Solar Radiation Data Sets

Solar Resource Assessment Workshop
Denver, Colorado

Steve Wilcox, Ray George, Daryl Myers

National Renewable Energy Laboratory

October 29, 2008

NREL/PR-550-44460

NREL is a national laboratory of the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy operated by the Alliance for Sustainable Energy, LLC

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- NWS no longer making manual cloud observations (total and opaque) required for METSTAT model and have been replaced by the Automated Surface Observing System (ASOS)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.

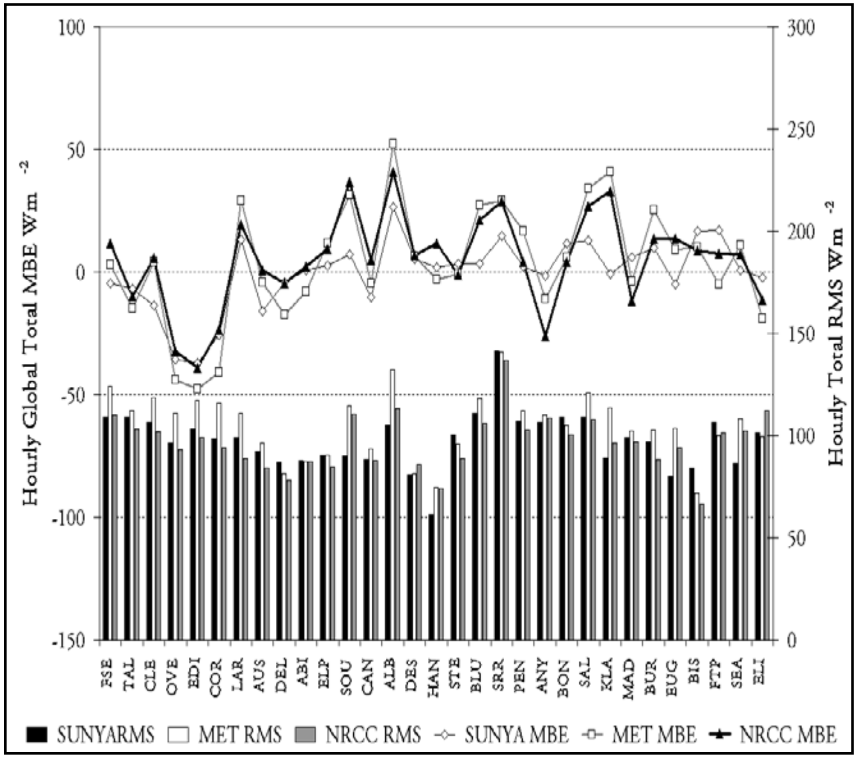
NSRDB *Model Selection*

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

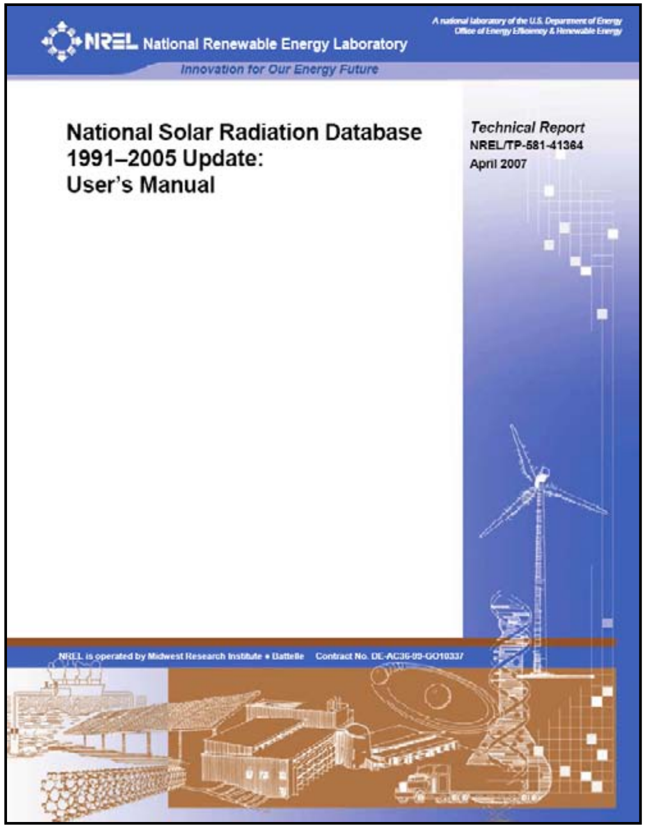
NSRDB *Aerosols, Water Vapor, Ozone*

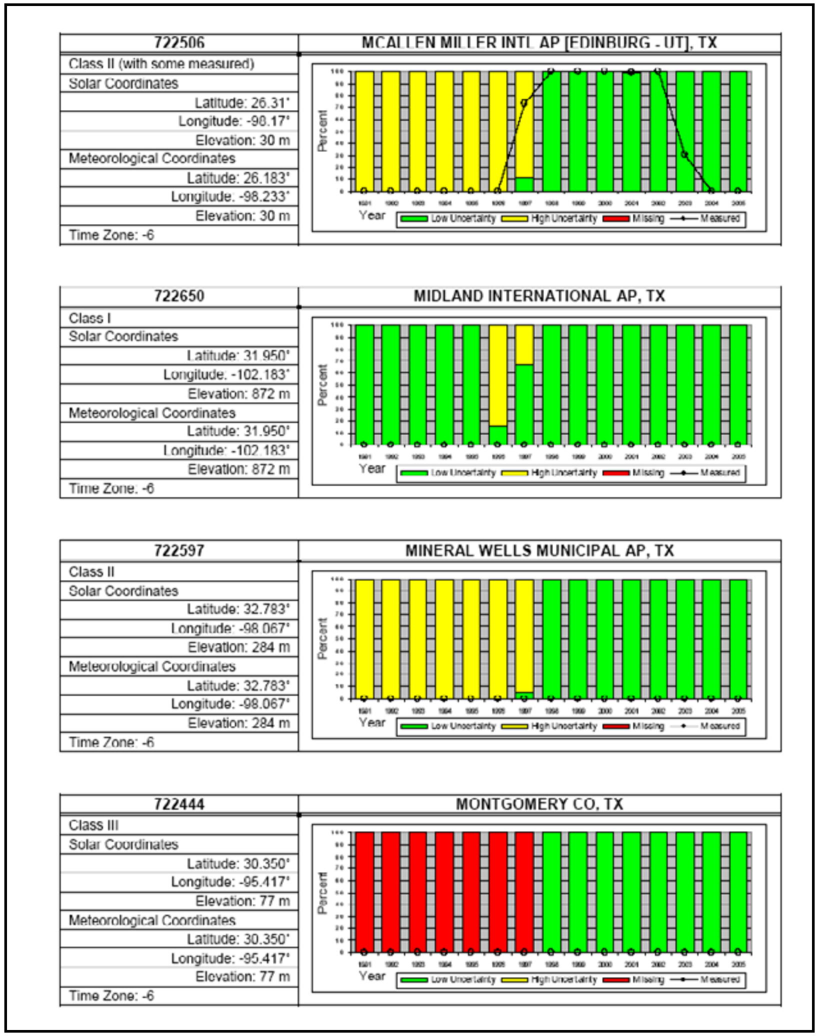
- 10-km gridded data set for aerosols, water vapor, and ozone.
- Aerosols derived from NASA MISR and MODIS satellite data, surface AERONET (sun photometry), and legacy NSRDB DNI broadband estimates. Data formed as climatological means
- Water vapor derived from NASA Water Vapor Project (NVAP) or North American Regional Reanalysis (NARR) (1ºx1º, 0.5ºx0.5º, or 32-km cells interpolated to 10-km cells)
- Ozone from Total Ozone Mapping Scanner (TOMS) (1ºx1¼º 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 (±10-15%)
  - ***Class II*** sites (637) have a complete period of record, but data are of higher uncertainty (±15-25%)
  - ***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*





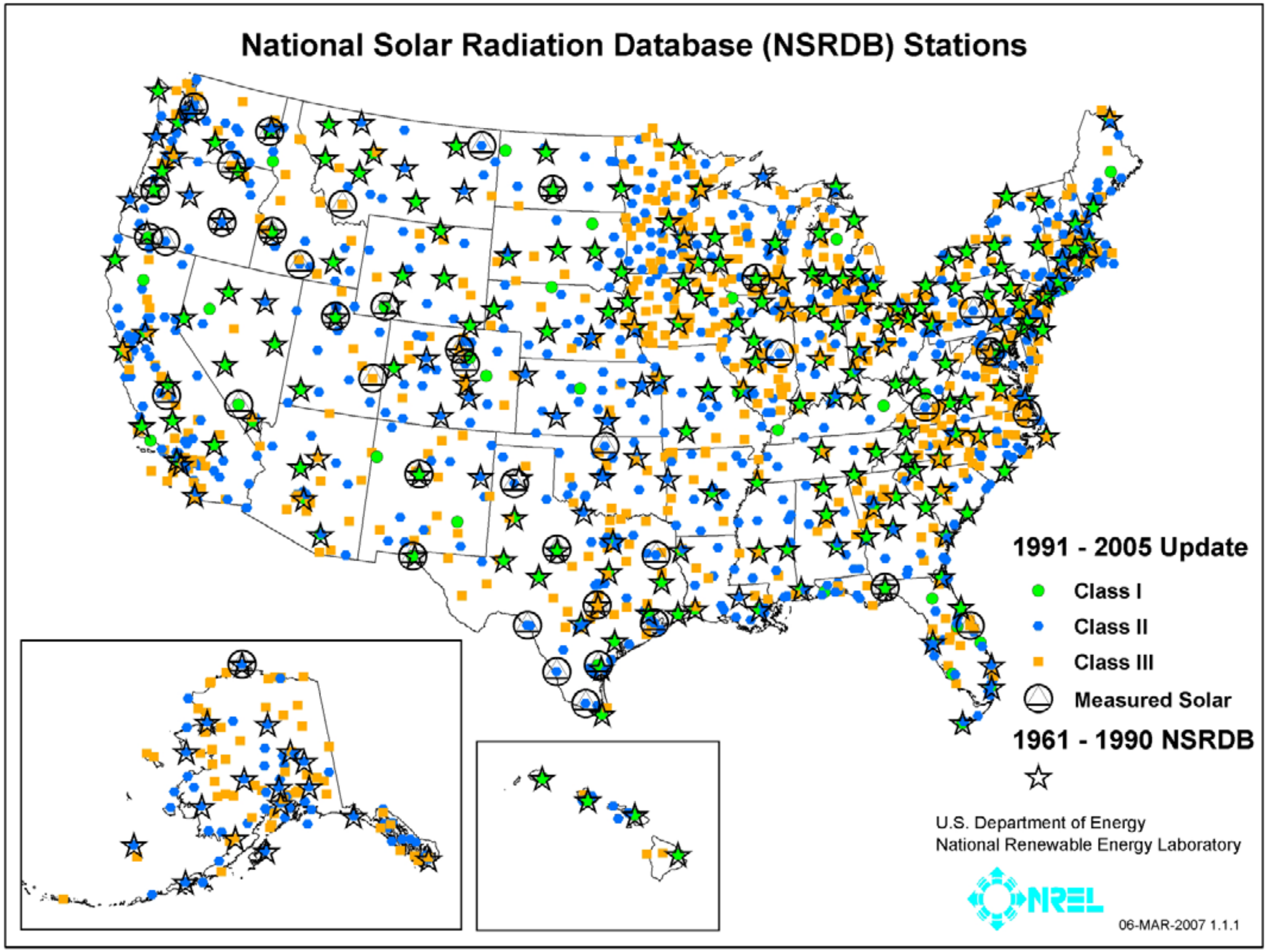
722506	MCALLEN MILLER INTL AP [EDINBURG - UT], TX
Class II (with some measured)	
Solar Coordinates	
Latitude: 26.31°	
Longitude: -98.17°	
Elevation: 30 m	
Meteorological Coordinates	
Latitude: 26.183°	
Longitude: -98.233°	
Elevation: 30 m	
Time Zone: -6	

722650	MIDLAND INTERNATIONAL AP, TX
Class I	
Solar Coordinates	
Latitude: 31.950°	
Longitude: -102.183°	
Elevation: 872 m	
Meteorological Coordinates	
Latitude: 31.950°	
Longitude: -102.183°	
Elevation: 872 m	
Time Zone: -6	

722597	MINERAL WELLS MUNICIPAL AP, TX
Class II	
Solar Coordinates	
Latitude: 32.783°	
Longitude: -98.067°	
Elevation: 284 m	
Meteorological Coordinates	
Latitude: 32.783°	
Longitude: -98.067°	
Elevation: 284 m	
Time Zone: -6	

722444	MONTGOMERY CO, TX
Class III	
Solar Coordinates	
Latitude: 30.350°	
Longitude: -95.417°	
Elevation: 77 m	
Meteorological Coordinates	
Latitude: 30.350°	
Longitude: -95.417°	
Elevation: 77 m	
Time Zone: -6	

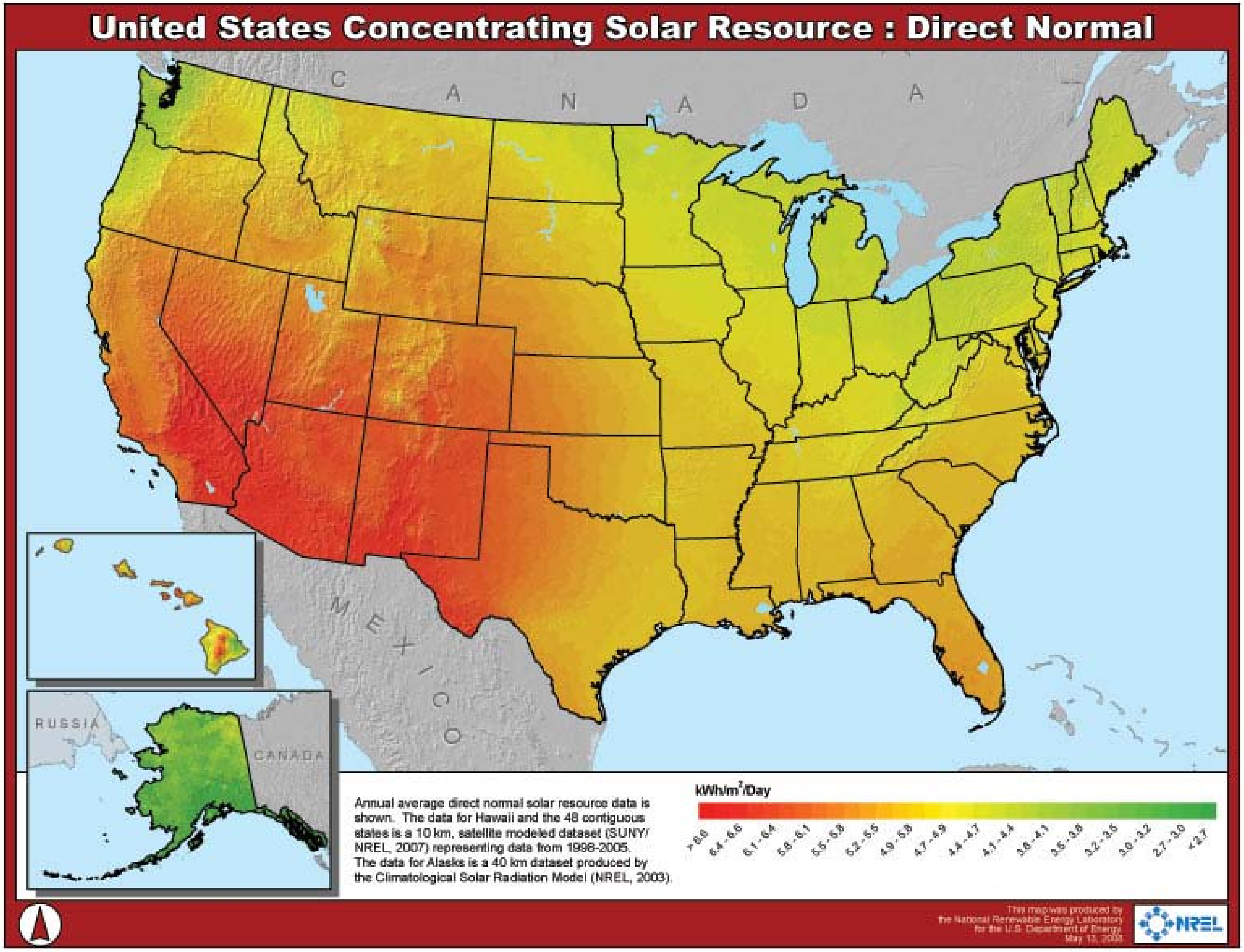
NSRDB *Site Map*



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*



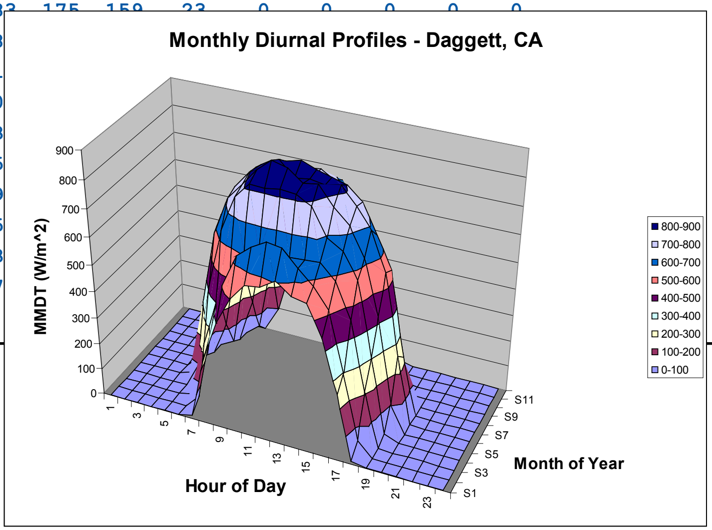
NSRDB *Hourly Statistics Files*

DIRECT MEANS

1	I6	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	I6	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	I6	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	I6	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	I6	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	I6	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	I6	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	I6	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	I6	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	I6	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	I6	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	I6	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	I6	0	0	0	0	8	109	292	486	613	684	712	716	707	672	621	535	388	207	54	0	0	0	0	0

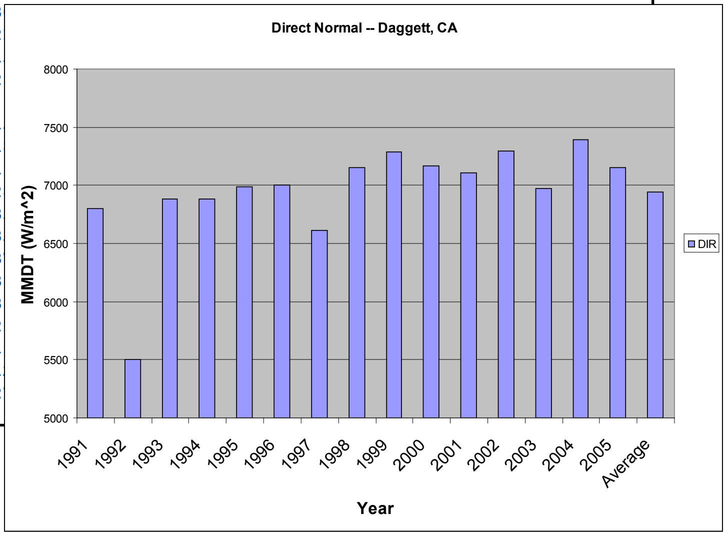
DIRECT STANDARD DEVIATIONS

1	I6	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	I6	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	I6	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	I6	0	0	0	0	0	79	180	176	123	143	167	166	189	174	214	183	175	159	23	0	0	0	0	0
5	I6	0	0	0	0	22	147	159	151	189	145	97	127	157	126	198	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	I6	0	0	0	0	34	156	194	199	193	183	155	237	226	207	177	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	I6	0	0	0	0	22	156	174	191	192	208	223	225	200	218	179	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	I6	0	0	0	0	0	102	182	200	142	201	245	214	220	252	217	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	I6	0	0	0	0	0	27	154	191	208	197	226	224	241	249	287	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	I6	0	0	0	0	0	6	123	167	172	188	155	182	183	200	233	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	I6	0	0	0	0	0	0	40	146	167	167	173	170	153	194	191	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	I6	0	0	0	0	0	0	3	91	187	224	258	238	236	226	213	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	I6	0	0	0	0	16	149	239	213	172	143	133	125	113	125	145	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]



NSRDB *Daily Statistics Files*

```
723815 DAGGETT BARSTOW-DAGGET CA  -8  N34 51  W116 48   586   945
 1991-2005
 MO AVGLO FL SDGLO AVDIR FL SDDIR AVDIF FL SDDIF AVETR AETRN  TOT  OPQ  H2O  TAU MAX_T MIN_T AVG_T AVGDT RH HTDD CLDD AVWS
  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  3.8
 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   296  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
.
.
.
```



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 (Run length in DAYS)																Number of runs of days solar energy LESS THAN threshold (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	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	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

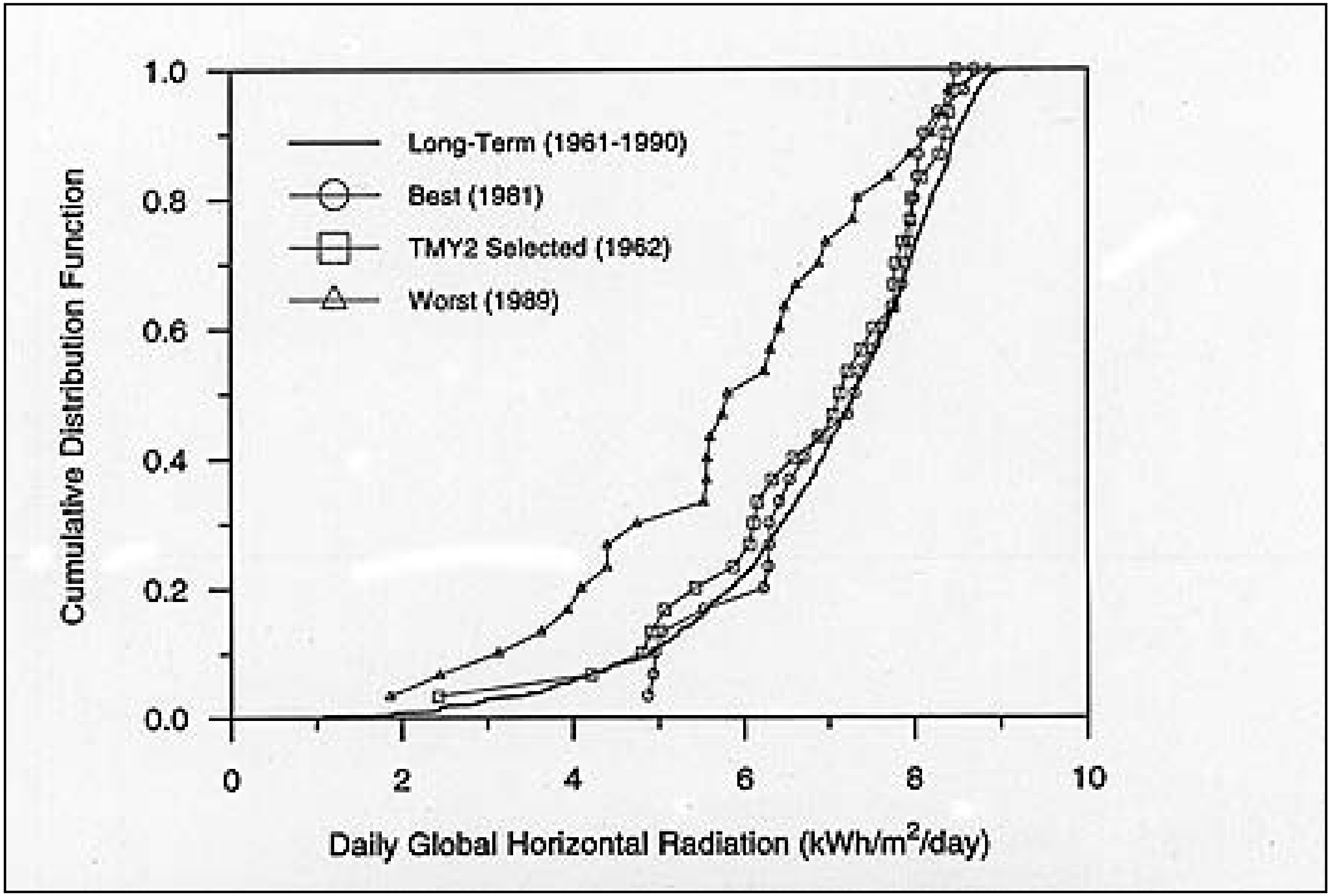
- The 30-year NSRDB data sets are used at sites where they were available
- The 15-year NSRDB data were used for the remaining sites.

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:

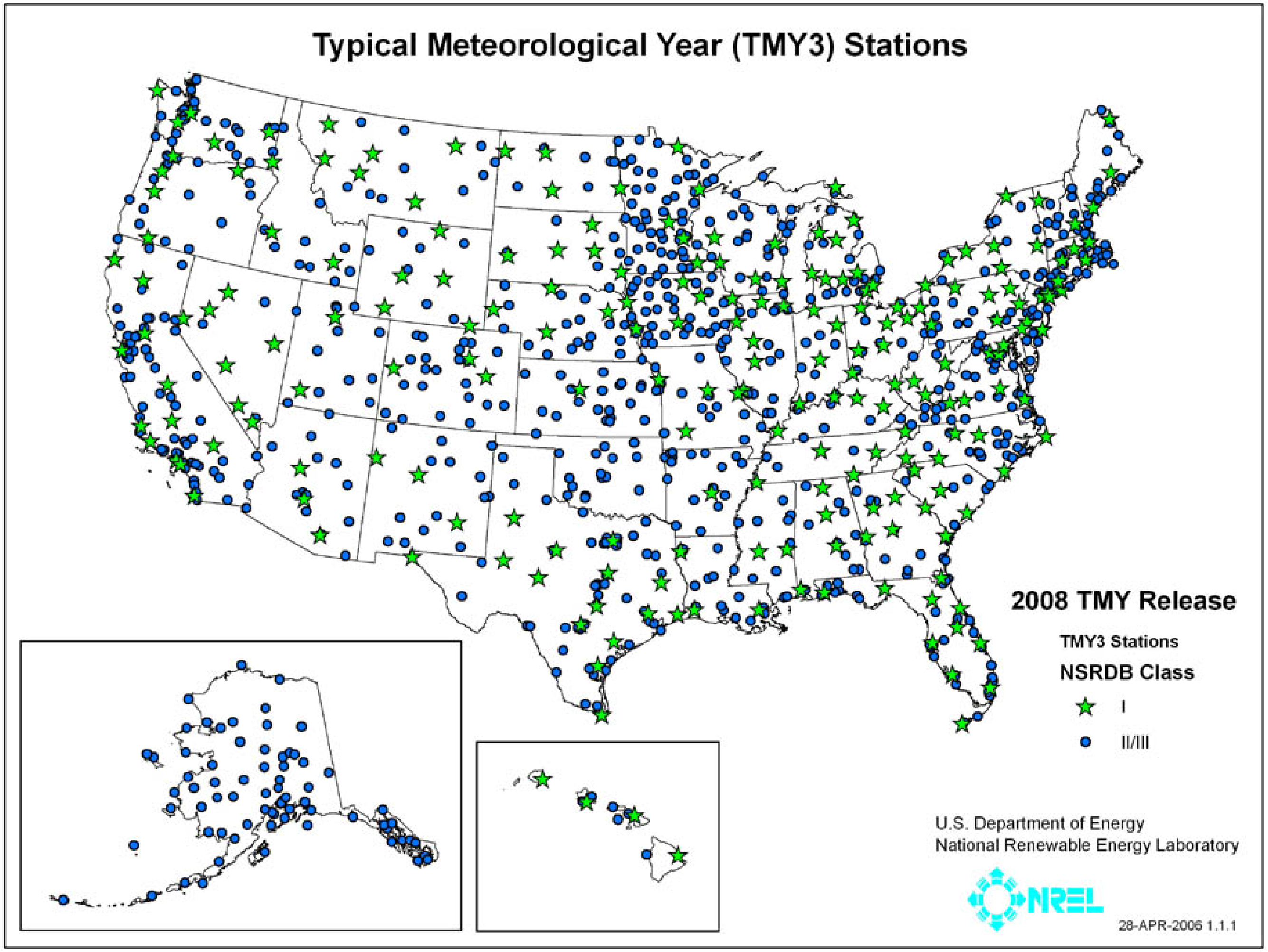
  - El Chichón in Mexico – March 1982
  - Mount Pinatubo in the Philippines – June 1991

- 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*

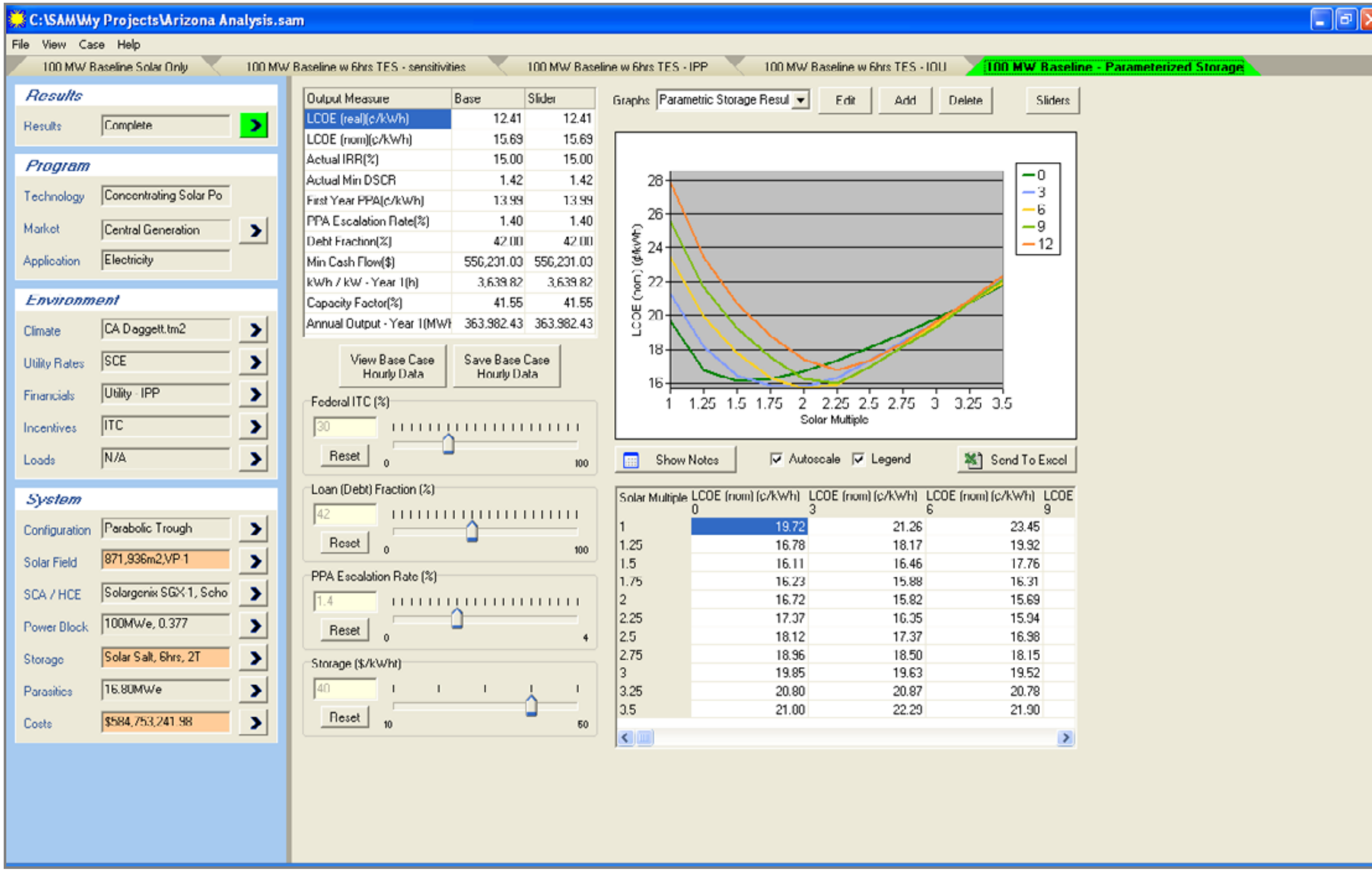
- Data available for unrestricted download from NREL (by site or entire data set)
- User's Manual available on line
- Conversion software (TMY3 to TMY2)

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))

$$K_t = K_n + K_d$$

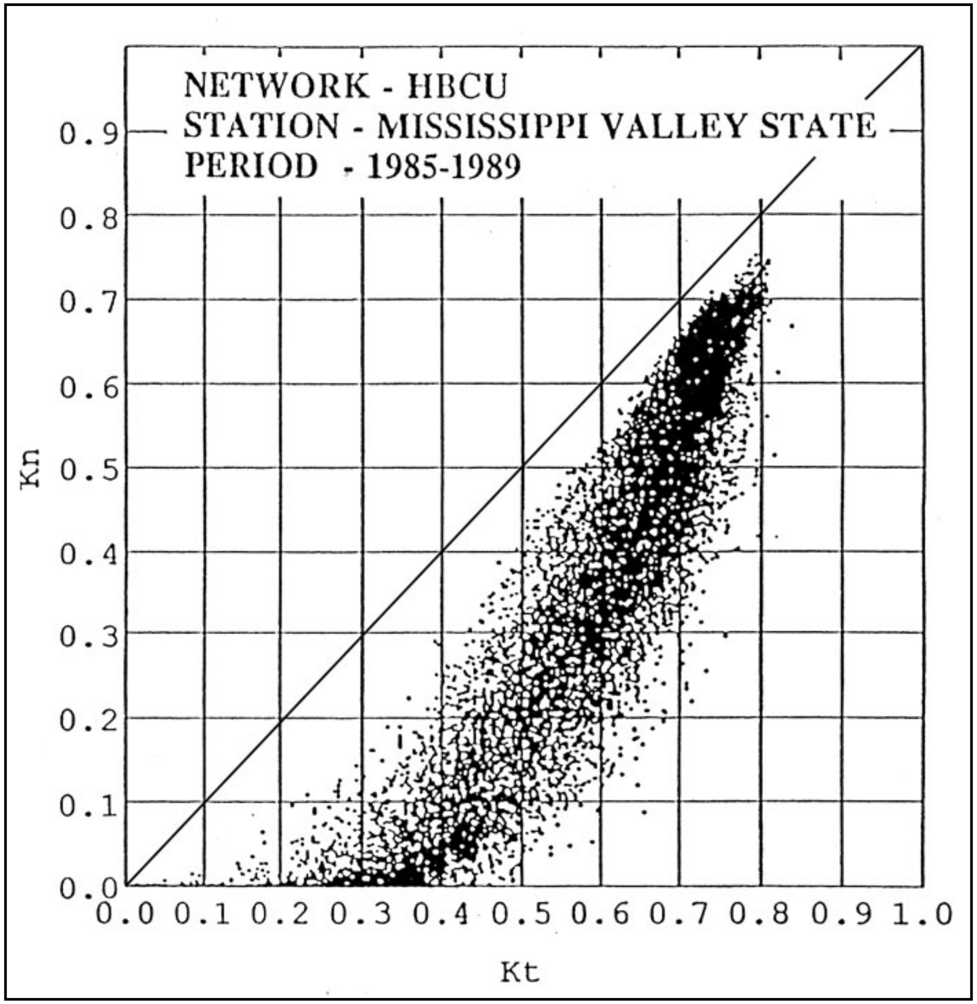
Three components give us data redundancy for fundamental data quality assessment

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

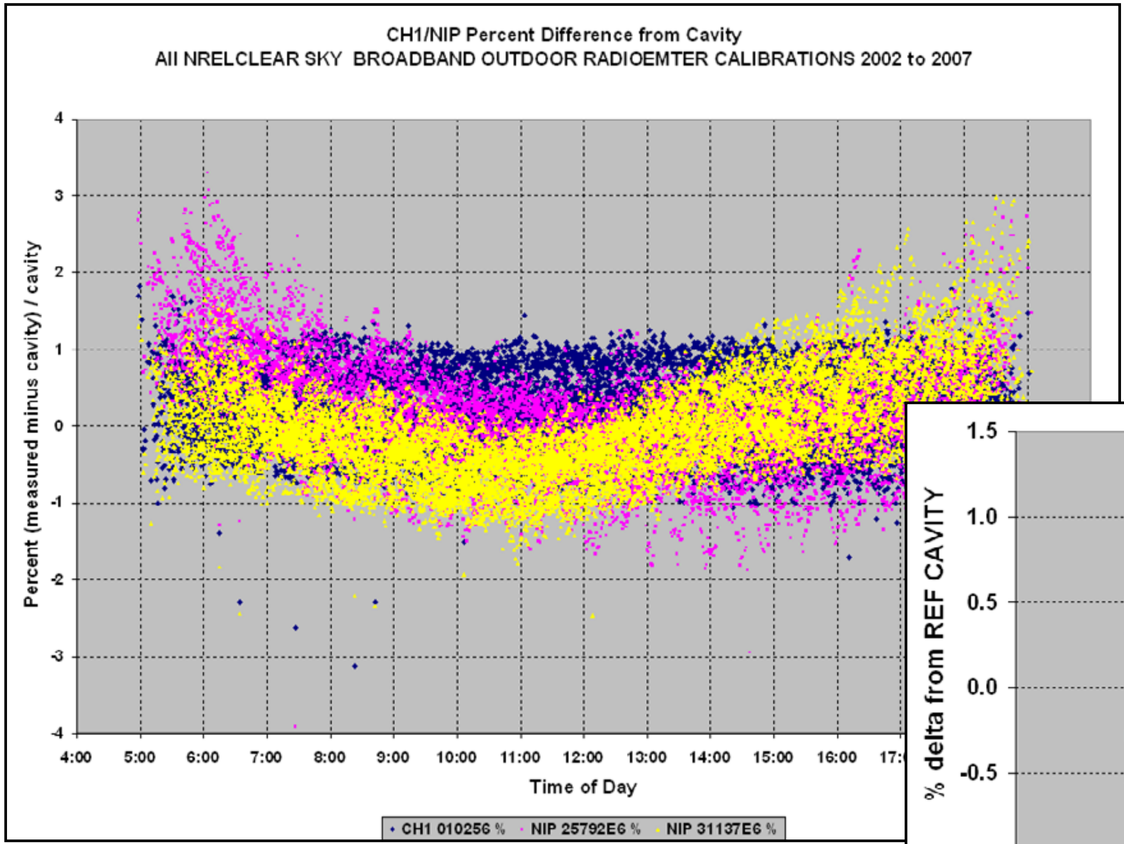
- Rough uncertainties in NREL radiometer calibration process:
  - Pyrheliometers about 0.6%
  - Pyranometers about 1%
- In practice (best instruments)
  - Pyrheliometers about 0.8%
  - Pyranometers about 1.2%
- Typical
  - Pyrheliometers about 1.5%
  - Pyranometers about 3%

Measurements *Uncertainty Estimates*

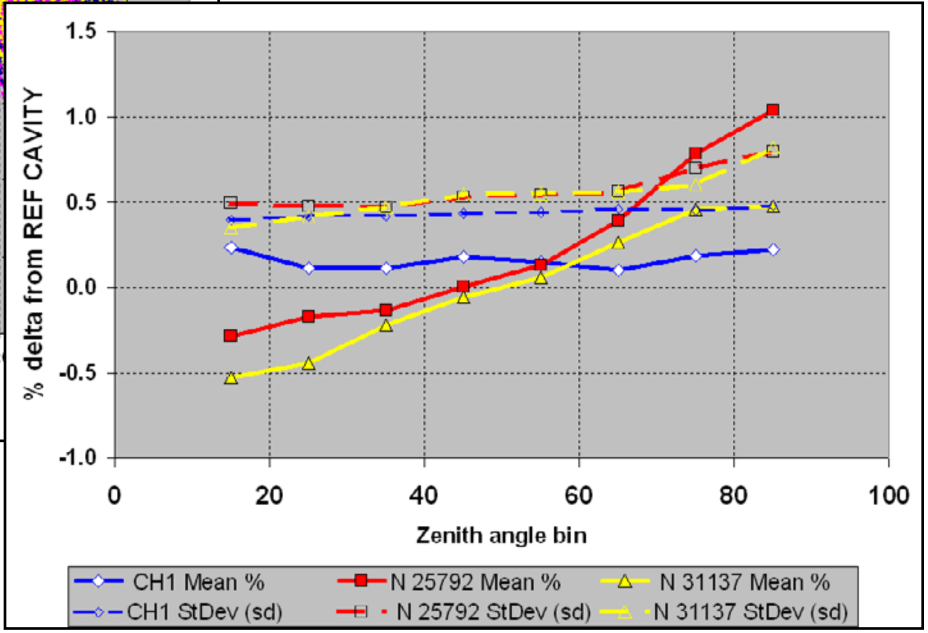
- NREL radiometer calibrations are done outdoors. *Calibration certificate is valid only for the day (or conditions) of the calibration*
- In field deployments, add uncertainties for
  - Environmental effects (temperature, wind, atmos. constituents)
  - Calibration drift
  - Soiling (dust, rain, birds)
  - 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 ±1-2% with best instruments and best maintenance practices.

Measurements *Uncertainty Examples*

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



- 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 pyrheliometer and diffuse
- RSR2 DNI compared against pyrheliometer
- Instruments include thermopile and photovoltaic

Fig. B5. Kipp & Zonen CM22 (ventilated) 010034

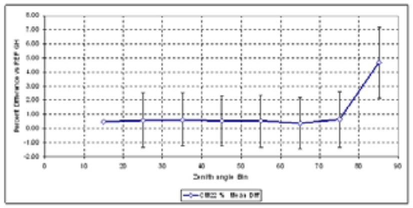
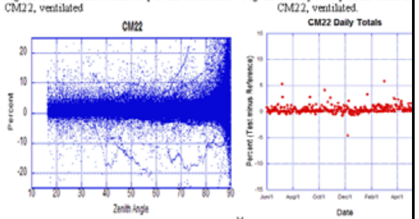


Table B5. Statistical summary one minute data by zenith angle bin CM22 010034 (Ventil

CM22	Count (N)	Sum	CM22 % Mean Diff	StDev (sd)	Maximum	Minimum	Range
15	5497	2455.4	0.447	1.947	30.1	-28.2	58.3
25	19111	11212.96	0.587	1.887	26.6	-22.4	48.9
35	24260	15068.77	0.621	1.769	51.6	-25.8	77.4
45	30018	15568.67	0.519	1.842	43.7	-33.1	76.9
55	39487	20603.2	0.522	1.823	51.3	-30.5	81.8
65	50754	18704.81	0.369	1.972	65.3	-49.7	115.0
75	40634	25611.97	0.630	2.548	56.9	-28.8	85.7
85	40339	188401.9	4.670	11.835	99.9	-99.3	199.2

Fig. B5.2 One Minute data set percent differences. CM22, ventilated

Fig. B5.3 Daily total percent differen CM22, ventilated.



35

K&Z CM22

Fig. B3. PSP Ventilated Uncorrected 28402F3

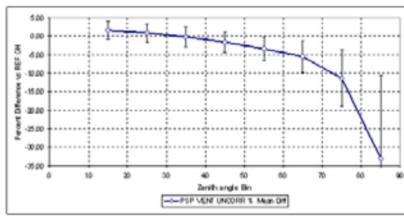
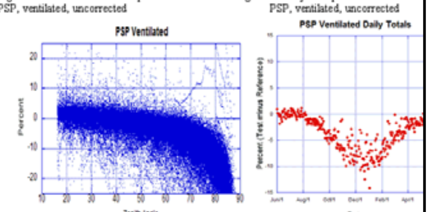


Table B3. Statistical summary one minute data by zenith angle bin PSP 28402F3 (Ventilated, Uncorrected)

PSP_V_U	Count (N)	PSP VENT UNCOR % Mean Diff	StDev (sd)	Maximum	Minimum	Range
15	5497	1.603	2.503	39.1	-28.1	67.2
25	19111	0.912	2.429	29.6	-24.1	53.7
35	24260	-0.148	2.711	64.3	-28.0	92.3
45	30018	-1.564	2.760	27.0	-38.0	65.0
55	39487	-3.390	3.229	62.5	-53.5	116.0
65	50754	-5.490	4.340	65.8	-73.2	139.0
75	40614	-11.305	7.629	19.0	-99.6	118.5
85	33743	-33.084	22.538	99.2	-99.9	199.2

Fig. B3.2 One Minute data set percent differences. PSP, ventilated, uncorrected

Fig. B3.3 Daily total percent difference PSP, ventilated, uncorrected



Eppley PSP

Fig. B11. Irradiance, Inc. RSR2 global corrected PY37627 (11 months Jul 2007 -May 2008)

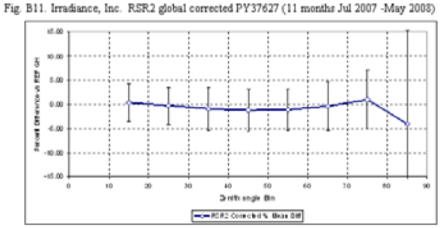
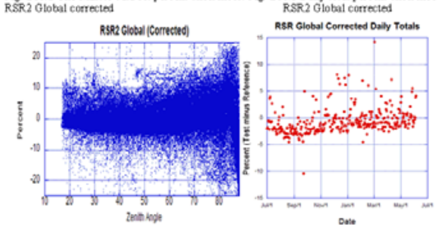


Table B11. Statistical summary one minute data by zenith angle bin RSR2 Global corrected

RSR2_C_G	Count (N)	RSR2 Corrected % Mean Diff	StDev (sd)	Maximum	Minimum	Range
15	3007	0.409	3.946	29.6	-20.8	50.4
25	15555	-0.312	3.863	30.8	-60.0	90.8
35	21172	-0.934	4.404	49.1	-73.6	122.6
45	27137	-1.221	4.350	28.2	-79.9	108.1
55	37364	-1.080	4.260	24.5	-66.0	90.5
65	48789	-0.351	5.008	41.6	-49.6	91.2
75	38434	1.034	6.080	67.4	-57.5	124.9
85	37287	-4.035	19.442	99.4	-98.7	198.1

Fig. B11.2 One Minute data set percent differences. RSR2 Global corrected

Fig. B11.3 Daily total percent difference RSR2 Global corrected



RSR2 Glo

Fig. B17. RSR Direct Corrected (11 months of data Jul 2007 -May 2008)

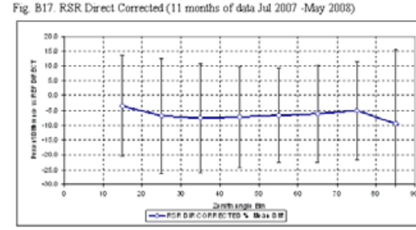
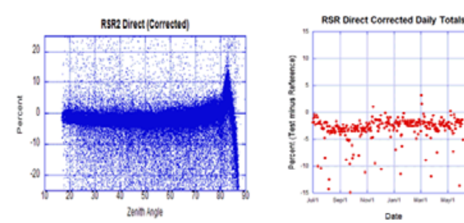


Table B17. Statistical summary one minute data by zenith angle bin RSR2 direct corrected

RSR DIR C	Count (N)	RSR DIR CORRECTED % Mean Diff	StDev (sd)	Maximum	Minimum	Range
15	2504	-3.507	17.0	97.41	-99.51	196.92
25	12387	-6.899	19.4	95.29	-99.99	195.28
35	16643	-7.509	18.4	92.79	-99.99	192.78
45	20957	-7.255	17.1	99.67	-99.97	199.64
55	29369	-6.606	15.9	94.73	-99.99	194.72
65	37420	-6.109	16.3	94.61	-99.97	194.58
75	27961	-5.025	16.5	86.66	-99.98	186.64
85	18818	-9.558	25.1	99.62	-99.99	199.61

Fig. B17.2 One Minute data set percent differences. RSR2 Direct corrected

Fig. B17.3 Daily total percent difference RSR2 Direct corrected



RSR2 DNI

Measurements *Type of Equipment*

$10-15K

$50-75K

Rotating Shadowband – three measurements in one self-contained instrument

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

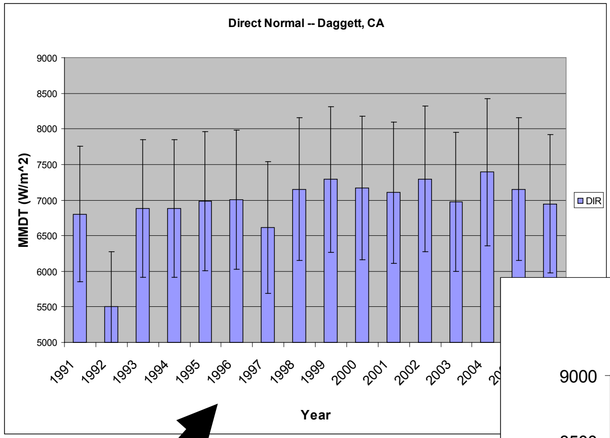
But why?

- 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

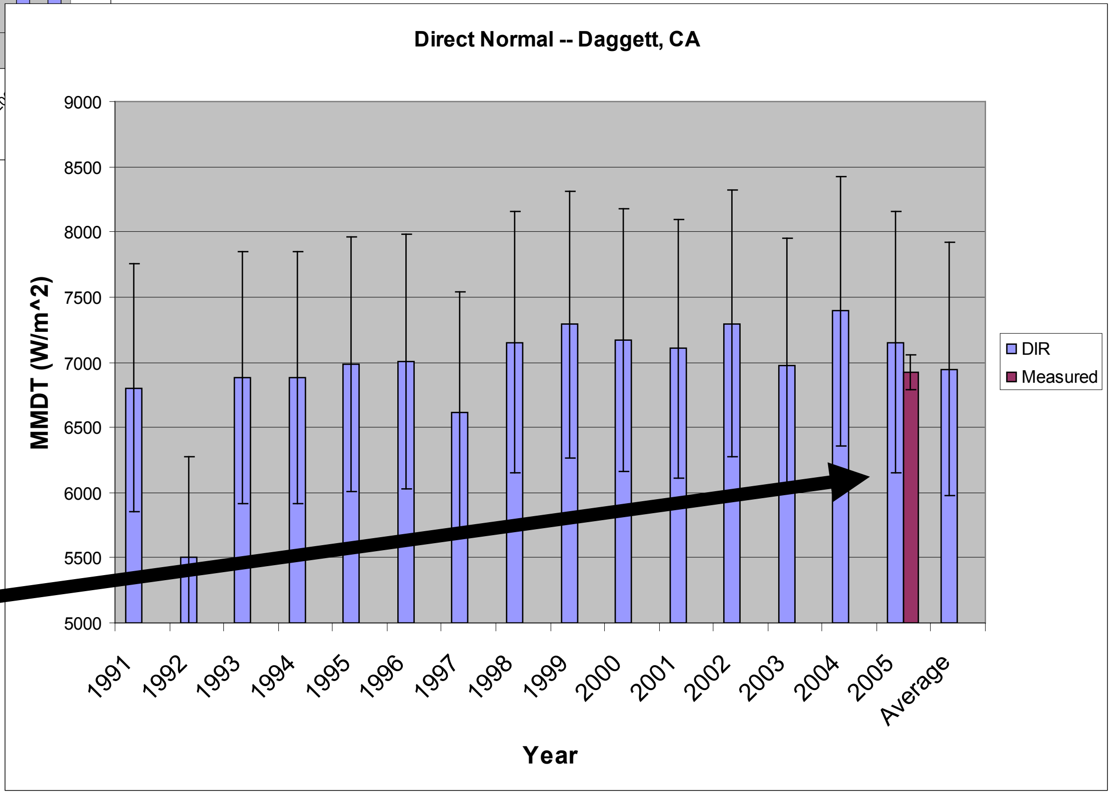
Measurements *Short to Long-term*

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)



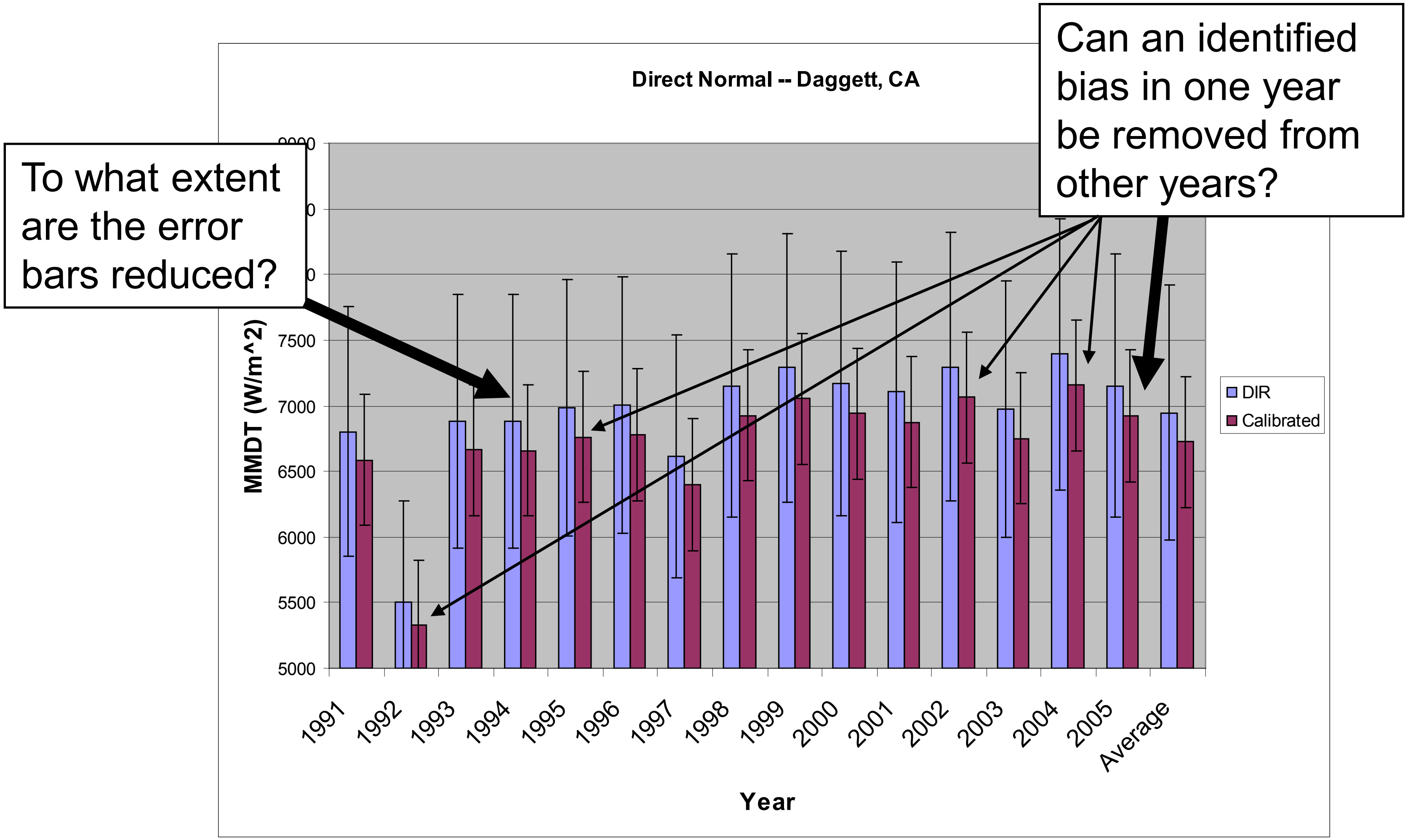
Long-term data set with large error bars



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.srrb.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.srrb.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://solardat.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 **Sol**ar **R**esource and **M**eteorological **A**ssessment **P**roject

Collaboration between NREL and industry for high quality solar measurements