Proposal for a Solar and Aerosol Optical Depth Network for the United States

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- Historic and current solar data
- Satellite options
- Ground-based network proposal
- Instruments
  - First-class instruments
  - MFRSR option

Definitions

- Global (total) irradiance on horizontal surface
- Direct (beam) irradiance normal to the sun
- Diffuse irradiance on horizontal surface

Lambert's Cosine Law

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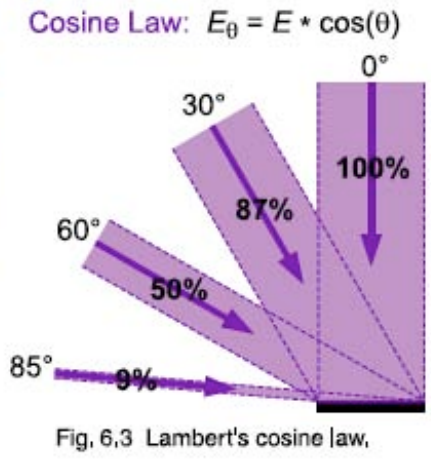


Fig. 6,3 Lambert's cosine law,

From Alex Ryer's "The Light Measurement Handbook" from Int'l Light

- Global = direct * cos(solar zenith angle) + diffuse

Historical & Current

- National Renewable Energy Laboratory summary of historic and current data; most are non-operational
  http://www.nrel.gov/rredc/solar_data.html

- **Global horizontal only** data (of unknown quality) gathered from available networks (3000+ in US)
  http://www.solardatawarehouse.com

- Best current networks that measure direct, too
  http://solardat.uoregon.edu/
  http://www.srrb.noaa.gov/surfrad/index.html

Cooperative Networks for Renewable Resource Measurements (CONFRRM) Solar Energy Resource Data
Provides solar radiation and wind measurement data for select U.S. locations **(discontinued)**.

Historically Black Colleges and Universities Solar Radiation Monitoring Network
Provides 5-minute measurements of solar irradiance for six stations in the southeastern United States from **1985 to 1996 (still operating using volunteers)**.

Lawrence Berkeley National Laboratory Reduced Circumsolar Radiation Database
Provides detailed intensity profiles of the solar and circumsolar region, direct normal radiation data, and total hemispherical solar radiation data for 11 U.S. locations from **1976 to 1981**.

Measurement and Instrumentation Data Center (MIDC)
Provides near real-time solar irradiance and meteorological data for several U.S. locations **(not all are functioning)**

National Aeronautics and Space Administration Remote Sensing Validation Data
Provides high-quality solar radiation monitoring data from a network of 12 stations in Saudi Arabia from **1995 to 2001**.

National Oceanic and Atmospheric Administration Solar Data
Provides archived solar radiation information from a network of 39 stations throughout the United States ≈ **1976 to 1981**.

National Renewable Energy Laboratory Spectral Solar Radiation Database
Provides spectral solar radiation data for several U.S. sites for **1986–1988**.

National Solar Radiation Database (NSRDB)
Provides hourly solar radiation and meteorological data for sites throughout the United States for **1961–1990 and 1991–2005**.

Solar Energy Measurement Research and Training Sites (SEMRTS) Data Set
Provides solar resource data for five sites across the United States for dates ranging from **1979 to 1984**.

Solar Spectra
Provides integrated standard spectral irradiance data for the United States from a variety of sources.

Typical Meteorological Year Data Sets
Provide hourly values of solar radiation and meteorological elements for U.S. sites and territories for a 1-year period **during 1961–1990 or 1991–2005**.

WEST Associates Solar Monitoring Network
Provides solar resource data for 52 stations in six Western U.S. states for **1976–1980**.

Table 17. Measurement Sites Used for NSRDB Model Evaluation (by State)

Site	Network	Site	Network	Site	Network
Barrow, AK	ARM	~~Albany, NY~~	~~SUNY~~	~~Corpus Christi, TX~~	~~UT~~
Hanford, CA	ISIS	ARM-SGP, OK	ARM	~~Del Rio, TX~~	~~UT~~
Golden, CO	NREL	Burns, OR	UO	~~Edinburg, TX~~	~~UT~~
FSEC, FL	FSEC	Eugene, OR	UO	~~El Paso, TX~~	~~UT~~
~~Tallahassee, FL~~	~~ISIS~~	Hermiston, OR	UO	~~Laredo, TX~~	~~UT~~
Bondville, IL	SURFRAD	Klamath Falls, OR	UO	~~Overton, TX~~	~~UT~~
Ft. Peck, MT	SURFRAD	Pennsylvania State College, PA	SURFRAD	Salt Lake City, UT	ISIS
Elizabeth City, NC	NREL	~~Abilene, TX~~	~~UT~~	Sterling, VA	ISIS
Bismarck, ND	ISIS	~~Austin, TX~~	~~UT~~	Seattle, WA	ISIS
Albuquerque, NM	ISIS	~~Canyon, TX~~	~~UT~~	Madison, WI	ISIS
Desert Rock, NV	SURFRAD	~~Clear Lake, TX~~	~~UT~~	Bluefield State College, WV	NREL

12 (funded)
09 (hanging on without funds)
12 (terminated - not reporting data)

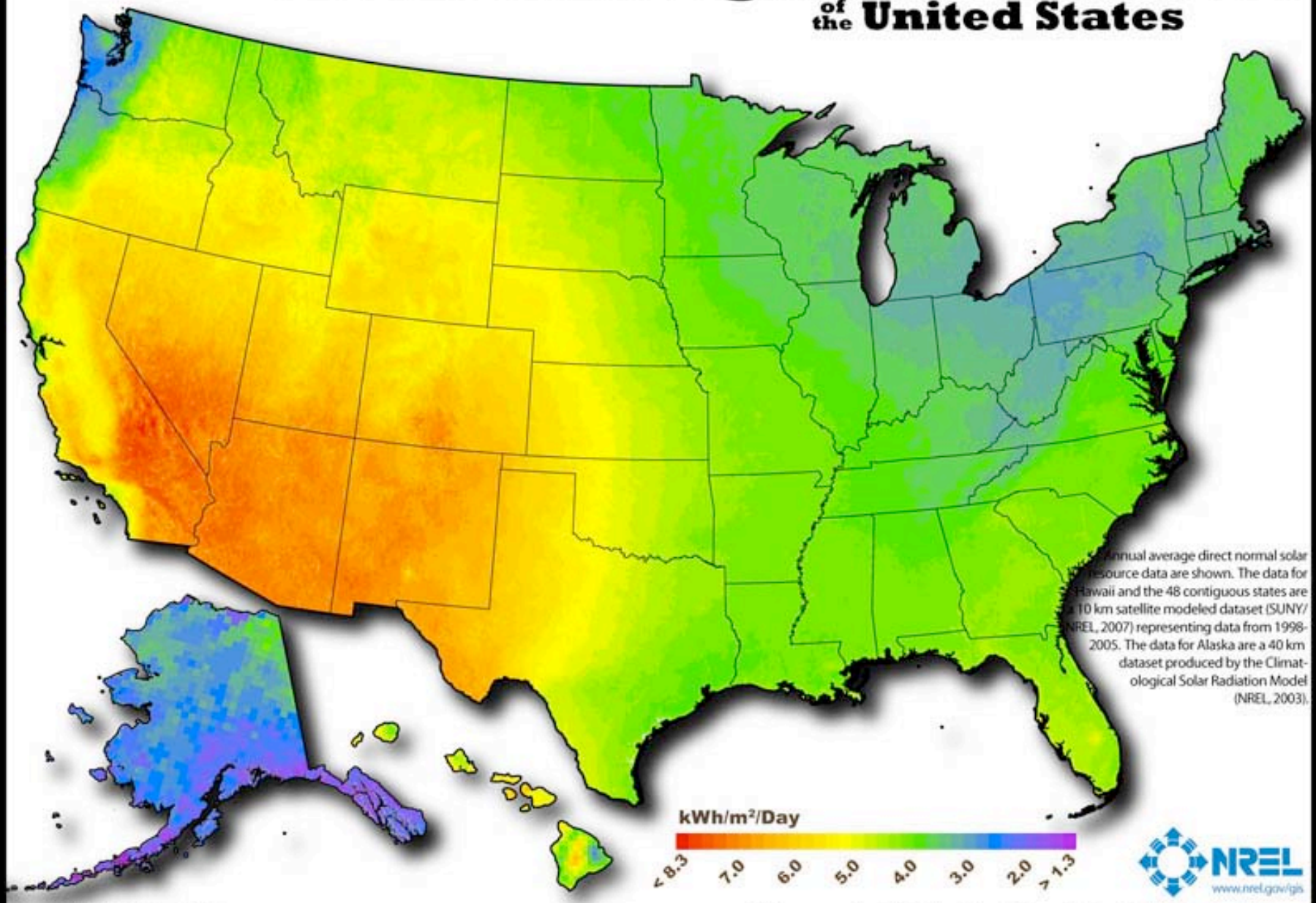
What about satellites?

- GOES (over U.S.)
  - images every 30 mins (or 15 mins if seen by GOES-E and GOES-W)
  - 1 km resolution in visible channel
  - 4 km resolution in infrared
  - www.goes.noaa.gov

Satellite Accuracy - Global and Direct
Hourly Estimates from GOES

Site	RMS Global	RMS Direct
Kimberly, ID	22 %	41 %
Burns, OR	18 %	38 %
Eugene, OR	17 %	37 %
Hermiston, OR	12 %	34 %
Klamath Falls, OR	14 %	35 %
ARM Site, OK	20 %	31 %
Albany, NY	21%	45%

Concentrating Solar Resource of the United States

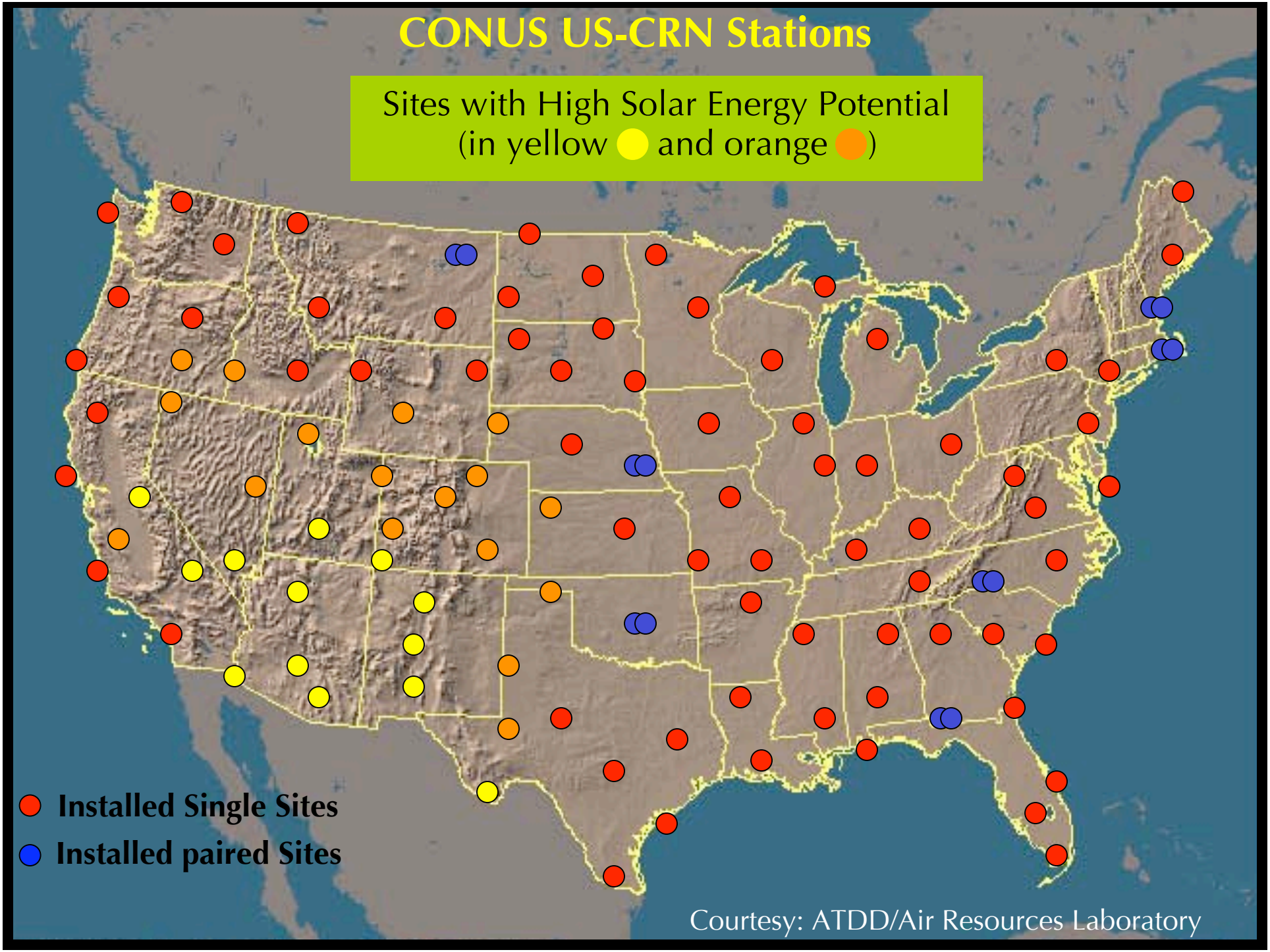


Annual average direct normal solar resource data are shown. The data for Hawaii and the 48 contiguous states are a 10 km satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2005. The data for Alaska are a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).

NREL
www.nrel.gov/gis

Author : Billy Roberts - October 20, 2008

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.


CONUS US-CRN Stations
Sites with High Solar Energy Potential
(in yellow and orange)
Installed Single Sites
Installed paired Sites
Courtesy: ATDD/Air Resources Laboratory

PA Avondale 2 N, Stroud Water Research Center

39.9 N 75.8 W 410'

June 2, 2006

Courtesy: National Climatic Data Center

NC Asheville 8 SSW, North Carolina Arboretum (Bierbaum Site)

35.5 N 82.6 W 2200'

November 14, 2000

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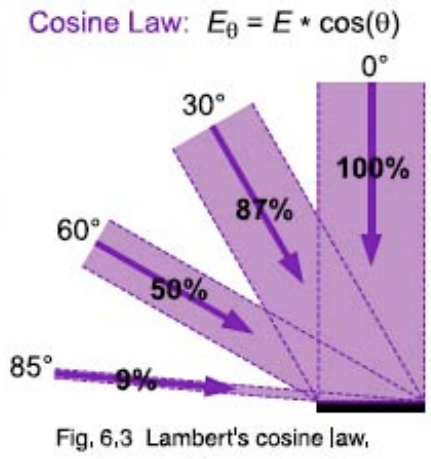

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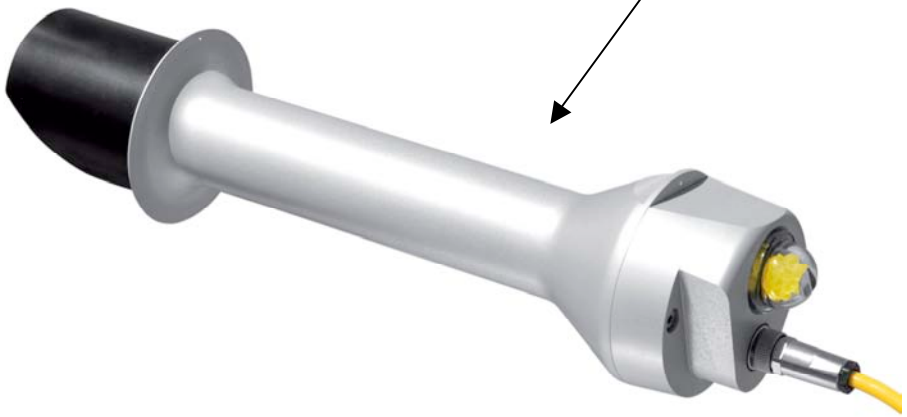
First-Class Solar Instruments Used to Measure Direct Beam, Scattered Solar, and Total Solar Irradiance at All Solar Wavelengths

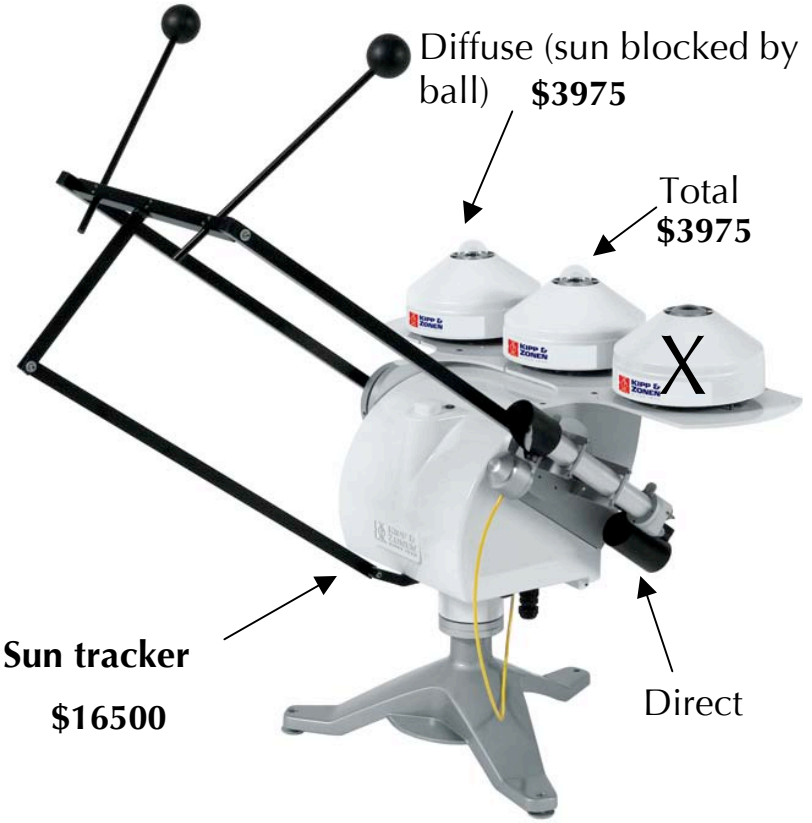
Direct Beam Sensor (pyrheliometer)

$3525



Diffuse (sun blocked by ball) **$3975**

Total **$3975**



Sun tracker

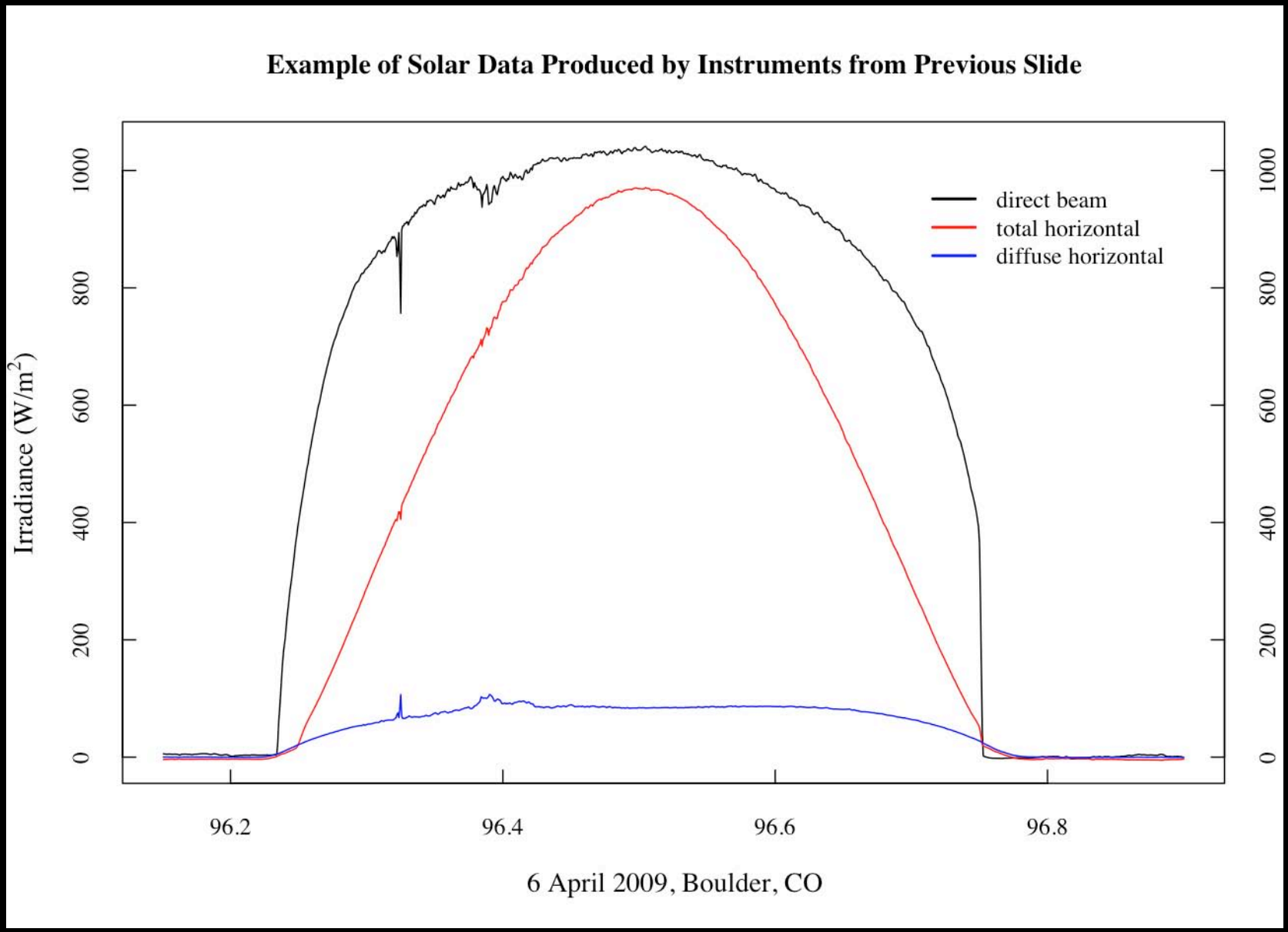
$16500

Direct

Same Sensor for Scattered and Total (pyranometer)

Figures from Kipp & Zonen

Total = $30,000 ($50,000 best)


Example of Solar Data Produced by Instruments from Previous Slide
Irradiance (W/m^2)
0
200
400
600
800
1000
direct beam
total horizontal
diffuse horizontal
96.2
96.4
96.6
96.8
6 April 2009, Boulder, CO

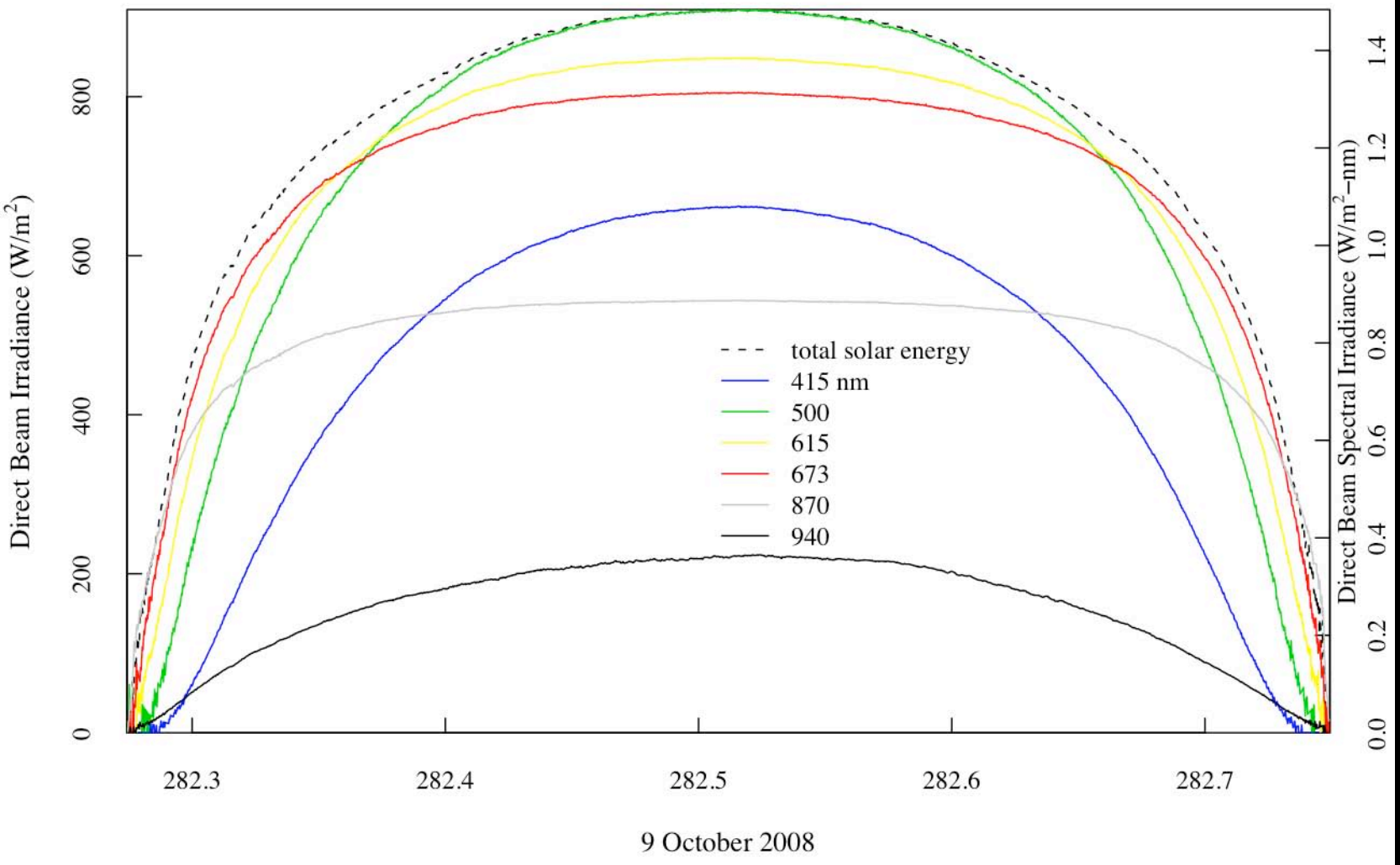
Possible Instrument for Deployment at Climate Reference Network (CRN) or HCN-M Sites: Multi-Filter Rotating Shadowband Radiometer (MFRSR)

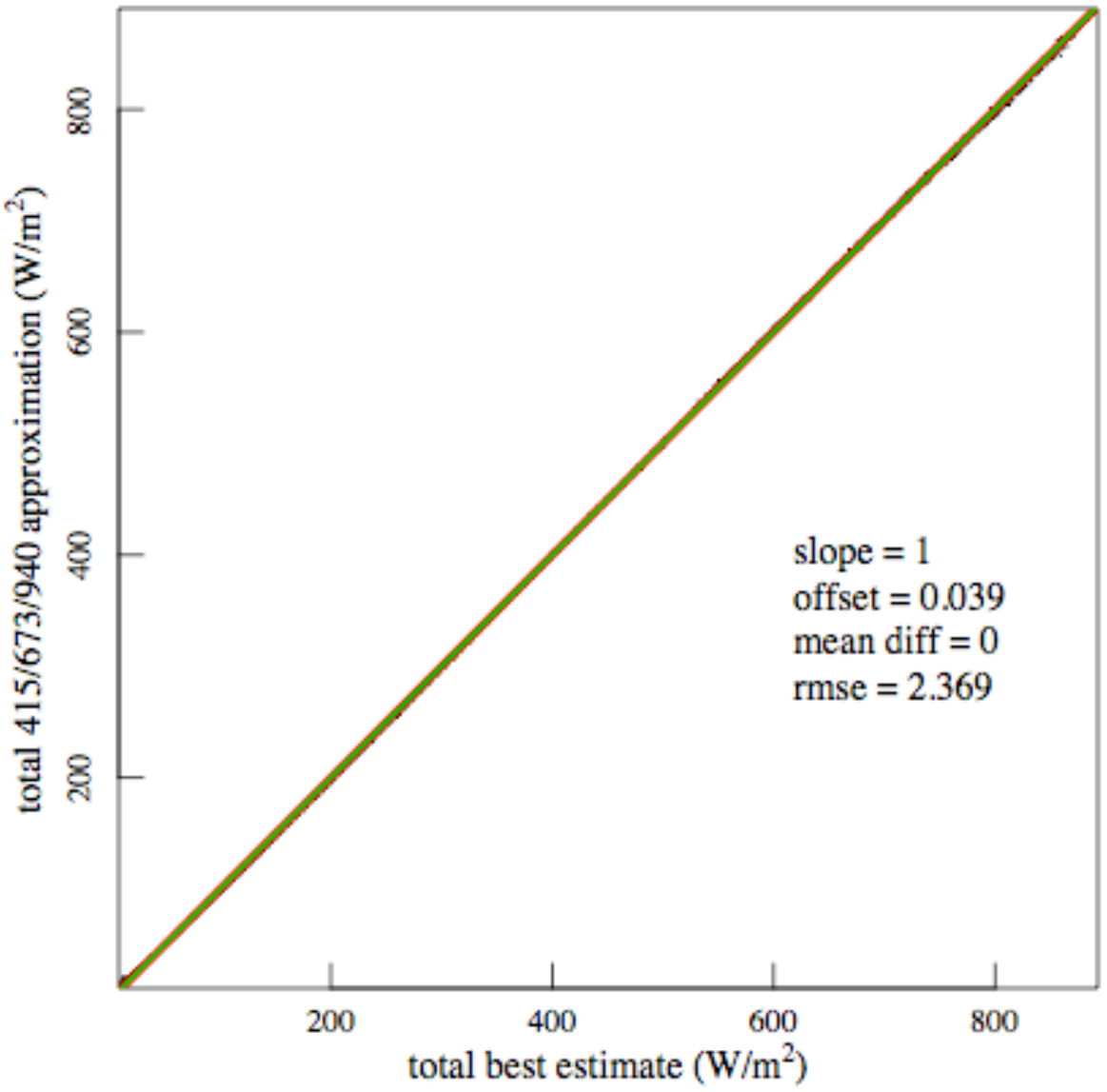
Figure from Yankee Environmental Systems, Inc.

The MFRSR measures solar beam radiation plus scattered solar radiation from the sky in seven channels simultaneously. One channel is for broadband solar radiation used by solar thermal devices and the six others are used for small portions of the solar spectrum providing useful information for PV devices and for measuring the extinction in the direct beam caused by aerosols and water vapor.

$15,200

MFRSR-measured Solar Beam --Total Energy + Spectral @ Six Wavelengths





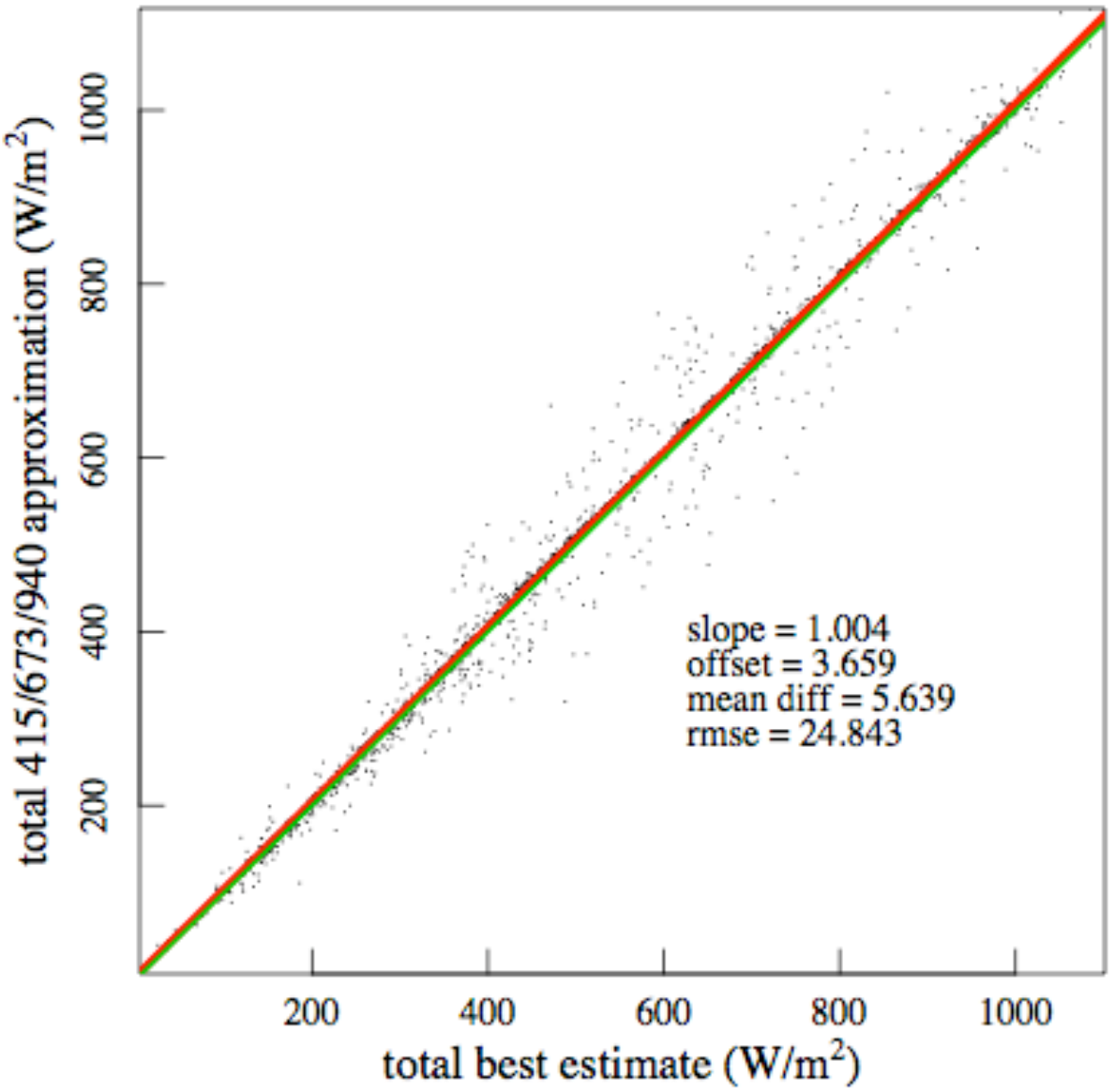
± 0.44% ➜ ± 0.42%

1-min avg 15-min avg

Direct Beam

± 1.30% ➜ ± 0.88%

1-min avg 15-min avg



± 5.09% ➔ ± 1.45%

1-min avg 15-min avg

Direct Beam

± 8.99% ➔ ± 2.41%

1-min avg 15-min avg

Main Points

- Ground-based network will provide basis for improving satellite retrievals
- Better knowledge of resource (lower uncertainties) allows better informed investments in renewables
- If the MFRSR is used, aerosol optical depth and spectral data useful for PV technology will be obtained concurrently with broadband solar data