Solar Radiation Measurements:

A Workshop For

The National Association of State Universities and Land Grant Colleges

By

Tom Stoffel & Steve Wilcox
Hydrogen & Electric Technologies & Systems Center

August 4, 2004

Outline

- Introductions
- *Shining On, A Primer on Solar Radiation Data*
  - What are solar radiation measurements?
  - Why do we need solar radiation data?
  - What influences the amount of solar radiation?
  - How do we use solar radiation data?
  - How accurate do the data need to be?
- How are we meeting our solar radiation data needs?
- Where can you obtain solar radiation data?
- Pop Quiz
  - No acronyms!

Introductions

Tom Stoffel & Steve Wilcox
Resource Integration Group
Measurement & Instrumentation Team
Geographic Information System Team

40^{+} years experience:

- Solar measurement station/network design
  - SRRL, HBCU, Saudi, DOE/ARM, NOAA, WMO/BSRN, GAW
- Radiometer calibration and characterization
  - BORCAL/RCC
  - IPCs, NPCs
- Solar data quality assessment
  - SERI-QC
  - DQMS

What are Solar Radiation Measurements?

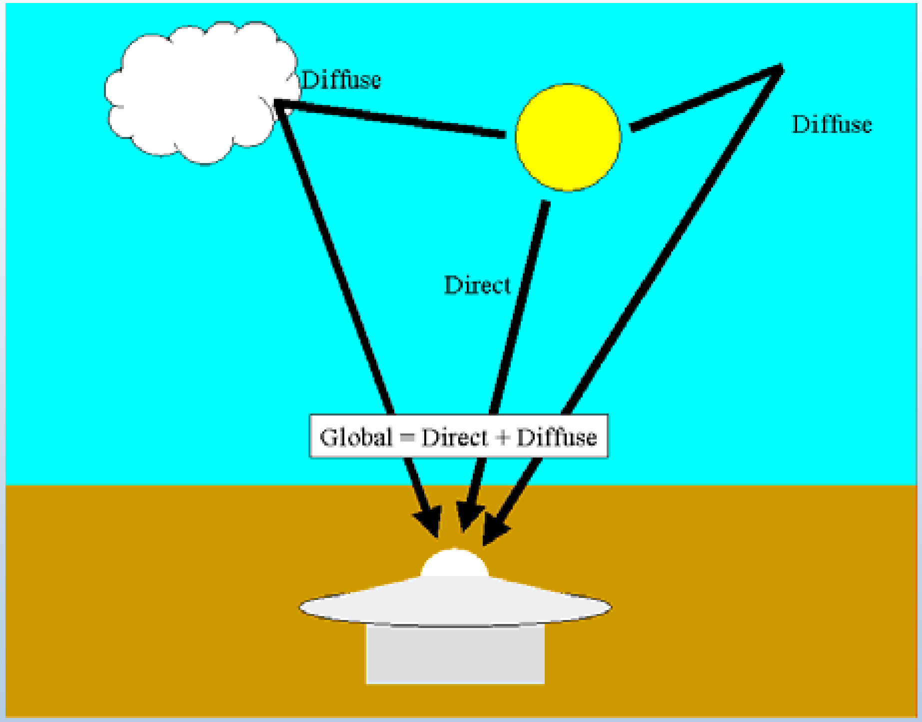
Energy from the Sun at the Earth's Surface

- Different parts of the sky
- Change with time (minutes, hours)
- Change with time (seasons, years, decades)
- Change with location

What are Solar Radiation Measurements?

Light from the sky dome

- Direct from the sun
- Everywhere but the sun
- Entire sky



We call it

- Direct (beam)
- Diffuse (sky)
- Global (total)

Global is the sum of direct and diffuse

What are Solar Radiation Measurements?

Direct Normal

Measured by a *Pyrheliometer* on a sun-following tracker

Global Horizontal

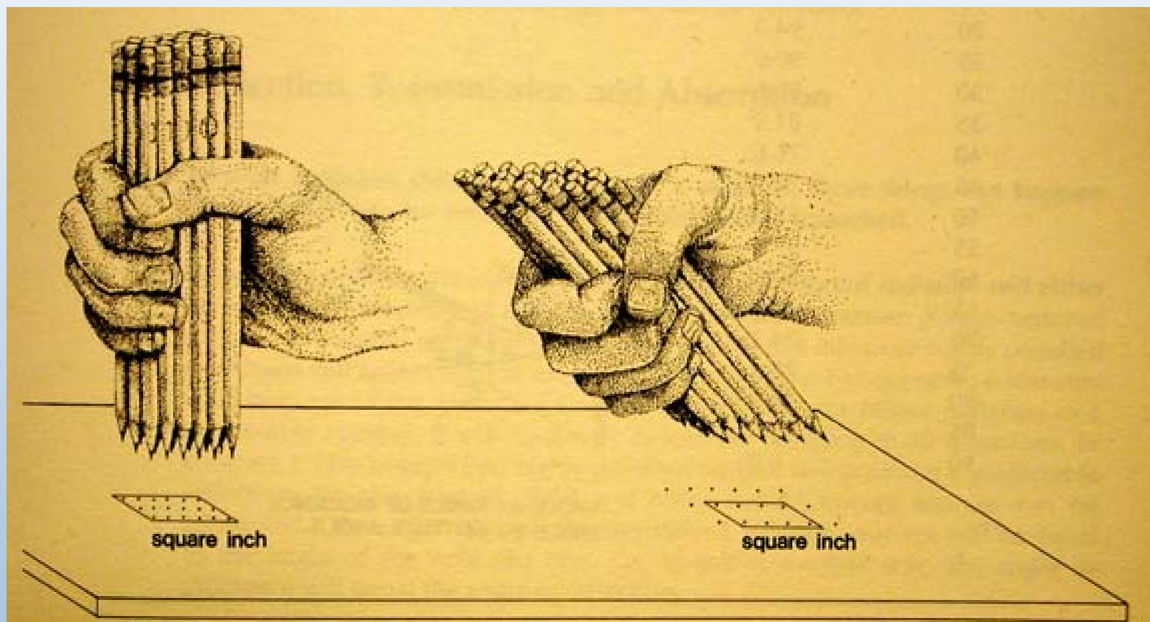
Measured by a *Pyranometer* with a horizontal sensor

Diffuse

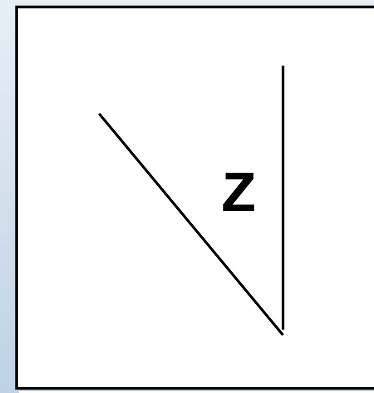
Measured by a shaded *Pyranometer* under a tracking ball

Solar Irradiance Components

Global = Direct Normal * Cos(Z) + Diffuse



18 dots **8 dots**

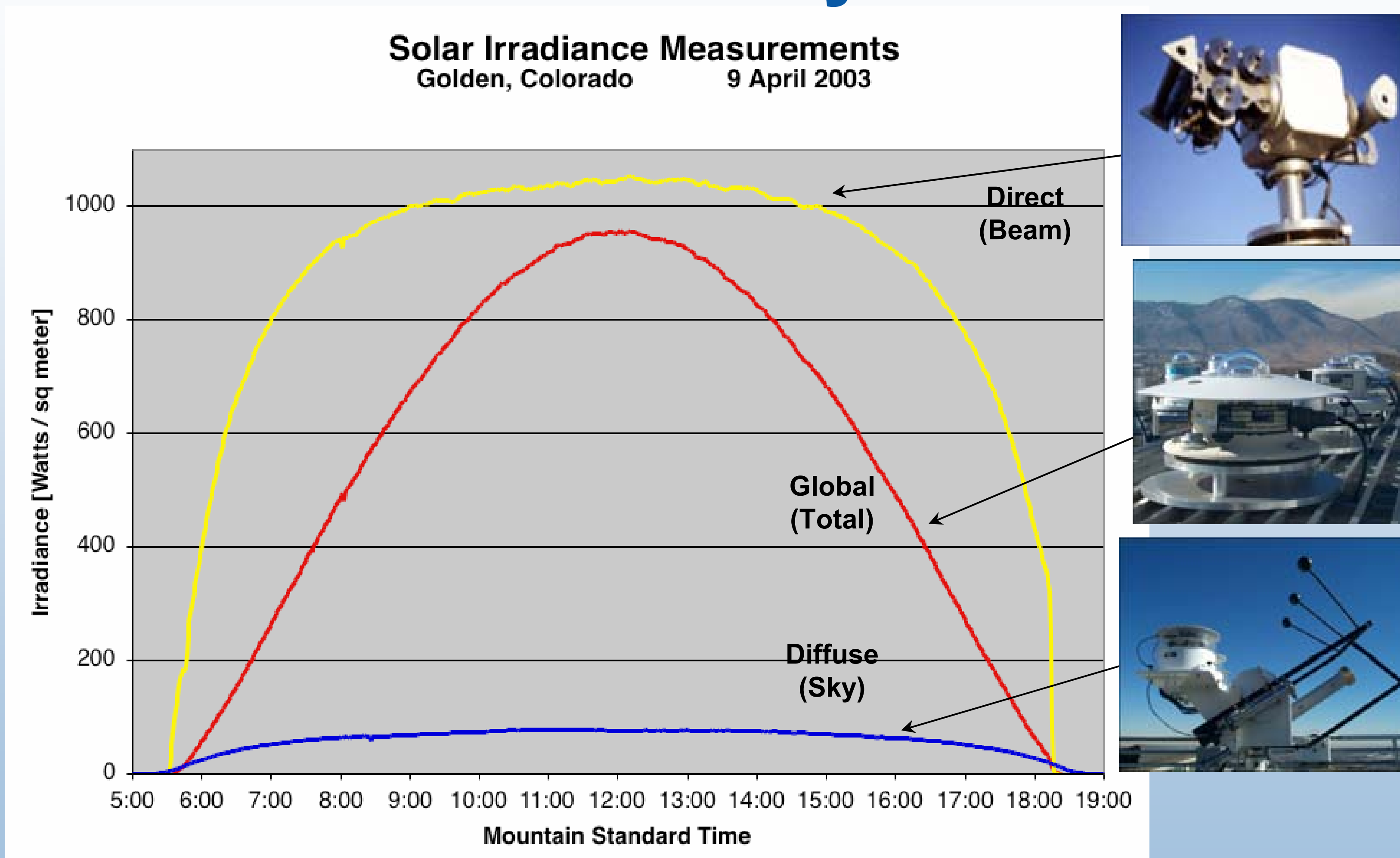


$\text{Cos}\ (Z) = 8/18$

$Z = \text{Cos}^{-1}(0.4444)$

$Z = 63.6^{\circ}$

Clear Sky



http://www.nrel.gov/srrl

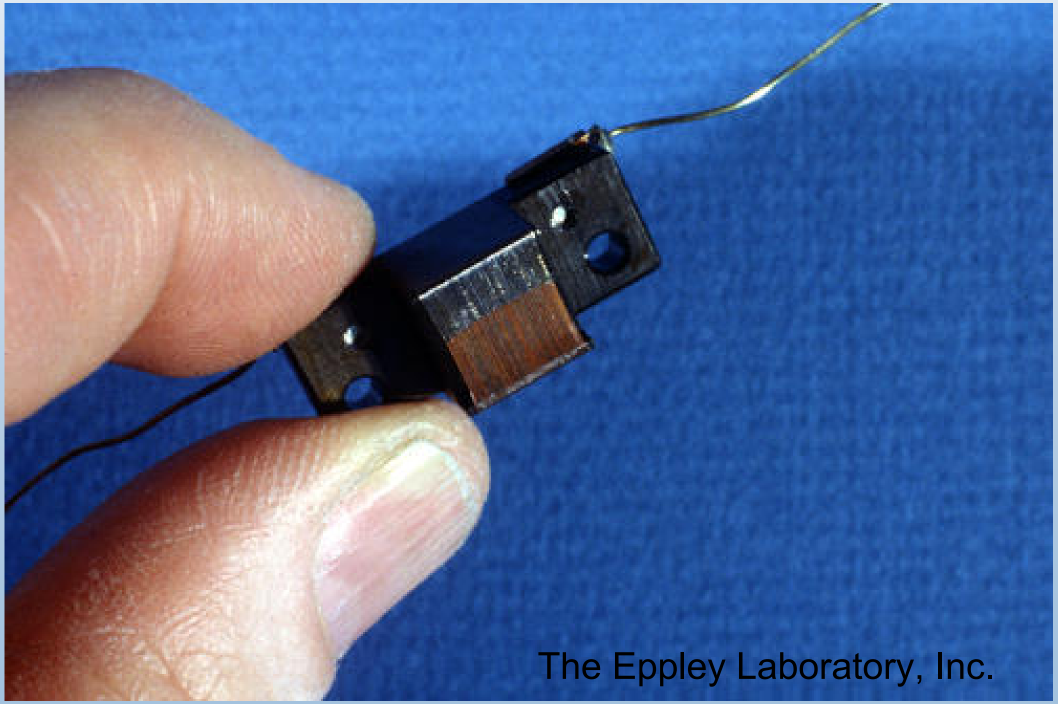
Thermopile Detectors

How do the radiometers work?

Thermo-electric detectors:

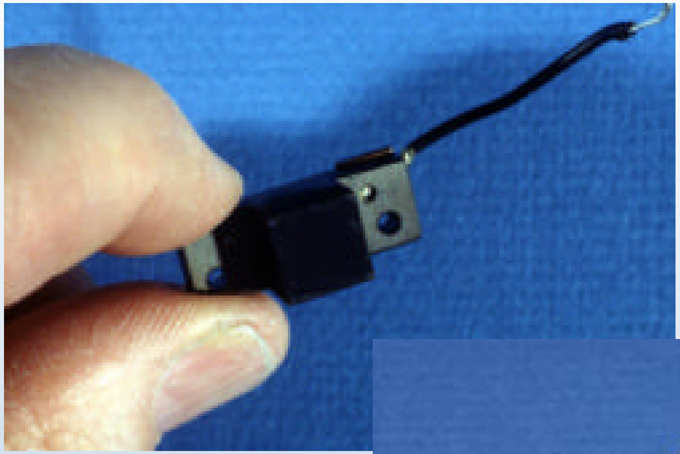
Two metals + Heat = Electrical Current

Copper-Constantan wire wound *Thermopiles*



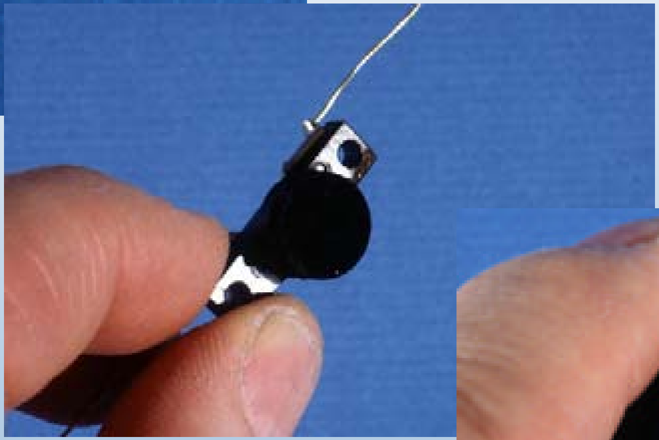
The Eppley Laboratory, Inc.

Thermopile Detectors



Pyrheliometer

1st Class $, Flat Spectral Response, “Slow”



Pyranometer

The Eppley Laboratory, Inc.

Photoelectric Detectors

www.kippzonen.com

www.licor.com

Fast, Low-Cost, with Reduced Spectral Response:

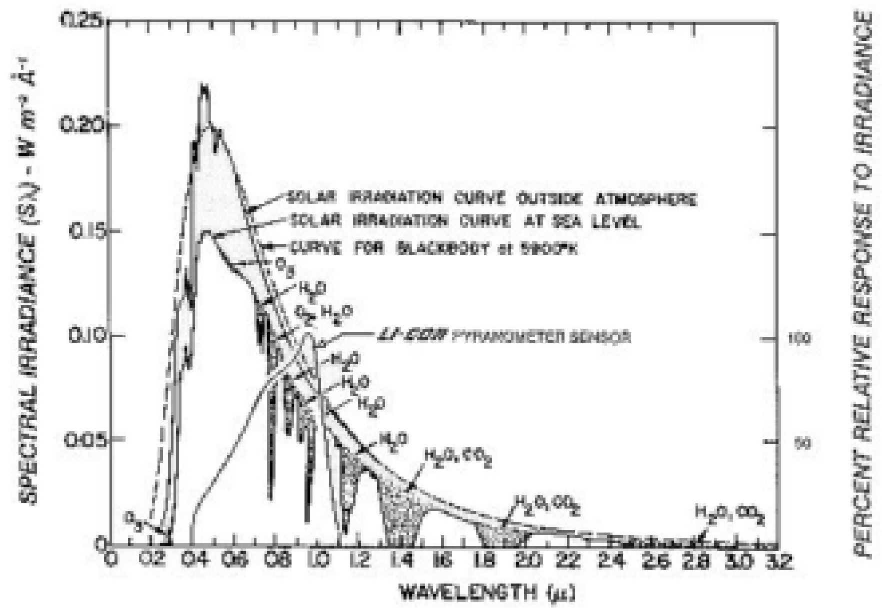
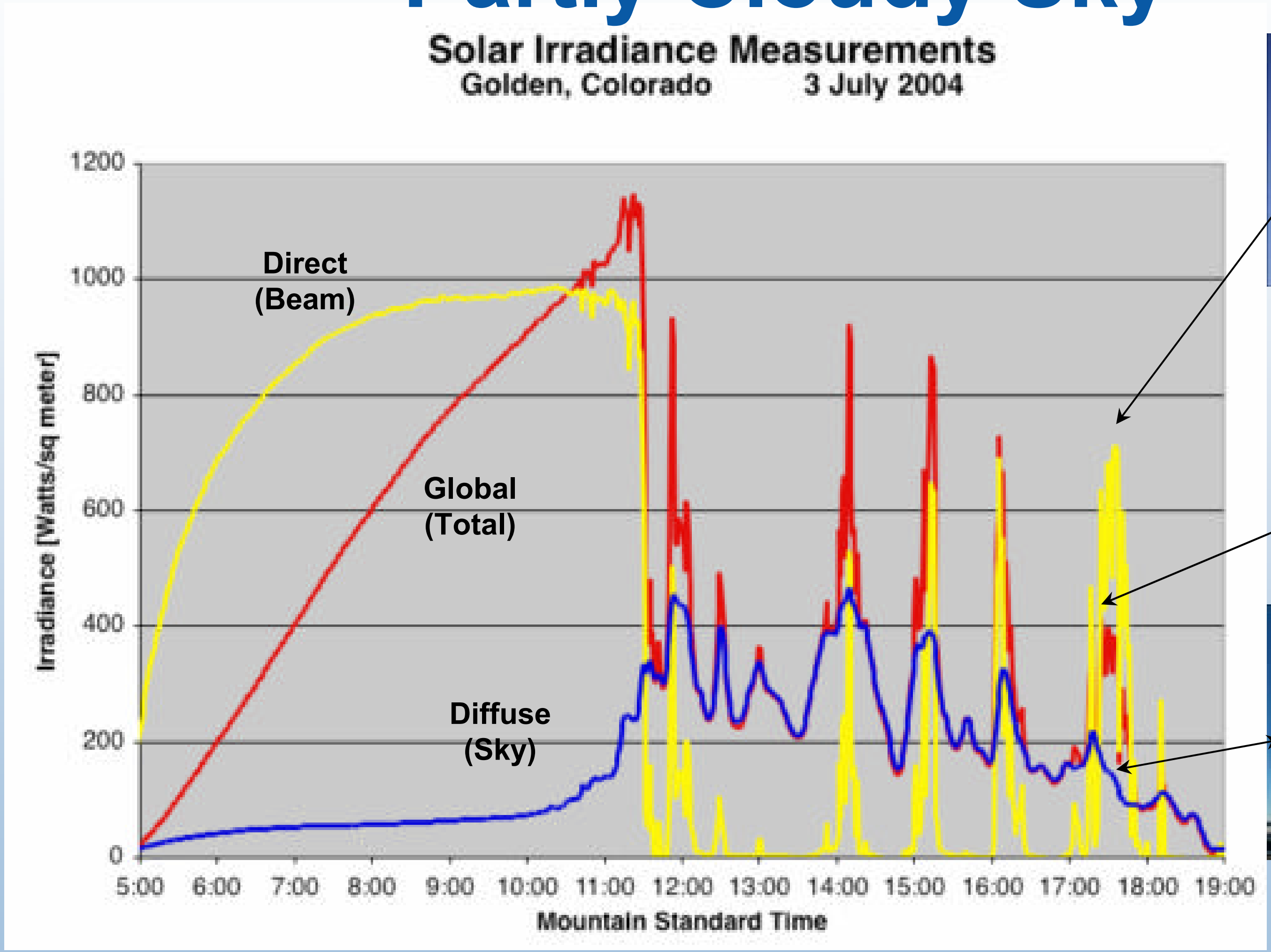


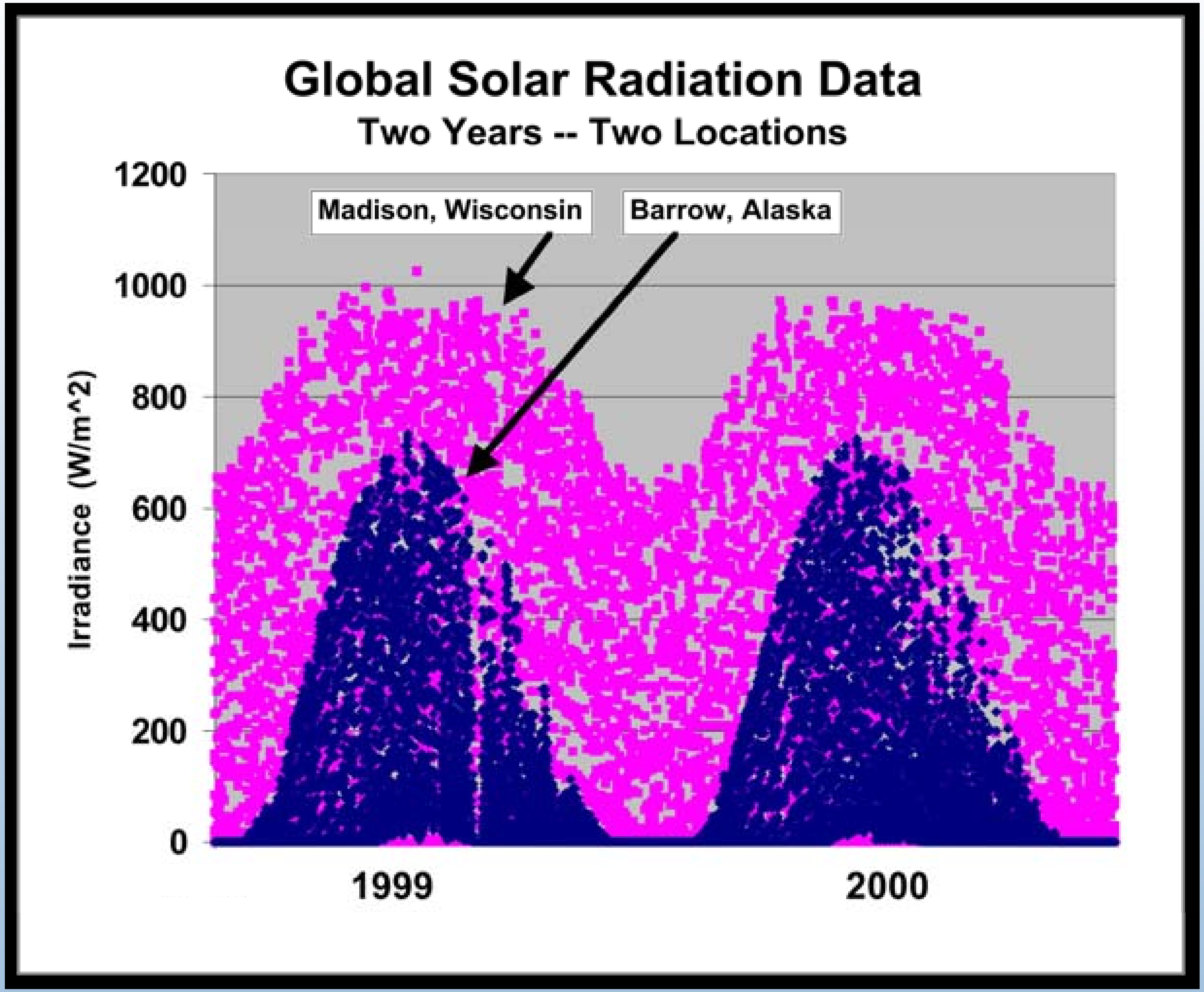
Figure 4. The LI-200SA Pyranometer spectral response is illustrated along with the energy distribution in the solar spectrum (8).

Partly Cloudy Sky

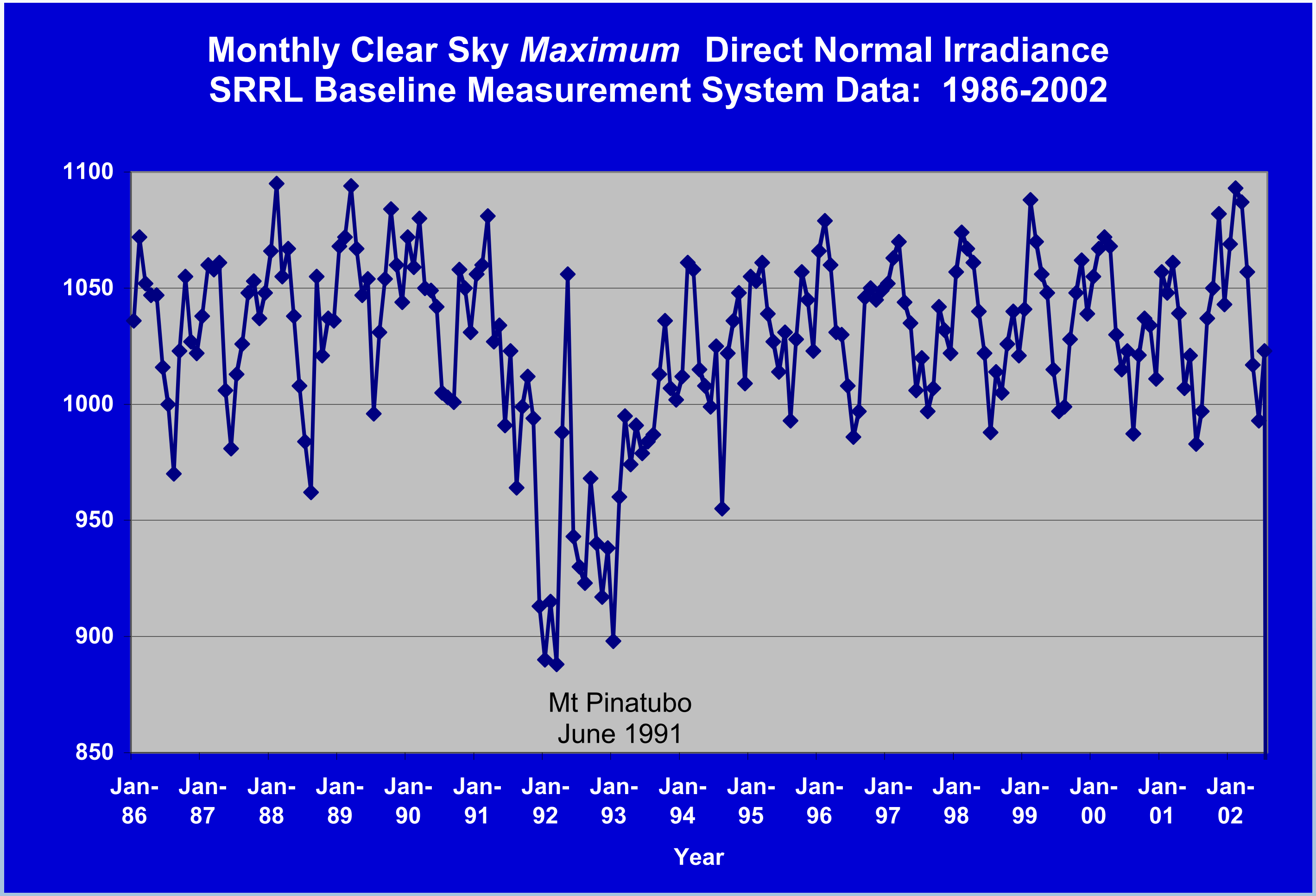


http://www.nrel.gov/srrl

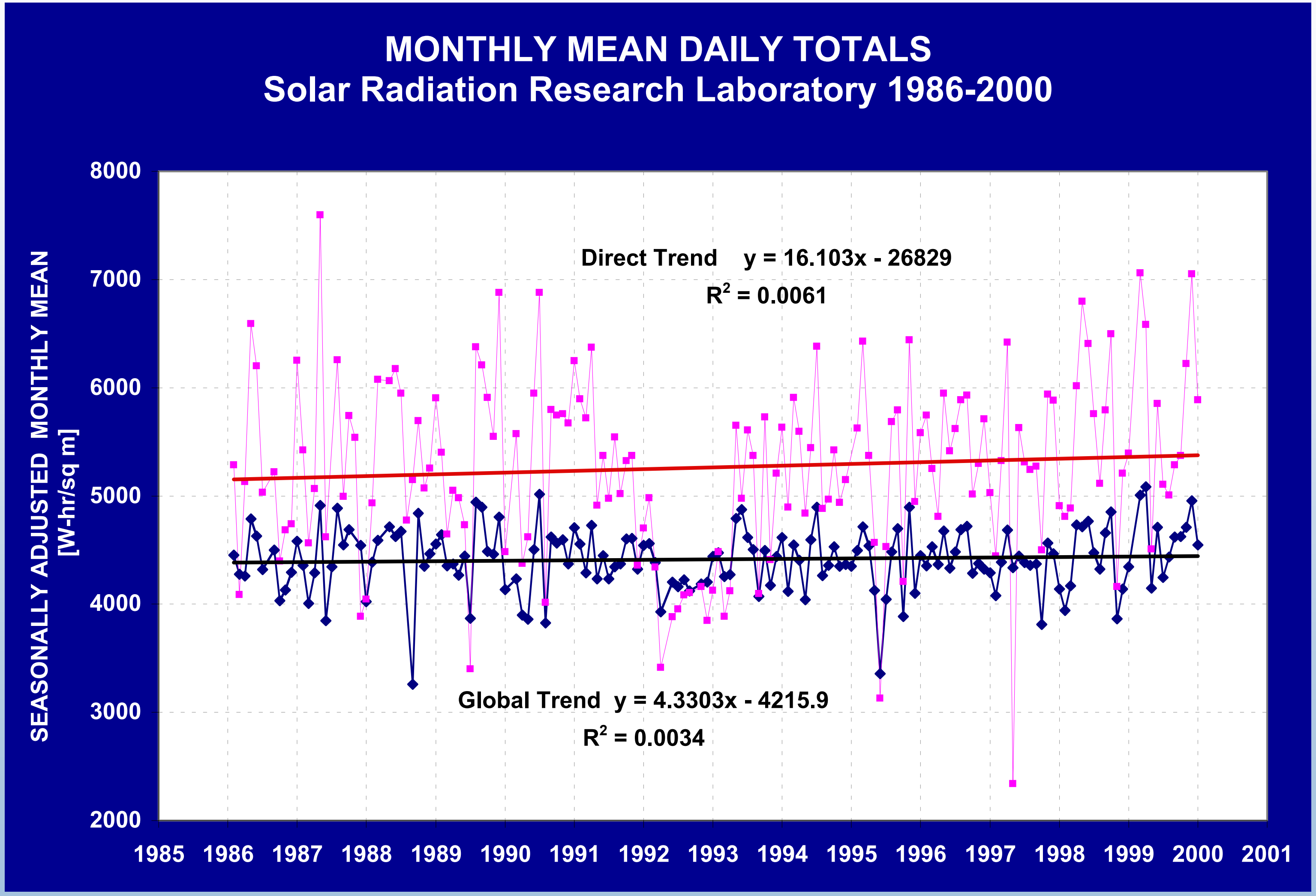
Changes with Time & Location: Annual Cycle



Changes with Time: Inter-annual



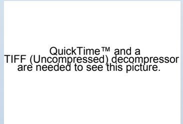
Changes with Time: Inter-annual



Spectral Distribution of Solar Radiation

Broadband Solar Radiation:

280 nm - 3,000 nm

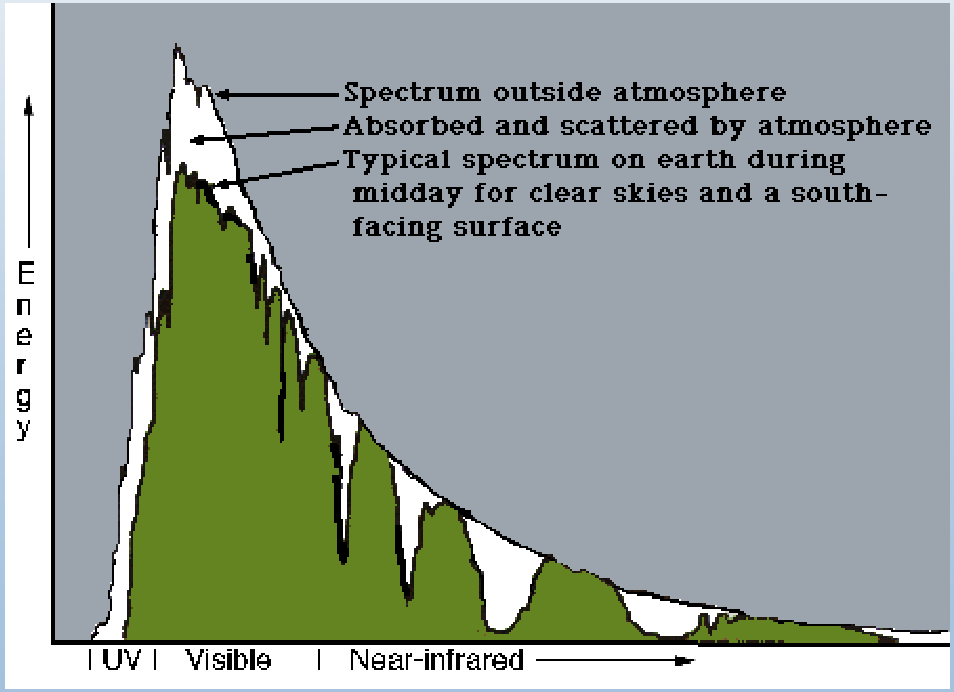


(99% of “shortwave” irradiance at the surface)

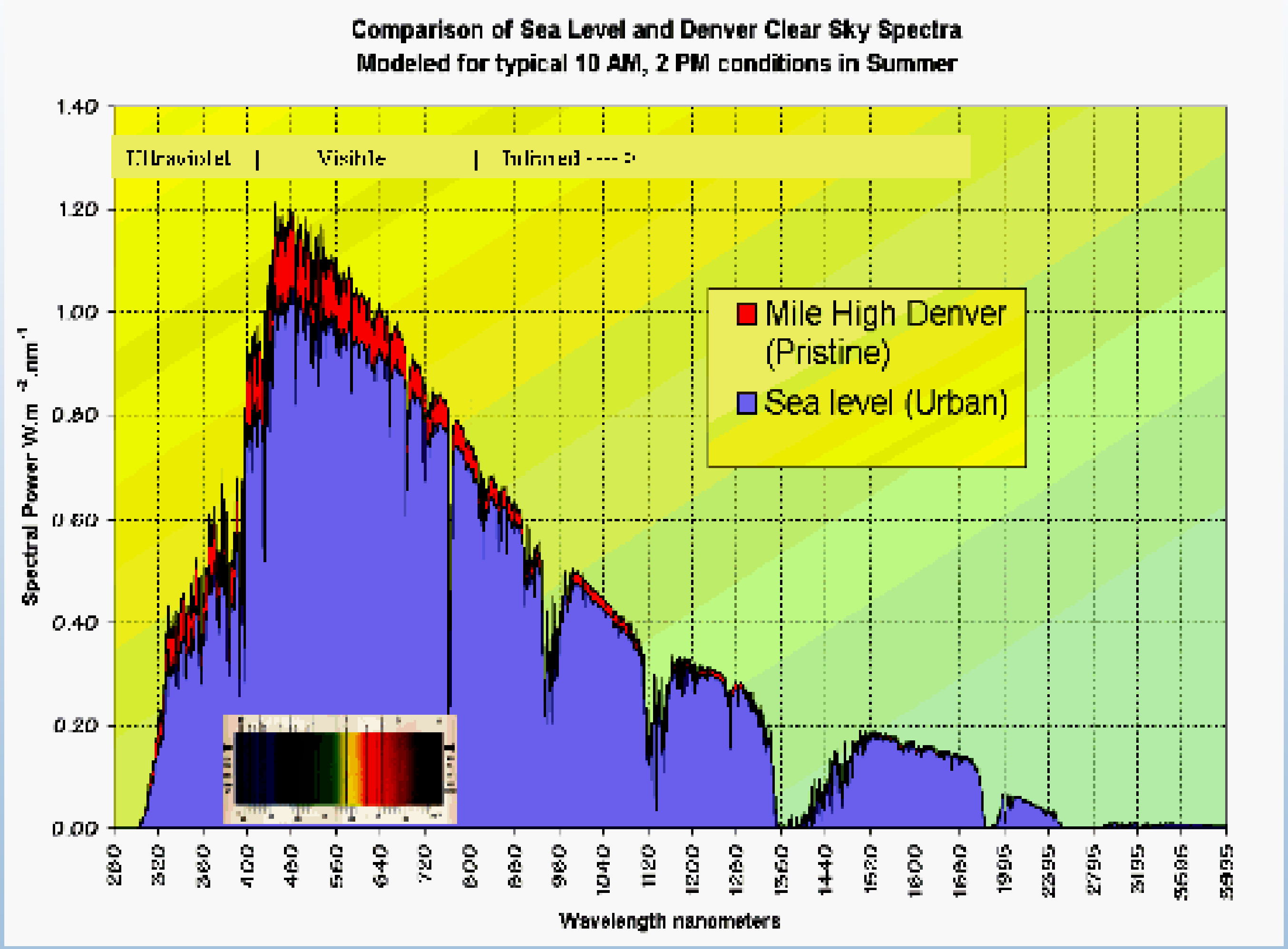
Spectral Irradiance

Basic Solar Spectral Regions:

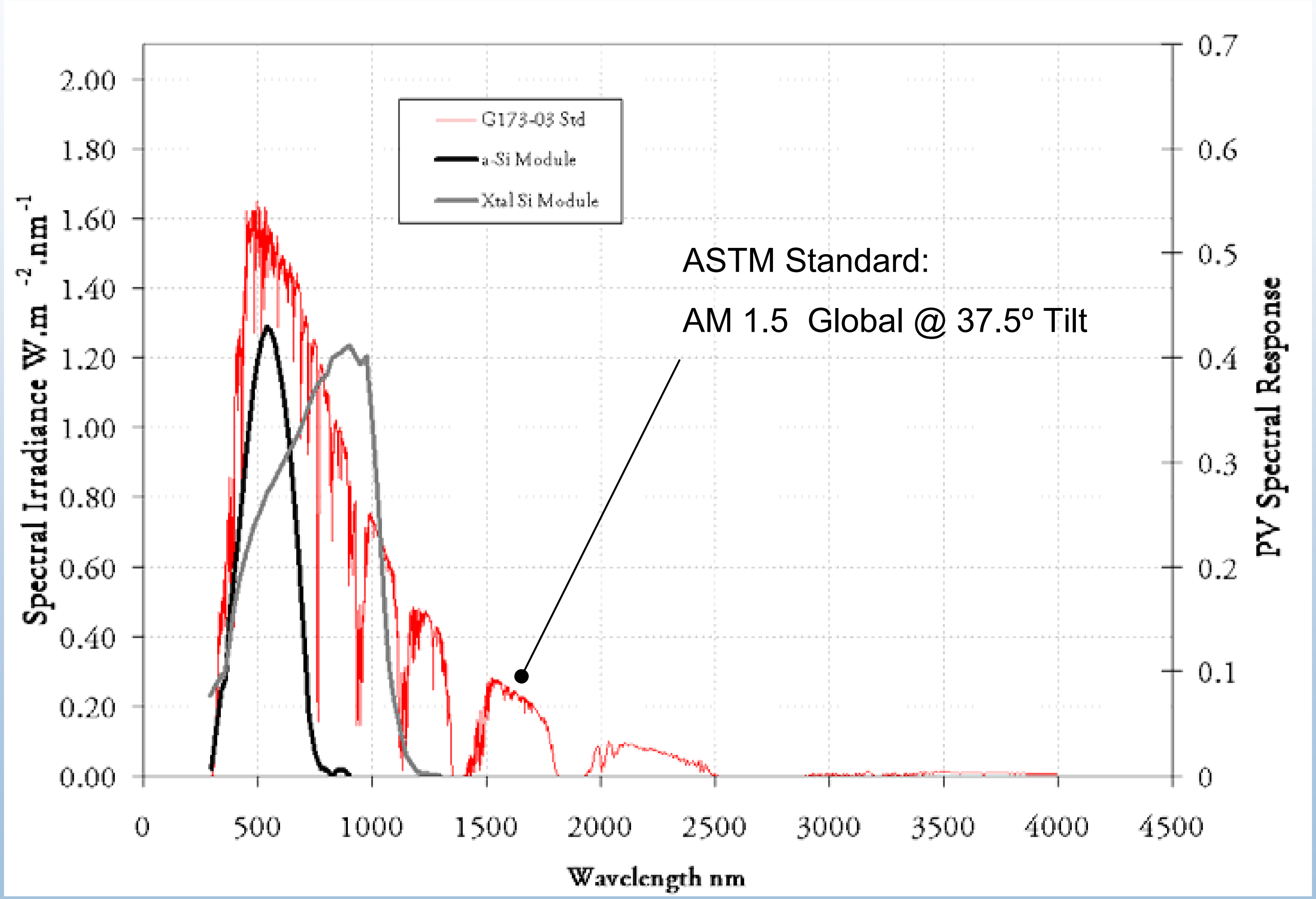
- Ultraviolet…..200 - 400 nm
- Visible……....400 - 700 nm
- Infrared……..700 - 3000 nm



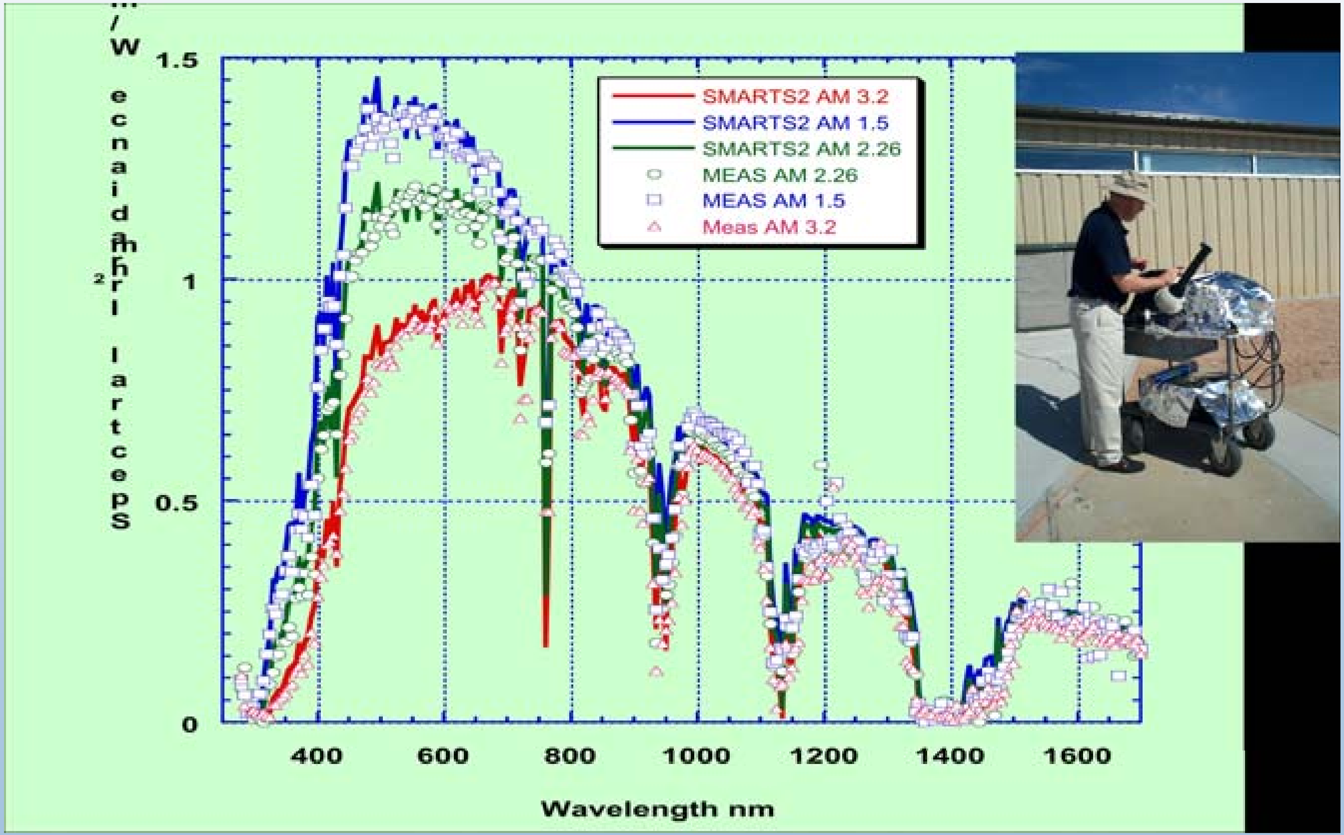
Follow the Photons!



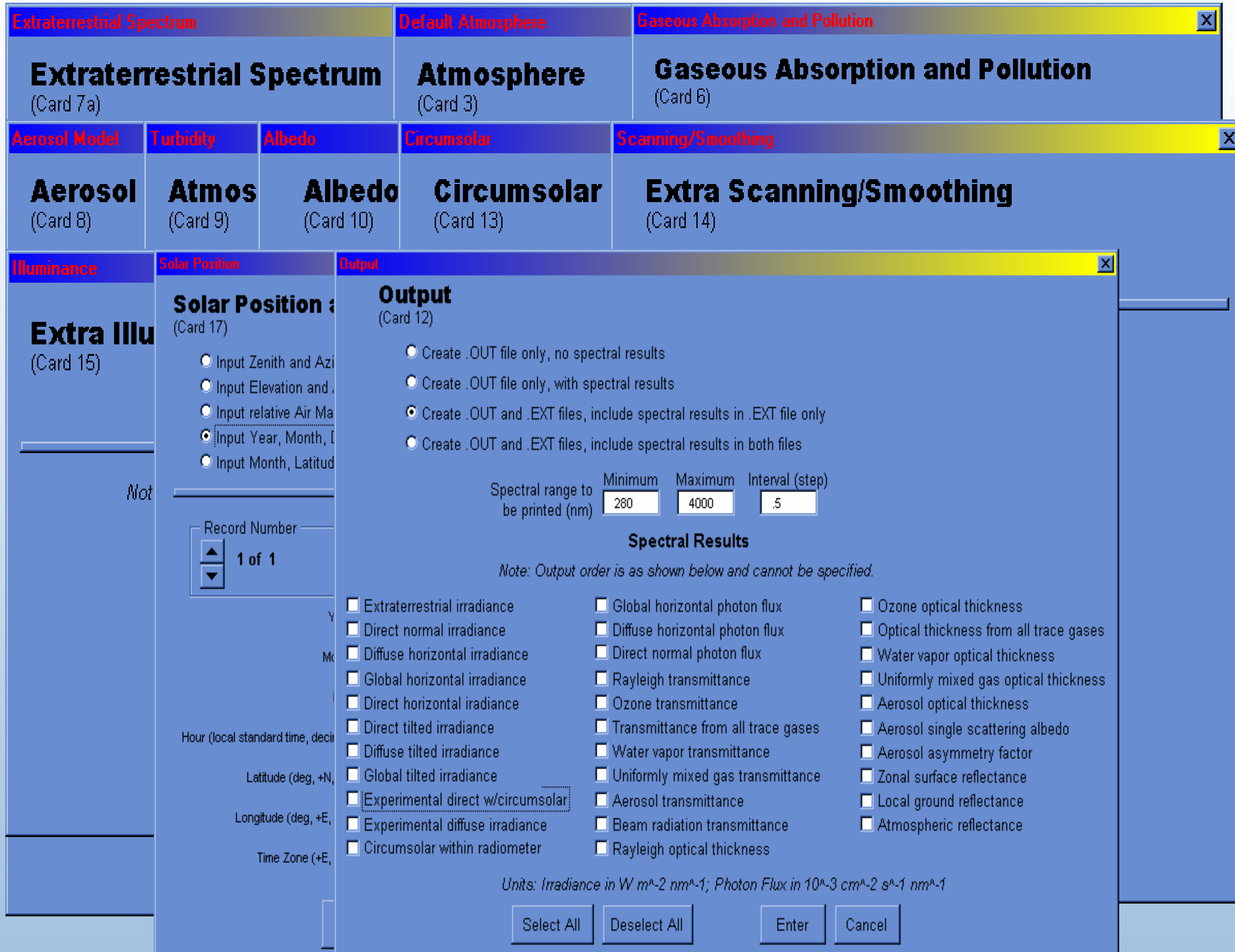
Photovoltaic Responses



Simple Model for Atmospheric Radiative Transfer of Sunshine SMARTS



SMARTS



Available from NREL: http://rredc.nrel.gov

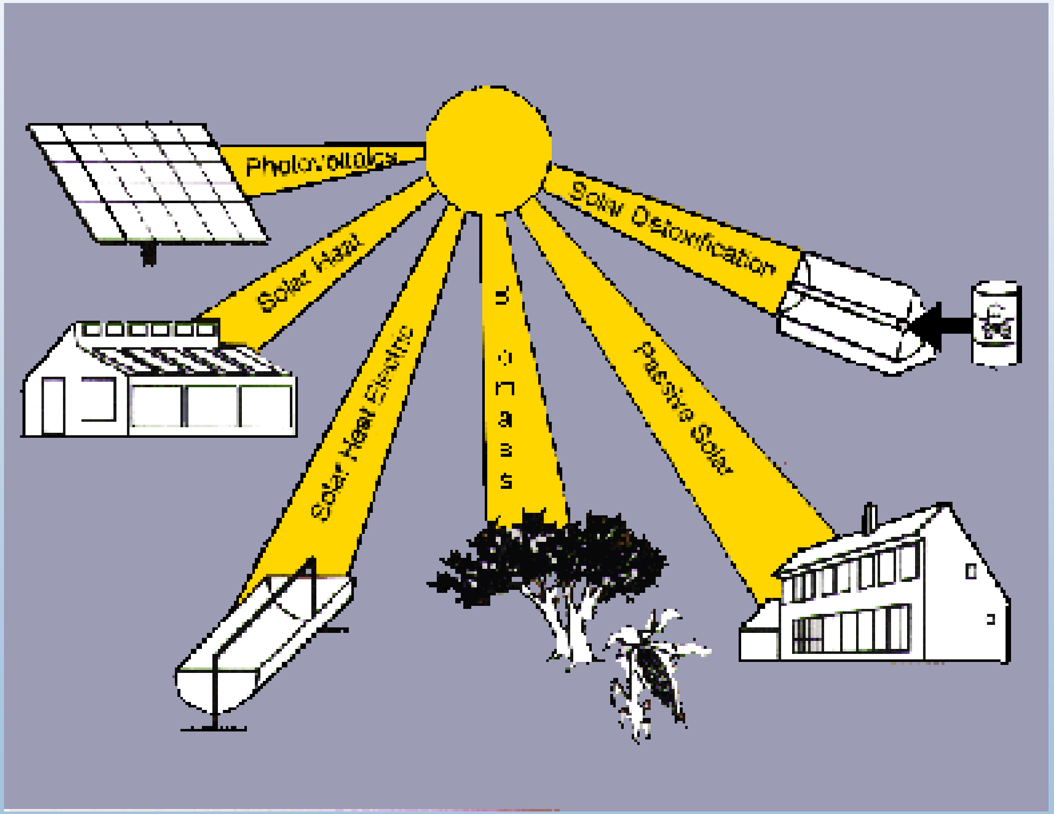
Why Do We Need Solar Radiation Data?

• Agriculture	Photosynthesis
• Astronomy	Solar Output Variation
• Atmospheric Science	Numerical Weather Prediction
• Climate Change	Energy Balance
• Health	UV effects on skin
• Hydrology	Evaporation
• Materials	Degradation
• Oceanography	Energy Balance
• Photobiology	Light and Life
• Renewable Energy	Sustainability

Why Do We Need Solar Radiation Data? Renewable Energy

The amount of solar energy reaching the earth's land areas in 1 hour is enough to supply the U.S. energy needs for 1 year (~100 Quads/yr)

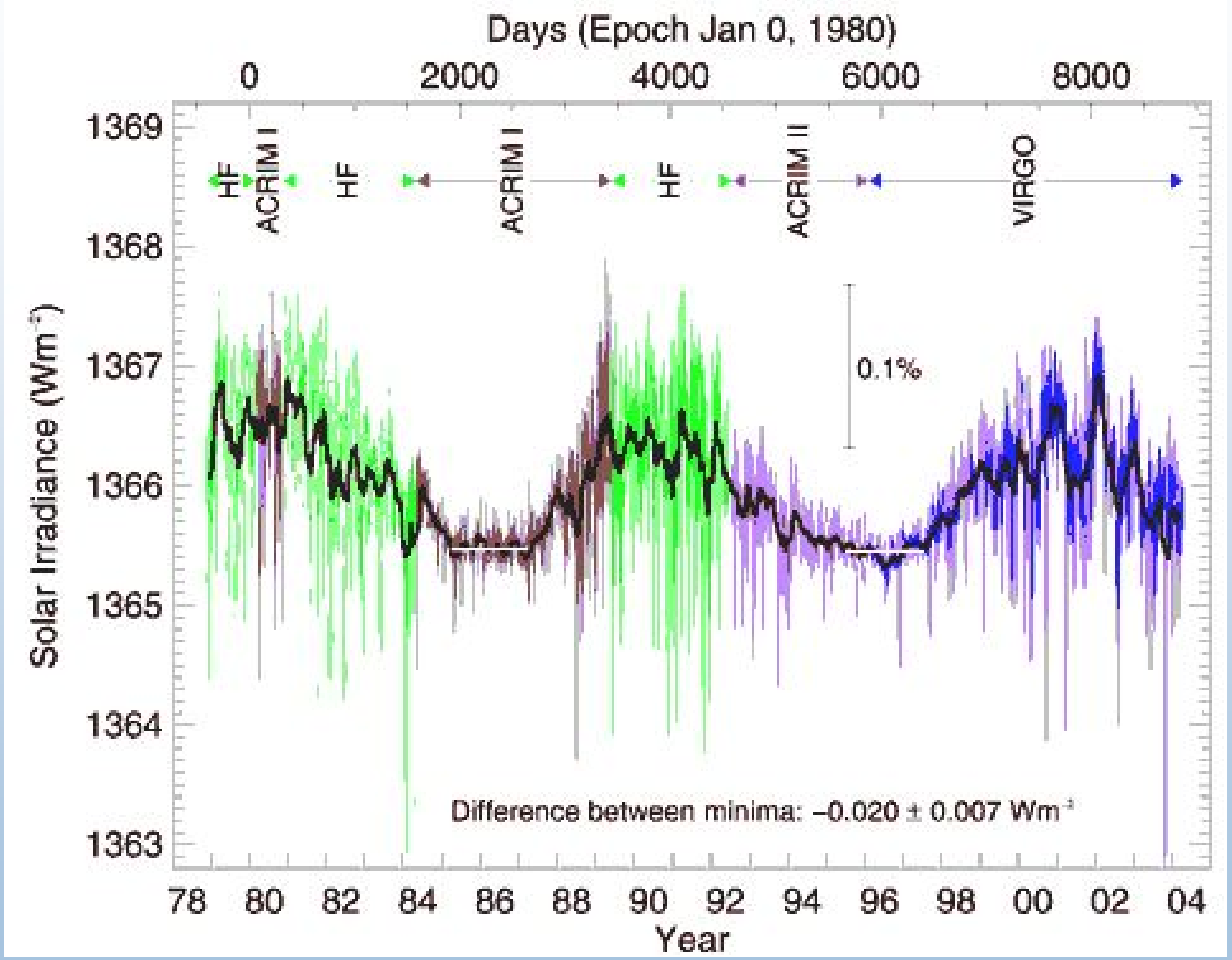
- Photovoltaics
- Solar Heat-thermal
- Solar Heat-electric
- Solar Fuel-biomass
- Passive Solar Lighting
- Building HVAC
- Solar Detoxification



What Influences the Amount of Solar Radiation?

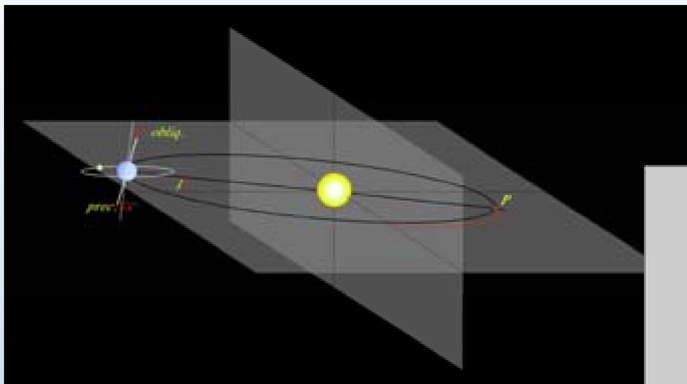
• Solar output	11 year solar cycle
• Earth-Sun distance	3.5% annual variation
• Clouds	Dominant factor
• Water vapor	Selective absorber
• Air pollution	40% less direct
• Smoke from forest fires	Natural or man-made
• Volcanic ash	Global effect for years
• Location	
• Time of day	Solar position
• Season	

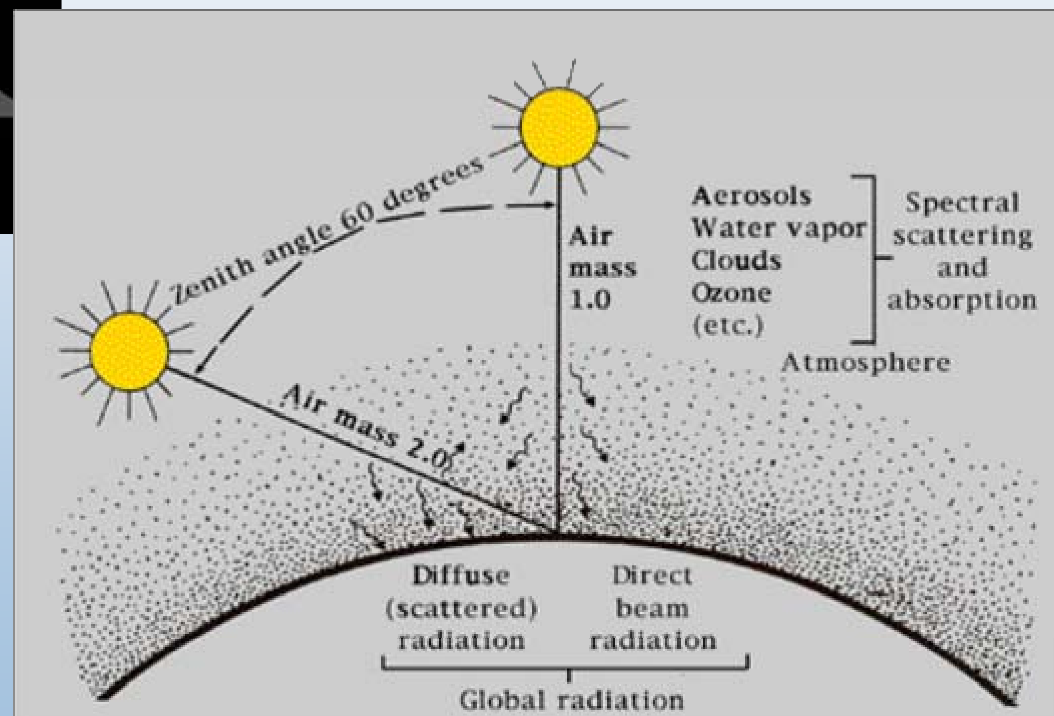
Solar "Constant"



World Radiation Center, Davos, Switzerland
http://www.pmodwrc.ch/

What Influences the Amount of Solar Radiation?



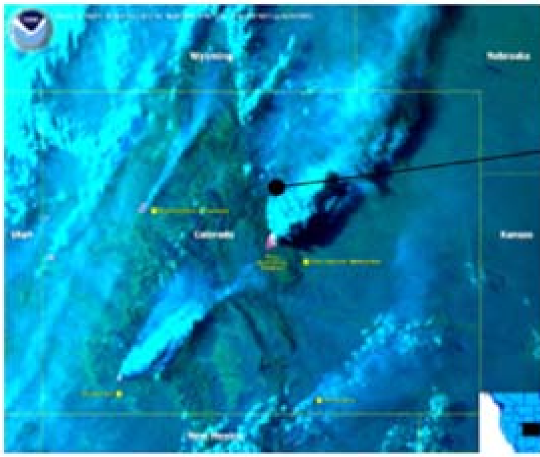


Earth’s Orbit:

- Earth-Sun distance
- Relative tilt
- Time of day

What Influences the Amount of Solar Radiation?

SRRL Measures Effects of Forest Fires on Solar Radiation



← NOAA Satellite Image

NREL

SRRL "SKYCAM" Image →
June 10, 2002

Fuzzy Sun and Shadows:
Increased scattering yields Higher-than-normal Circumsolar Radiation

Changes in Direct "Beam" Irradiance

-A- Morning Haze Before Shift in Wind:

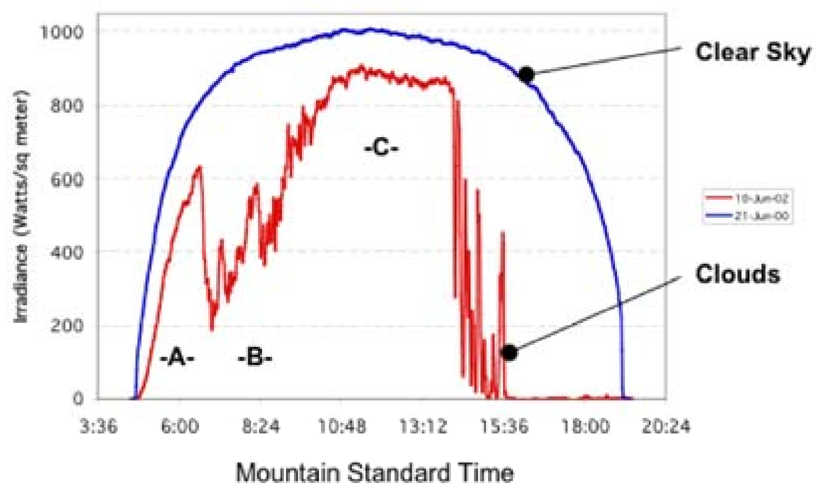
75% of Clear Sky (7:00)

-B- Thick Smoke Cloud:

23% of Clear Sky (7:30)

-C- Midday Haze:

90% of Clear Sky

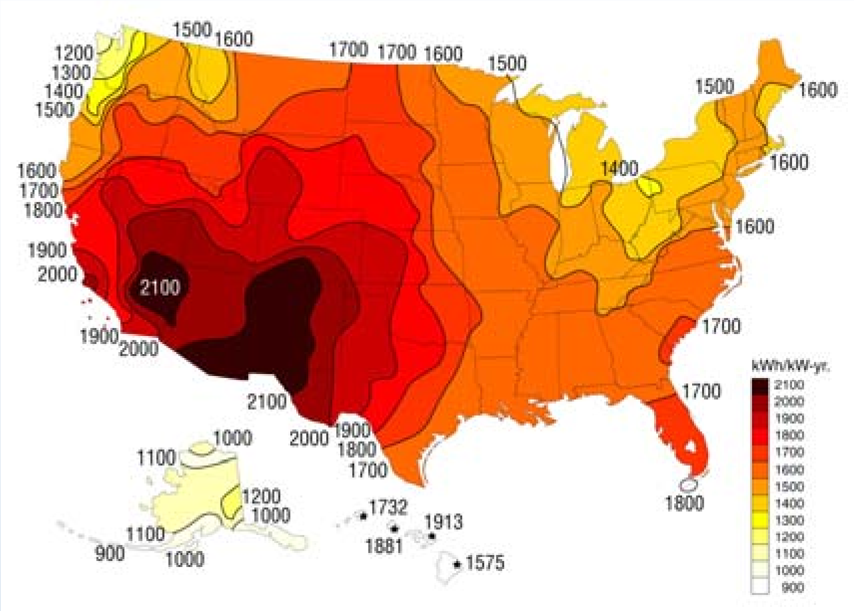


How Do We Use Solar Radiation Data?

- Technology Selection
- Siting
- System Design
- Performance Monitoring

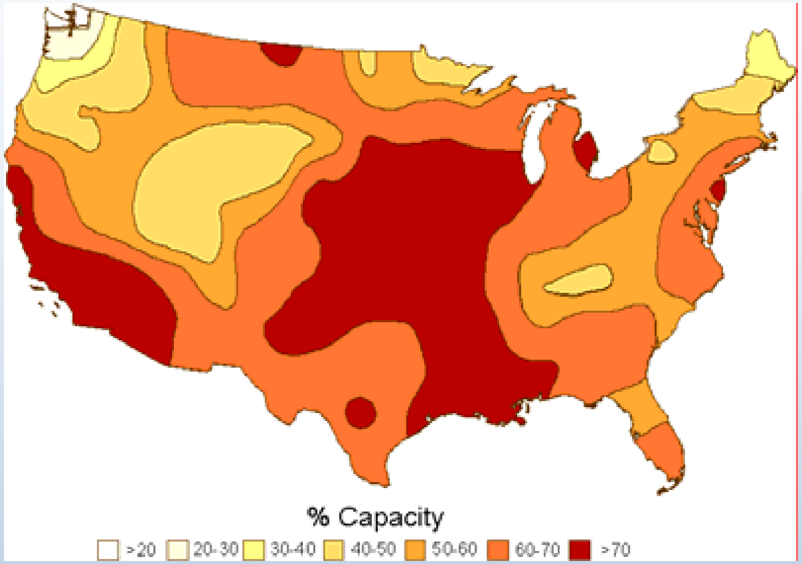
Flat Plate and
Concentrating Collectors

PV Energy kWh/kW-yr



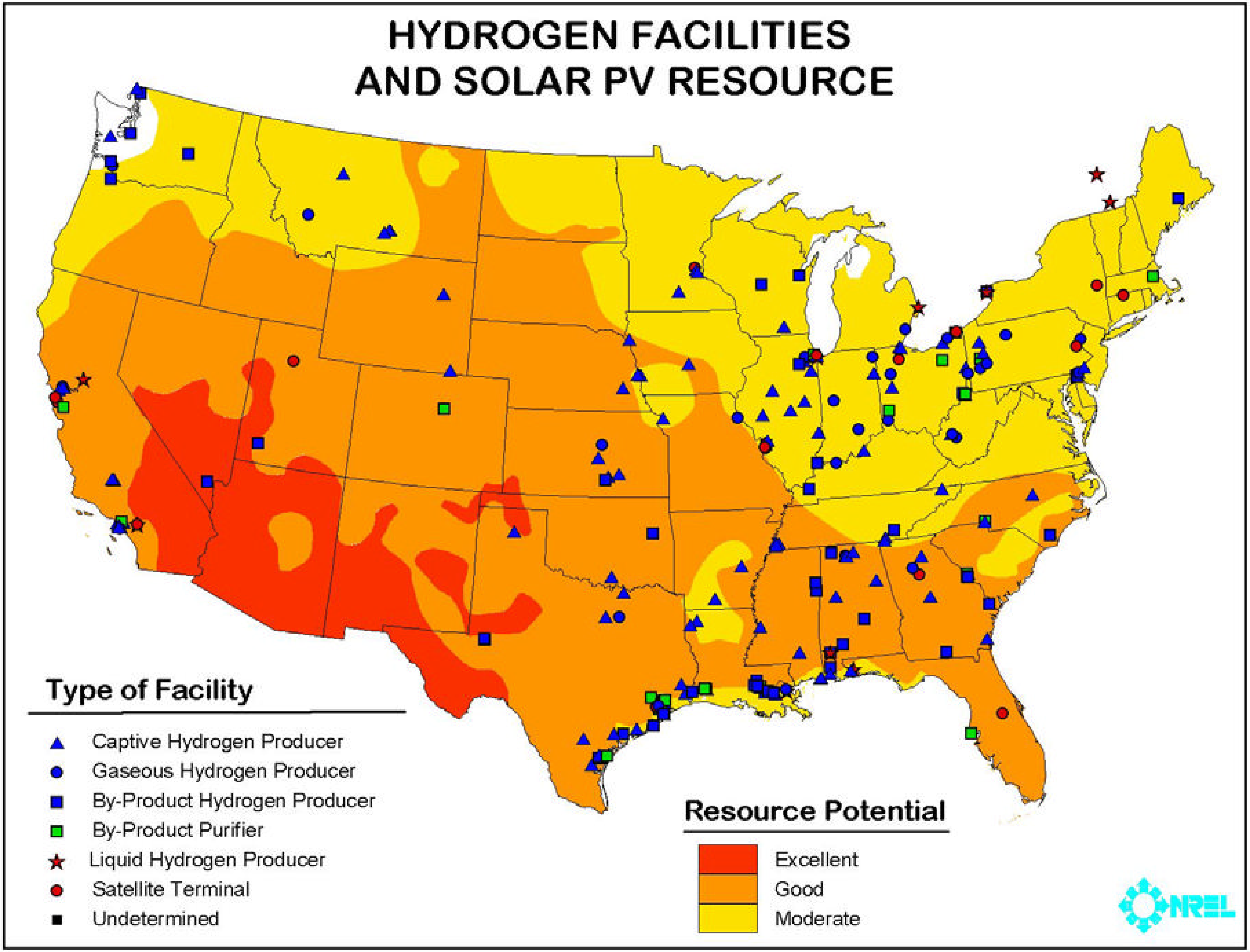
Effective Load

Carrying Capacity

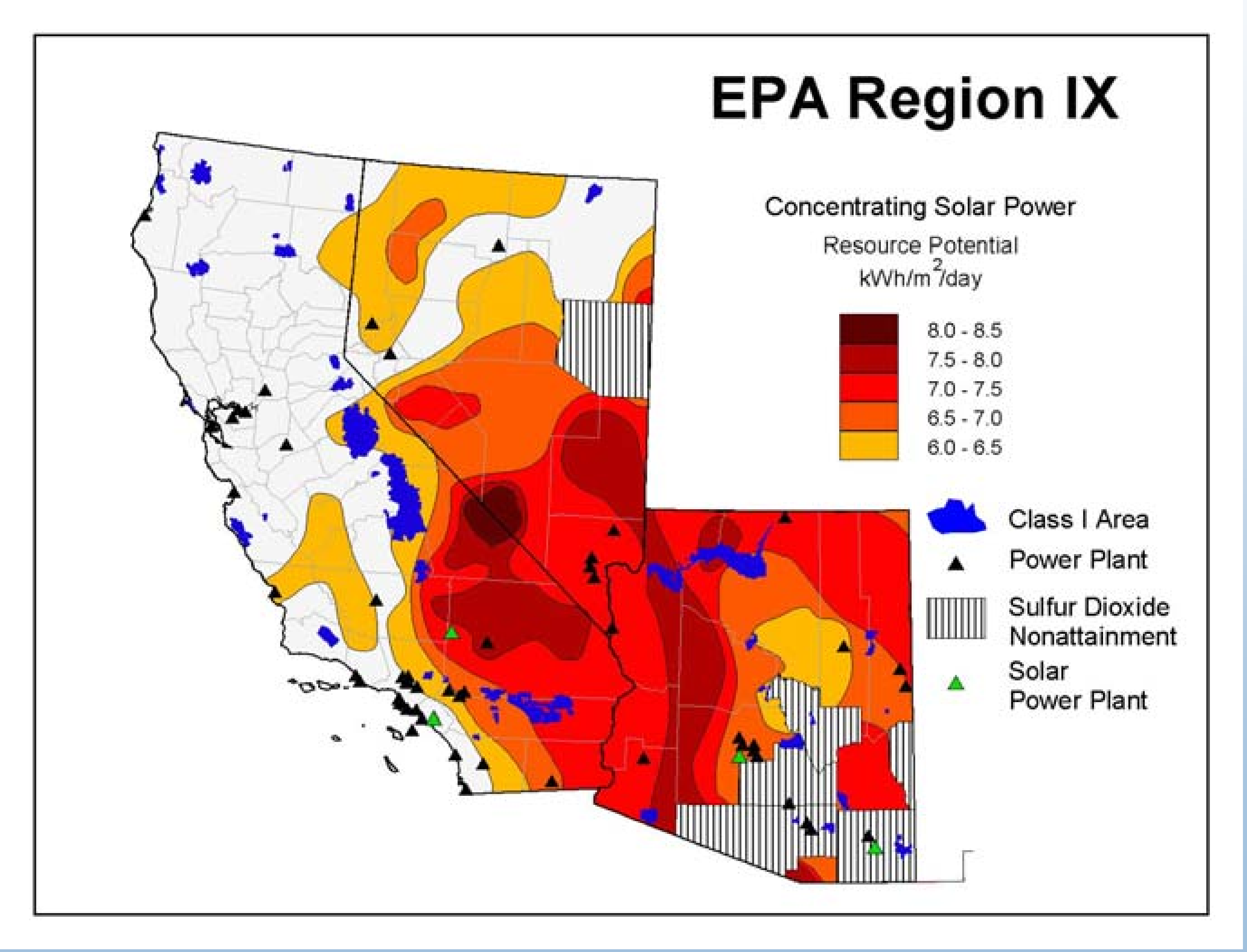


Source: Christy Herig (NREL) and Richard Perez (SUNY/Albany)

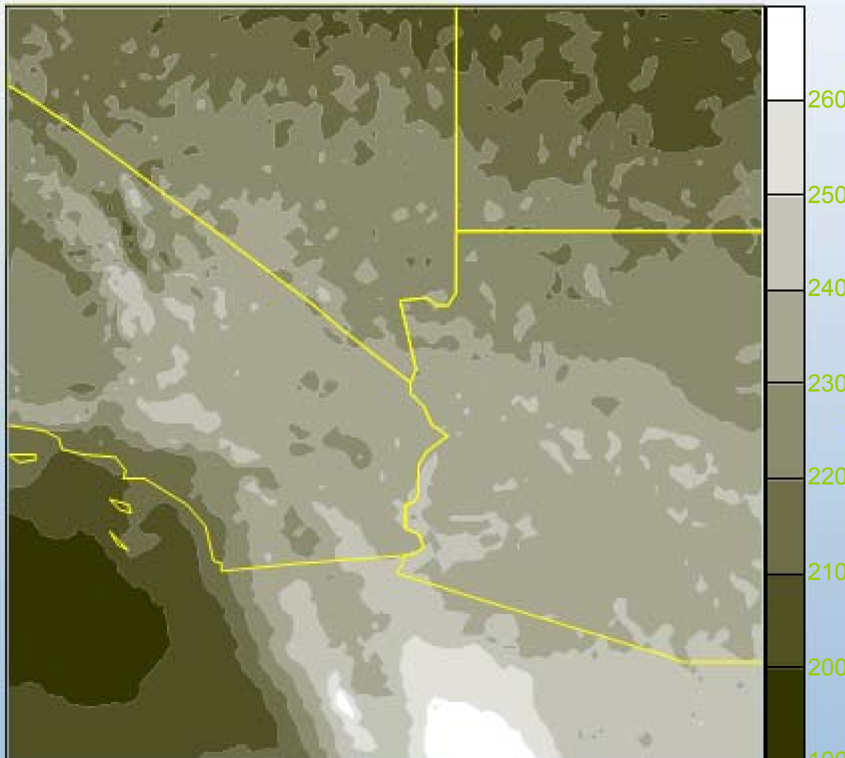
- PV can provide peak shaving in many parts of U.S.
- During off-peak periods, PV capacity can be applied to hydrogen generation


HYDROGEN FACILITIES
AND SOLAR PV RESOURCE
Type of Facility
Captive Hydrogen Producer
Gaseous Hydrogen Producer
By-Product Hydrogen Producer
By-Product Purifier
Liquid Hydrogen Producer
Satellite Terminal
Undetermined
Resource Potential
Excellent
Good
Moderate
NREL

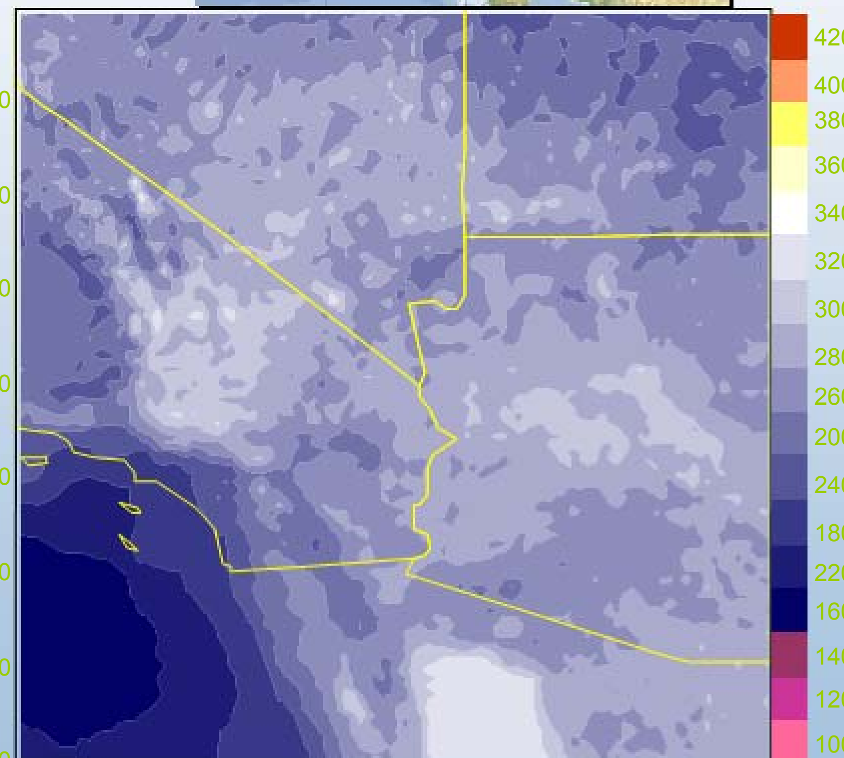
An Integrated Analysis Utilizing GIS can Assist With Energy and Environment Planning Efforts



Satellite-Derived Techniques Provide Improved Site-Time Coverage (SUNY/Albany)



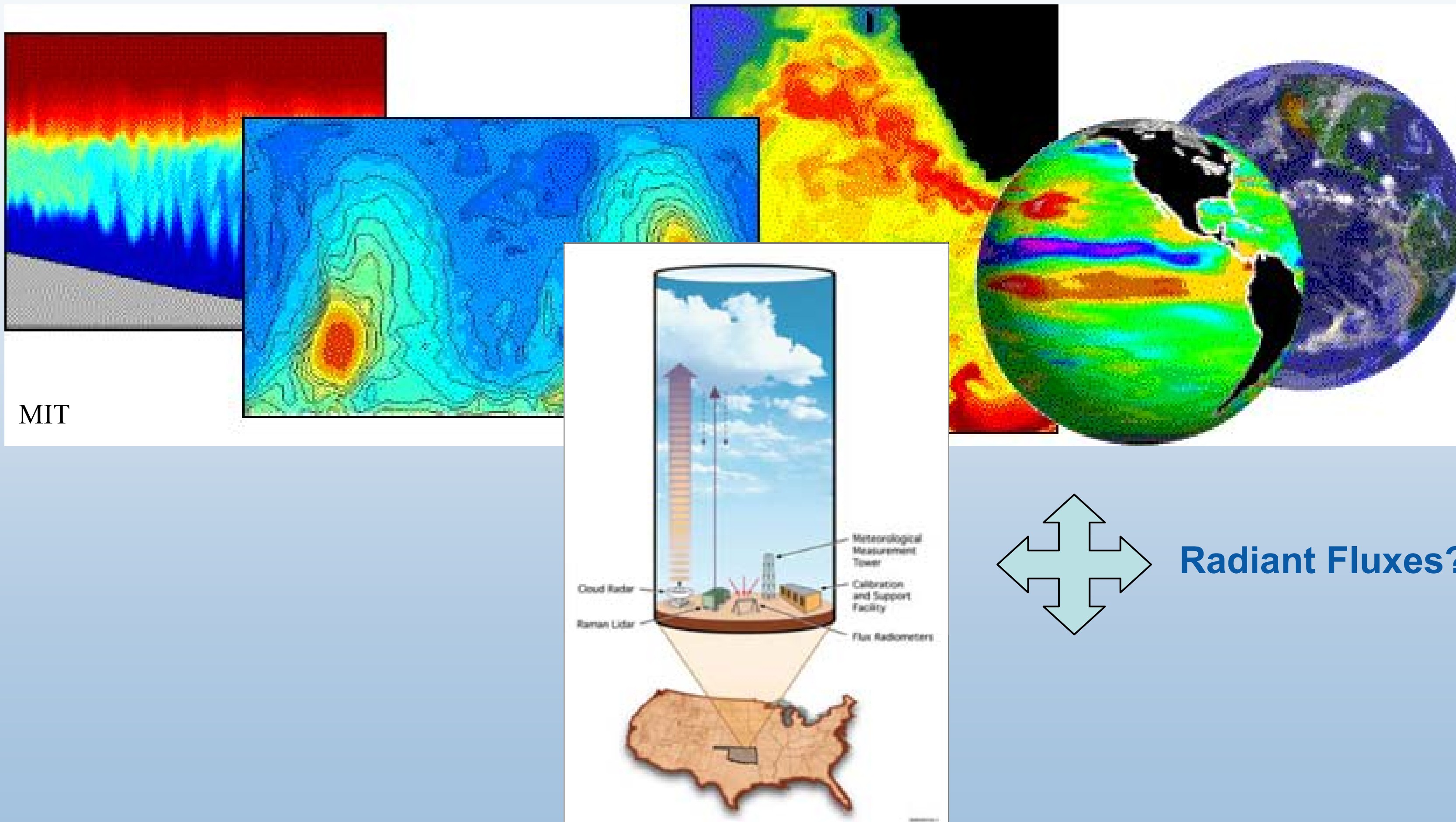
GLOBAL IRRADIANCE (average W/sq.m)



DIRECT IRRADIANCE (average W/sq.m)

How Do We Use Solar Radiation Data?

General Circulation Model Development



DOE/Atmospheric Radiation Measurement (ARM) Program

Radiant Fluxes?

How Accurate Do the Data Need to Be?

- What are the risks?
  - Cost/Benefit of Resource Assessment approach
- What is the application?
  - Daylighting & building thermal performance
  - Concentrating Collector Solar Power Plant
  - Cloud forcing analyses for climate change research
- What is the period of interest?
  - Measurement uncertainties decrease with longer averaging intervals (averaging can remove random errors)
  - Recent data more accurate than historical records (technology advancements)

How Accurate Do the Data Need to Be?

What is possible?

Measurement Uncertainty Estimates*

	Pyrheliometer (Direct Normal)	Pyranometer (Global)
Calibration	±1.6%	±4.2%
Field Data (Best practice)	~ ±5%	~ ±5%

* Instantaneous data intervals

How Will We Meet Our Solar Radiation Data Needs?

Research Activities:

- Solar Radiation Research Laboratory
  - Metrology
  - Optics
  - Electronics
  - Data Acquisition
- Photovoltaic Program
  - Radiometric Measurements
- Climate Change
  - Broadband Radiometer Mentor
- Collaborations
  - WMO, UNEP, NCAR, NOAA, state & local govt, academia

Solar Radiation Research Lab

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

Solar Radiation Research Lab

Baseline Measurements

(98 data elements)

http://www.nrel.gov/midc

Rotating Shadowband Pyranometer

Radiometer Calibrations

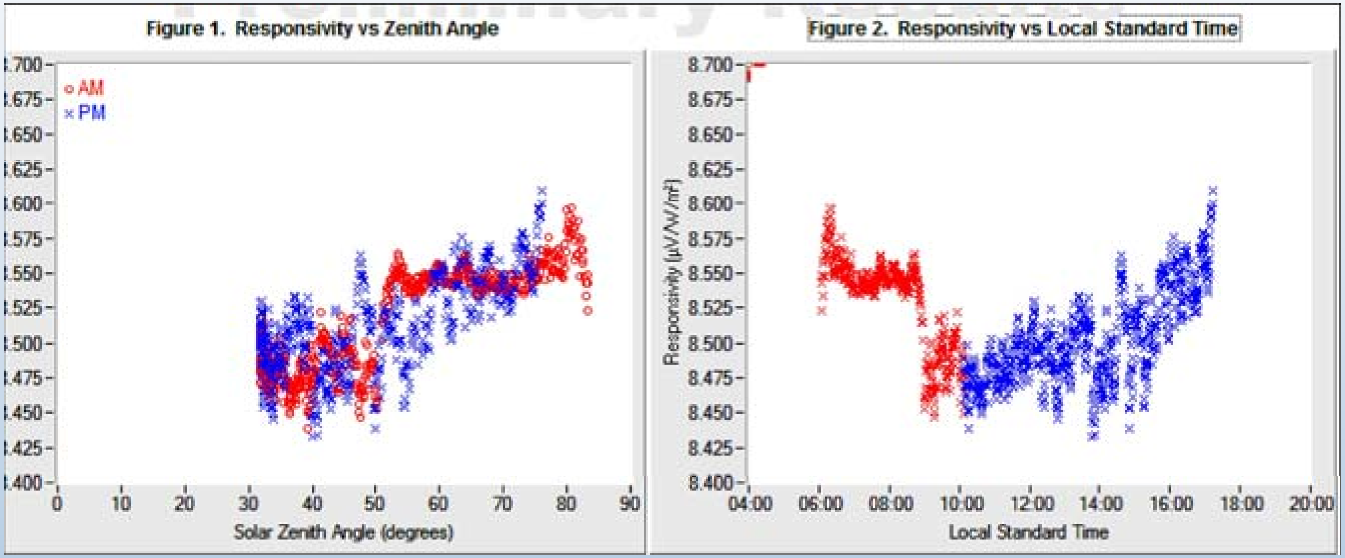
World Radiometric Reference

NREL Transfer Standards

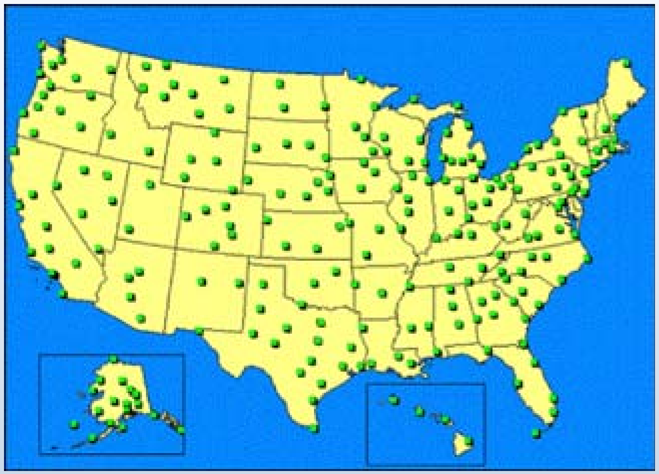
NPC

At SRRL

Radiometer Calibrations

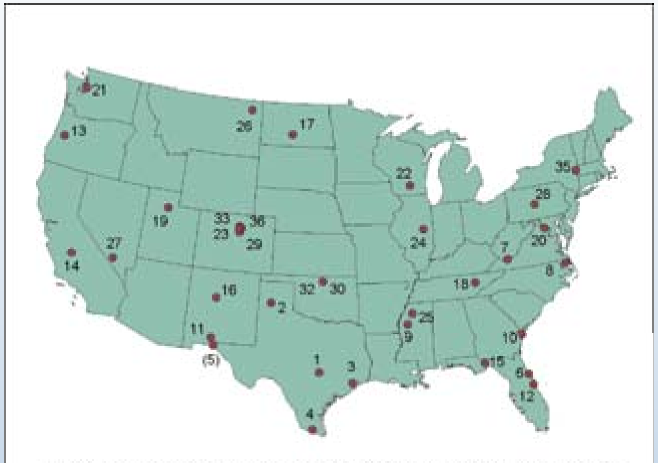


National Solar Radiation Data Base



NSRDB Stations

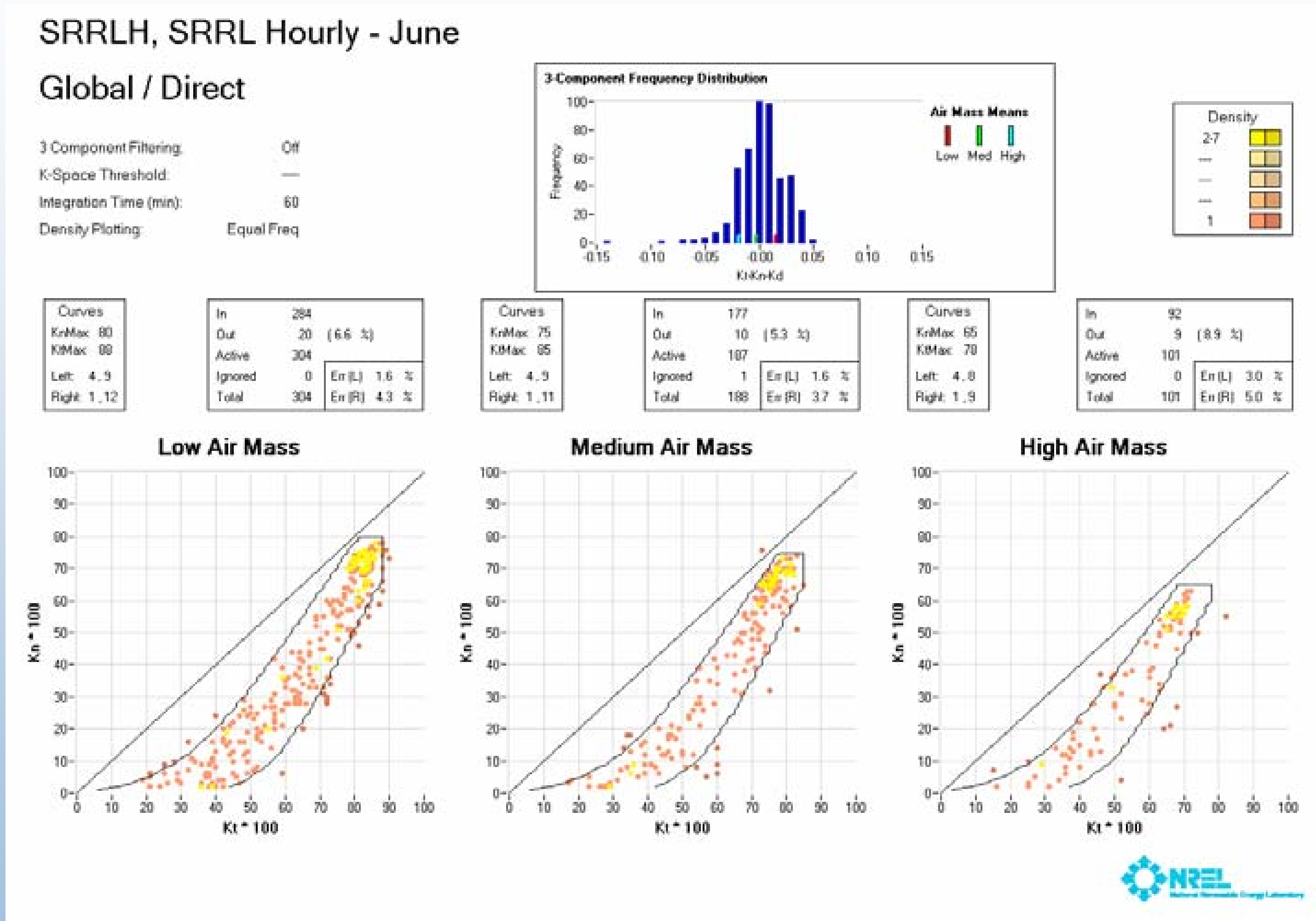
(1961-1990)



The current national network for the 48 conterminous United States

Solar Measurement Stations
(1990 - Present)

Automatic Data Quality



Where Can You Obtain solar Radiation Data?

- Renewable Resource Data Center
  - http://rredc.nrel.gov
- Measurement & Instrumentation Data Center
  - http://www.nrel.gov/midc
- NREL Map Server
  - http://www.nrel.gov/maps
- World Radiation Data Center
  - http://wrdc-mgo.nrel.gov
- National Climatic Data Center
  - http://www.ncdc.noaa.gov
- DOE Atmospheric Radiation Measurement Program
  - http://www.arm.gov
- NOAA Climate Monitoring & Diagnostic Laboratory
  - http://www.cmdl.noaa/gov/star
- NOAA Surface Radiation Research Branch
  - http://www.srrb.noaa.gov

Key Points

- Accurate information is important for policy decisions, technology selection, siting, designing,and monitoring the performance of solar energy conversion systems
- Accurate measurements are important for model development
- The work we do to improve solar measurements
  - Calibration
  - Instrument characterization
  - Measurement techniques (operations and maintenance, radiometer selection, installation considerations, etc.)
  - Data Quality Assessment
  - Training
- Data distribution to meet user needs (MIDC, RReDC, NSRDB)

Solar Radiation Measurement

Thank you!

Questions?

POP Quiz

Write the relationship between Global, Direct, & Diffuse irradiance.

$$\text{Global} = \text{Direct Normal} * \text{Cos}(Z) + \text{Diffuse}$$

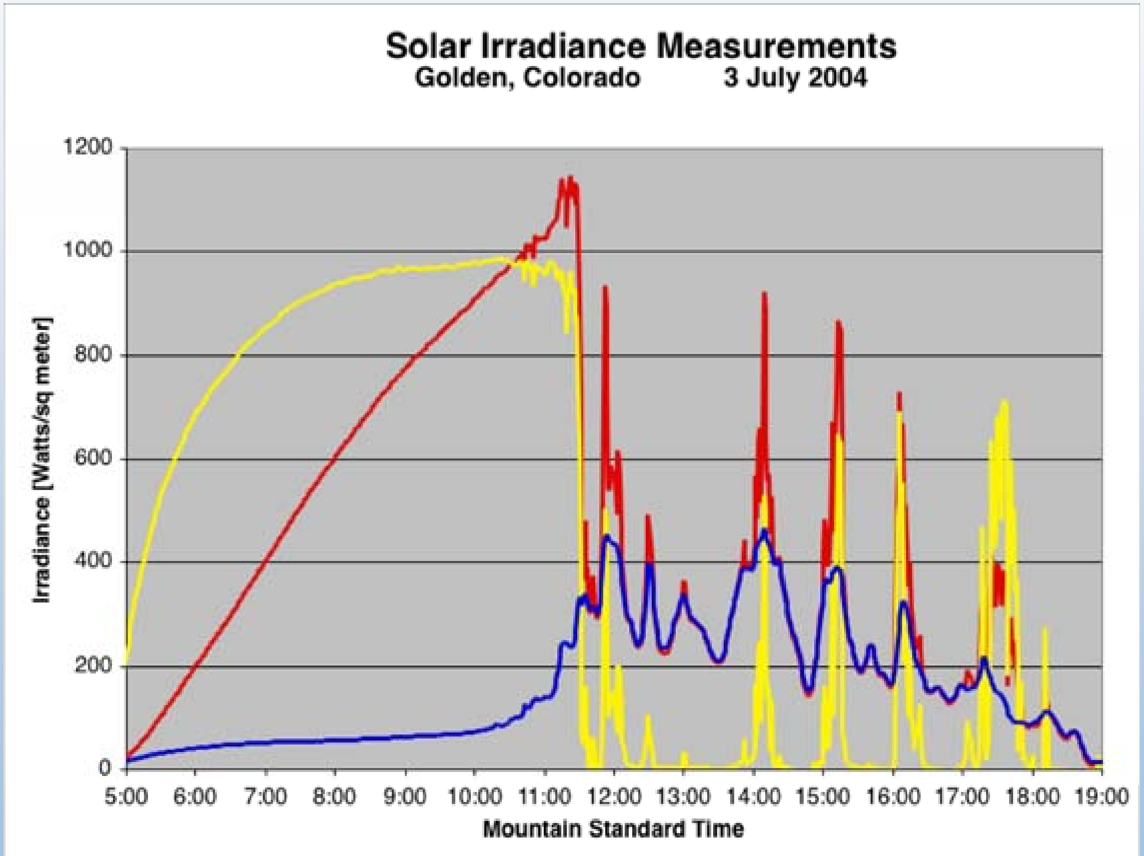
POP Quiz

Indicate which properties (quick, accurate, or cheap) apply to these pyranometer detector types:

- ✓ Photodiode — Fast, Cheap, Spectrally selective
- ✓ Thermopile — Accurate, $$, Slow

POP Quiz

T/F: The Global irradiance can never exceed the solar constant.



POP Quiz

The presently accepted value of the Solar Constant:

a) 1.96 Langleys per minute
b) 1366 Watts per square meter
c) 432.7 BTUs per hour-square foot
d) All of the above