20 Years of Solar Measurements:
The Solar Radiation Research Laboratory (SRRL) at NREL

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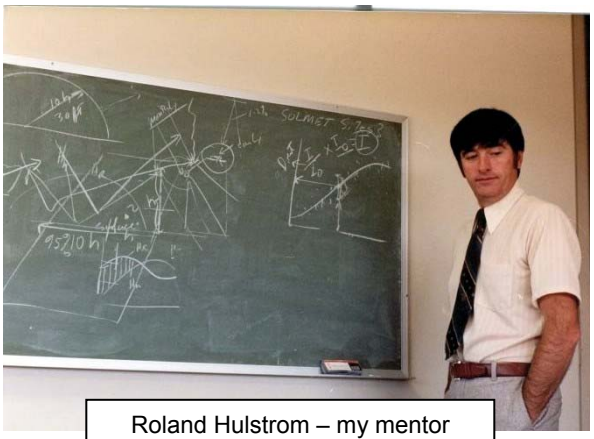
April 6, 2005

The development of SRRL began immediately following President Carter's visit to SERI on May 3, 1978, when Roland Hulstrom directed me to develop an outdoor research laboratory to provide for:

- Maximum annual solar access
- Continuous measurements of key solar radiation resources
- Calibrations of instruments used to measure solar radiation
- Training of meteorological station operators
- Development of novel systems for resource monitoring.

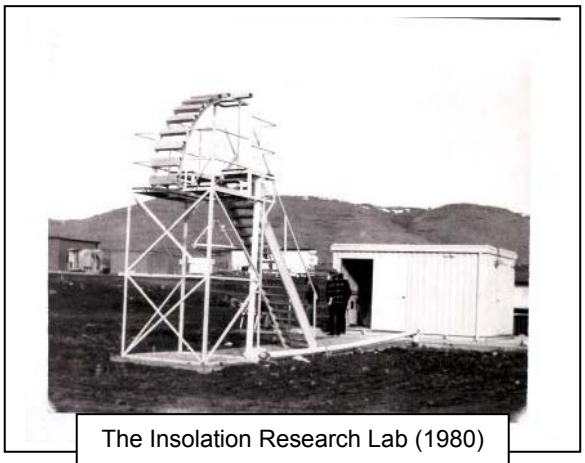
At the time, we had access to the top of South Table Mountain, but the land still belonged to the State of Colorado. In the absence of electrical and telecommunications services (remember, this was before cellular networks and the personal computer), Bob Rader and I used available surplus equipment to take the first solar radiation measurements at SERI.



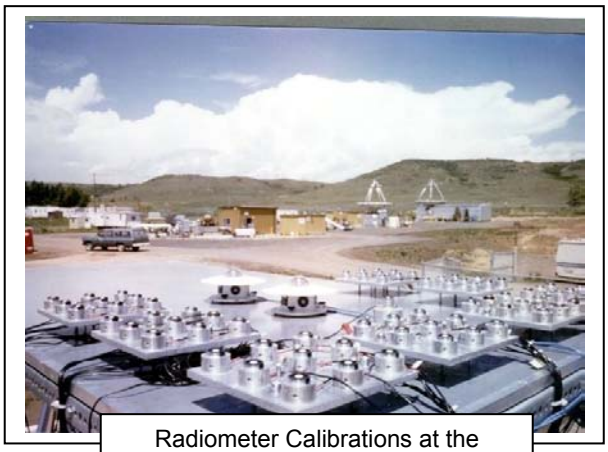
Roland Hulstrom – my mentor

First Solar Measurements on South Table Mountain (1978)

While waiting for the transfer of land ownership to the DOE, SERI rented the Interim Field Test Site at the base of South Table Mountain (now the location of the Denver West Marriott Hotel). With access to basic utilities, we established the Insolation Research Laboratory and began our more permanent research measurements in 1980.



The Insolation Research Lab (1980)



Radiometer Calibrations at the Interim Field Test Site (1983)

By early 1985, we planned and built the first Solar Radiation Research Laboratory (SRRL) on top of South Table Mountain. Using surplus meteorological monitoring sheds built for the EPA in the early 1970's, we met the original design functions for the lab.

Daryl Myers calibrating radiometers (1983)

The Solar Radiation Research Lab (1985)

Having outgrown the mouse-infested EPA sheds, a new Solar Radiation Research Laboratory building was completed in December,1999. Today, the 2,400 ft^2 building serves as the offices for six members of the Measurement & Instrumentation Team in the Electric & Hydrogen Technologies & Systems Center. In addition to the outdoor laboratory areas, the SRRL houses the NREL Metrology Lab, Optics Lab, Data Acquisition Lab, and Electronics Lab.

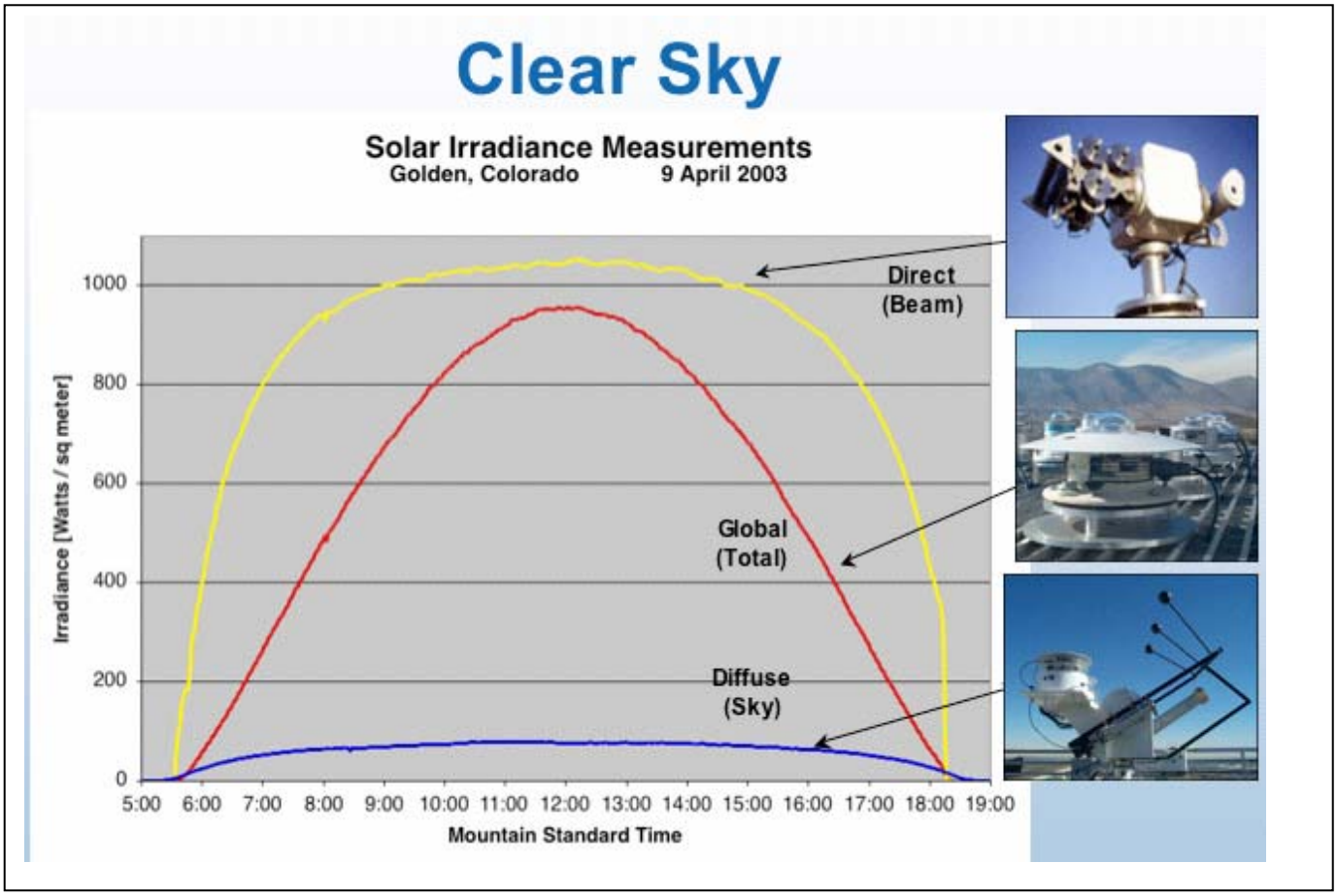
New SRRL Building (1999)

Ibrahim Reda and NOAA colleagues calibrate radiometers (2000)

April 8, 2005 marks the 20th year of continuous solar radiation measurements from SRRL. Data since that day to the minute you read this are available from our Measurement & Instrumentation Data Center (http://www.nrel.gov/midc/srrl_bms/). Of course, in the early years before the internet, we could only distribute data on floppy disks, paper reports, or, for the technically savvy, 9-track tape. In January 1997, we first connected SRRL to the internet, greatly enhancing our philosophy of open and free access to this valuable scientific data set. Since then we have kept pace with internet capabilities and can now make data available to users within six seconds of the measurements.

Over the years we have added instruments and measurement systems to meet the growing research demands. Since January 2004, data for 131 parameters are available for each minute of the day and night. Samples of these research-quality measurements are described below to summarize our understanding of the solar climatology for Golden, Colorado.

How does the amount of solar radiation vary throughout the day?

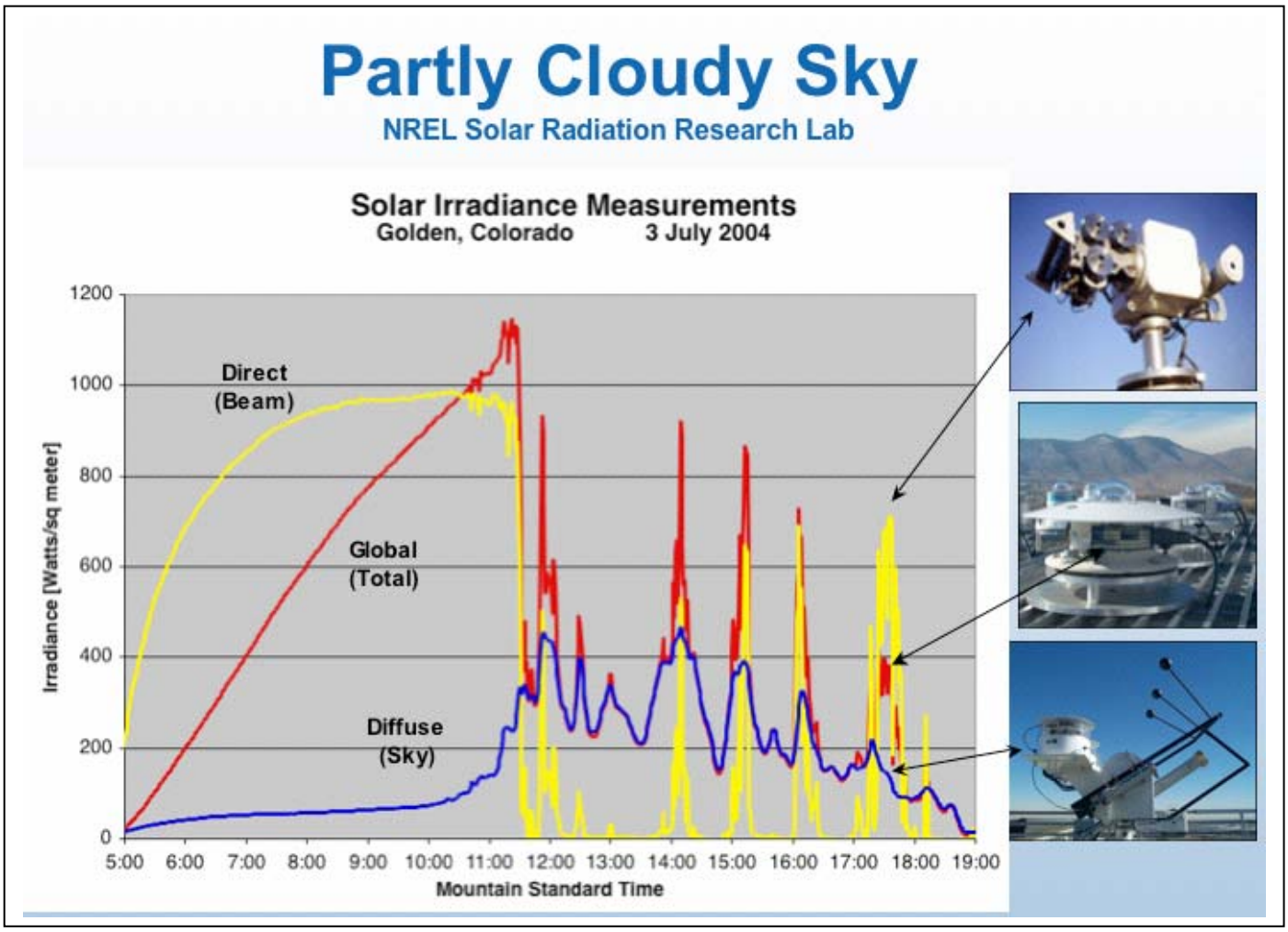


The above figure illustrates the typical daily cycle of solar radiation available for a single day and the three basic instruments (radiometers) used to make the measurements. Under clear-sky conditions, the energy amounts are predictably smooth based on the solar constant, day of the year, and location on the earth. Each solar radiation component has applications in renewable energy.

Measurement	Method	Application
Direct (Beam)	Pyrheliometer tracking the sun all day	Concentrating collectors for PV or solar thermal
Global (Total)	Pyranometer viewing the entire sky dome (as plotted) or tilted towards the south like a solar collector	Thermal performance of buildings, biomass, PV, solar thermal, and climatology
Diffuse (Sky)	Shaded pyranometer (beam is blocked by a shade ball or disk)	Daylighting, biomass, and PV

http://www.nrel.gov/midc/srrl_bms

How does the amount of solar radiation vary throughout the day? (Part 2)



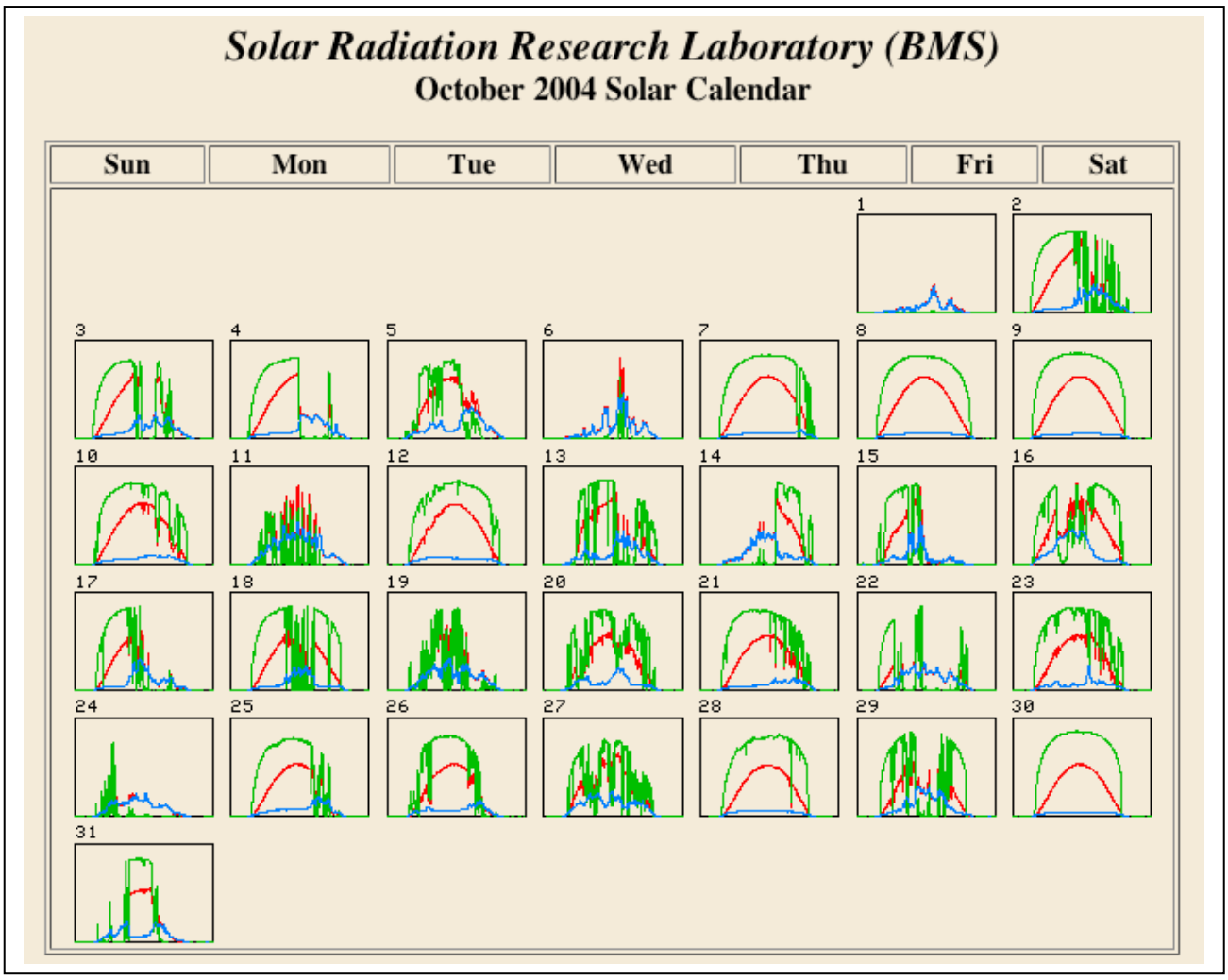
Clouds can rapidly change the amount of solar radiation reaching the earth's surface. Note the increased diffuse (sky) irradiance – clouds can be bright white – and the attendant decreases in direct (beam) irradiance.

Daily variations in the amounts of solar energy components vary with the types, amounts, and distribution of the clouds, amounts of water vapor, aerosols, ozone and other atmospheric constituents, the changing position of the sun in the sky, and many other factors.

All-sky image, same view as pyranometer, showing partly cloudy scene at 11:00 MST on July 3, 2004.

http://www.nrel.gov/midc/srrl_bms

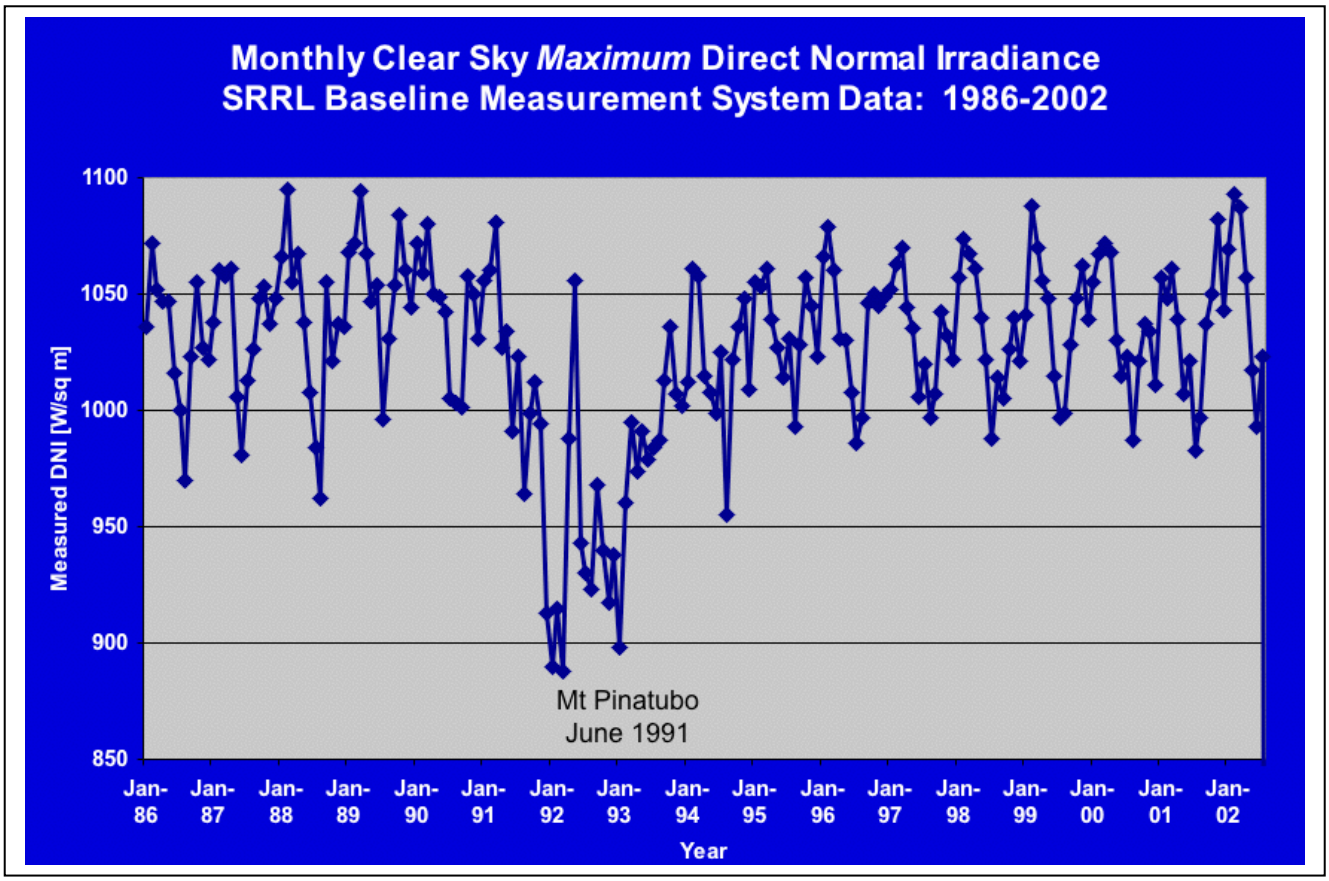
How do the amounts of daily solar radiation vary by week?



A ***Solar Calendar*** for October 2004 shows the variability of solar radiation. Clear-sky periods have smooth curves for direct normal [**green**], diffuse [**blue**] and global irradiances [**red**] (October 8 & 9). Partly-cloudy intervals are indicated by the erratic up and down energy levels (October 11 & 19). Overcast skies, with or without precipitation, can be identified by the suppressed irradiance levels in all three solar components (October 1).

http://www.nrel.gov/midc/srrl_bms

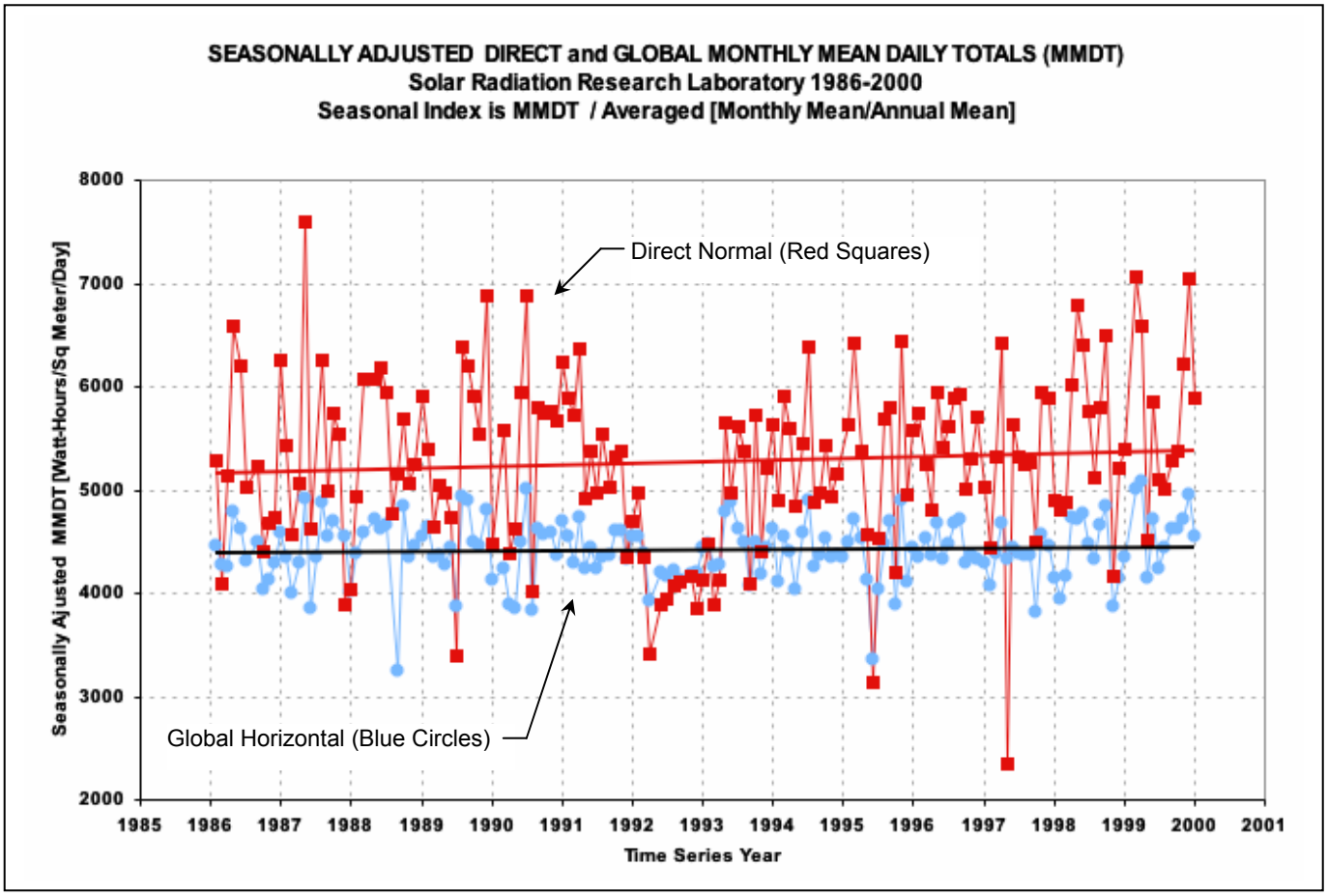
What about the variations of solar resources from year to year?



The amount of solar radiation varies with the season and from year to year. The effects of volcanic eruption are present in the SRRL measurements during 1991-1994. During this period, the global dust veil reduced the amount of direct normal irradiance by as much as 20%.

What solar radiation climate trends can we detect?

All radiometers used to measure solar irradiance at SRRL are calibrated annually using absolute cavity radiometers traceable to the World Radiometric Reference maintained by the World Radiation Center at the Physikalisch-Meteorologisches Observatorium Davos, Switzerland. Daily maintenance procedures contribute to the research-quality of the measurements at SRRL.



Accounting for the seasonal variations in monthly mean daily totals of solar radiation, we can estimate the longer-term trends in irradiance for this 15-year analysis of SRRL data:

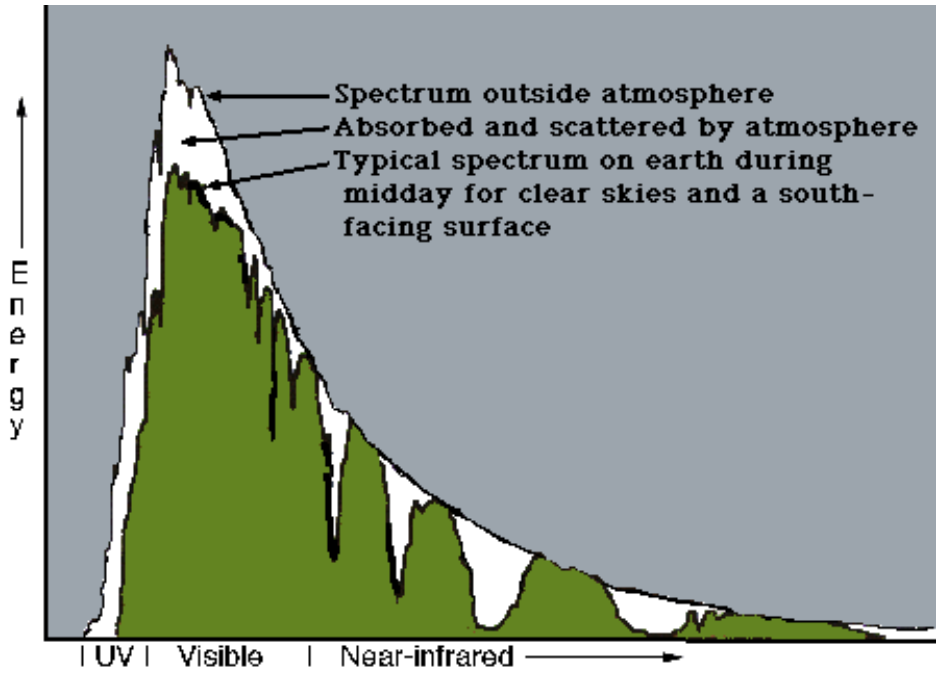
Direct Normal (Beam)	=	4.7% increase
Global Horizontal (Total)	=	2.1% increase

These trends must be considered with the estimated measurement uncertainties. I estimate a 1% to 2% measurement uncertainty for these measurements. I should also caution that extrapolating this data beyond the 15 years will not yield valid results. Significant variations from one decade to the next are common, and a sustained increase in solar irradiance such as that shown here would be climatically devastating.

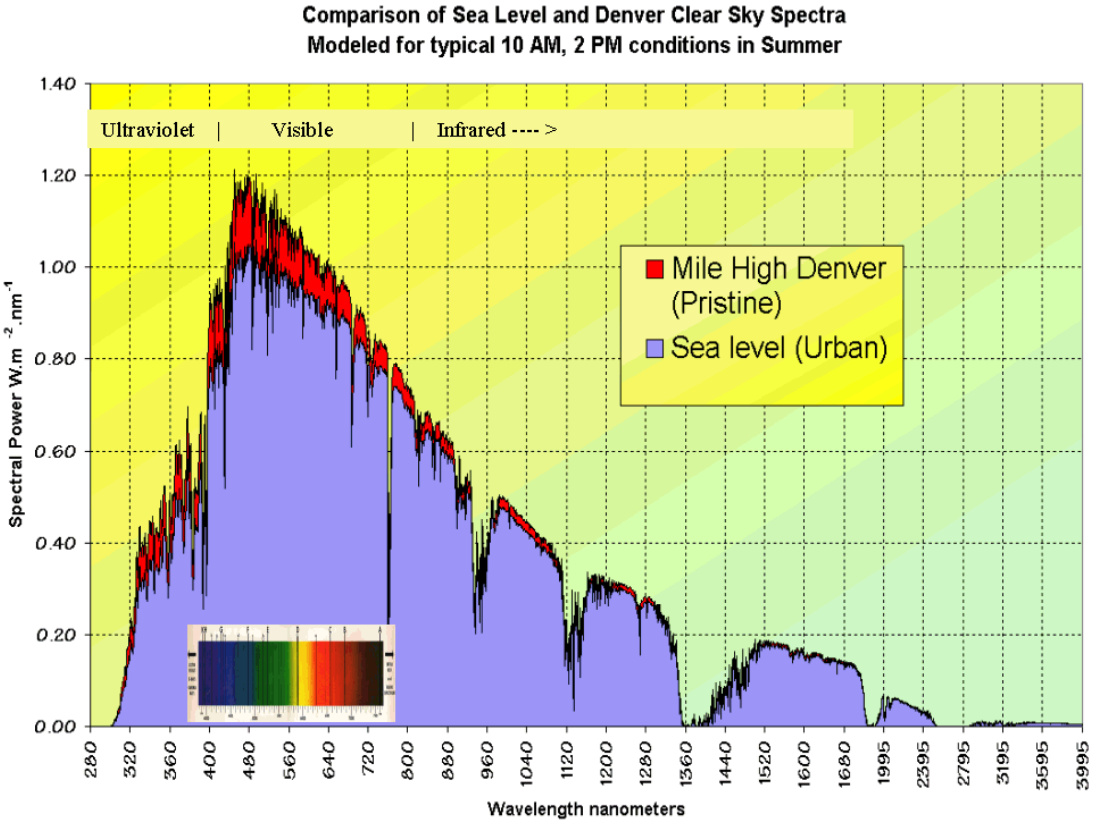
The data so far have been the integrated, or ***broadband*** irradiance from the sun. The ***spectral distribution*** of solar irradiance is another factor for renewable energy applications.

What about the *spectral distributions* of solar irradiance?

The sun's energy is not evenly distributed over all wavelengths. The emitted radiation by the sun from space is greatest in the visible portion of the spectra. The variations of solar intensity at the earth's surface are greatly effected by the complex interactions with the atmosphere. PV devices, plants, and our eyes respond to different parts of the spectrum.



The effects of high altitude (less atmosphere) can be seen in the comparison below:



Additional information can be found at our web sites:

- Solar Radiation Research Laboratory (SRRL) http://www.nrel.gov/srrl
  - Purpose
  - Staff
  - Facilities
  - Current Research Topics
  - Past Affiliations

- Measurement & Instrumentation Data Center http://www.nrel.gov/midc
  - Current Weather Display
  - Solar & Meteorological Data from 1985 to present
  - Time-series Plots
  - Sky Images
  - Spectral Measurements
  - Wind Roses
  - Instrument Calibrations

- Renewable Resource Data Center http://rredc.nrel.gov
  - Solar / Wind / Biomass / Geothermal
  - Publications
  - Historical Data
  - PVWATTS Analysis
  - Glossary
  - Kidz Links
  - Energy Tidbits
  - Unit Conversions

- Geographic Information System Map Server http://www.nrel.gov/gis
  - Dynamic Maps
  - GIS Data

- Electric & Hydrogen Technologies & Systems Center
  http://www.nrel.gov/eis/about_ehts.html
  - Resource Integration Group
    - Geographic Information Systems Team
    - Measurement & Instrumentation Team
  - Energy Systems Group
    - Distributed Power Systems Integration Team
    - Hydrogen Technologies & Systems Team