	2.0	2.22	0.14	35.67	20.12	27.72	30.40	35	0	287	3.8
10	4646	I5	626	6058	I6	1730	1351	I5	435	7130	15490	1.5	0.9	1.40	0.17	3							
11	3426	I5	445	5053	I6	1358	1104	I5	274	5524	14411	2.1	1.0	1.21	0.18	2							
12	2424	I5	514	2962	I6	1546	1186	I5	234	4740	13856	4.3	2.9	1.16	0.21	1							
13	5527	I5	2110	6803	I6	2138	1394	I5	264	8405	16534	2.7	1.8	1.45	0.11	2							
1992																							
1	2757	I5	811	3673	I6	2166	1139	I5	314	5169	14230	3.3	2.3	0.92	0.22	1							
2	3396	I5	1152	3266	I6	2165	1654	I5	389	6593	15276	5.1	3.6	1.23	0.24	1							
3	4013	I5	1494	3226	I6	2752	2062	I5	523	8426	16508	5.6	4.4	1.22	0.24	1							
4	6447	I5	792	5538	I6	1662	2622	I5	536	10078	17702	4.5	1.8	1.31	0.26	2							
5	7219	I5	763	6041	I6	2120	2800	I5	788	11150	18653	4.3	2.1	1.70	0.23	3							
6	7973	I5	915	7900	I6	2217	2269	I5	728	11551	19079	1.4	0.8	1.72	0.20	3							
7	7236	I5	1482	6794	I6	2778	2357	I5	721	11281	18744	2.6	2.0	2.25	0.19	3							
8	6907	I5	748	7233	I6	1877	1954	I5	583	10354	17816	1.7	1.2	2.58	0.17	3							
9	5964	I5	617	6892	I6	1837	1650	I5	568	8878	16663	1.8	1.0	1.87	0.14	3							
10	4401	I5	1101	5761	I6	2585	1308	I5	452	7087	15463	2.5	1.8	1.52	0.14	2							
11	3435	I5	541	5626	I6	1960	942	I5	381	5493	14387	2.4	1.3	1.18	0.11	1							
12	2530	I5	708	4089	I6	2385	912	I5	286	4735	13854	3.8	2.9	0.99	0.11	1							
13	5190	I5	1965	5503	I6	1602	1806	I5	643	8400	16531	3.2	2.1	1.54	0.19	2							
1993																							
1	2757	I5	811	3673	I6	2166	1139	I5	314	5169	14230	3.3	2.3	0.92	0.22	1							
2	3396	I5	1152	3266	I6	2165	1654	I5	389	6593	15276	5.1	3.6	1.23	0.24	1							
3	4013	I5	1494	3226	I6	2752	2062	I5	523	8426	16508	5.6	4.4	1.22	0.24	1							
4	6447	I5	792	5538	I6	1662	2622	I5	536	10078	17702	4.5	1.8	1.31	0.26	2							
5	7219	I5	763	6041	I6	2120	2800	I5	788	11150	18653	4.3	2.1	1.70	0.23	3							
6	7973	I5	915	7900	I6	2217	2269	I5	728	11551	19079	1.4	0.8	1.72	0.20	3							
7	7236	I5	1482	6794	I6	2778	2357	I5	721	11281	18744	2.6	2.0	2.25	0.19	3							
8	6907	I5	748	7233	I6	1877	1954	I5	583	10354	17816	1.7	1.2	2.58	0.17	3							
9	5964	I5	617	6892	I6	1837	1650	I5	568	8878	16663	1.8	1.0	1.87	0.14	3							
10	4401	I5	1101	5761	I6	2585	1308	I5	452	7087	15463	2.5	1.8	1.52	0.14	2							
11	3435	I5	541	5626	I6	1960	942	I5	381	5493	14387	2.4	1.3	1.18	0.11	1							
12	2530	I5	708	4089	I6	2385	912	I5	286	4735	13854	3.8	2.9	0.99	0.11	1							
13	5190	I5	1965	5503	I6	1602	1806	I5	643	8400	16531	3.2	2.1	1.54	0.19	2							
1994																							
1	2757	I5	811	3673	I6	2166	1139	I5	314	5169	14230	3.3	2.3	0.92	0.22	1							
2	3396	I5	1152	3266	I6	2165	1654	I5	389	6593	15276	5.1	3.6	1.23	0.24	1							
3	4013	I5	1494	3226	I6	2752	2062	I5	523	8426	16508	5.6	4.4	1.22	0.24	1							
4	6447	I5	792	5538	I6	1662	2622	I5	536	10078	17702	4.5	1.8	1.31	0.26	2							
5	7219	I5	763	6041	I6	2120	2800	I5	788	11150	18653	4.3	2.1	1.70	0.23	3							
6	7973	I5	915	7900	I6	2217	2269	I5	728	11551	19079	1.4	0.8	1.72	0.20	3							
7	7236	I5	1482	6794	I6	2778	2357	I5	721	11281	18744	2.6	2.0	2.25	0.19	3							
8	6907	I5	748	7233	I6	1877	1954	I5	583	10354	17816	1.7	1.2	2.58	0.17	3							
9																							

NSRDB – Threshold Statistics Files

MONTHLY PERSISTENCE REPORT, SITE #723815, DAGGETT BARSTOW-DAGGET (CA), MONTH 1, DIRECT																													
Number of runs of days solar energy EXCEEDED threshold															Number of runs of days solar energy LESS THAN threshold														
(Run length in DAYS)															(Run length in DAYS)														
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+ Wh/m2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 10000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 15
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 9000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 15
9	1	1	0	0	0	0	0	0	0	0	0	0	0	0 8000	2	0	0	2	1	1	1	0	1	0	0	1	2	1	13
45	10	3	2	0	0	0	0	0	0	0	0	0	0	0 7000	16	16	8	5	6	5	3	1	2	0	0	1	1	2	7
47	26	7	4	2	0	1	0	0	1	0	0	0	0	0 6000	34	24	11	9	1	5	4	0	0	1	1	0	0	1	3
28	20	12	11	4	3	1	0	2	1	0	0	0	0	1 5000	33	26	8	5	5	3	1	0	1	0	1	1	0	0	1
26	15	11	8	5	3	2	1	2	2	2	1	0	1	2 4000	37	25	8	3	1	0	2	0	1	0	1	0	0	0	0
22	7	8	3	3	4	6	2	1	3	3	3	0	0	4 3000	34	17	4	4	1	1	1	0	0	0	0	0	0	0	0
16	10	5	4	1	2	2	3	1	2	2	0	0	1	9 2000	30	15	1	3	0	1	0	0	0	0	0	0	0	0	0
9	12	4	1	0	2	2	3	0	1	0	0	0	1	14 1000	31	6	2	0	0	0	0	0	0	0	0	0	0	0	0
6	7	1	3	2	2	1	0	0	0	1	0	0	0	15 500	19	6	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	15 0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

NSRDB Data Distribution

- Free data
 - Solar fields (satellite and ground modeled, measured, extraterrestrial, clear-sky modeled)
 - Aerosols, water vapor, ozone,
 - Solar geometry (zenith/azimuth)
- Fee-based data
 - Conventional meteorological fields (temperature, humidity, wind, clouds, barometric pressure, visibility, ceiling height, precipitation)

NSRDB Products

Data Set	Distributor	URL
NSRDB solar and filled meteorological fields	NCDC	ftp://ftp.ncdc.noaa.gov/pub/data/noaa [No-cost access is domain-restricted to .mil, .gov, .edu, and .k12. A fee-access restriction applies to all other domains]
NSRDB solar and ISH meteorological fields (no data filling)	NCDC	http://cdo.ncdc.noaa.gov [No-cost access is domain-restricted to .mil, .gov, .edu, and .k12. A fee-access restriction applies to all other domains]
NSRDB solar fields; NO meteorological	NCDC	ftp://ftp.ncdc.noaa.gov/pub/data/nsrdb-solar (no fee)
SUNY 10-km gridded data	NCDC	ftp://ftp.ncdc.noaa.gov/pub/data/nsrdb-solar (no fee)
NSRDB statistical summaries	NCDC	ftp://ftp.ncdc.noaa.gov/pub/data/nsrdb-solar (no fee)
NSRDB research solar fields; NO meteorological	NREL	http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005 (no fee)

NSRDB *Ongoing Updates*

- NREL Plans to update the NSRDB with more recent data in the near future
- Currently negotiating an agreement to obtain the more recent SUNY data (now proprietary to Clean Power Research)
- More current data (i.e. 2006-present) is presently available from commercial sources.

SUNY Satellite Gridded Data

Ray George

NSRDB Data Uncertainty

Daryl Myers

Typical Meteorological Year (TMY)

- Represents a year of actual data that typifies the climate for a location
- Widely used by building designers and for modeling renewable energy conversion systems
- Provides a data set with natural diurnal and seasonal variations
- Does not reveal climate extremes (e.g. minimum or maximum temperatures, unusual persistence, climatic anomalies, etc.)
- Originally intended for use to *compare* various modeling scenarios – NOT for absolute performance based on climate.
- **Should not be used for real-time system validation or weather prediction.**

TMY3 Features

- TMY3 is a new data set derived from the 1991-2005 NSRDB Update
- 1020 locations (vs. 239 for the TMY2)
- New format – comma separated value (CSV) format.
More compatible with modern software that ingest CSV data.
- Includes TMY3 to TMY2 conversion utility for compatibility with legacy software

TMY3 Site Selection Dilemma

How to incorporate the 91-05

NSRDB Update for TMY...

- 1) Create a TMY based on the 30 most recent years of data (1976-2005) from the 237 sites that overlap the old and new NSRDB (**fewer sites, better data pool**)
- 2) Create a TMY based on the 15 most recent years of data for approximately 1000 sites from the NSRDB update (**more sites, smaller data pool**)

TMY3 Site Selection Decision

A hybrid solution that optimizes both temporal and spatial considerations

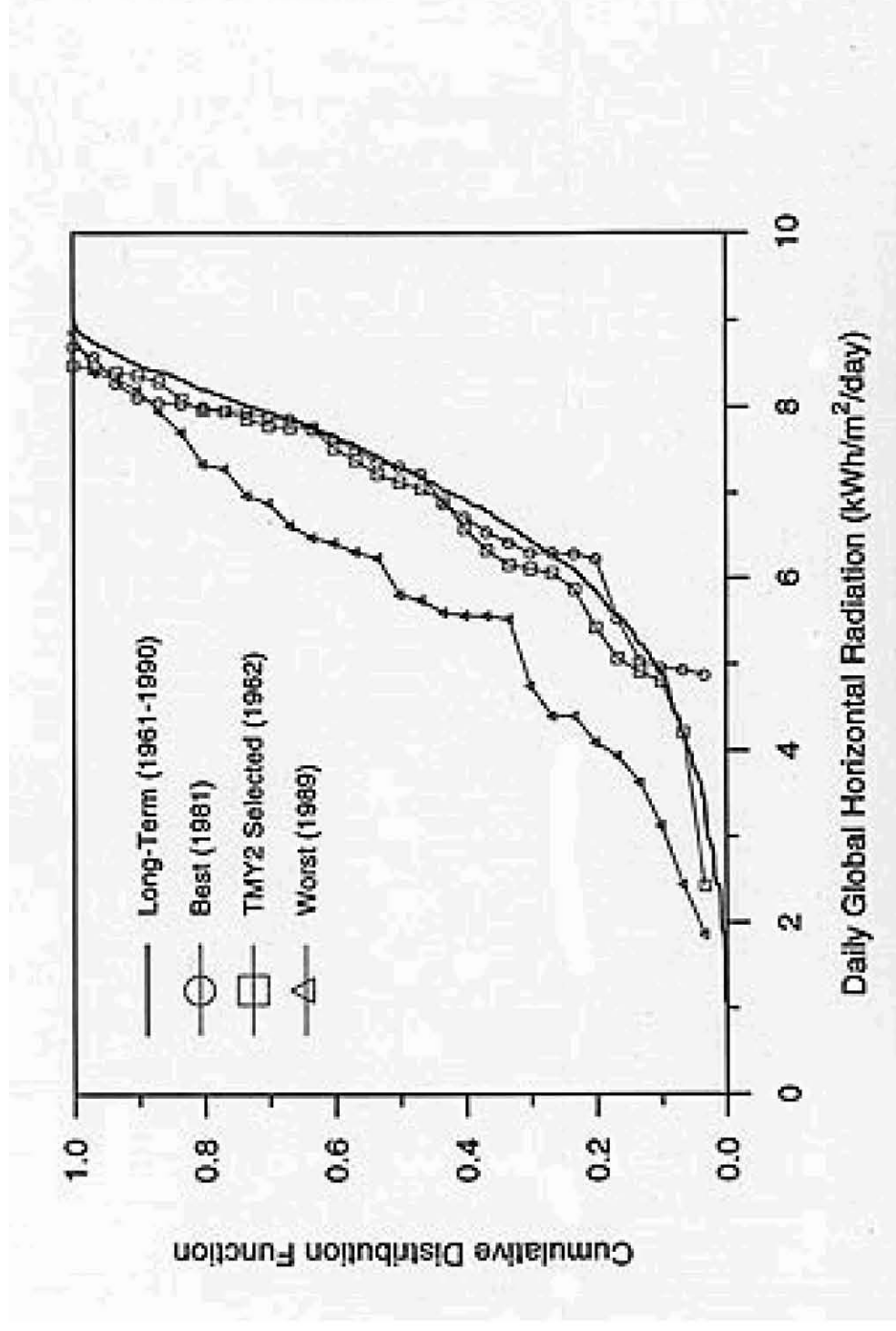
- The 30-year NSRDB data sets are used at sites where they were available
- The 15-year NSRDB data were used for the remaining sites.

TMY3 Algorithm

Based on Hall, Prairie, Anderson, and Boes (Sandia National Labs)

- Start with multi-year data set.
- Build cumulative frequency distributions for each *conglomerated* month (e.g. 30 Januarys, 30 Februarys, etc) for the entire pool of data
- Build CFDs for each *individual* month
- Compare individual monthly CFDs with long-term conglomerate monthly CFDs using FS statistic
- Select the month with the best match (with other factors)

TMY3 CFD Comparison



TMY3 Ten Weighted Parameters

Index	Sandia Method	NSRDB TMY
Max Dry Bulb Temp	1/24	1/20
Min Dry Bulb Temp	1/24	1/20
Mean Dry Bulb Temp	2/24	2/20
Max Dew Point Temp	1/24	1/20
Min Dew Point Temp	1/24	1/20
Mean Dew Point Temp	2/24	2/20
Max Wind Velocity	2/24	1/20
Mean Wind Velocity	2/24	1/20
Global Radiation	12/24	5/20
Direct Radiation	Not Used	5/20

TMY3 Algorithm Summary

1. Create CFDs for all 10 parameters; weight and score comparisons with FS statistic
2. Examine top five candidate months
3. For these months, examine the persistence of mean dry bulb and irradiance for frequency and length of runs above 67th and below 33rd percentiles
4. Reject the months with the longest run, the most runs, and with zero runs.
5. Select the highest ranked month still remaining
6. Repeat for all months; then concatenate all 12 selected months

Results in 12 months of REAL data from the original data set

TMY3 Volcanic Eruptions

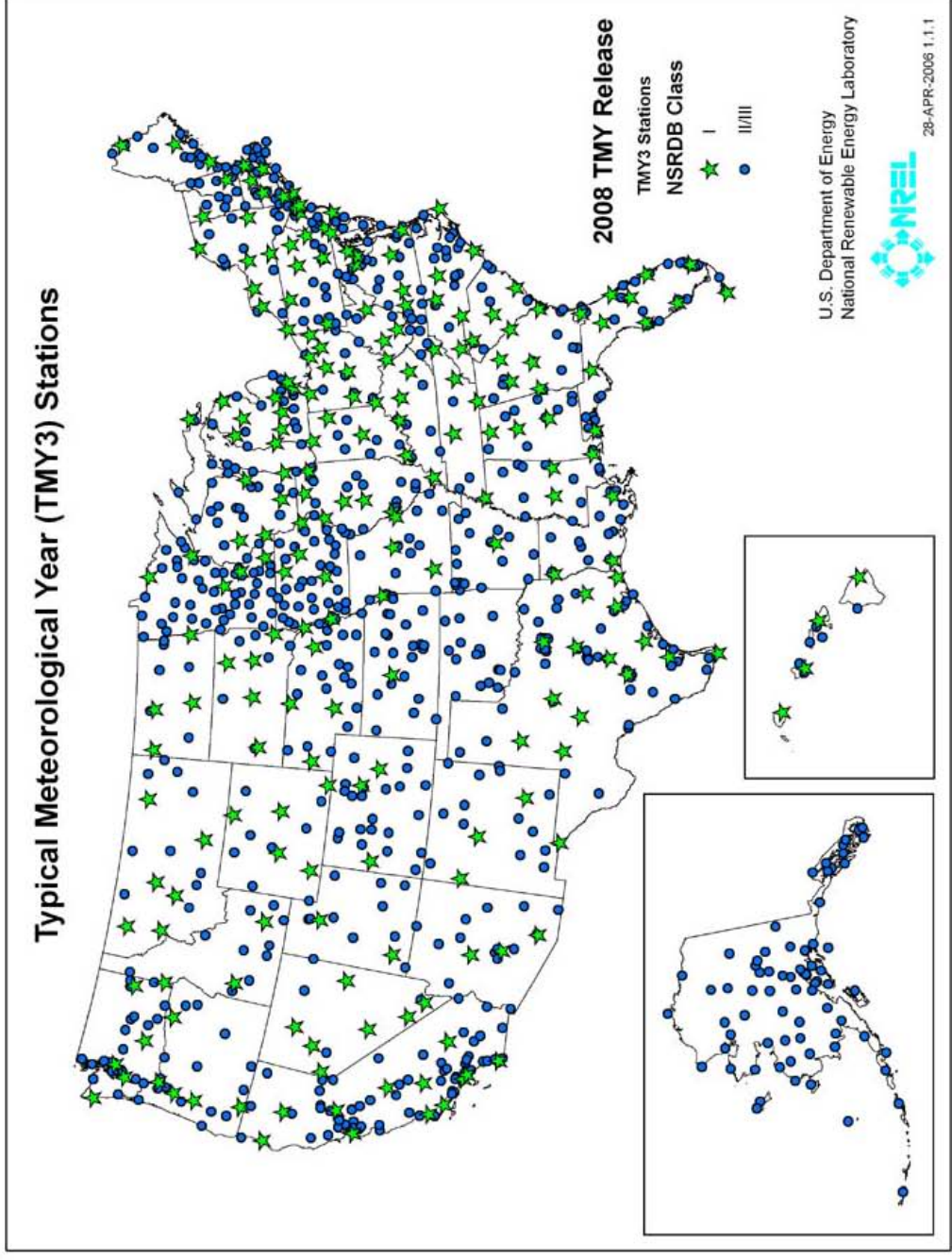
We considered two significant eruptions:

- El Chichón in Mexico – March 1982
- Mount Pinatubo in the Philippines – June 1991
- Aerosols affected solar radiation for two to three years
- May 1982 to December 1984 and June 1991 to December 1994 are not included in the TMY3 data sets (atypical)

TMY3 Data Quality and Uncertainty

- NSRDB uncertainty is included with hourly records, and is with respect to the original modeled data, **NOT** how well it typifies a site and its climate.
- The NSRDB Site Class (I, II, III) are significant, and that information is carried through for the user to evaluate for a particular application
- The pool of source years is documented for each site (the more years, the greater the likelihood of finding a typical year)
- NREL does not rank site quality – *the user must evaluate data quality for the particular application*

TMY3 Site Map



TMY3 Data Distribution

- Data available for unrestricted download from NREL (by site or entire data set)
- User's Manual available on line
- Conversion software (TMY3 to TMY2)

http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/

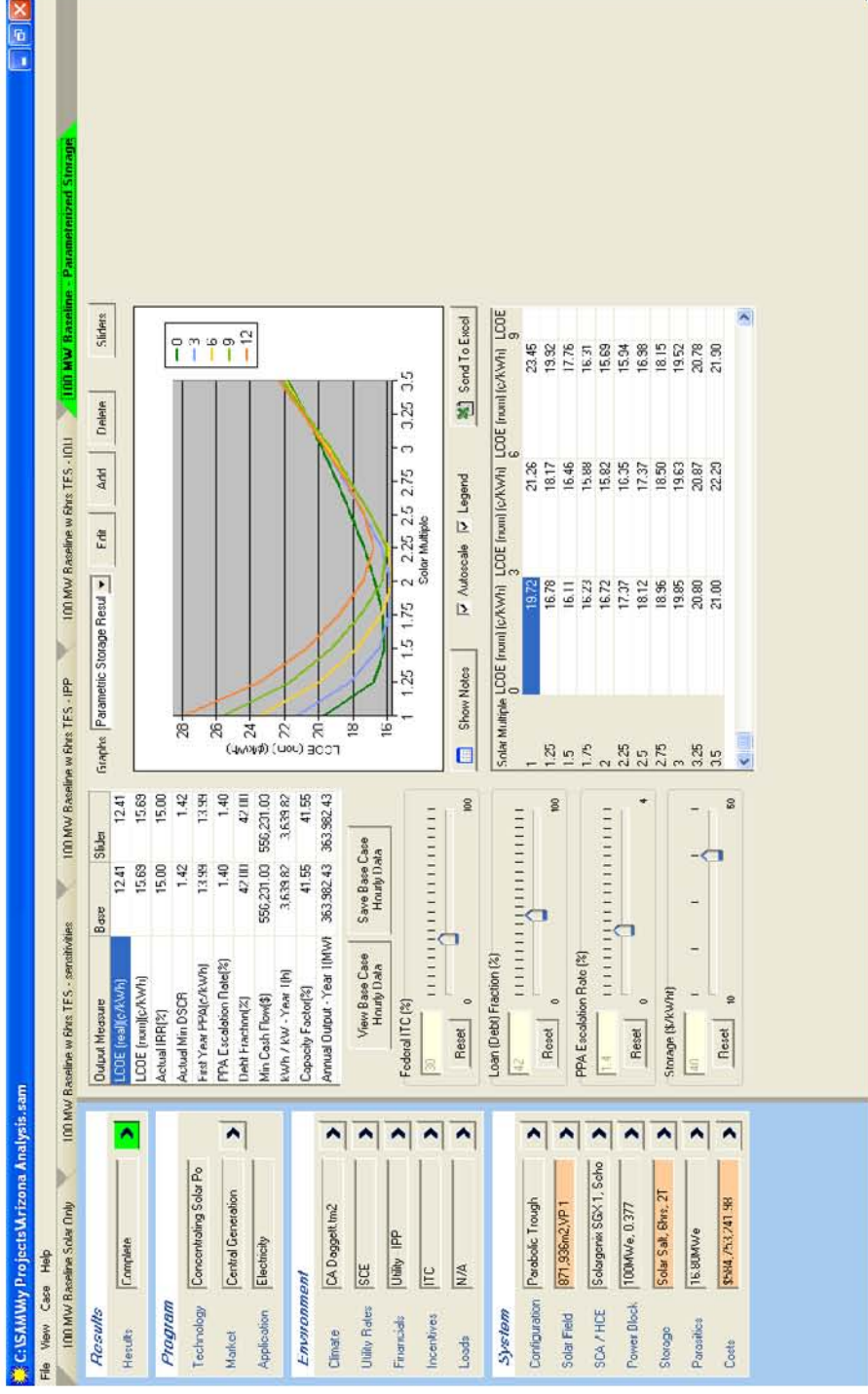
(Google NREL RREDC)

TMY3 Solar Advisor Model (TMY3→TMY2)

- Models solar performance, cost, finance, and incentives

- Performance models include CSP (troughs) and PV (fixed and tracking, flat plate PV, CPV)

- Financial models include utility (IPP, IOU), commercial, and residential finance



Download at <http://www.nrel.gov/analysis/sam>

Solar Measurements

Understand where you need to go before starting

- What is your purpose?
 - Prospecting, site selection, economic viability, performance monitoring
- What uncertainty do you need?
 - Must be quantified (not just “as good as possible”)
 - Consider deficiencies of existing data sets for your application; will measurements address the requirements?
- What can you afford (or not afford)?
 - How much data do you need (one year; decade...)
 - What resources exist to do measurements
 - Impacts on long-term success of the project
- What is your expertise?
 - Do your knowledge and expertise match the capabilities of the equipment
 - Will you add or subtract from the credibility of your measurements
- What ancillary measurements may be required (Meteorological)

Measurements *Instrumentation*

Direct Normal

Measured by a
Pyrheliometer on a sun-
following tracker



Global Horizontal

Measured by a
Pyranometer with a
horizontal sensor



Diffuse

Measured by a shaded
Pyranometer under a
tracking ball



Global, Direct, and Diffuse in a Single Instrument

Measured by a *Rotating
Shadowband Radiometer*



Measurements *What to measure*

Most common solar measurements

- Global Horizontal
- Direct Normal
- Diffuse Horizontal
- Plane of Array

Measurements Why 3 components?

K-space: Fraction of Total Possible

Variable	Definition
K_t	Global / (ETRN * cos (Z))
K_n	Direct / ETRN
K_d	Diffuse / (ETRN * cos(Z))

$$K_t = K_n + K_d$$

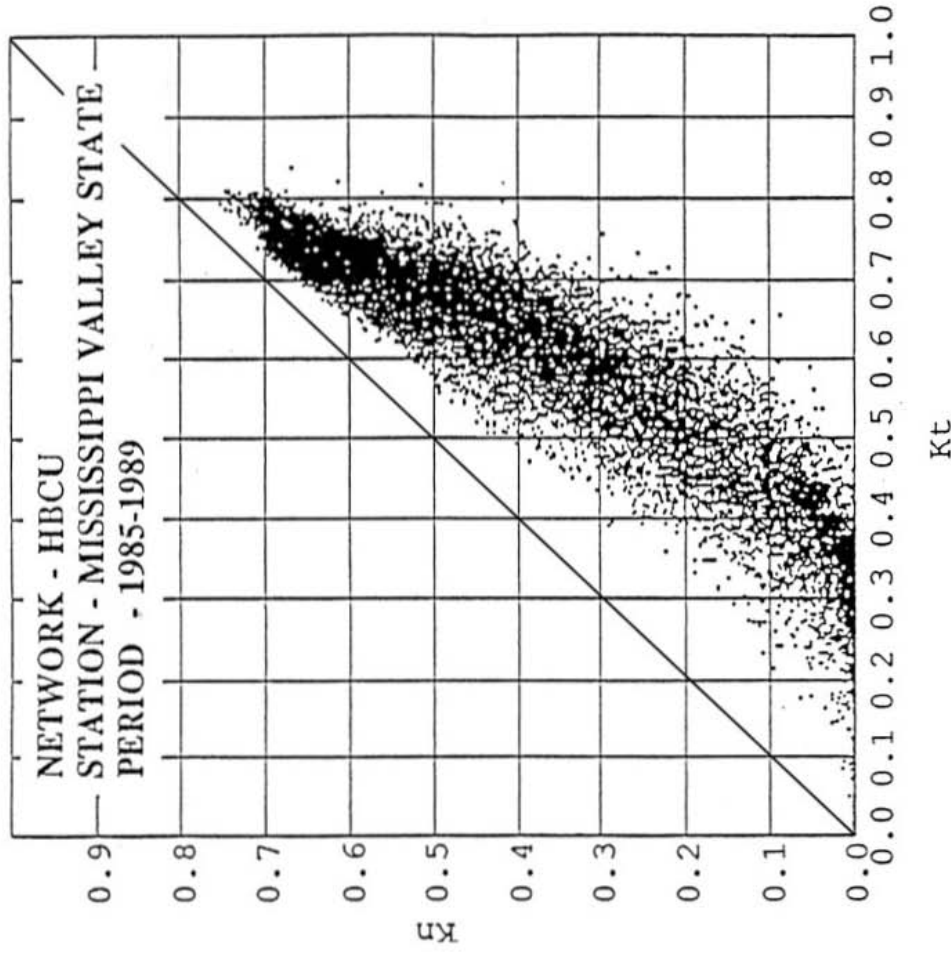
Three components give us data redundancy for fundamental data quality assessment

Three *different* instruments are better than three *identical* instruments (e.g., three pyrheliometers) because they measure in different realms. Allows better cross-checking of multiple parameters for best validation of all parameters. (Downside: more opportunity for error, but errors will be evident.)

Measurements *Why not 2 components*

Since a third component can be derived from two, why not just measure two?

Data redundancy is lost with two components. However, the correlation between two components affords some information on data quality, reducing the range of expected values in a measurement set.



Measurements *Uncertainty Estimates*

Uncertainty starts with calibrations

- Rough uncertainties in NREL radiometer calibration process:
 - Pyrheliometers about 0.6%
 - Pyranometers about 1%
- In practice (best instruments)
 - Pyrheliometers about 0.8%
 - Pyranometers about 1.2%
- Typical
 - Pyrheliometers about 1.5%
 - Pyranometers about 3%

Measurements Uncertainty Estimates

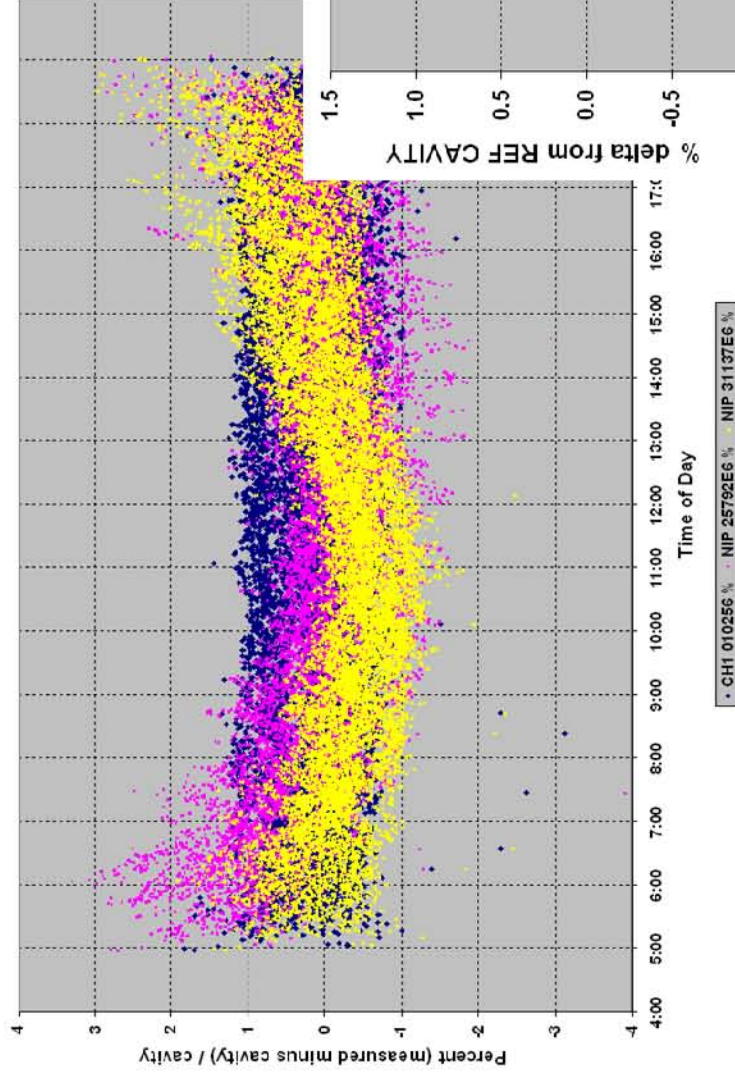
- NREL radiometer calibrations are done outdoors. *Calibration certificate is valid only for the day (or conditions) of the calibration*
- In field deployments, add uncertainties for
 - Environmental effects (temperature, wind, atmos. constituents)
 - Calibration drift
 - Soiling (dust, rain, birds)
 - Maintenance frequency
 - Equipment (trackers, loggers)
- Typical well run site with Class I instruments: 95-98% of data falls within a 5% threshold of expected values
- Potential is $\pm 1\text{-}2\%$ with best instruments and best maintenance practices.

Measurements *Uncertainty Examples*

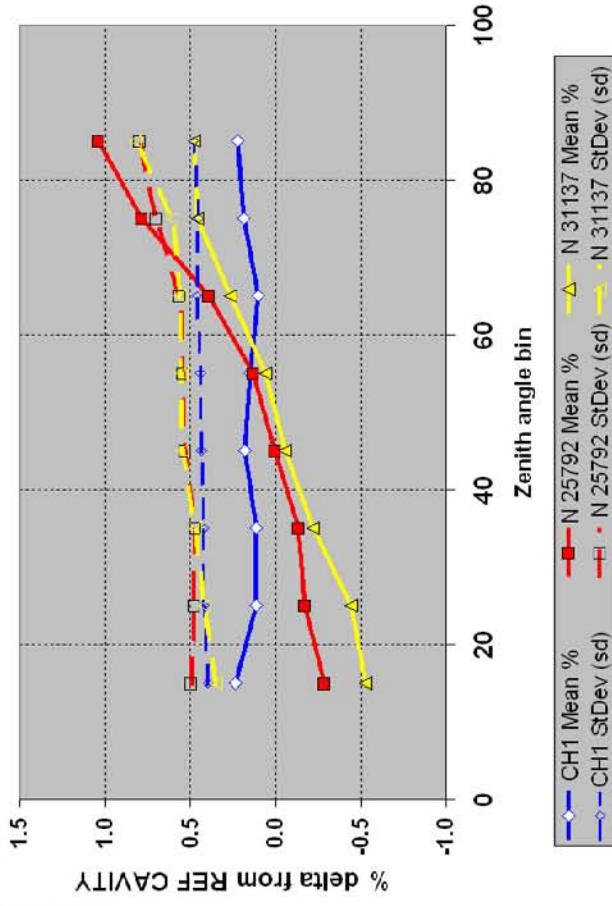
Ten Years of Limited Clear Sky Comparison between Absolute Cavity Radiometer and Windowed Pyrheliometers

CH1/NIP Percent Difference from Cavity

All NREL CLEAR SKY BROADBAND OUTDOOR RADIOEMETER CALIBRATIONS 2002 to 2007



- 3-4 days per year during NREL calibration events – 1 minute data
- Two Eppley NIP and 1 Kipp & Zonen CH1
- Instruments in field deployment configuration (part of NREL fulltime baseline measurements)



Measurements Uncertainty Examples

One Year of Full-time Comparisons between Pyranometers/RSR2 and NREL Baseline Instruments

- Pyranometers compared against global calculated from pyrhelimeter and diffuse
- RSR2 DNI compared against pyrhelimeter
- Instruments include thermopile and photovoltaic

Fig. B5: K&Z Zenon CM22 (ventilated) 010034

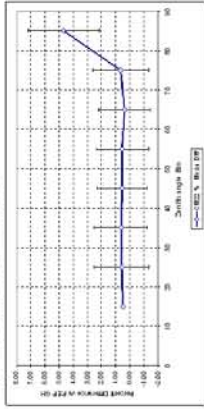
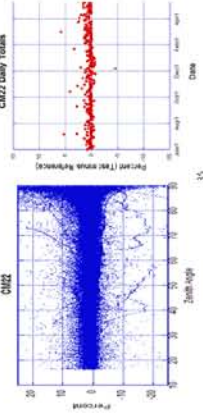


Table B5: Statistical summary one minute data by zenith angle bin CM22 010034 (Ventil)

Count (N)	Sum	CM22 Mean	SEDev (Std)	Maximum	Minimum	Range
15	6487	2455.4	0.247	1.947	-28.2	58.3
35	16400	1588.97	0.257	1.765	-25.8	47.8
55	30108	15568.97	0.519	1.842	-33.1	76.9
75	39487	20002.2	0.522	1.823	-51.3	101.8
95	50754	19704.81	0.369	1.972	-65.3	48.77
115	60228	18803.91	0.470	1.936	-98.9	188.7

Fig. B5.2: One Minute data set percent differences: Fig. B5.3 Daily total percent difference CM22, ventilated



K&Z CM22

Eppley PSP

Fig. B3: PSP Ventilated Uncorrected 2640ZF3

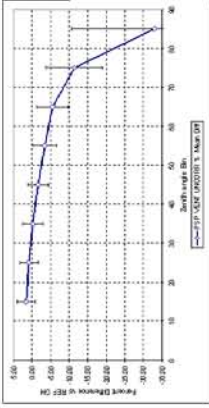


Table B3: Statistical summary one minute data by zenith angle bin PSP 2640ZF3 (Ventilated, Uncorrected)

Count (N)	PSP V.U. Count	PSP V.U. SEDev (Std)	Maximum	Minimum	Range
15	6487	0.247	1.947	-28.2	58.3
35	16400	0.257	1.765	-25.8	47.8
55	30108	0.519	1.842	-33.1	76.9
75	39487	0.522	1.823	-51.3	101.8
95	50754	0.369	1.972	-65.3	48.77
115	60228	0.470	1.936	-98.9	188.7

Fig. B3.2: One Minute data set percent differences: Fig. B3.3 Daily total percent difference PSP, Ventilated, uncorrected

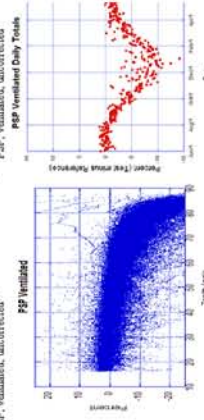


Fig. B11: Irradiance, Inc. RSR2 global corrected PY3927 (11 months Jan 2007 - May 2008)

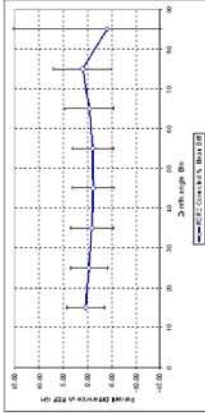
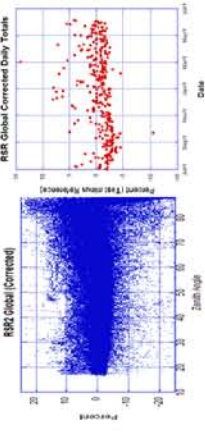


Table B11: Statistical summary one minute data by zenith angle bin RSR2 Global corrected

Count (N)	RSR2 Global Corrected Count	RSR2 Global Corrected SEDev (Std)	Maximum	Minimum	Range
15	1007	0.12	0.83	-20.8	50.4
35	2172	0.12	0.83	-20.8	50.4
55	2172	0.12	0.83	-20.8	50.4
75	2172	0.12	0.83	-20.8	50.4
95	2172	0.12	0.83	-20.8	50.4
115	2172	0.12	0.83	-20.8	50.4

Fig. B11.2: One Minute data set percent differences: Fig. B11.3 Daily total percent difference RSR2 Global corrected



RSR2 GIO

Fig. B17: RSR2 Direct Corrected (11 months of data Jan 2007 - May 2008)

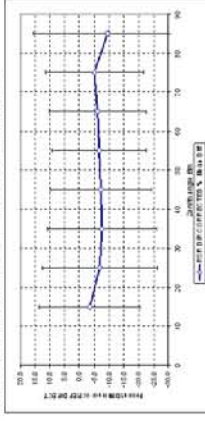
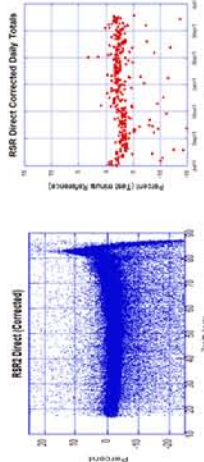


Table B17: Statistical summary one minute data by zenith angle bin RSR2 Direct corrected

Count (N)	RSR2 Direct Corrected Count	RSR2 Direct Corrected SEDev (Std)	Maximum	Minimum	Range
15	1007	0.12	0.83	-20.8	50.4
35	2172	0.12	0.83	-20.8	50.4
55	2172	0.12	0.83	-20.8	50.4
75	2172	0.12	0.83	-20.8	50.4
95	2172	0.12	0.83	-20.8	50.4
115	2172	0.12	0.83	-20.8	50.4

Fig. B17.2: One Minute data set percent differences: Fig. B17.3 Daily total percent difference RSR2 Direct corrected



RSR2 DNI

Measurements *Type of Equipment*

\$10-15K



Rotating Shadowband – three measurements in one self-contained instrument

\$50-75K



Conventional three-component measurements with three radiometers on a tracker.

Measurements *Equipment Maintenance*

Thermopile Instruments (with clear domes or windows)

- Daily cleaning and tracker inspection; maintenance log

Rotating Shadowband

- 2-3 times per week
- cleaning and mechanical inspection; maintenance log

Calibrations

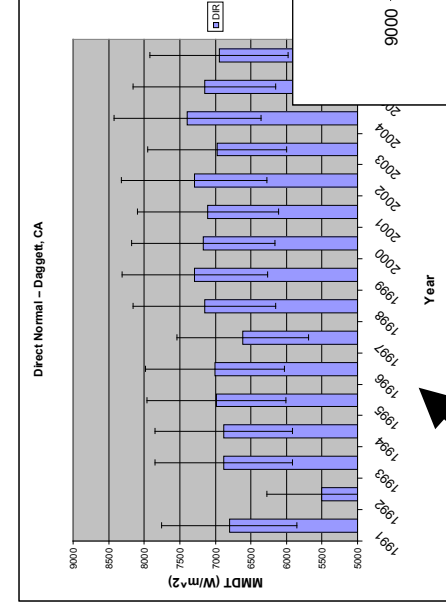
- Annually
-

But why?

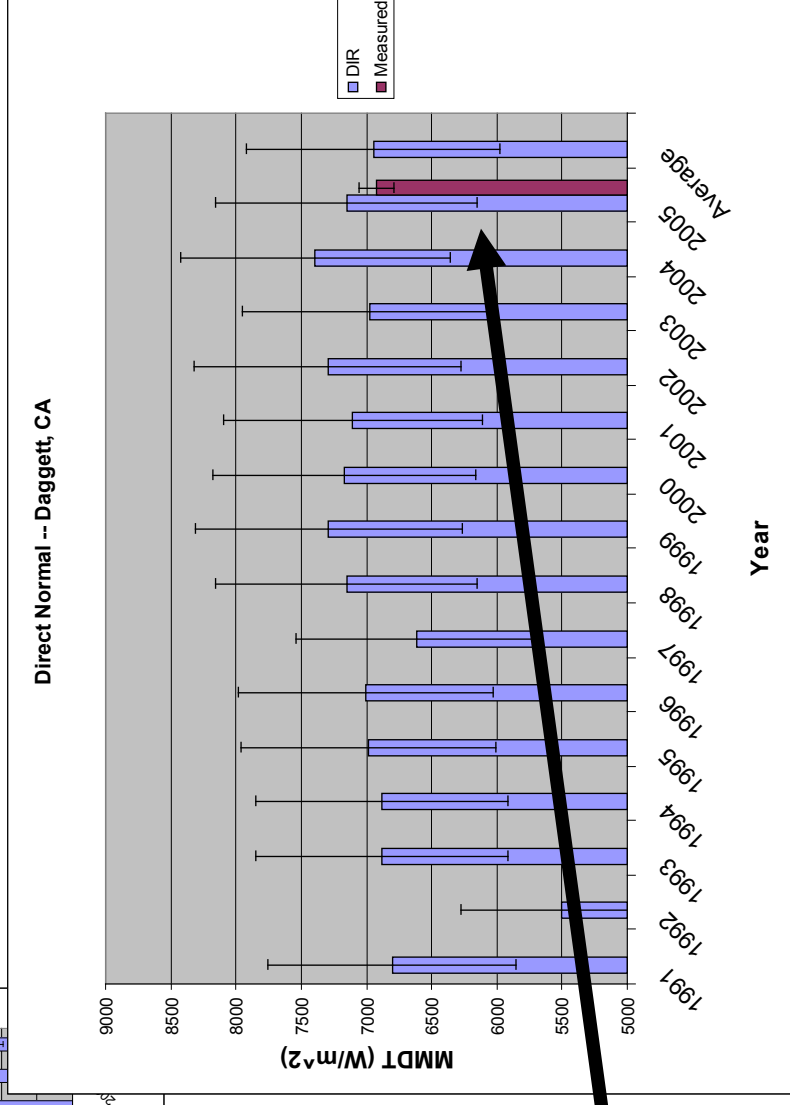
- Removes uncertainty due to soiling and sensor drift
 - Soiling usually causes lower measurements, but can be higher, and the effects are variable and difficult to quantify
- Increases confidence in system operation and resulting data
 - You cannot be certain of what's happening when you're not there.
- **You need to be able to justify your uncertainty claims**

Measurements Short to Long-term

How do short term measurements help?



Short term measurements (~1 year) cannot provide a complete characterization of the solar resource (e.g. means, high/low years, interannual variability)

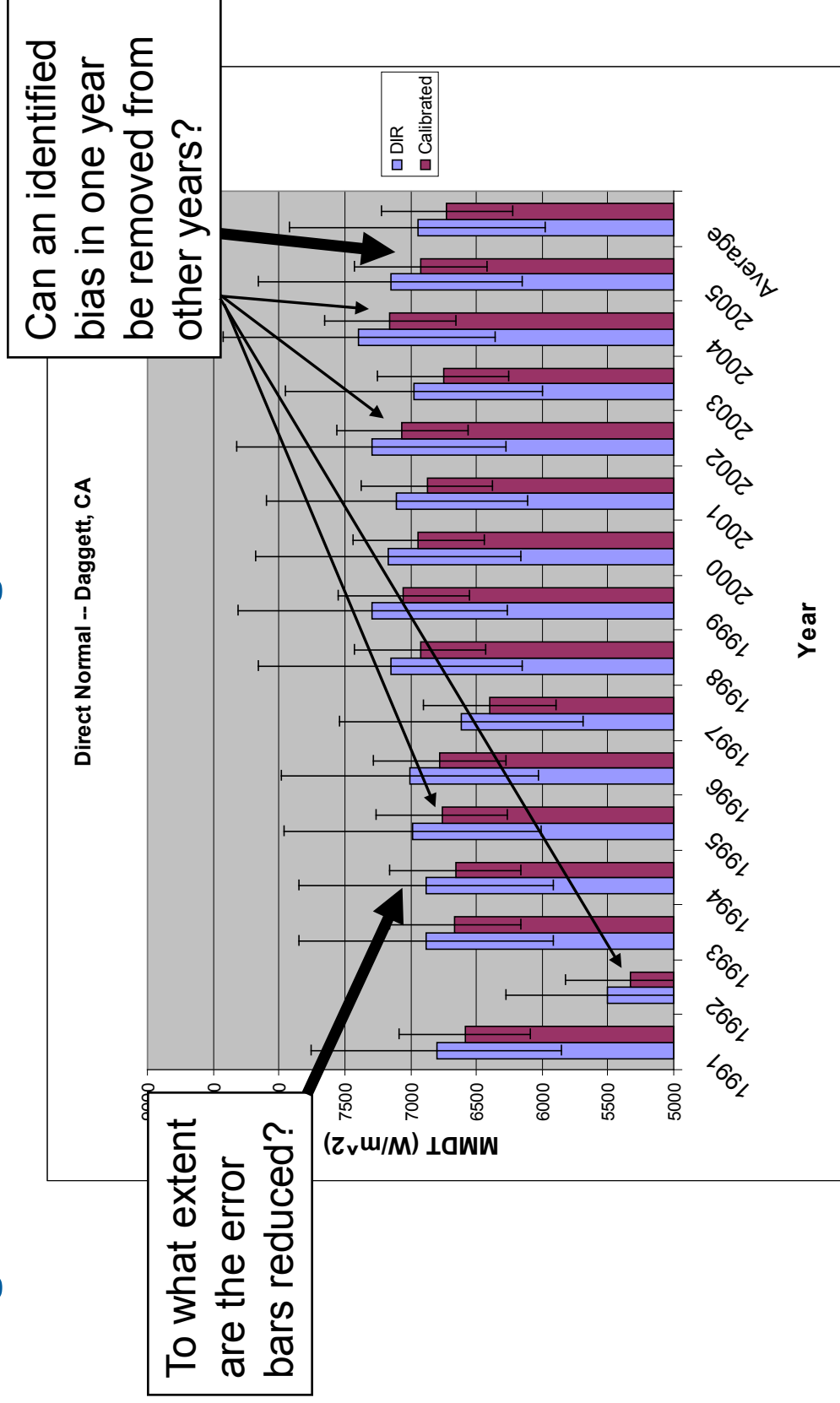


Long-term data set
with large error bars

Short-term measured
data with small error
bars, but doesn't
represent climate
variability.

Measurements Short to Long-term

Work underway at NREL to evaluate the approach of removing long-term bias and understanding how that affects uncertainty.



Measurements Several Sources of Data

SURFRAD

These data sets are administered by the National Oceanic and Atmospheric Administration through the Global Monitoring Division in Boulder, CO. Solar data from the SURFRAD stations are recorded as three-minute integrated values. <http://www.srnb.noaa.gov/surfrad/index.html>

ISIS

The Integrated Surface Irradiance Study (ISIS) network was commissioned in 1994 for analyzing spatial distributions of solar irradiance and time trends at regionally representative sites. The network is operated by the National Oceanic and Atmospheric Administration through the Global Monitoring Division in Boulder, CO. <http://www.srnb.noaa.gov/isis/index.html>

University of Oregon

The University of Oregon Solar Monitoring Laboratory Network in the Pacific Northwest and western U.S. includes sites with the longest period of record of high quality solar measurements in the United States. The network presently has data from 37 sites in Oregon, Idaho, Montana, Utah, and Wyoming with varying instrumentation and periods of record. <http://solaradat.uoregon.edu/index.html>

University of Texas

The University of Texas (UT) Solar Radiation Database has roots starting in 1982 and is housed at the Mechanical Engineering Department at UT Austin. Funding for ongoing solar measurements was discontinued in 2003, but the archive is still being maintained. <http://www.me.utexas.edu/~solarlab/>

NREL HBCU/CONFRRM

NREL established the Historically Black Colleges and Universities (HBCU) Solar Radiation Network in 1985 in response to a mandate from President Ronald Reagan to bring science and technology to HBCUs. The 13-station network is no longer funded, but several stations continue to collect data <http://www.nrel.gov/midc/>.

BSRN

The Baseline Surface Radiation Network (BSRN) was established under the auspices of the World Meteorological Organization's World Climate Research Programme to investigate the effect of solar irradiance on the earth's climate processes. The BSRN archives data from several dozen sites worldwide, of which nine are within the United States <http://bsrn.ethz.ch/>

DOE-ARM

The U.S. Department of Energy's Atmospheric Radiation Measurement Network (ARM) establishes and operates field research sites to study the effects of clouds on global climate change. Three primary locations—Southern Great Plains, Tropical Western Pacific, and North Slope of Alaska—were identified as representing the range of climate conditions that should be studied. <http://www.arm.gov/data/>

World Radiation Data Center

International data sets from throughout the world dating back to 1963. Mostly global horizontal – very little DNI. More recent data are posted with about a two-year lag. <http://wrdc-mgo.nrel.gov/>

Measurements *Expertise*

SOLRMAP

The **Solar Resource** and **Meteorological Assessment Project**

Collaboration between NREL and industry for high quality solar measurements