

Solar Radiation Data Sets



Solar Resource Assessment Workshop Denver, Colorado

Steve Wilcox, Ray George, Daryl Myers

National Renewable Energy Laboratory

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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- NWS no longer making manual cloud observations (total and opaque) required for METSTAT model and have been replaced by the Automated Surface Observing System (ASOS)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 ASOSspecific 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°x1°, 0.5°x0.5°, or 32-km cells interpolated to 10-km cells)
- Ozone from Total Ozone Mapping Scanner (TOMS) (1°x1¼° 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





NSRDB Site Map



- Solar Radiation
 - Global, Direct, Diffuse (measured, modeled, modeled clearsky).
 - 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	5																							
1 16	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 16	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	
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1 16	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 16	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	182	175	150	23	0	0	0	0	0	
5 I6	0	0	0	0	22	147	159	151	189	145	97	127	157	126	198	18			Month	ly Diur	nal Pr	ofiles -	Dagge	ett, CA	
6 I6	0	0	0	0	34	156	194	199	193	183	155	237	226	207	177	21				_					
7 I6	0	0	0	0	22	156	174	191	192	208	223	225	200	218	179	20				_					
8 I6	0	0	0	0	0	102	182	200	142	201	245	214	220	252	217	23	900-			_					
9 I6	0	0	0	0	0	27	154	191	208	197	226	224	241	249	287	25	800-								
10 I6	0	0	0	0	0	6	123	167	172	188	155	182	183	200	233	19	700-	///							
11 I6	0	0	0	0	0	0	40	146	167	167	173	170	153	194	191	15	2 600-	///			XX		_		800-900
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NSRDB *Daily Statistics Files*

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1	2955 KF	314	4674 K6	1030	997	к5	112	5183 1	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	к5	156	6596 1	15276	4.4	3.3	1.02	0.06	17.96	5.23	11.24	13.81	49	191	ō	4.2		
3	5306 KF	436	6570 K6	1069	1503	к5	172	8409 1	16501	3.2	2.4	1.03	0.08	22.10	8.13	14.90	17.54	42	112	12	5.1		
4	6753 KF	276	7335 K6	696	1904	к5	222 10	0065 1	17695	2.6	1.6	1.07	0.12	25.73	10.86	18.17	20.80	34	53	52	6.2		
5	7681 KF	305	8326 K6	883	1969	к5	283 1	1144 1	18648	2 3	1 4	1 37	0 10	31 60	15 81	23 75	25 92	30	8	175	6 4		
6	8217 K	5 174	9349 K6	603	1707	к5	232 1	1551 1	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	к5	226 1	1286 1	18749	1.6	1.2	2.03	0.08	40.04	23.36	31.81	34.00	25	0	414	5.3		
8	6936 KF	206	8032 K6	467	1617	к5	138 10	0365 1	17824	1 6	1 3	2 17	0 09	39 57	23 15	31 36	34 14	26	0	404	4 9		
9	6034 KF	213	7840 K6	668	1292	к5	178	8894 1	16671	1.4	1.0	1.73	0.07	35.31	19.15	27.12	29.97	29	ő	267	4.5		
10	4700 KF	174	6779 K6	540	1130	K5	126	7104 1	15470	1 8	1 3	1 20	0 07	28 39	13 17	20 39	23 44	32	25	101	4 3		
11	3473 K	128	5845 KG	481	940	K5	83 1	5505 1	1/305	2 7	1 8	1 08	0.07	20.35	5 99	12 59	15 87	38	159	3	3.9		
12	2786 K	\$ 231	4915 KG	884	880	K5	114	4737 1	13854	3 4	2 5	0 98	0.00	15 61	2 35	8 42	11 24	45	290	0	3.4		
12	5523 KE	120	6046 K6	110	1414	KE	117 0	9403 1	16534	2.5	1 0	1 36	0.00	27 43	12 53	10 77	22 42	36	1105	1725	1 9		
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2	2057 IS	: 000	4730 10 5627 T6	2/30	1151	15	190	6579 1	15262	4.5	2.0	1 03	0.04	22 10	6 70	12 70	9.74	32	110	0	2.4		
2	1005 TE	1515	6134 T6	2020	1440	15	630	0370 1	16/01	3.0	2.0	1 00	0.05	17 50	5 02	11 14	12 27	50	21.0	0	5.0		
2	4905 IS	: 600	0134 10	1700	1621	15	650 0 661 10	0044 1	17677	2.9	5.0	1 10	0.00	24 66	0.70	17 10	10 60	26	210	15	6.5		
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5	8044 13 0060 TE	000	9319 16	1085	1520	15	514 1.	1540 1	10070	2.0	1.0	1.28	0.09	28.25	10 55	20.79	22.76	31	22	95	1.2		
6	8260 15	8//	9806 16	2251	1530	15	646 L.	1005 1	19078	1.7	1.0	1.52	0.08	34.93	18.55	26.73	28.96	28	0	252	6.2		
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Year

NSRDB – Threshold Statistics Files

Run	leng	th i	n DA	ZS)												(Run	leng	th i	n DA	YS)										
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
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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)

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 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

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
- 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



- 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

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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 sunfollowing 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



Measurements Uncertainty Examples

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



Measurements *Type of Equipment*

\$10-15K





\$50-75K

Rotating Shadowband – three measurements in one selfcontained 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?



National Renewable Energy Laboratory

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. <u>http://www.srrb.noaa.gov/surfrad/index.html</u>

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. <u>http://www.srrb.noaa.gov/isis/index.html</u>

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 <u>http://www.nrel.gov/midc/</u>.

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. <u>http://www.arm.gov/data/</u>

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/

SOLRMAP

The Solar Resource and Meteorological Assessment Project

Collaboration between NREL and industry for high quality solar measurements