Solar Resource Data

Tom Stoffel & Ray George
Resource Integration Section
Electric Systems Center

NREL Parabolic Trough Technology Workshop

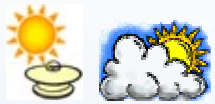
8-9 March 2007

Solar Resource Data

- Resource Assessment
- National Solar Radiation Database
- Satellite Remote Sensing
- Surface Measurements
- RA Capabilities at NREL
- Summary

Resource Integration

Resource *DATA* → **Technology *INFORMATION***



Real-Time Data

Databases

Maps

Climate Summaries

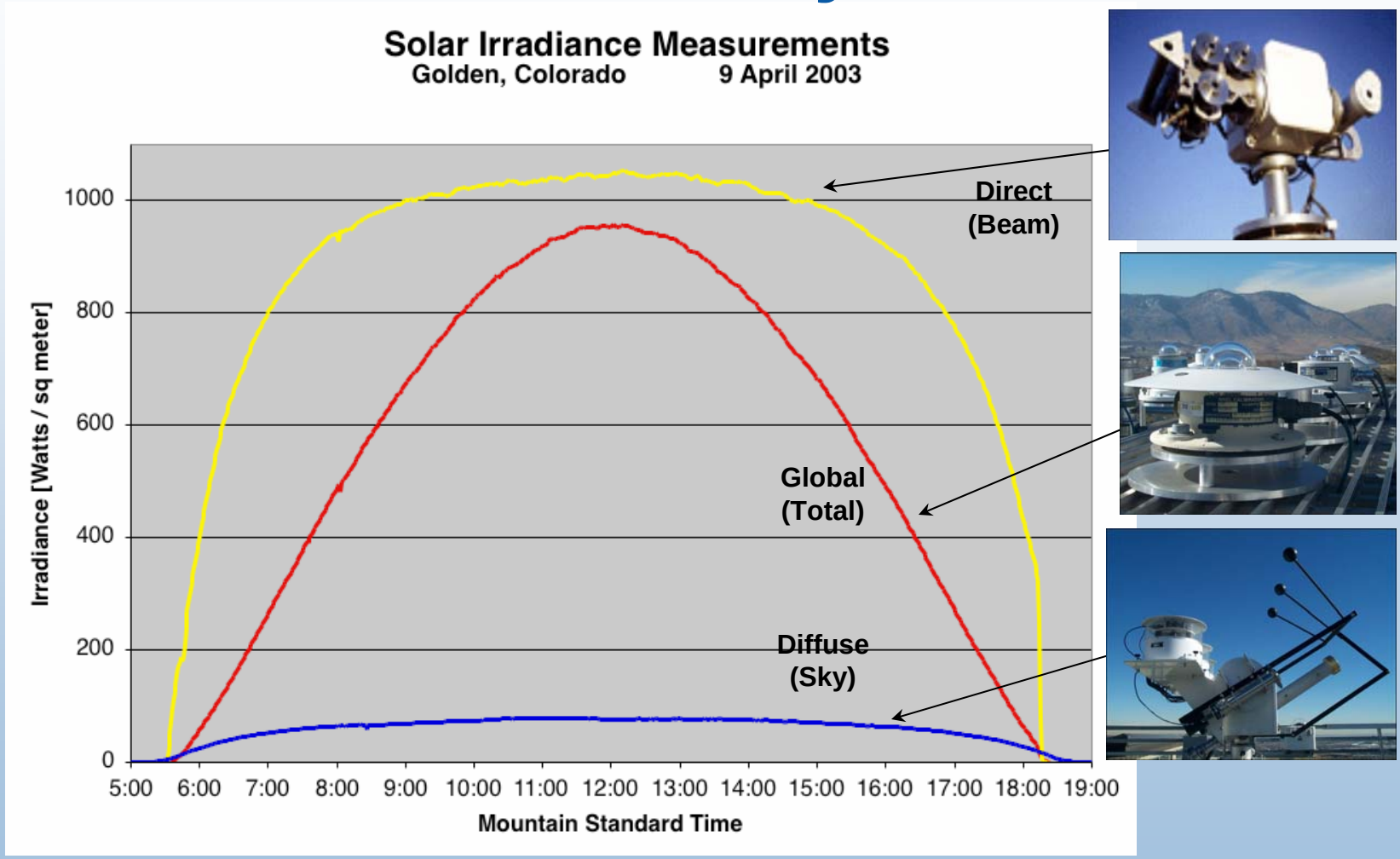
Models

Solar Radiation Research Lab

- Baseline Measurements
- Radiometer Calibrations
- Instrument Development
- Station Operator Training

Geographic Information System
GIS Lab

Clear Sky

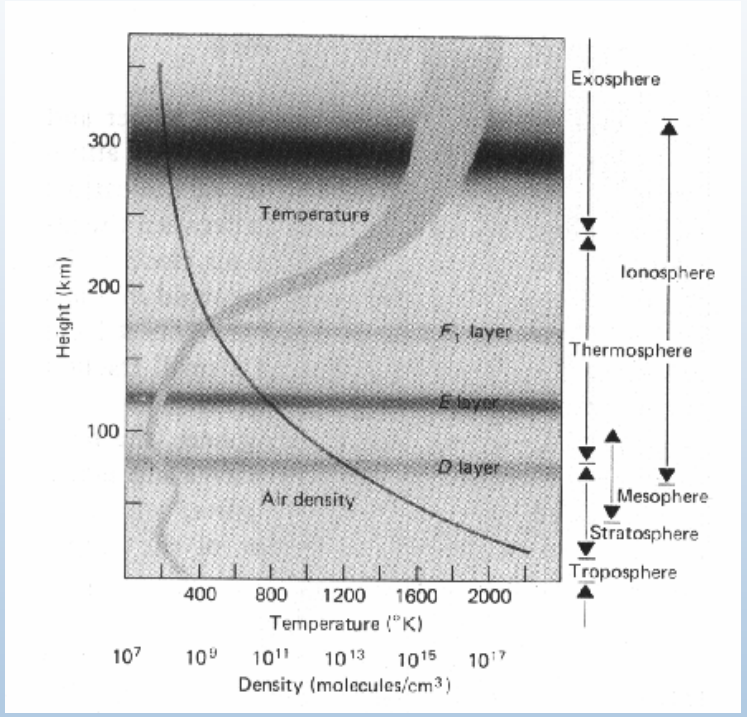


http://www.nrel.gov/srrl

Modeling Solar Irradiance

Atmospheric Composition

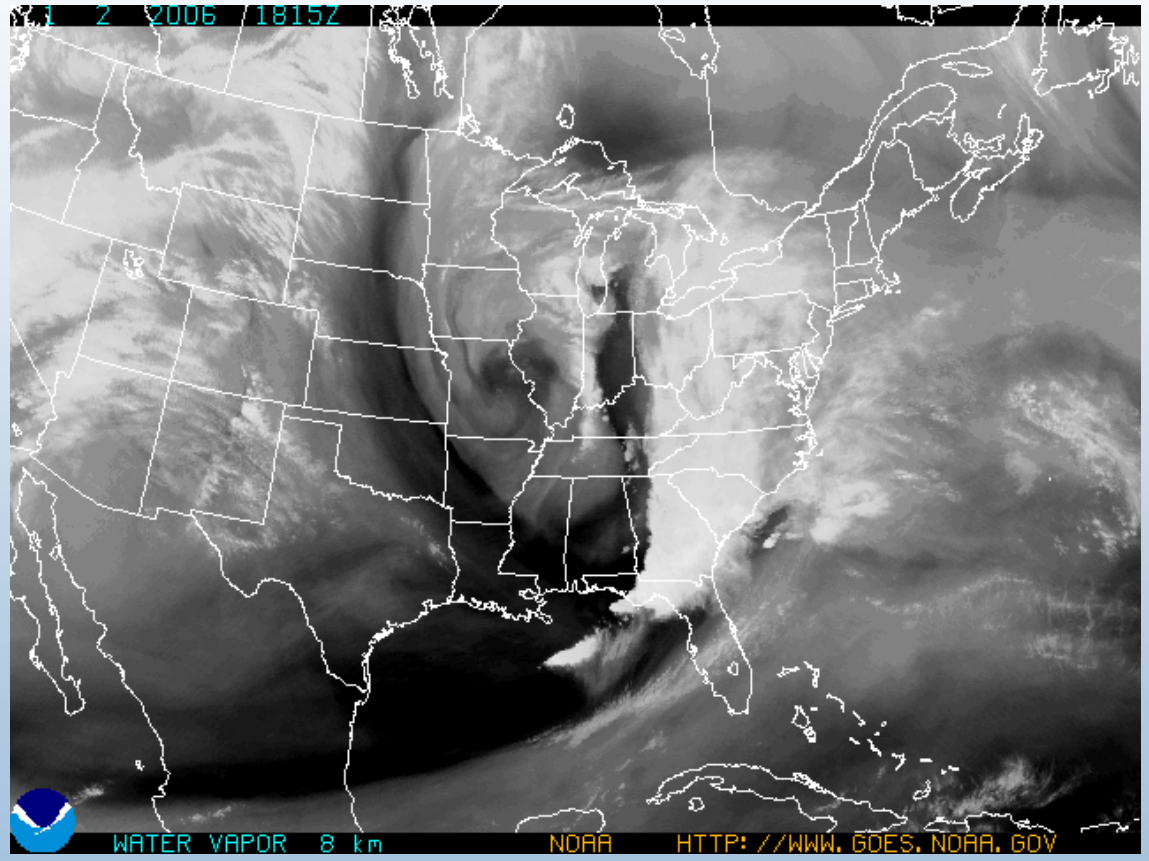
- Clouds
- Temperature
- Pressure
- H_2O_v
- Aerosols
- Gases
- Etc.



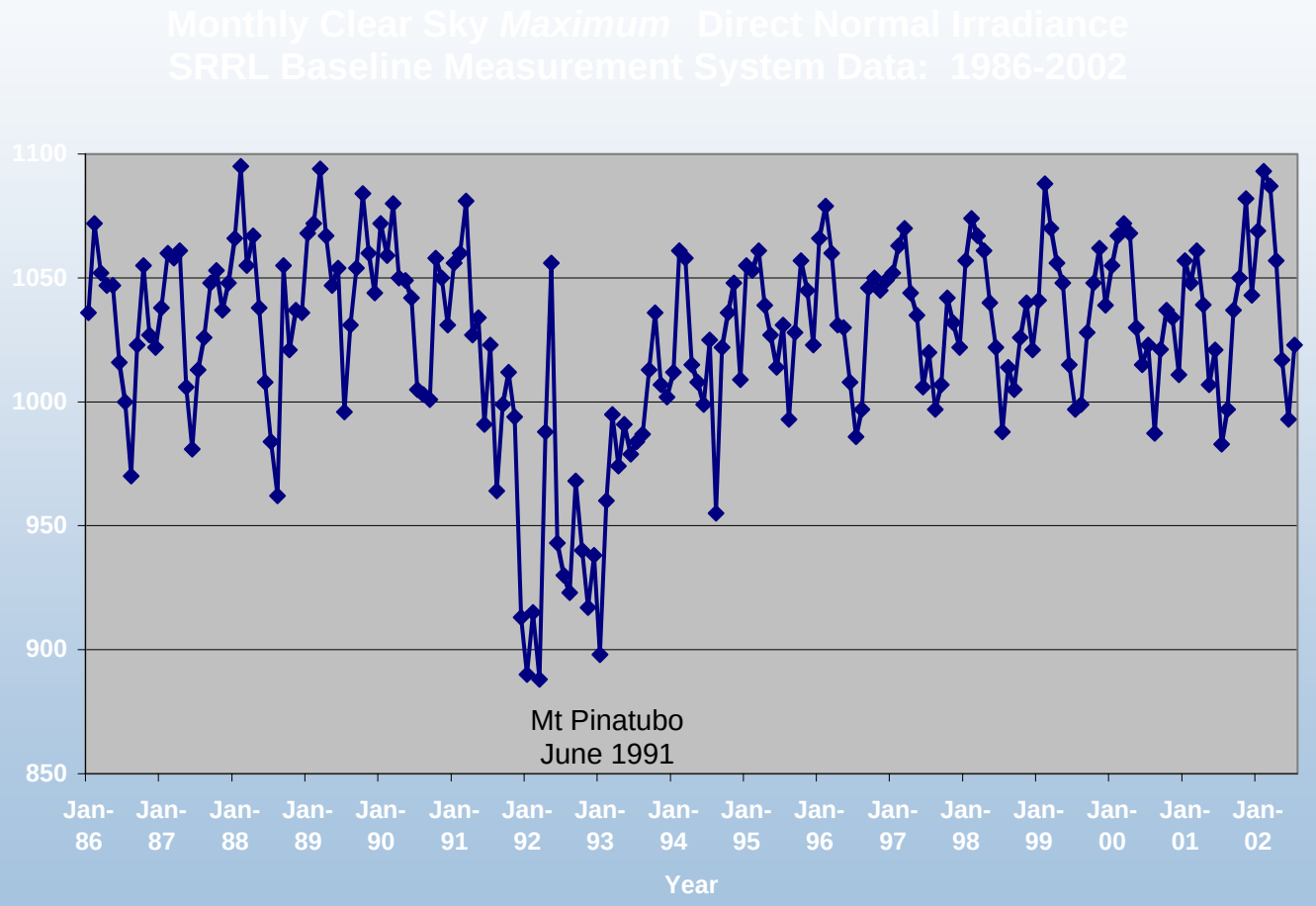
Simple Model of the Atmospheric Radiative Transfer of Sunshine - SMARTS http://rredc.nrel.gov/solar/models/SMARTS

Modeling Solar Irradiance

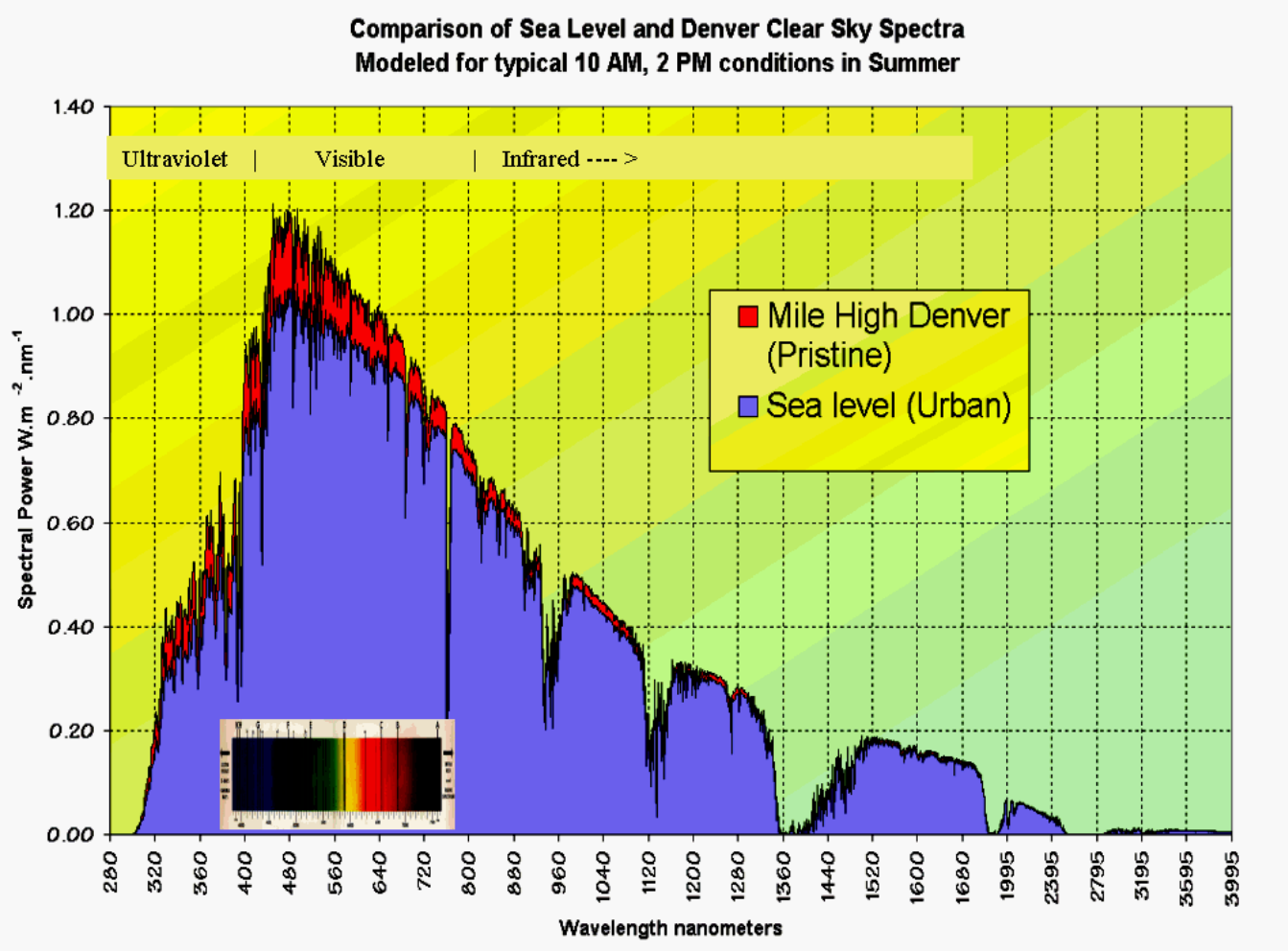
Satellite Remote Sensing



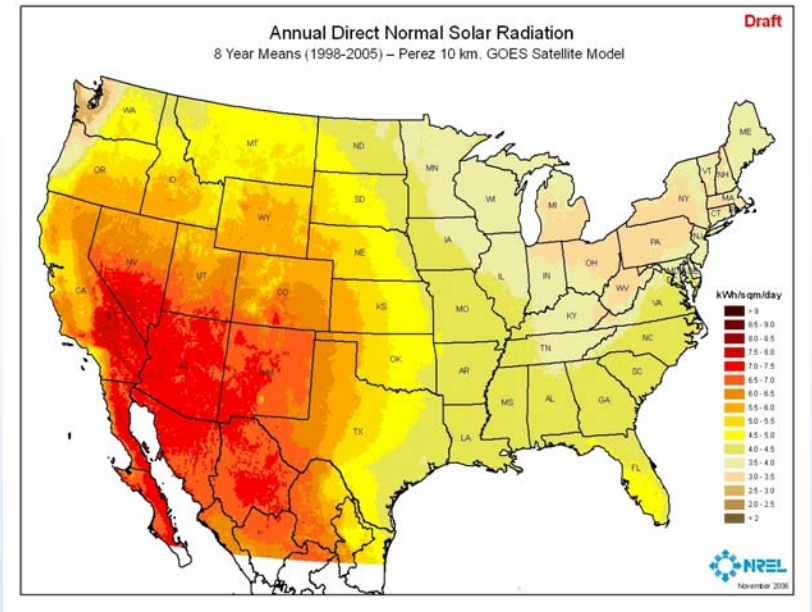
Changes with Time: Inter-annual

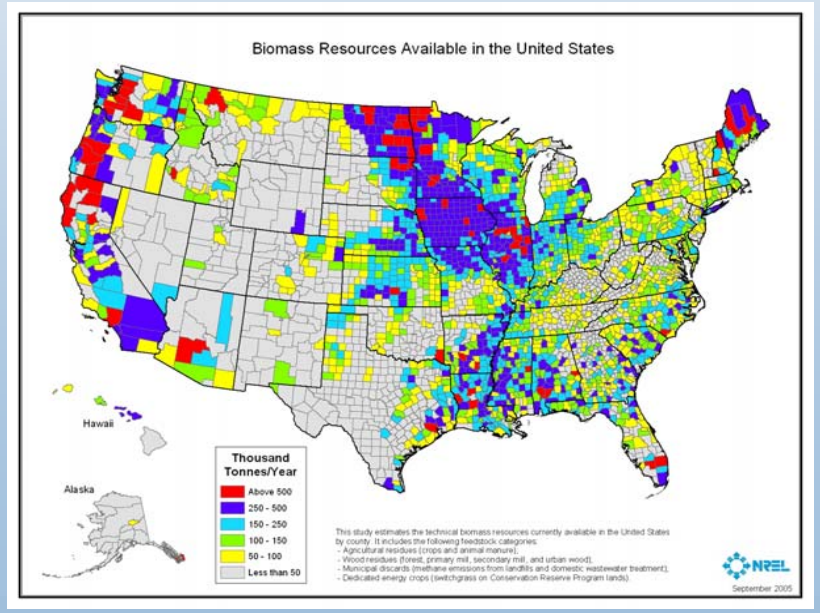


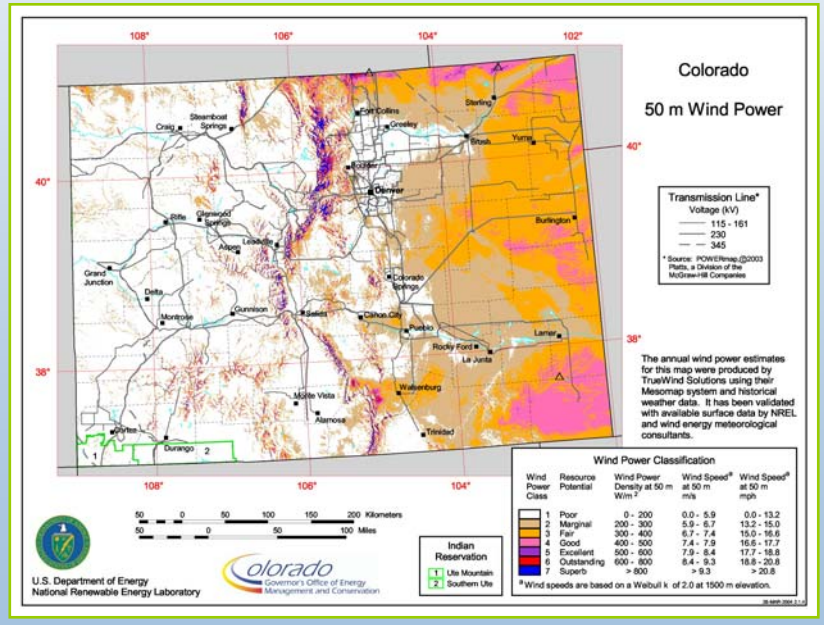
Solar Spectral Distribution



Regional Resource Assessment

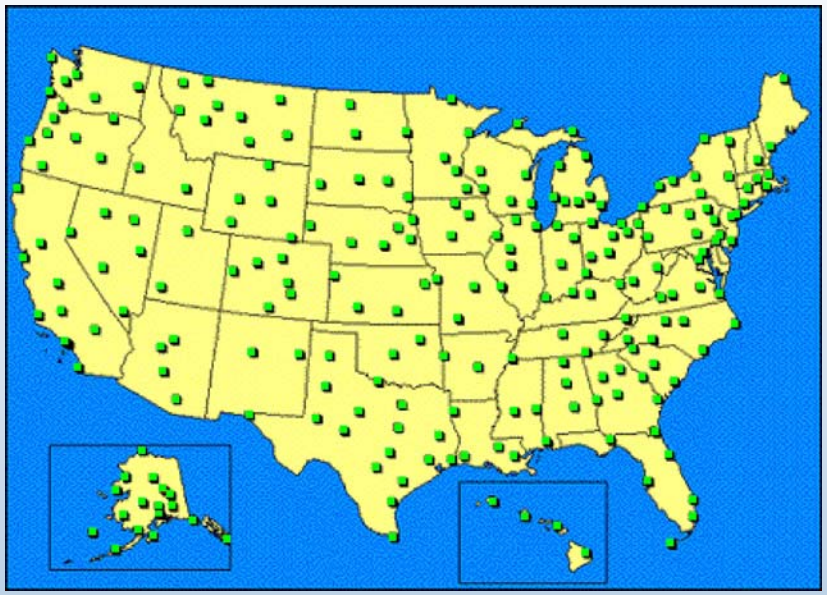






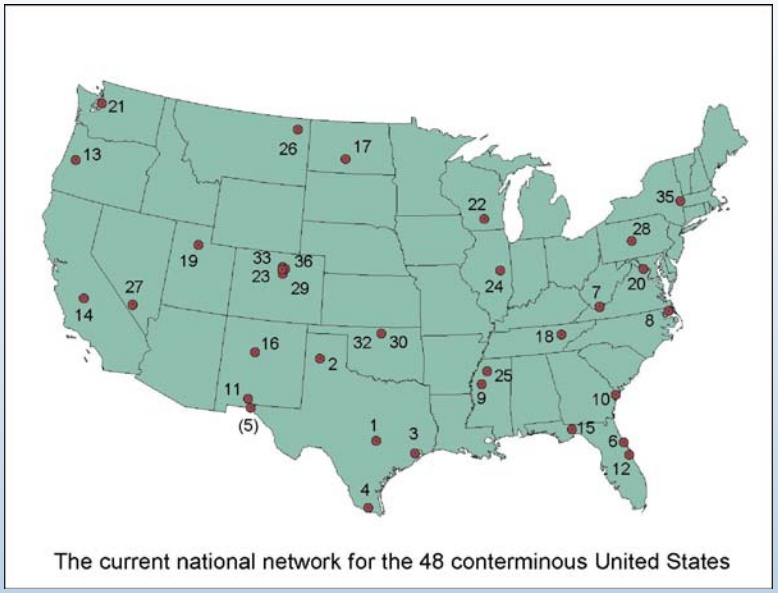
National Solar Radiation Data Base

1995



NSRDB Stations
239

(1961-1990)



The current national network for the 48 conterminous United States

Solar Measurement Stations
36
(1990 - 2003)

Renewable Resource Data Center http://rredc.nrel.gov/solar

National Solar Radiation Data Base

Period of Record	1961-1990
Temporal Resolution	Hourly (serially complete)
Irradiance Data Source	Sfc Cloud Obs (96%) Sfc Measurements (4%)
Number of Stations	239
Data Products	TMY2, Monthly & Daily Statistics, Maps

Ten years after the NSRDB release…

Rationale for an Update 1991-2005

- Access to the most recent data

  NSRDB more than 15 years out of date - most recent data may best represent the future resources

- Inter-annual and inter-decadal variability and trends are of increasing importance to industry

  Extend the period of record

- Exploit advances in solar radiation instrumentation and modeling New National Weather Service observations (ASOS)
- Satisfy numerous inquiries about a comprehensive update *More recent data from more sites*

NSRDB Update Site Classifications

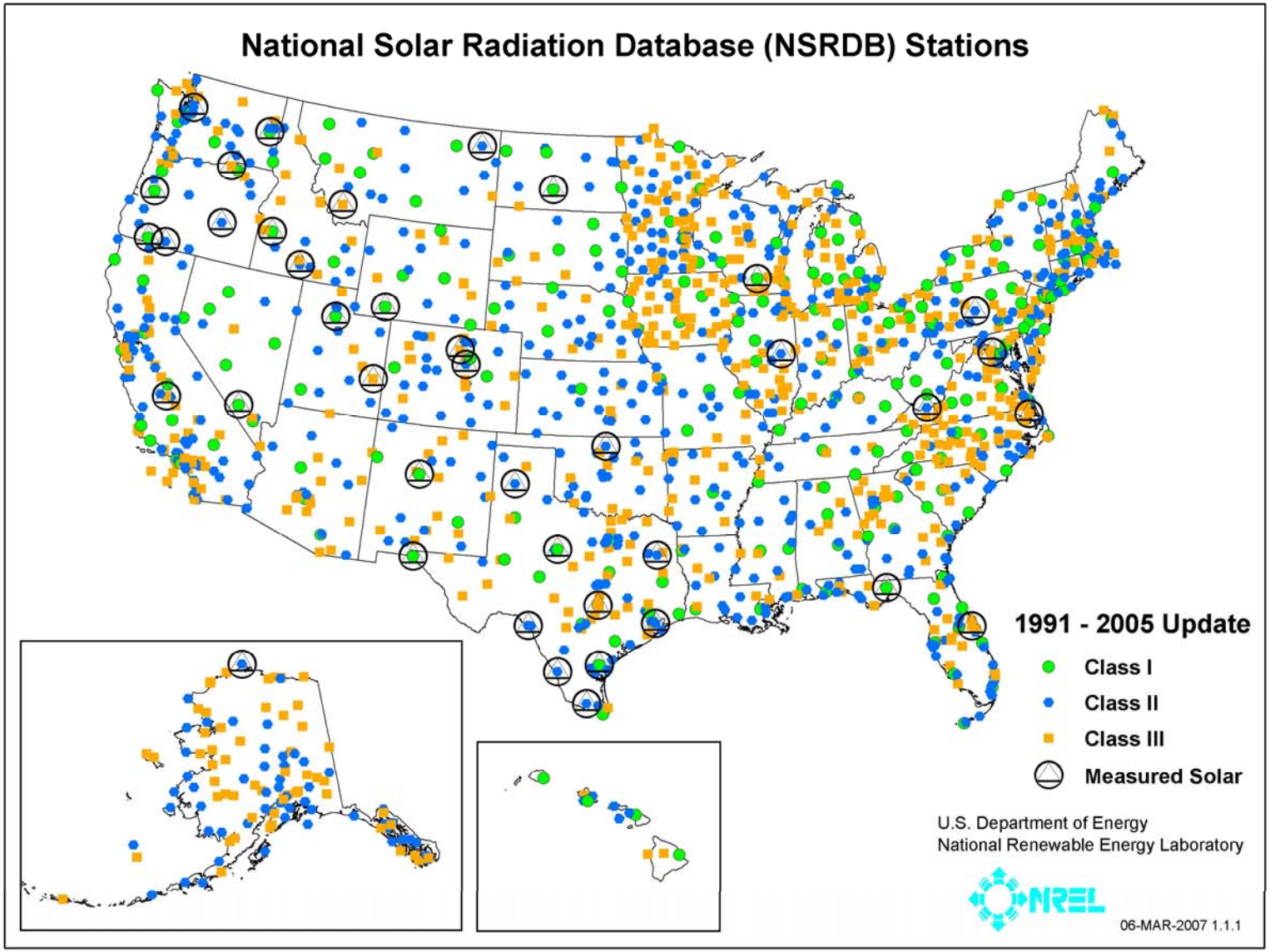
- The 1454 sites are segregated based on availability and completeness of data:

  221 Class I - Complete period of record with more than 75% "low" uncertainty
  637 Class II - Complete period of record with less than 75% "low" uncertainty
  596 Class III - At least three years of data throughout to period of record

- This classification scheme helps optimize the quantity of data available for a range of applications

Notes:

- The inclusion of measured data has no bearing on a station's class. Measured data appear when available in any class of site.
- Class I sites correspond fairly well with the 239 sites in old NSRDB)
- Total Class I and II (those with complete 15-year period of record) = 858


National Solar Radiation Database (NSRDB) Stations
1991 - 2005 Update
Class I
Class II
Class III
Measured Solar
U.S. Department of Energy
National Renewable Energy Laboratory
NREL
06-MAR-2007 1.1.1

Updated NSRDB Data Quality

- Almost all solar data are modeled (some measured data at 40 sites)
- METSTAT model used again (Cloud amounts from NWS observer/ASOS)
- SUNY model used for 10 km gridded data set derived from GOES satellite data for 1998-2005
- Estimated Uncertainties (optimal):

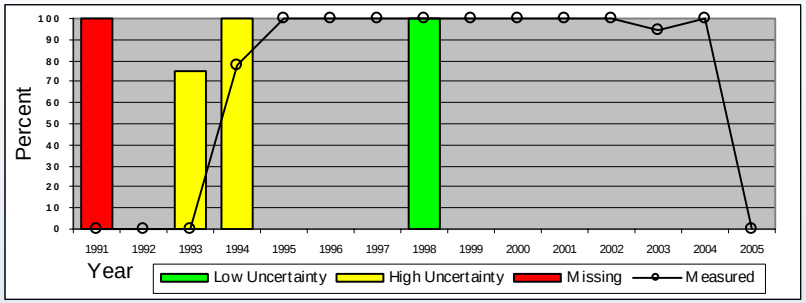
Data Source	Global/Diffuse	Direct Normal
Measured	+/- 6%	+/- 5%
SUNY	+/-8%	+/-15%
METSTAT	+/-10%	+/-16%

Sub-optimal values can range up to 25% based on ASOS cloud observations used in METSTAT, snow cover or high latitude locations for SUNY model

NSRDB Update

Data Quality Summaries are Available for All Sites

724776	MOAB/CANYONLANDS [UO], UT
Class III (with some measured)	
Solar Coordinates	
Latitude: 38.58˚	
Longitude: -109.54˚	
Elevation: 1000 m	
Meteorological Coordinates	
Latitude: 38.75˚	
Longitude: -109.75˚	
Elevation: 1388 m	
Time Zone: -7	



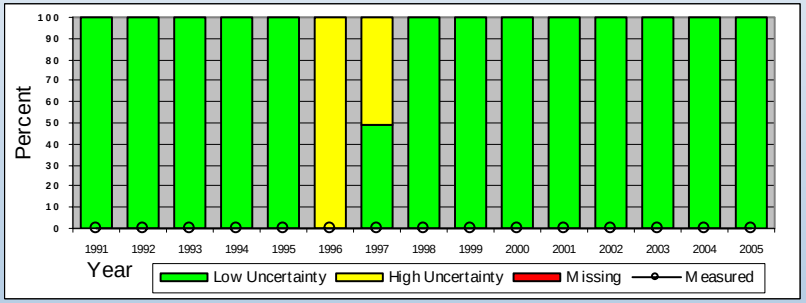
Green: Proportion of "low" uncertainty data

Yellow: Proportion of "high" uncertainty data

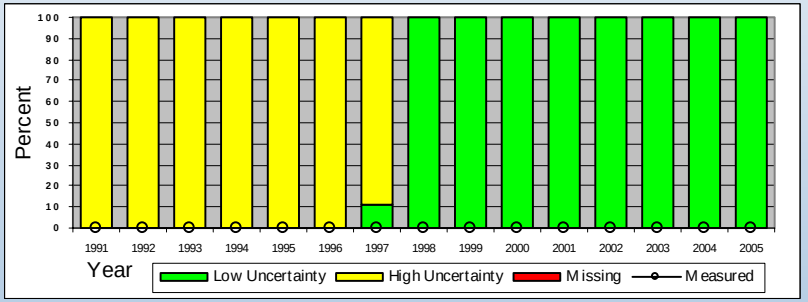
Red: Proportion of missing data

Black Line: Percentage of measured data

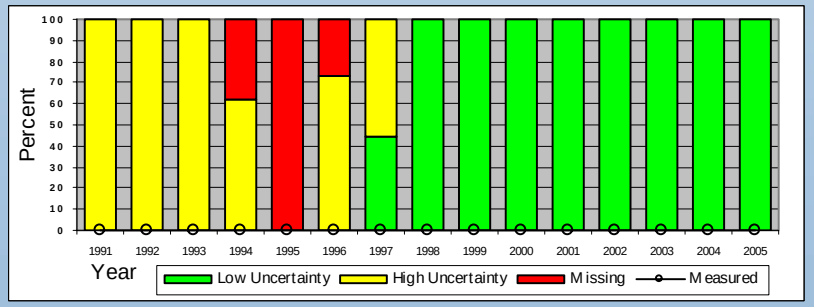
Typical Class I Site (Tucson, AZ)



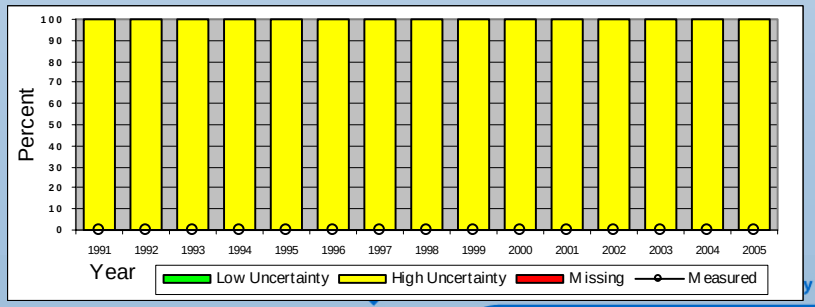
Typical Class II Site (Stillwater, OK)



Typical Class III Site (Sandburg, CA)



Typical Alaska Site (Sand Point, AK)



NSRDB Products

- Time-series of hourly ***solar and met*** data at 1454 sites for technology deployment
- Time-series of hourly ***solar*** and associated fields for research
- Gridded hourly 10 km ***solar*** data for 100,000 grid locations
- Statistical summaries of ***solar and met*** data at Class I & II sites
- Maps of ***solar*** monthly & annual mean daily totals

Data Distribution

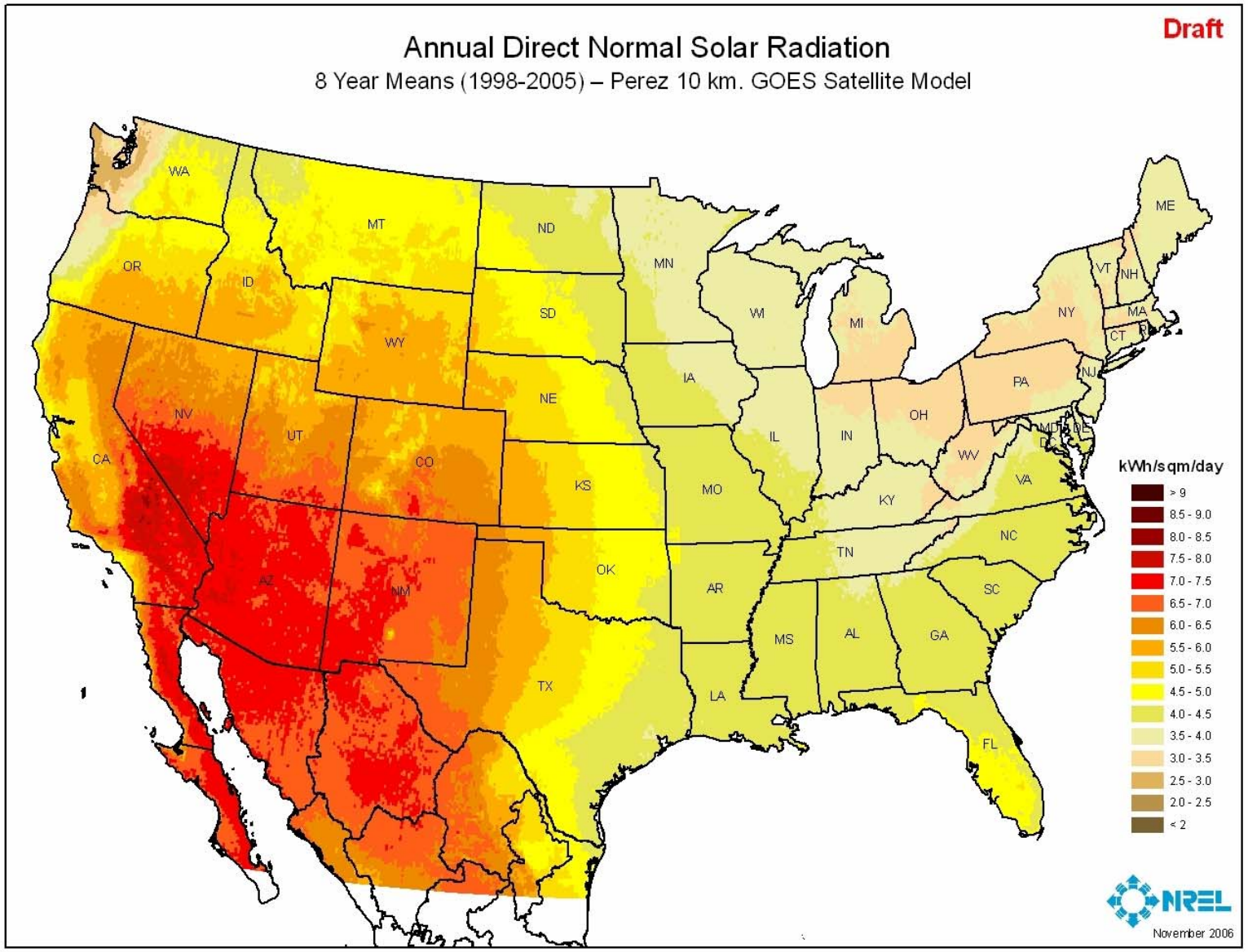
- Updated NSRDB will be distributed by the National Climatic Data Center (NCDC)

  http://www.ncdc.noaa.gov/
- NREL will distribute solar research data set (no met)
- Data format will be CSV ASCII
- Satellite data set distributed by NCDC at no charge
- NSRDB station data $140/100 site-yr, but NCDC policy is *no-cost* for requests by *.edu*, *.k12*, *.mil*, and *.gov*
- Tiered release begins April 2007

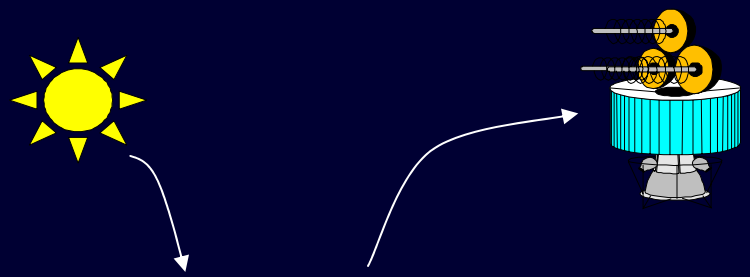
New Satellite DNI Data - Outline

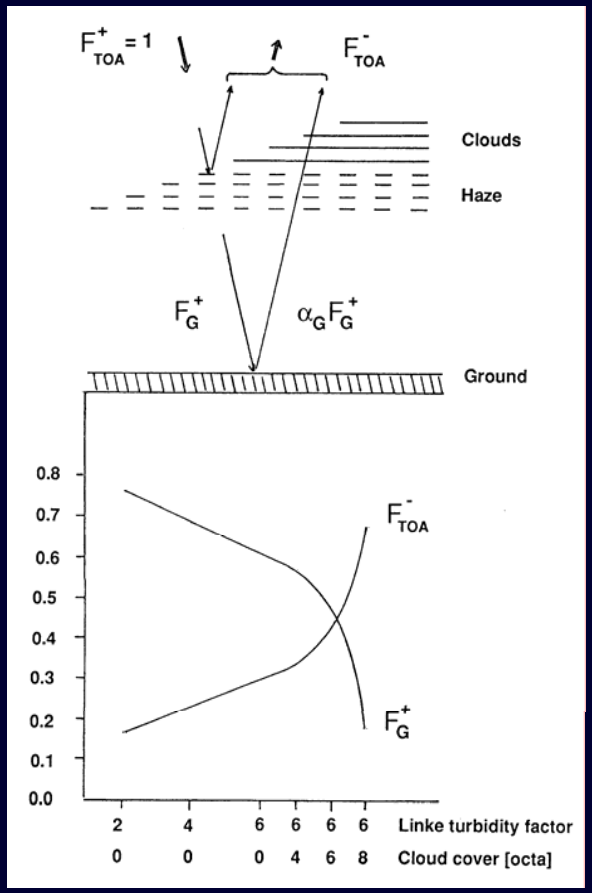
- Methodology
- Map product description
  - Yearly Map Grids
  - 8-year map “Climatological”
  - Map adjustments
  - Uncertainties
  - How to obtain
- Time Series Product
  - Time shifting
  - Diffuse editing
  - How to obtain

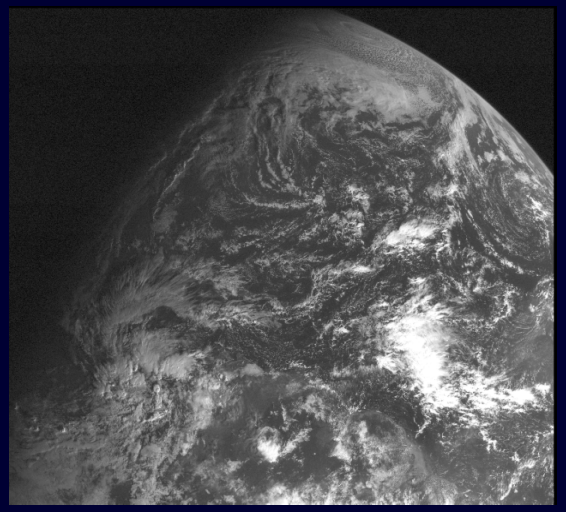
Satellite DNI Data- Maps



Basic principle

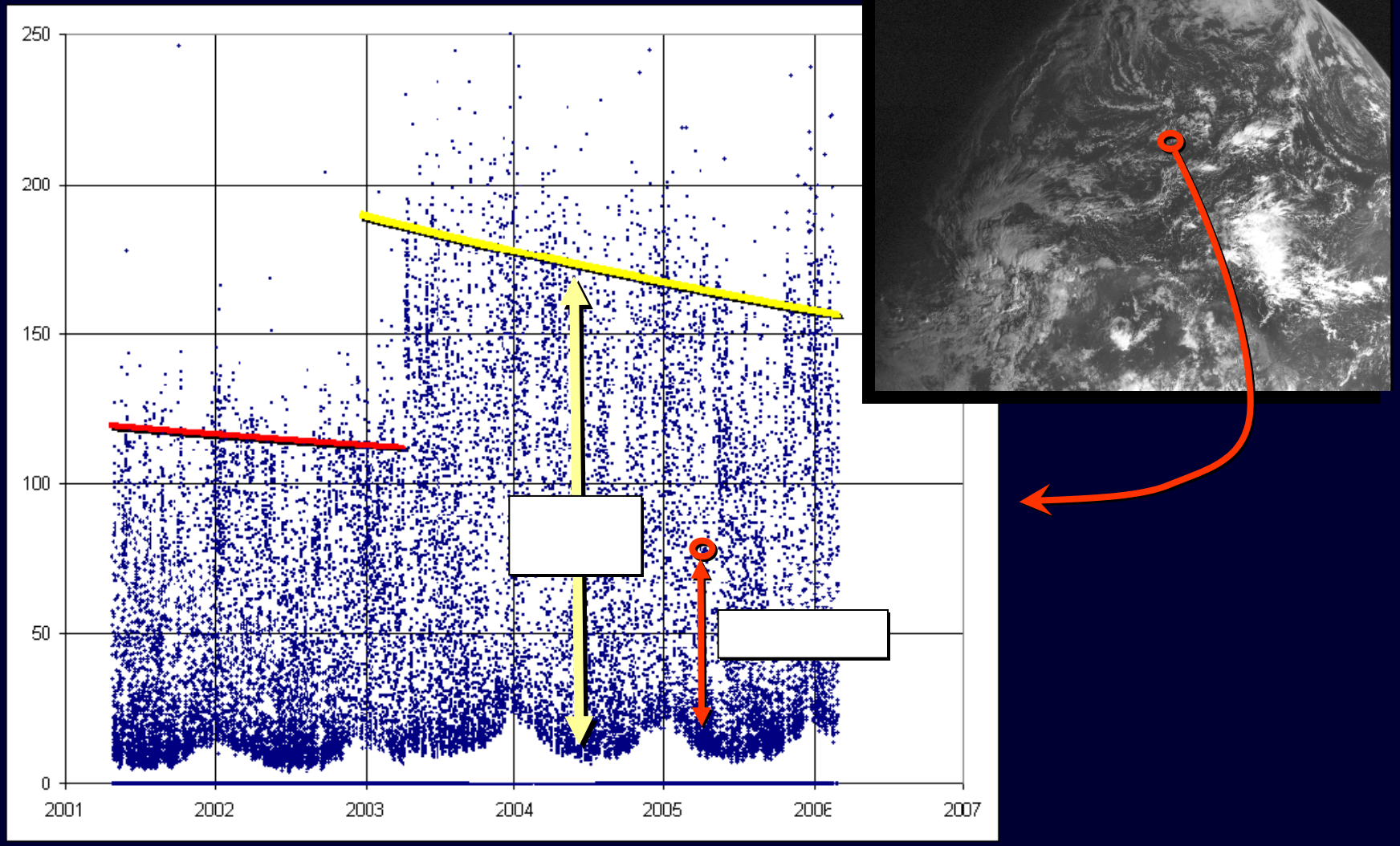






$$T = \frac{F^+_G}{F^+_{TOA}} = a - b\,\frac{F^-_{TOA}}{F^+_{TOA}}$$

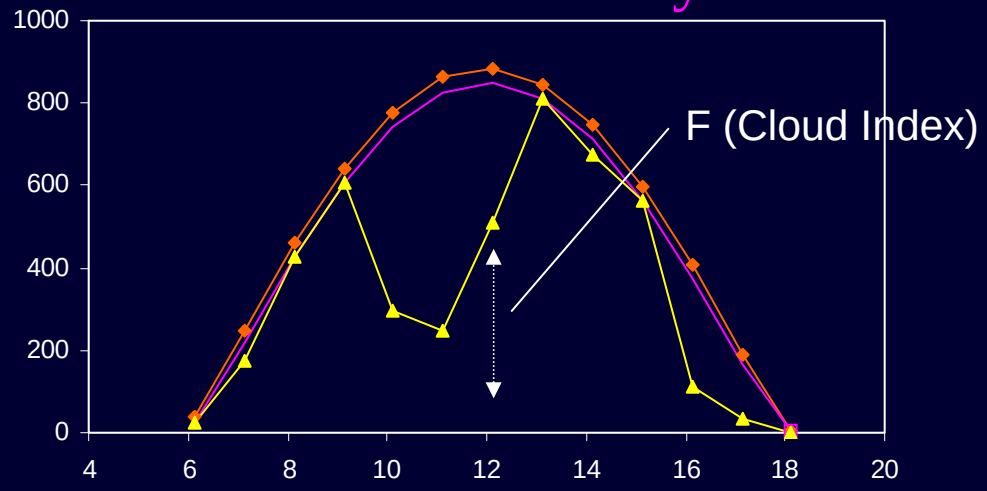
Richard Perez, et al.

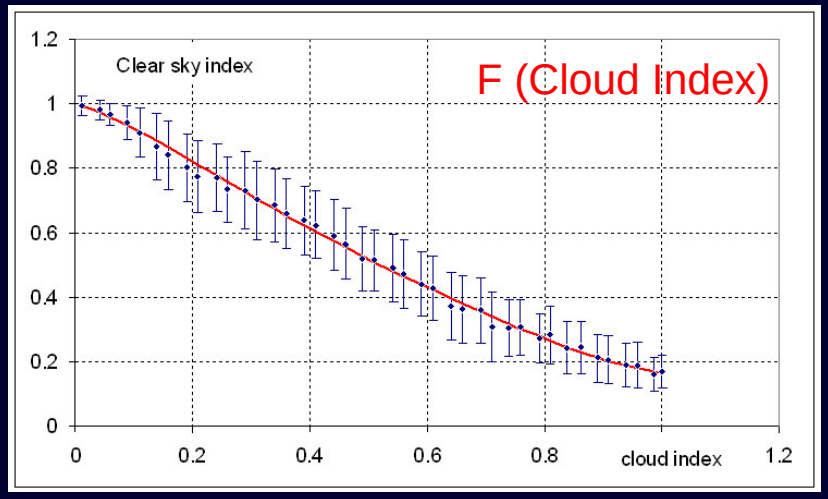


Richard Perez, et al.

GLOBAL IRRADIANCE

SOLIS clear sky model

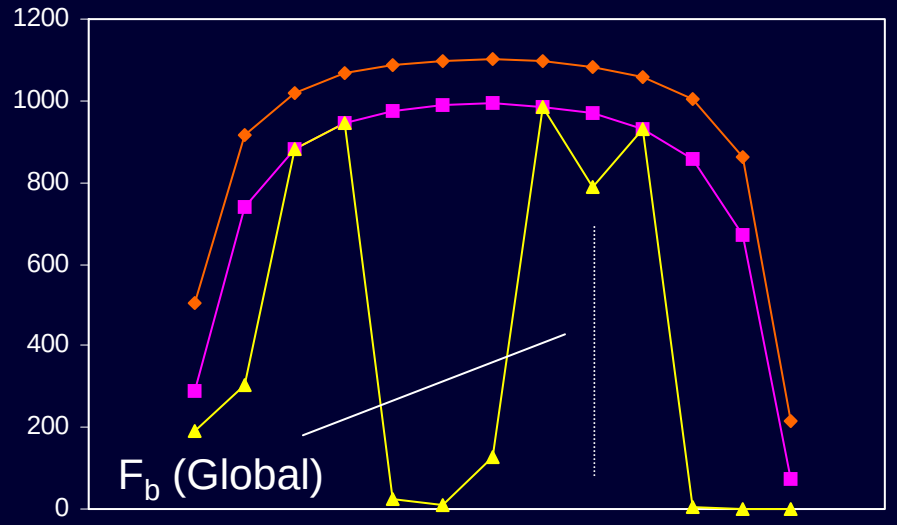




Richard Perez, et al.

Dirindex Model: DNI = Bird * f_b (GHI)

BIRD MODEL f (elevation, AOD, ozone, water vapor)

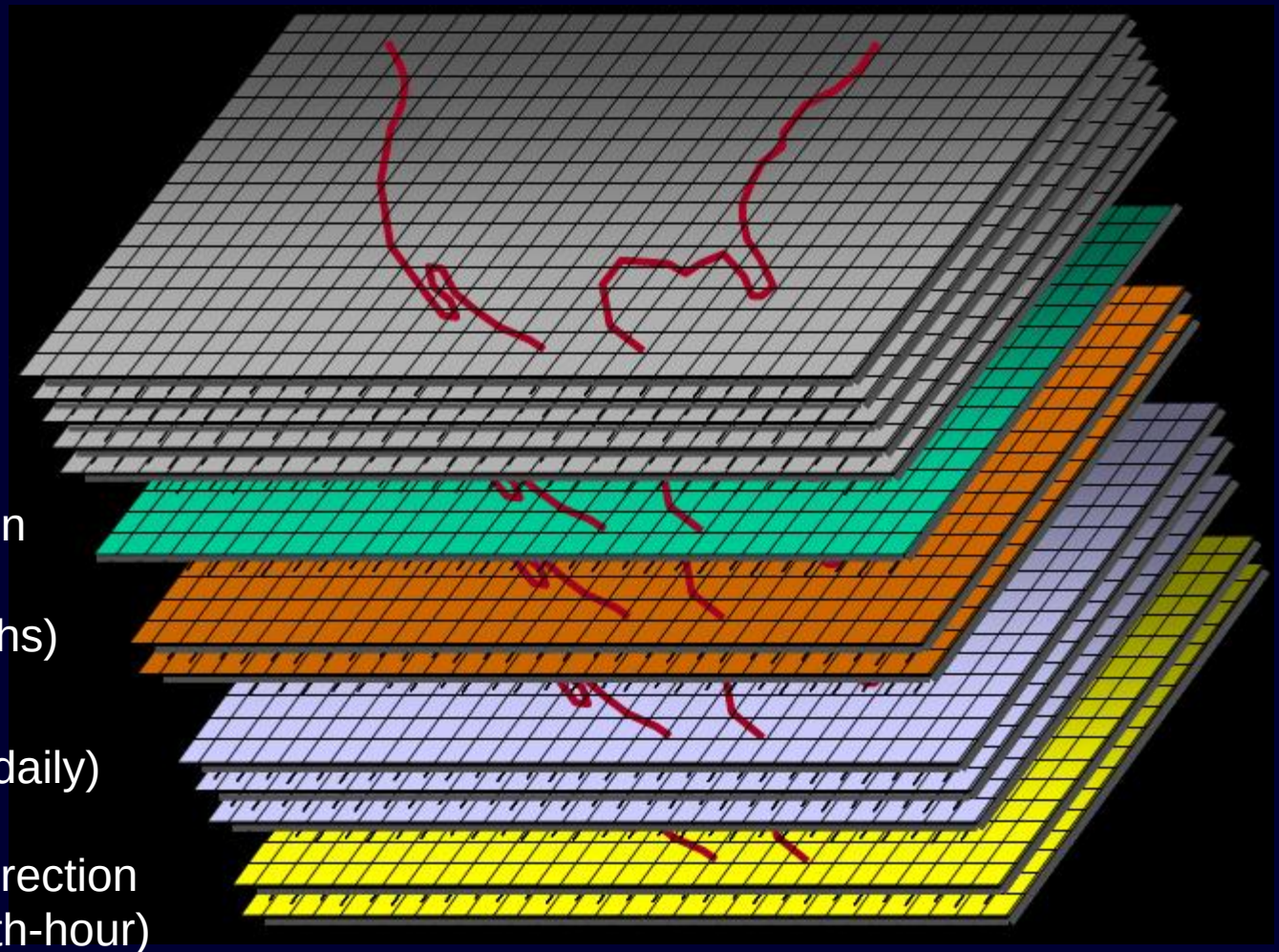


$$F_b = \frac{\text{Dirint (GHI)}}{\text{Dirint (GHI}_{clear}\text{)}}$$

Dirint = NREL's DISC model modified per ASHRAE, 1993

Richard Perez, et al.

Operational Model



Pixels hourly

Terrain elevation

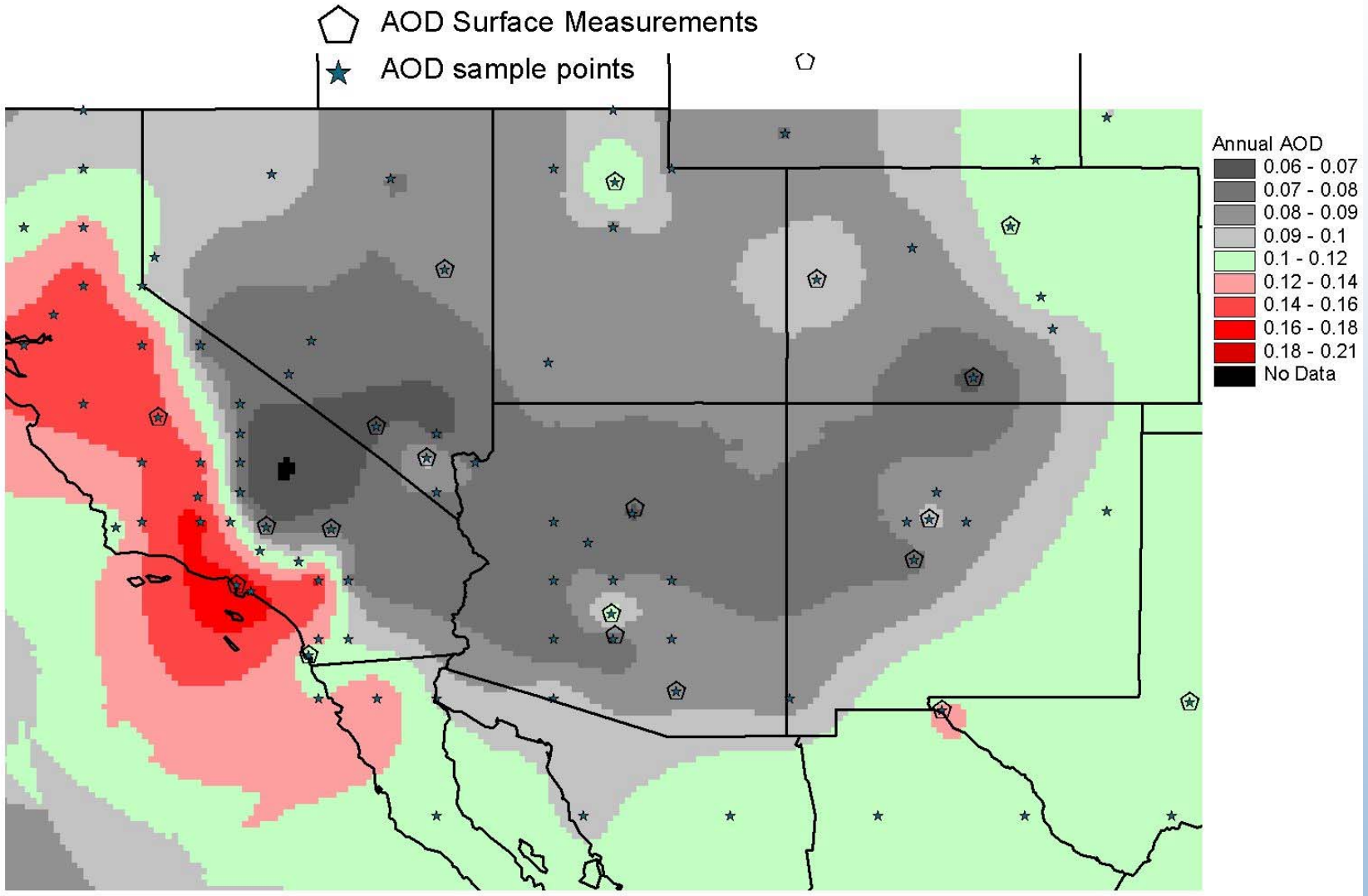
AOD, H_2O, O_3 (12 months)

Snow cover (daily)

Specular correction (month-hour)

Richard Perez, et al.

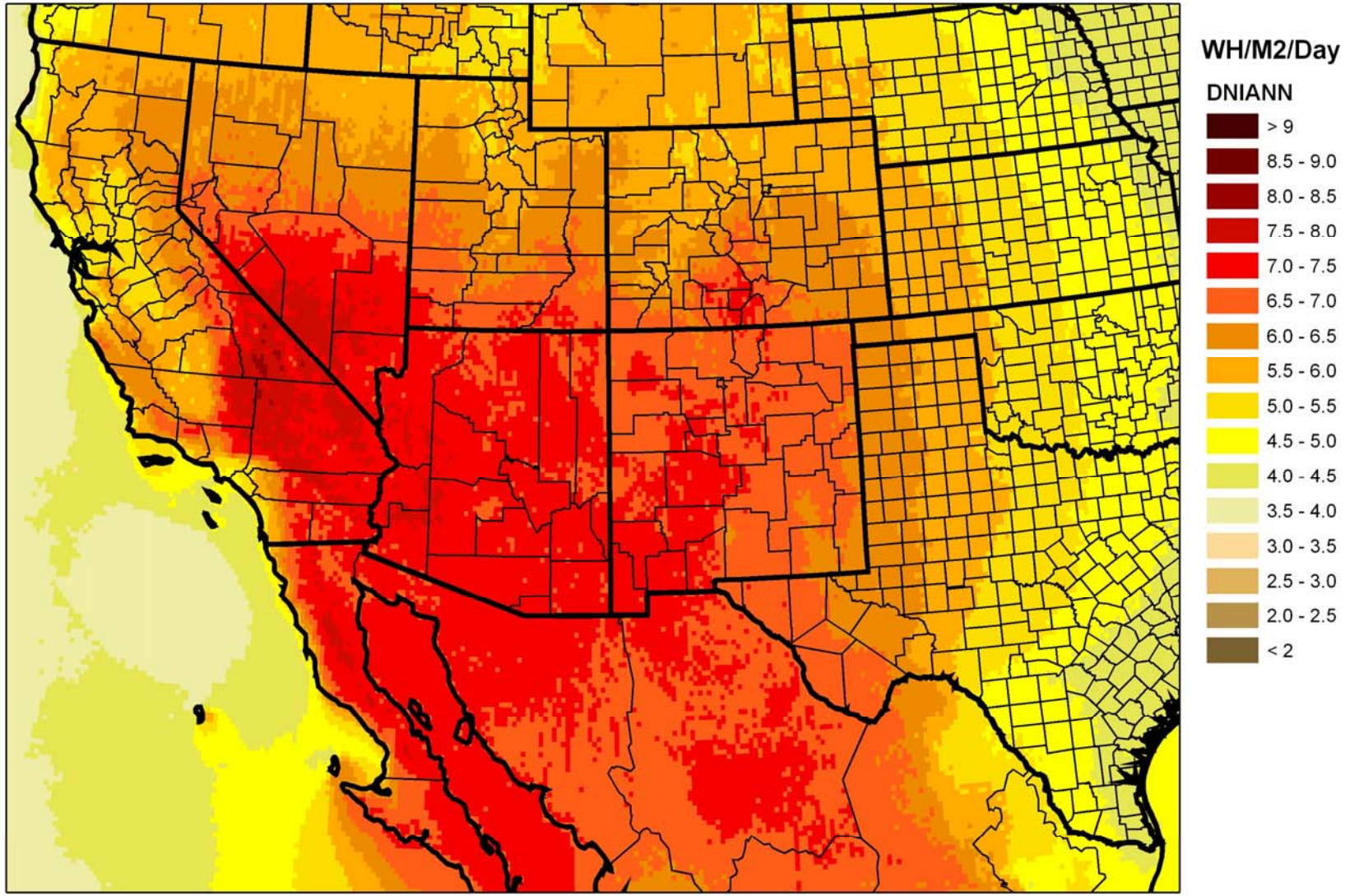
Annual AOD Adjusted to Sea Level



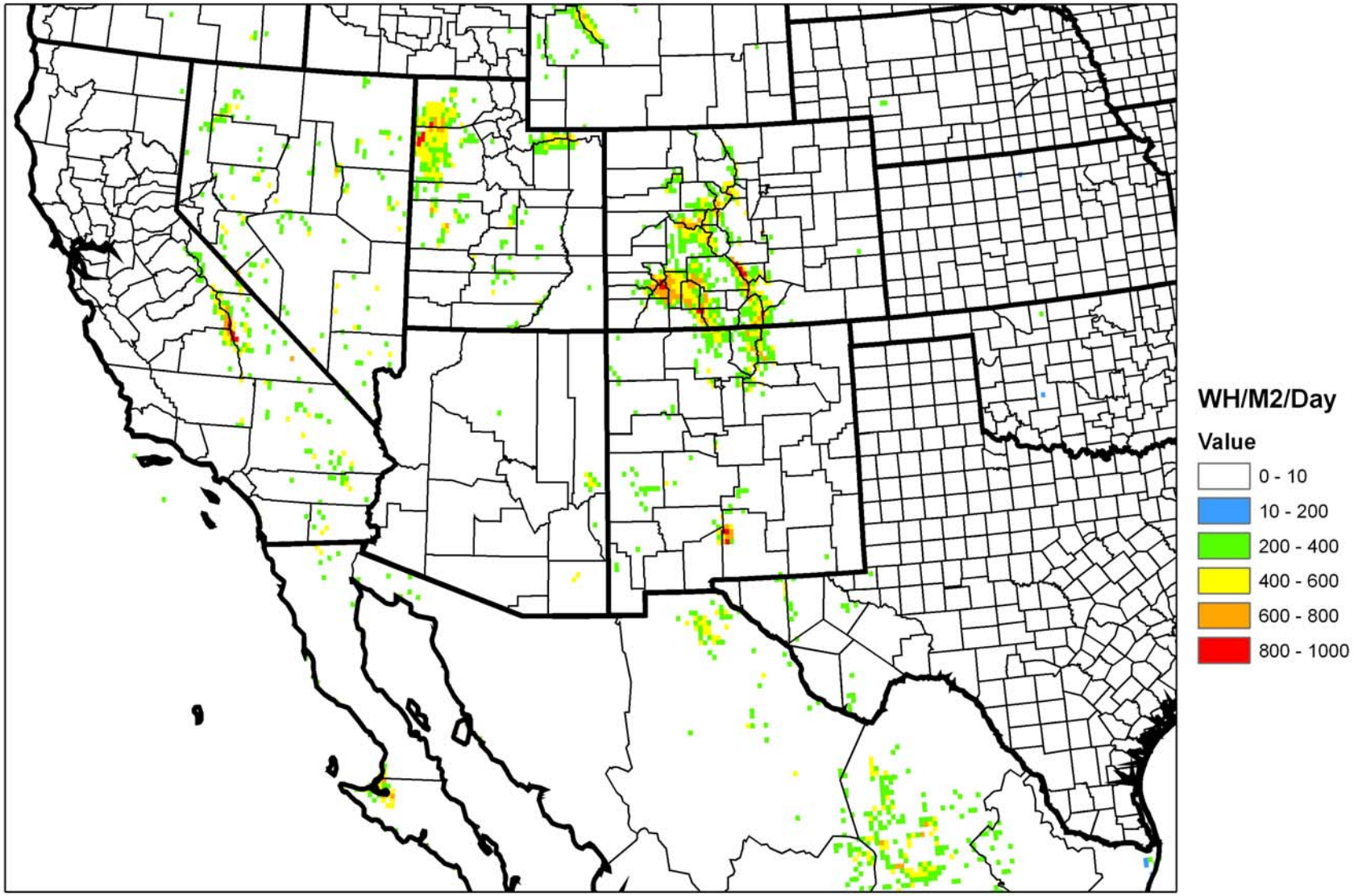
Satellite DNI Map Products

- 0.1 degree grid – nominal 10 km spacing
- Coverage CONUS, Northern Mexico, HI
- 8 years X 12 months = 96 grids available
- Data adjusted to eliminate low anomalies
  - (caused by very bright backgrounds)
  - Adjusted to match a smoothed map
- Available soon from www.nrel.gov/gis data download website.

NSRDB/SUNY DNI - Annual Average 1998-2005



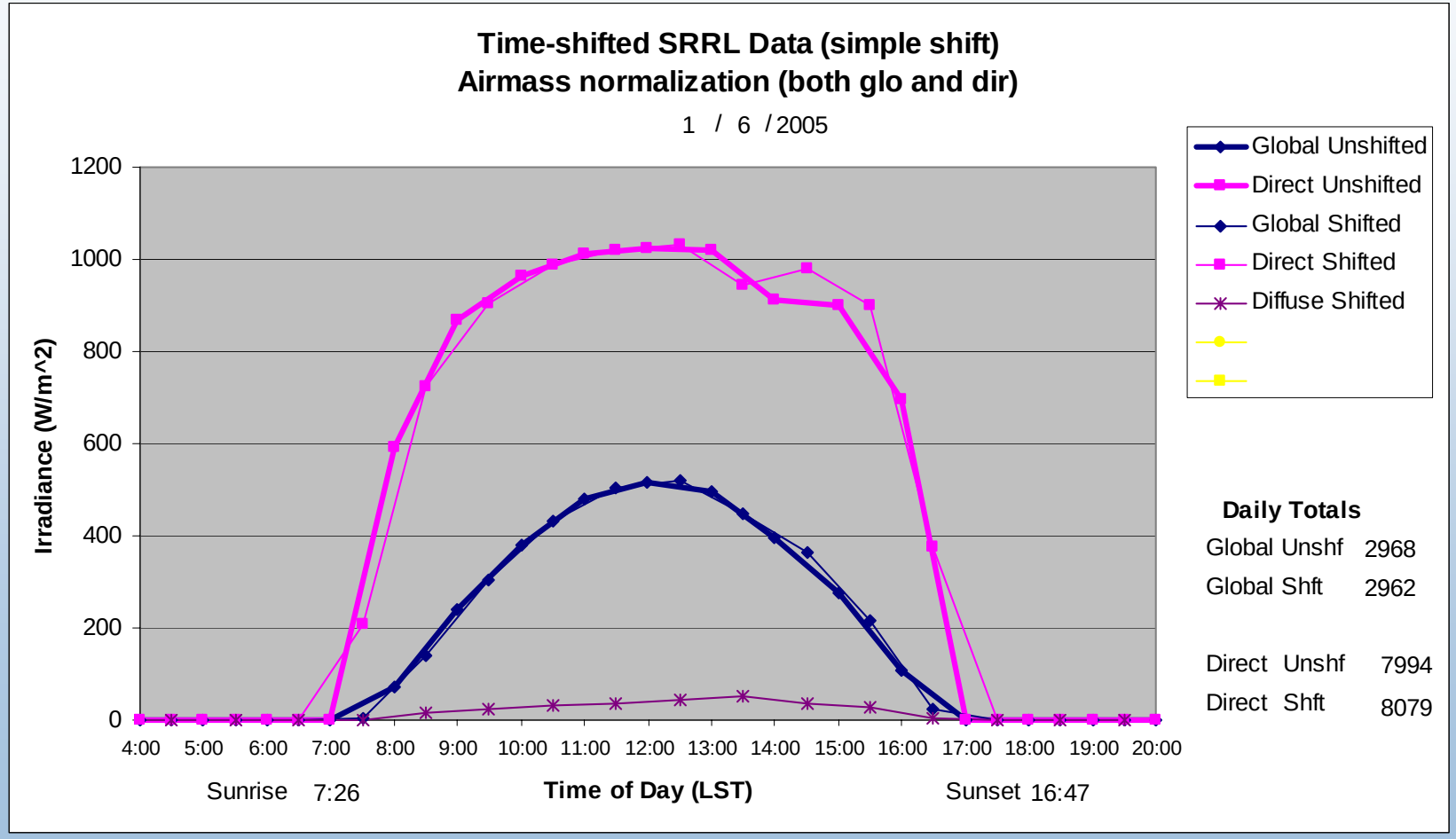
NSRDB/SUNY DNI - Corrections to Annual Average 1998-2005



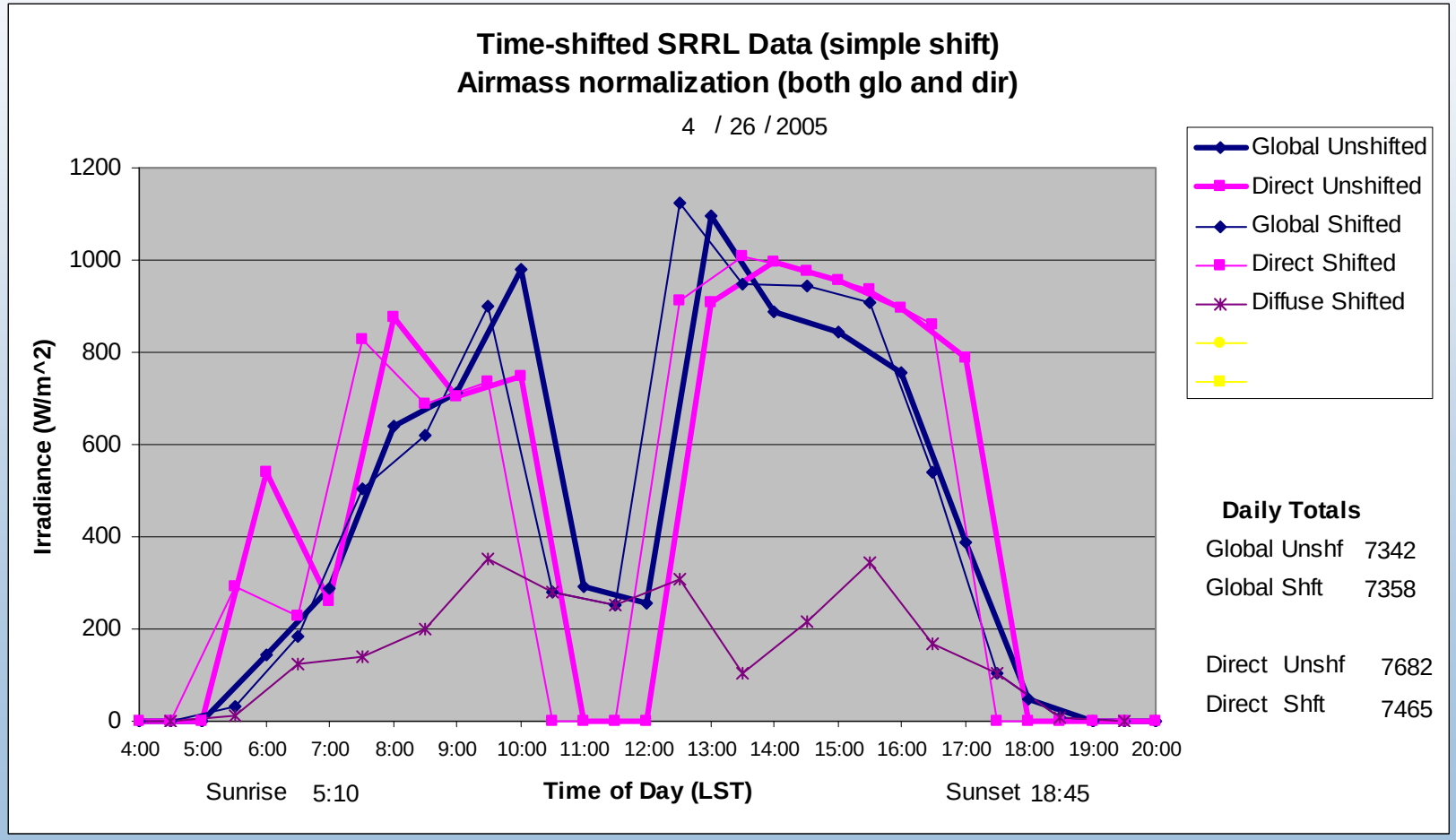
Satellite DNI Time Series

- Hourly for 8 years
- Unshifted or Time Shifted
- Unshifted – On the hour for West, 15 minutes after hour for East
- Time Shifted Data – on the hour, Represents Radiation in Previous Hour.

Time Shifting – Clear Day



Time Shifting – Partly Cloudy



Gridded Satellite and Weather Data

- Weather Data from NSRDB (surface measured) or NARR
- NARR = North American Regional Reanalysis, 32 km grid, 3 hourly data.
- Stations assigned to each 10km solar grid point as a function of proximity and elevation.

Obtaining Satellite Time Series

- NSRDB – combined with weather data for 1452 sites – from NCDC
- NSRDB – shifted and unshifted radiation, no WX – from NCDC – free
- NREL – all sites combined with NARR – distribution pending

International DNI Data

- SWERA – Solar and Wind Eneregy Resource Assessment
- CSR 40 km modeled DNI over large regions.
- Higher resolution (SUNY, DLR) DNI over smaller areas
- TMYs for selected countries.
- Swera.unep.net

SWERA.UNEP.NET – Download Data and Maps

Main Menu

Home Page
About SWERA
About Solar and Wind
Products
Countries
Agencies
Calendar
Links
Search
Metadata Help
SWERA Intranet

Languages

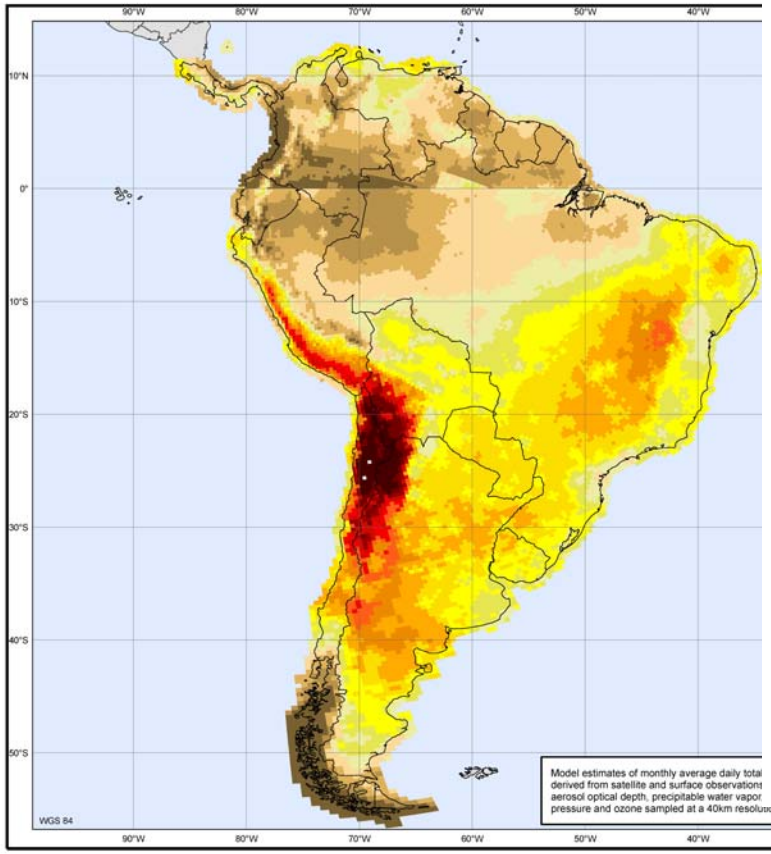
Welcome To SWERA

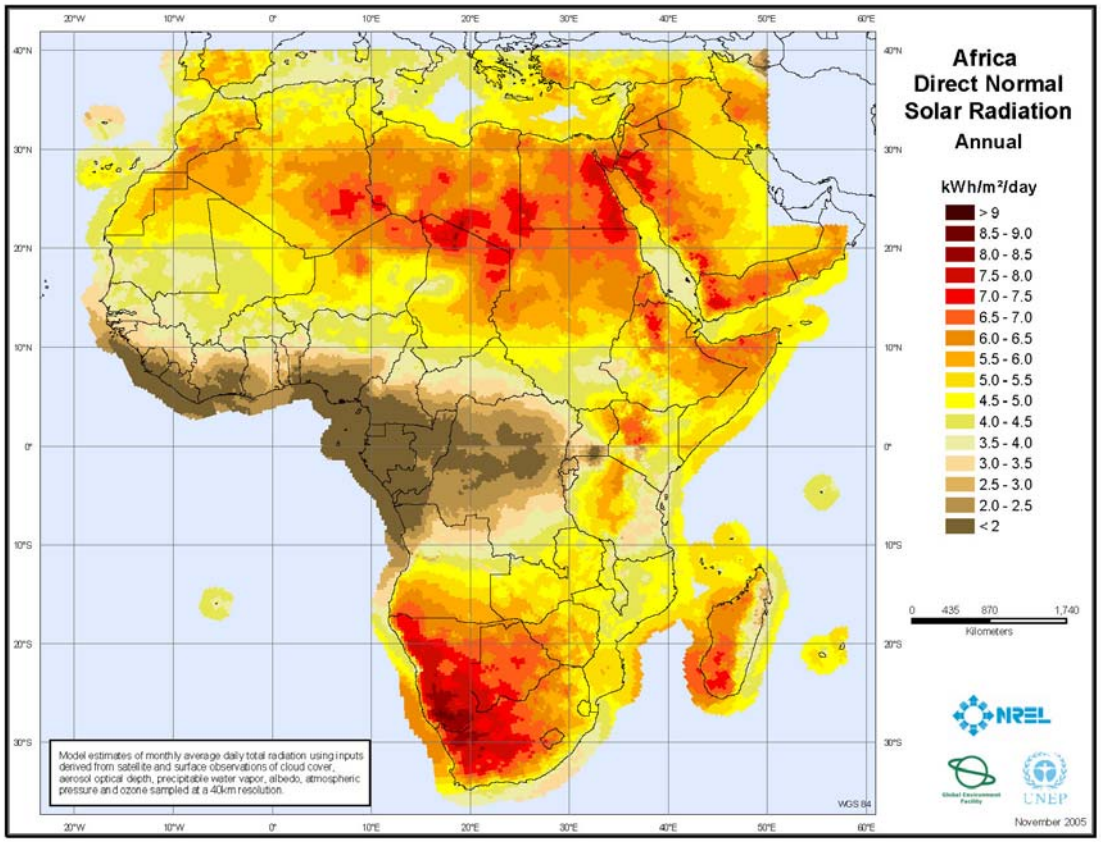
The SWERA website provides information about solar and wind energy resources in thirteen partner countries around the world. Products held in the SWERA archive include data on wind and solar energy potential, plus detailed country energy analyses. To learn more about renewable energy in each country or the partner agencies, click on the map or the menu. SWERA is a UNEP (United Nations Environment Programme) project with co-financing from GEF. The goal is to provide solar and wind energy assessments to potential investors and the public to promote more effective use of alternative energy resources.
Now with the completion of the successful pilot project, SWERA is being expanded into a full Programme offering resource information and mapping tools across the spectrum of renewable energy sources. All information and tools can be found in one on-line location with a common user interface... click here for more details.

NREL National Renewable Energy Laboratory

SWERA DNI Regional Maps

Africa, South America, East Asia, Mexico





Instrumentation Options

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

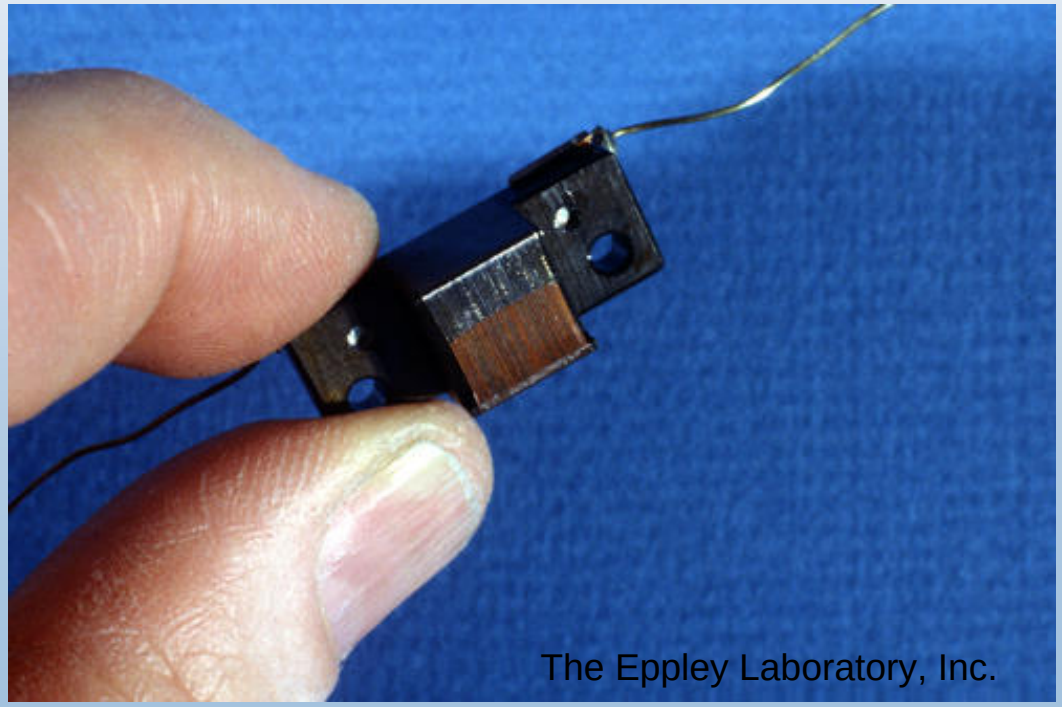
Radiometer Designs

Thermo-electric detectors:

Two metals + Heat = Electrical Current

Accurate, Slow, Expensive

Copper-Constantan wire wound *Thermopiles*



The Eppley Laboratory, Inc.

Photoelectric Detectors

www.kippzonen.com

www.licor.com

Fast, Low-Cost, with Reduced Spectral Response:

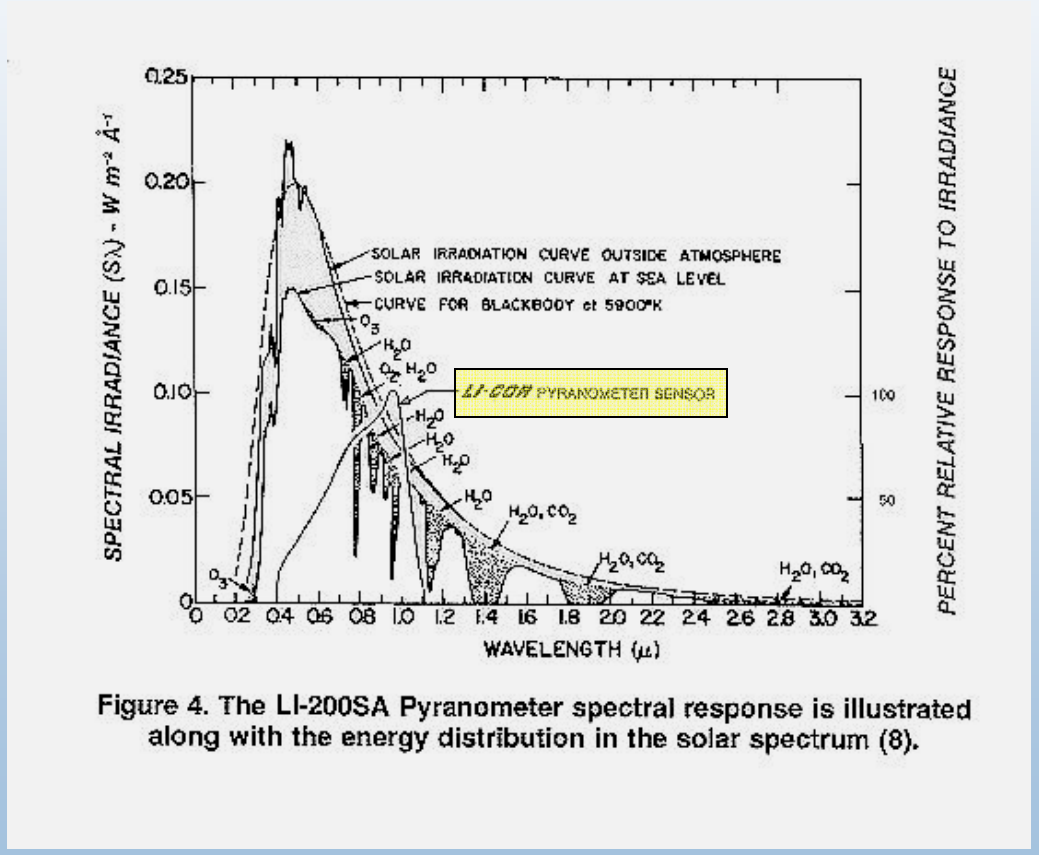
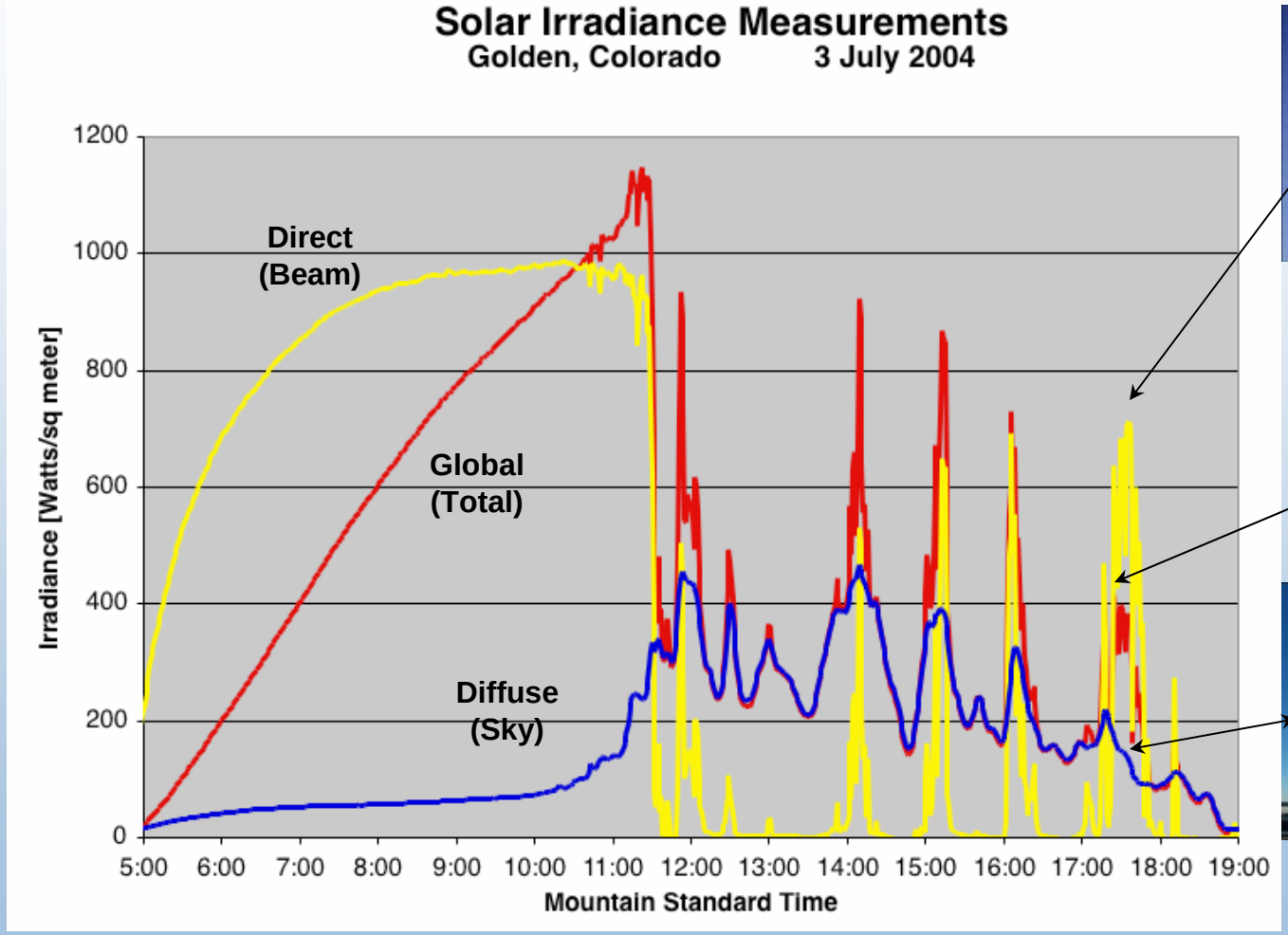


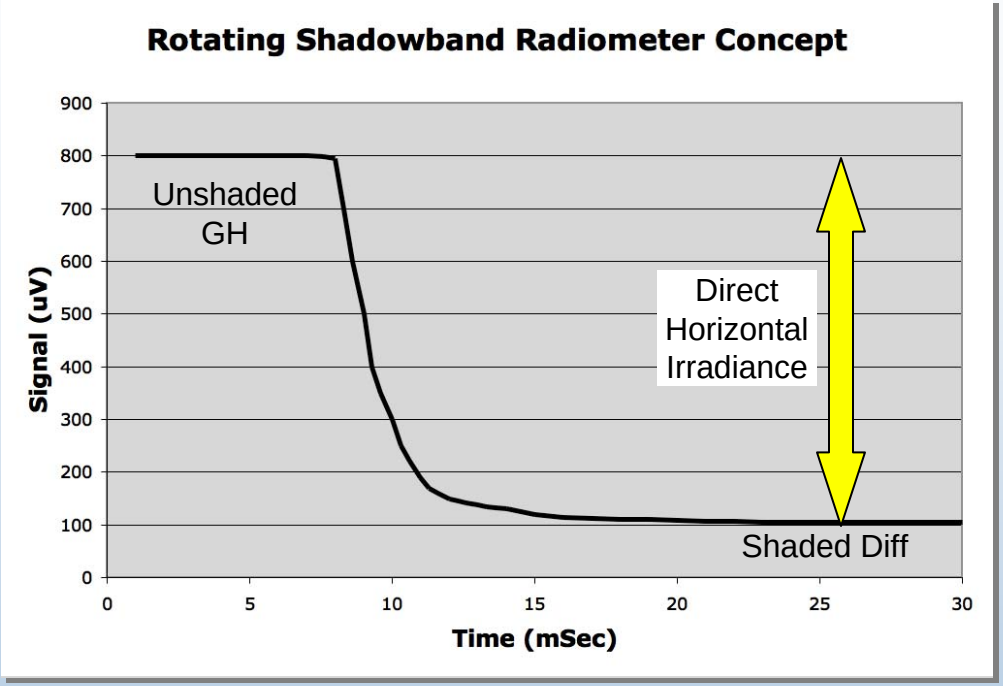
Figure 4. The LI-200SA Pyranometer spectral response is illustrated along with the energy distribution in the solar spectrum (8).

Partly Cloudy Sky



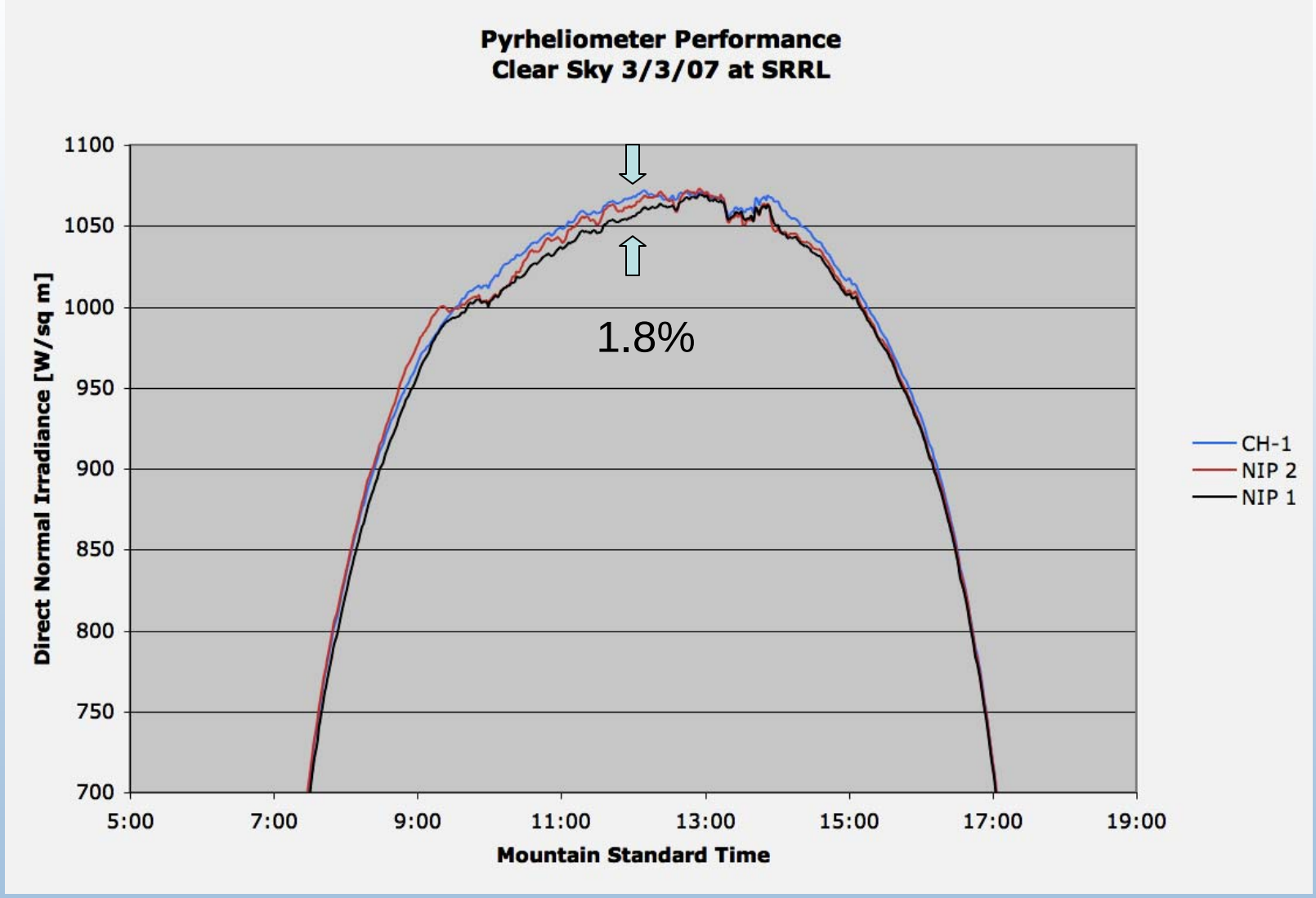
Global = Direct x Cos (Z) + Diffuse

Rotating Shadowband Radiometer



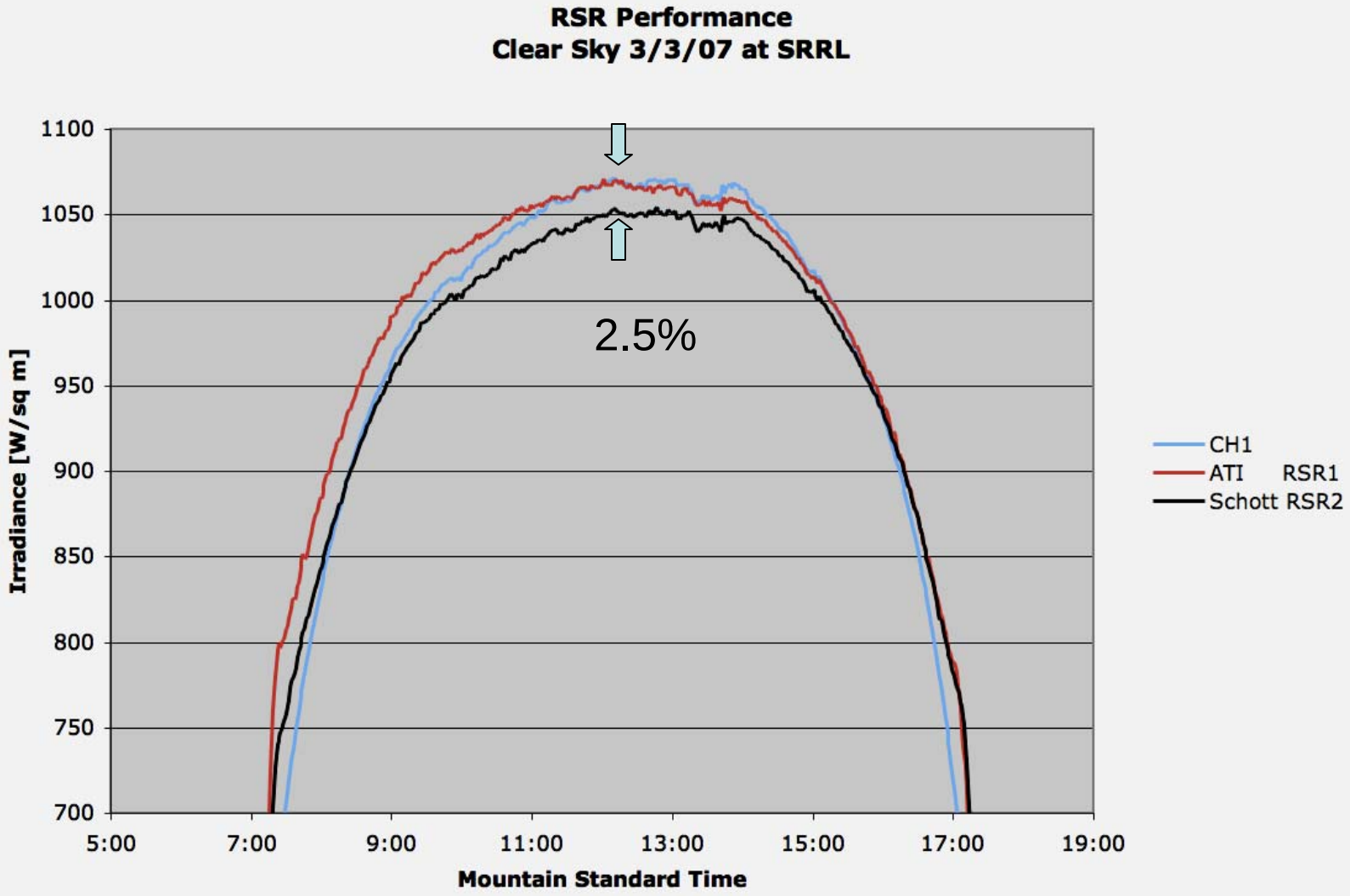
DNI = (GH - Diff) / Cos (Z)

Measuring DNI Thermopile Pyrheliometers

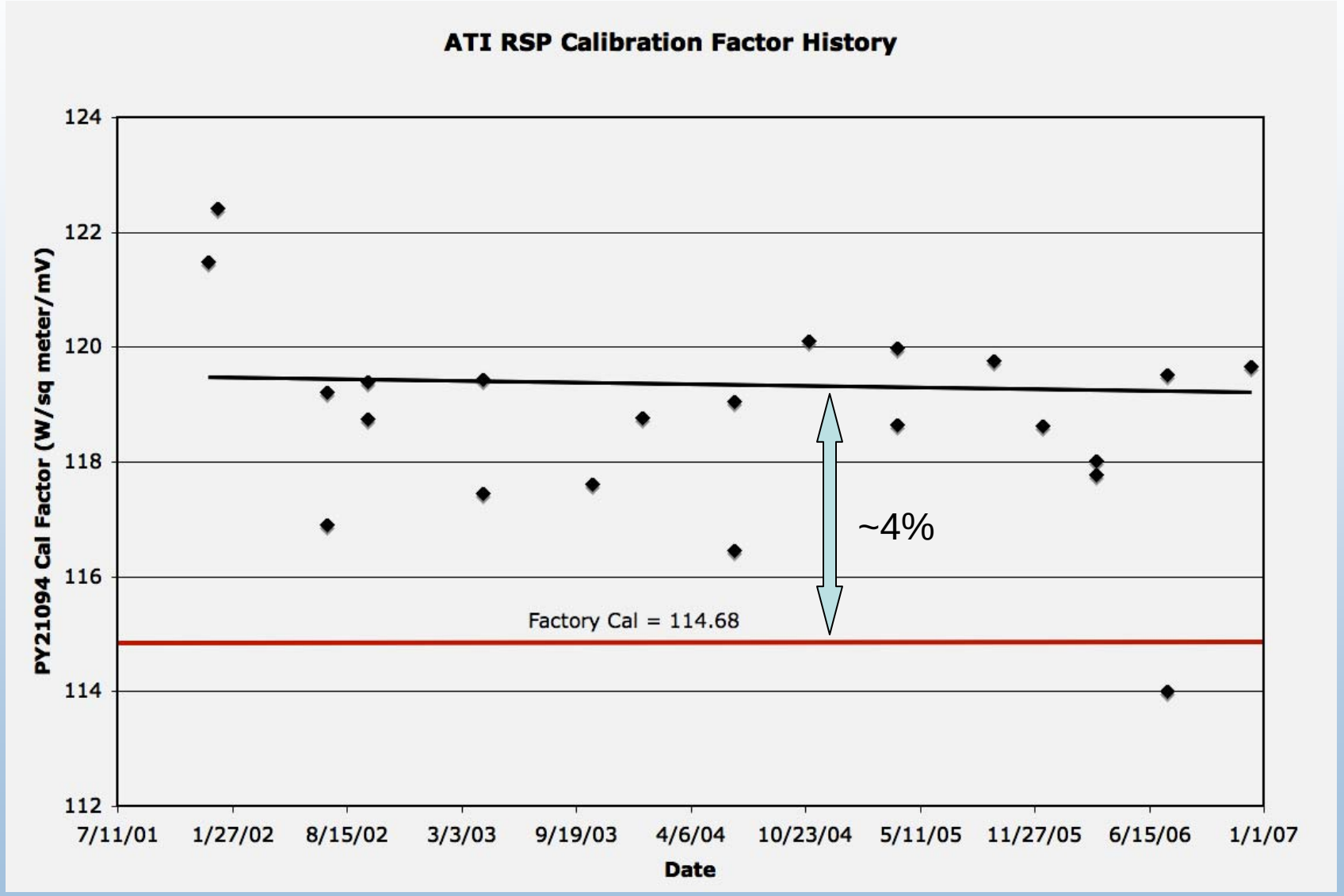


Measuring DNI

Rotating Shadowband Radiometers



RSR Calibration Stability



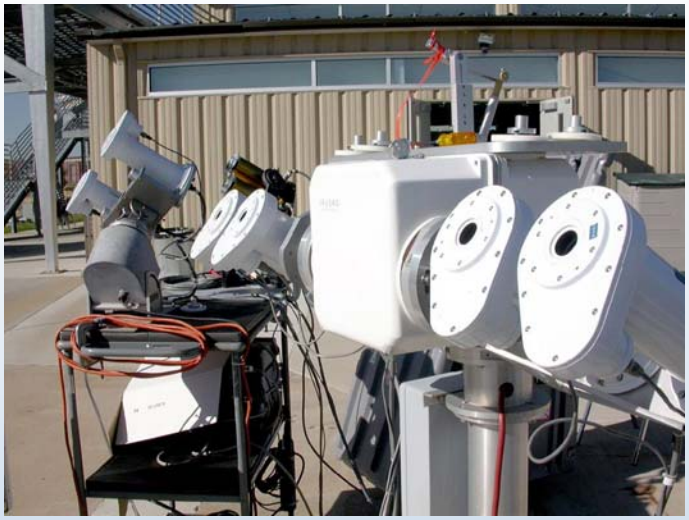
Calibrations

Broadband Outdoor Radiometer Calibration (BORCAL)

Infrared Radiometer Calibration (IRCAL)

Calibration Traceability

World Radiometric Reference



NREL Reference Standards

Annual NREL Pyrheliometer Comparisons

Transfer Standards

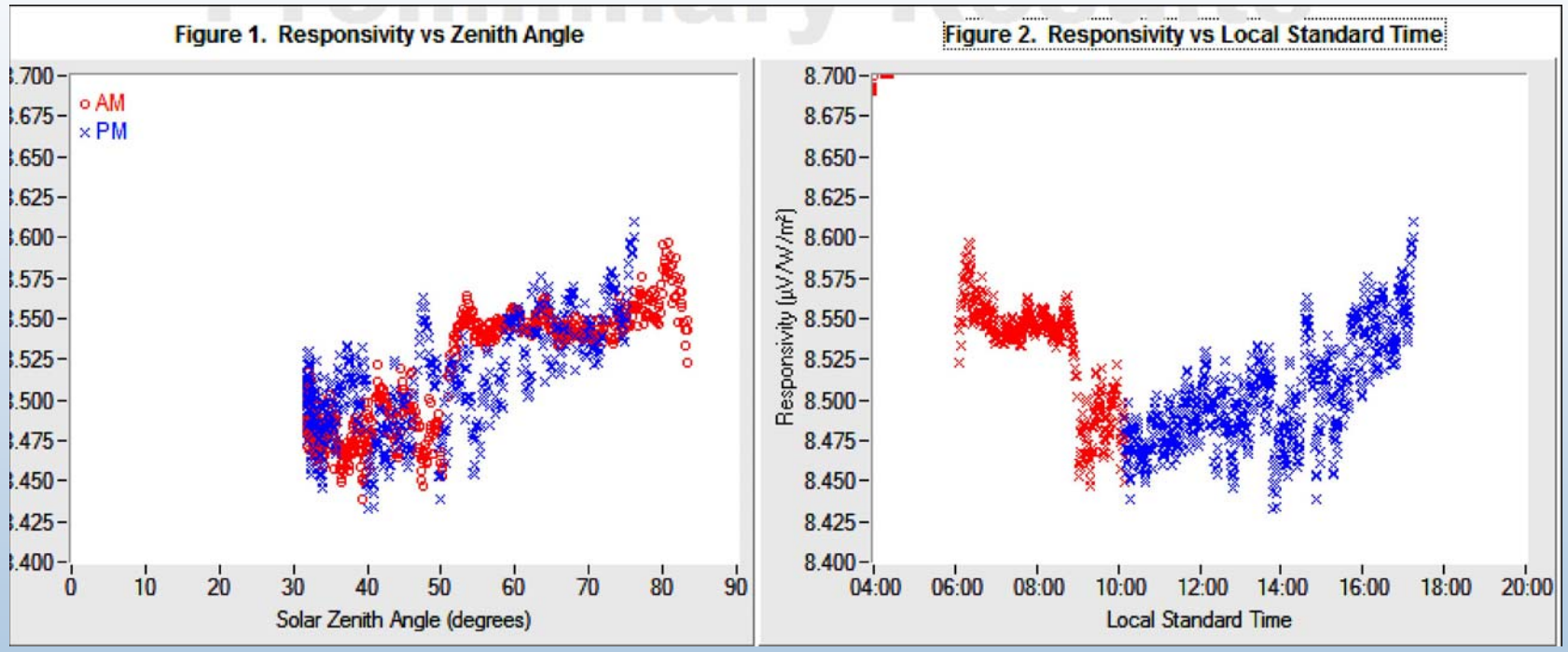
Broadband Outdoor Radiometer Calibrations

Reference Absolute Cavity
Radiometer traceable to WRR

- Pyrheliometers
- Pyranometers

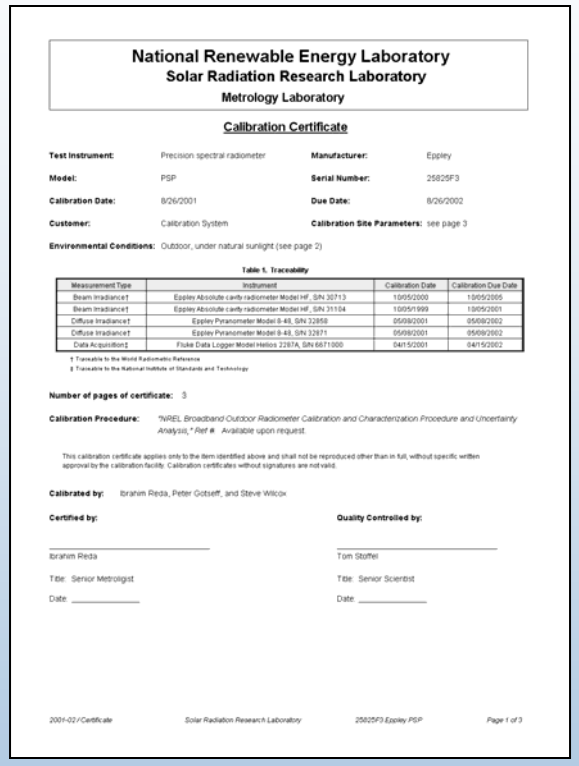
www.nrel.gov/srrl

Radiometer Calibrations



Responsivity (Z,t) = microVolts per Watt/meter^2

Calibration Certificates



National Renewable Energy Laboratory
Solar Radiation Research Laboratory
Metrology Laboratory

Calibration Certificate

Test Instrument: Precision spectral radiometer **Manufacturer:** Eppley
Model: PSP **Serial Number:** 25825F3
Calibration Date: 8/26/2001 **Due Date:** 8/26/2002
Customer: Calibration System **Calibration Site Parameters:** see page 3
Environmental Conditions: Outdoor, under natural sunlight (see page 2)

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance†	Eppley Absolute cavity radiometer Model HF, S/N 30713	10/05/2000	10/05/2005
Beam Irradiance†	Eppley Absolute cavity radiometer Model HF, S/N 31104	10/05/1999	10/05/2001
Diffuse Irradiance†	Eppley Pyranometer Model 8-48, S/N 32858	05/09/2001	05/09/2002
Diffuse Irradiance†	Eppley Pyranometer Model 8-48, S/N 32871	05/09/2001	05/09/2002
Data Acquisition‡	Fluke Data Logger Model Helios 2287A, S/N 6871000	04/15/2001	04/15/2002

† Traceable to the World Radiometric Reference
‡ Traceable to the National Institute of Standards and Technology

Number of pages of certificate: 3
Calibration Procedure: *"NREL Broadband Outdoor Radiometer Calibration and Characterization Procedure and Uncertainty Analysis," Ref #: Available upon request.*

This calibration certificate applies only to the item identified above and shall not be reproduced other than in full, without specific written approval by the calibration facility. Calibration certificates without signatures are not valid.

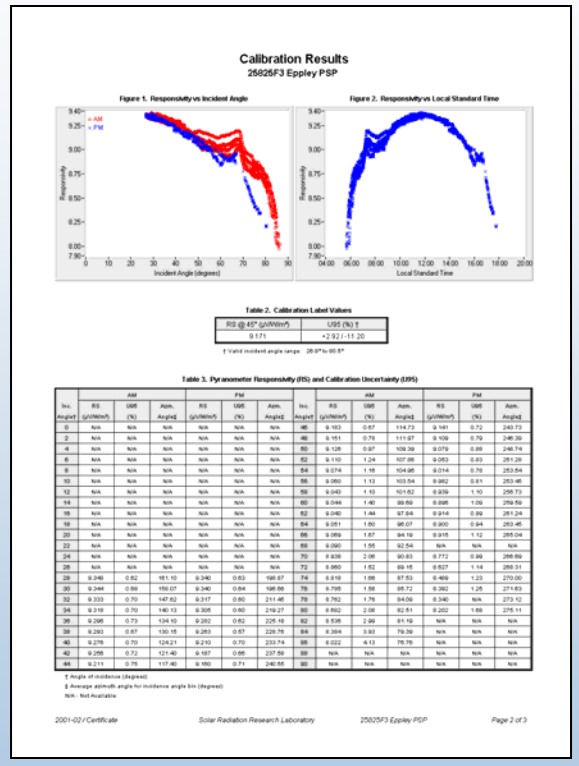
Calibrated by: Ibrahim Reda, Peter Gotseff, and Steve Wilcox

Certified by:
Ibrahim Reda
Title: Senior Metrologist
Date: _____

Quality Controlled by:
Tom Stoffel
Title: Senior Scientist
Date: _____

2001-02 / Certificate Solar Radiation Research Laboratory 25825F3 Eppley PSP Page 1 of 3

Traceability and Certification



Calibration Results
25825F3 Eppley PSP

Figure 1. Responsivity vs Incident Angle
Figure 2. Responsivity vs Local Standard Time

Table 2. Calibration Label Values

RS @ 45° (μV/W/m²)	U95 (%) †
9.171	+2.92 / -11.20

† Valid incident angle range: 26.0° to 80.5°

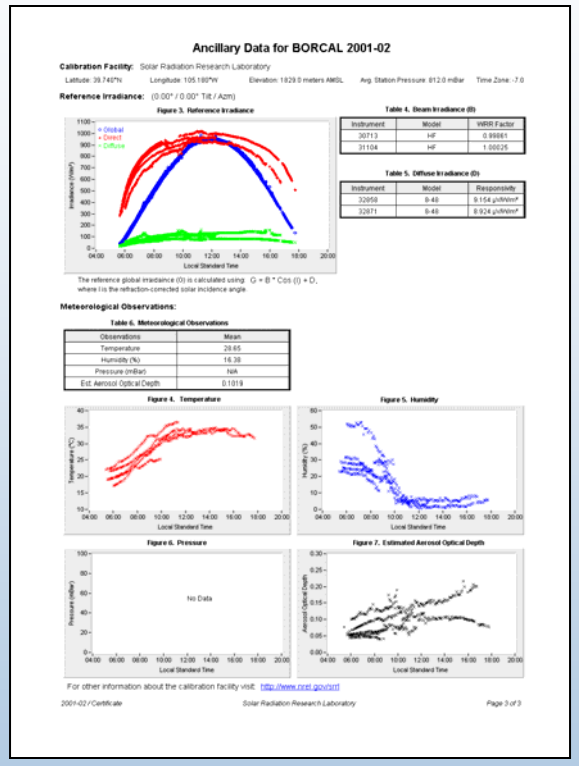
Table 3. Pyranometer Responsivity (RS) and Calibration Uncertainty (U95)

Inc. Angle†	AM RS (μV/W/m²)	AM U95 (%)	AM Azm. Angle‡	PM RS (μV/W/m²)	PM U95 (%)	PM Azm. Angle‡	Inc. Angle†	AM RS (μV/W/m²)	AM U95 (%)	AM Azm. Angle‡	PM RS (μV/W/m²)	PM U95 (%)	PM Azm. Angle‡
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.163	0.67	114.73	9.161	0.72	240.73
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.151	0.79	111.97	9.109	0.79	248.39
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.126	0.97	109.39	9.079	0.88	248.74
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.110	1.24	107.06	9.063	0.83	251.26
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.074	1.16	104.95	9.014	0.79	253.54
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.060	1.13	103.04	9.982	0.81	253.46
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.043	1.10	101.62	8.939	1.10	258.73
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.046	1.40	99.62	8.896	1.09	259.59
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.040	1.44	97.84	8.914	0.99	261.24
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.051	1.50	96.07	8.900	0.94	263.45
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.069	1.67	94.19	8.915	1.12	265.04
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.090	1.55	92.54	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	70	9.838	2.06	90.83	8.772	0.98	268.69
26	N/A	N/A	N/A	N/A	N/A	N/A	72	9.860	1.82	89.16	8.827	1.14	268.31
28	9.340	0.62	161.10	9.340	0.63	198.87	74	9.819	1.68	87.53	8.469	1.23	270.00
30	9.344	0.68	159.07	9.340	0.64	196.66	76	9.795	1.56	85.72	8.392	1.25	271.63
32	9.333	0.70	147.62	9.317	0.60	211.46	78	9.762	1.76	84.09	8.340	N/A	273.12
34	9.318	0.70	140.13	9.305	0.60	219.27	80	9.662	2.08	82.61	8.202	1.68	276.11
36	9.295	0.73	134.10	9.282	0.62	225.18	82	8.535	2.99	81.19	N/A	N/A	N/A
38	9.283	0.67	130.18	9.283	0.67	228.76	84	8.364	3.93	79.39	N/A	N/A	N/A
40	9.279	0.70	124.21	9.210	0.70	233.74	86	8.022	4.13	76.76	N/A	N/A	N/A
42	9.256	0.72	121.40	9.167	0.66	237.56	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.211	0.76	117.40	9.160	0.71	240.55	90	N/A	N/A	N/A	N/A	N/A	N/A

† Angle of incidence (degrees)
‡ Average azimuth angle for incidence angle bin (degrees)
N/A - Not Available

2001-02 / Certificate Solar Radiation Research Laboratory 25825F3 Eppley PSP Page 2 of 3

Calibration Results



Ancillary Data for BORCAL 2001-02

Calibration Facility: Solar Radiation Research Laboratory
Latitude: 39.740°N Longitude: 105.180°W Elevation: 1829.0 meters AMSL Avg. Station Pressure: 812.0 mBar Time Zone: -7.0
Reference Irradiance: (0.00° / 0.00° Tilt / Azm)

Figure 3. Reference Irradiance

Table 4. Beam Irradiance (B)

Instrument	Model	WRR Factor
30713	HF	0.99861
31104	HF	1.00025

Table 5. Diffuse Irradiance (D)

Instrument	Model	Responsivity
32858	8-48	9.154 μV/W/m²
32871	8-48	8.924 μV/W/m²

The reference global irradiance (G) is calculated using: G = B * Cos (i) + D, where i is the refraction-corrected solar incidence angle.

Meteorological Observations:

Table 6. Meteorological Observations

Observations	Mean
Temperature	28.65
Humidity (%)	16.38
Pressure (mBar)	N/A
Est. Aerosol Optical Depth	0.1019

Figure 4. Temperature
Figure 5. Humidity
Figure 6. Pressure
No Data
Figure 7. Estimated Aerosol Optical Depth

For other information about the calibration facility visit: http://www.nrel.gov/srrl

2001-02 / Certificate Solar Radiation Research Laboratory Page 3 of 3

Calibration Conditions

Resource Assessment Capabilities

- rredc.nrel.gov
  - Renewable Resource Data Center
- www.nrel.gov/srrl
  - Radiometer Calibrations
  - Solar Climatology for Golden (1981 - present)
- www.nrel.gov/gis
  - Geographic Information System Internet Map Server
- www.nrel.gov/midc
  - Measurement & Instrumentation Data Center

Nearly Real-Time Data Access www.nrel.gov/midc

Welcome to the Measurement and Instrumentation Data Center (MIDC), providing Irradiance and Meteorological Data from the following stations:

SRRL Baseline Measurement System (BMS)
NREL/SRRL, Golden, Colorado

National Wind Technology Center M2 Tower
NREL/NWTC, Boulder, Colorado

Nevada Power Clark Station (NPCS)
Nevada Power CSP, Las Vegas, Nevada

University of Nevada, Las Vegas (UNLV)
UNLV Campus, Las Vegas, Nevada

Bluefield State College (BSC)
Bluefield, West Virginia

Elizabeth City State University (ECSU)
Elizabeth City, North Carolina

Phoenix Federal Correctional Institution (PFCI)
Phoenix, Arizona

South Park Mountain Data (SPMD)
South Park, Colorado

San Clemente Island Data (SCID)
San Clemente, California

Lamar Low-Level Jet Project (LLLJP)
Lamar, Colorado

ARM Radiometer Characterization System (RCS)
SGP Central Facility, Oklahoma

SRRL Baseline Surface Radiation Network (BSRN)
NREL/SRRL, Golden, Colorado

SRRL Atmospheric Optical Calibration System (AOCS)
NREL/SRRL, Golden, Colorado

SRRL Schott Rotating Shadowband Pyranometer (RSP)
NREL/SRRL, Golden, Colorado

SRRL Ascension Technology Inc. RSP (ATI)
NREL/SRRL, Golden, Colorado

Summary

- Measurements vs. Modeled Data
  - Users must be aware of uncertainties in the data
  - Radiometer systems = $$ to install and operate, but offer resource accuracies for site analyses and system performance monitoring
  - Rotating Shadowband Radiometers offer lower cost DNI
  - Modeled data = spatial variations, longer period of record, satellite-remote sensing offers relief from inadequate surface cloud observations for regional scale prospecting
- NSRDB + NSRDB Update = 1961-2005 (serially complete 239 sites)
- Satellite model (SUNY) = future direction (forecast) = most consistent data we have 1998-2005 and best spatial resolution - 10 km grid
- Measurement & Instrumentation Data Center welcomes additional ground stations

Thank You!