National Renewable Energy Laboratory
Innovation for Our Energy Future

8 MW Solar Field, Alamosa, Colorado, USA: Photo courtesy of SunEdison and Zinn Photography

Resource Assessment Tools

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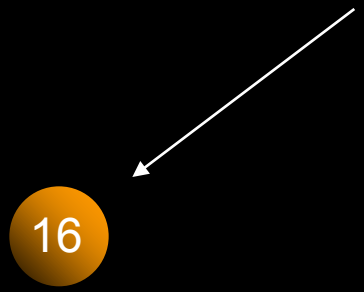
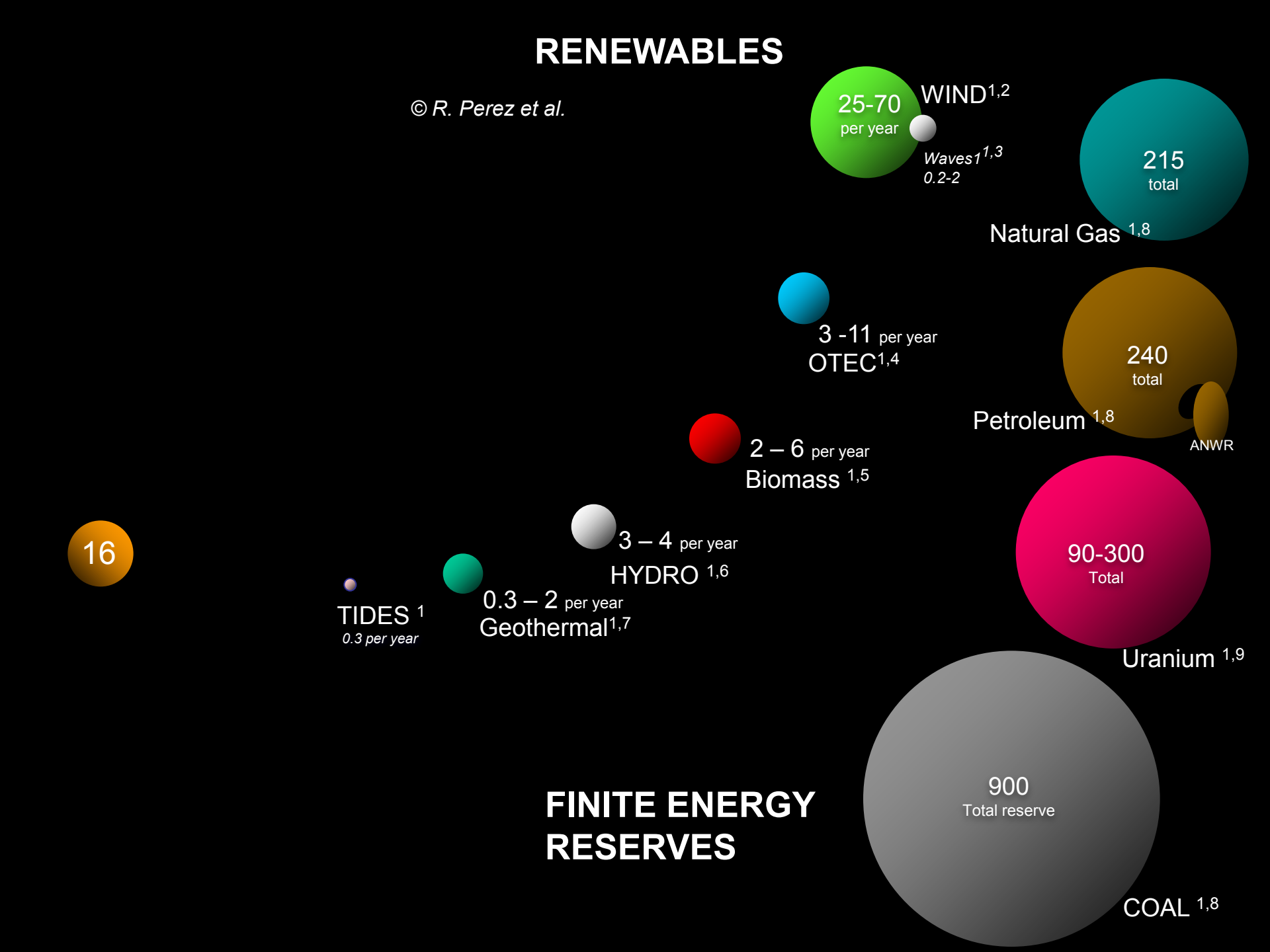
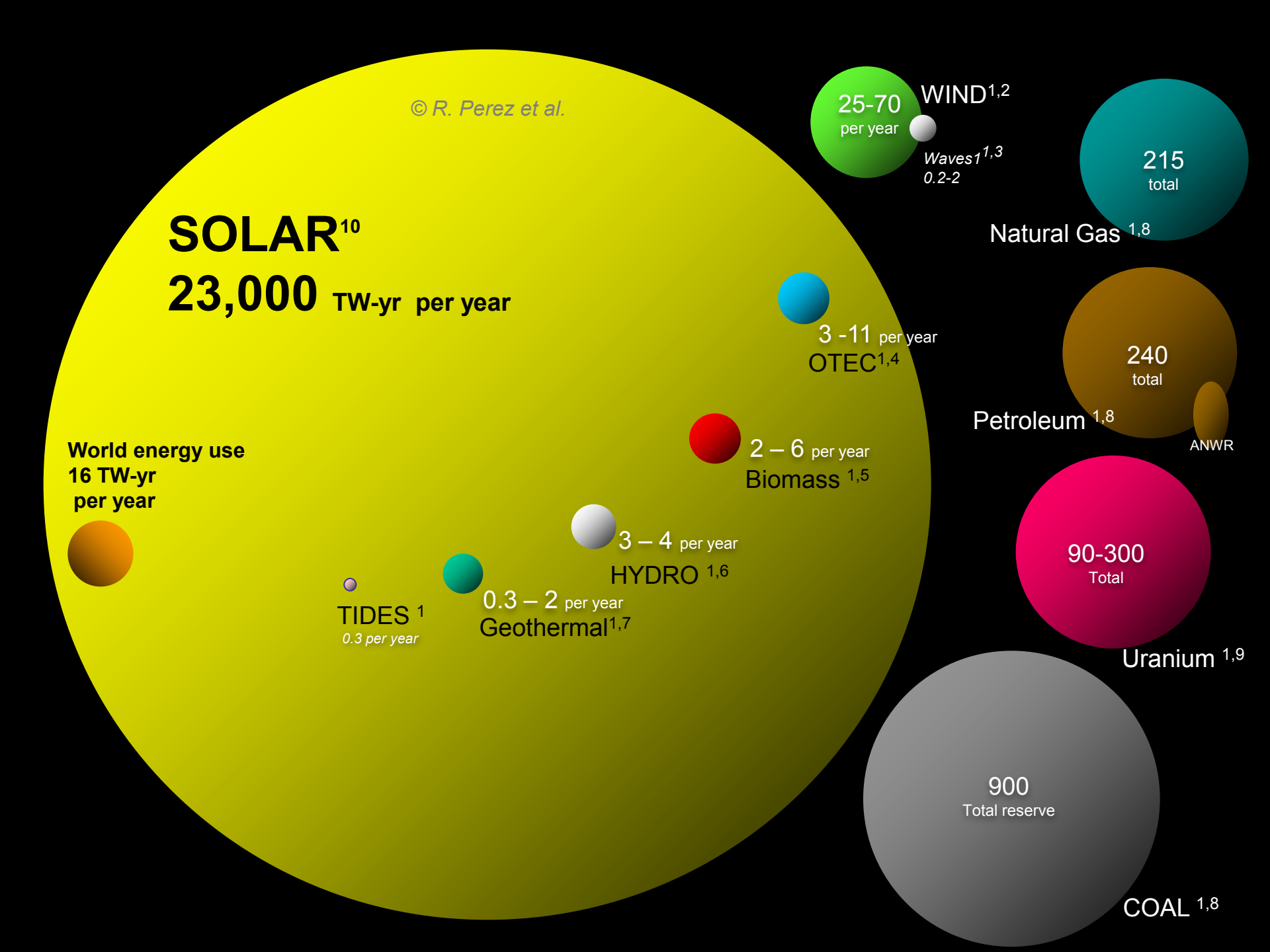
International PV Reliability Workshop II
Tempe, AZ USA
30 July 2009

World energy use 16 TW-yr per year



~ 475 exajoules
~ 460 Quads


RENEWABLES
© R. Perez et al.
25-70
per year
WIND[1,2]
Waves1[1,3]
0.2-2
215
total
Natural Gas [1,8]
3 -11 per year
OTEC[1,4]
240
total
Petroleum [1,8]
ANWR
2 – 6 per year
Biomass [1,5]
16
3 – 4 per year
HYDRO [1,6]
0.3 – 2 per year
Geothermal[1,7]
TIDES [1]
0.3 per year
90-300
Total
Uranium [1,9]
900
Total reserve
COAL [1,8]
FINITE ENERGY
RESERVES


© R. Perez et al.
SOLAR[10]
23,000 TW-yr per year
World energy use
16 TW-yr
per year
25-70
per year
WIND[1,2]
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Total reserve
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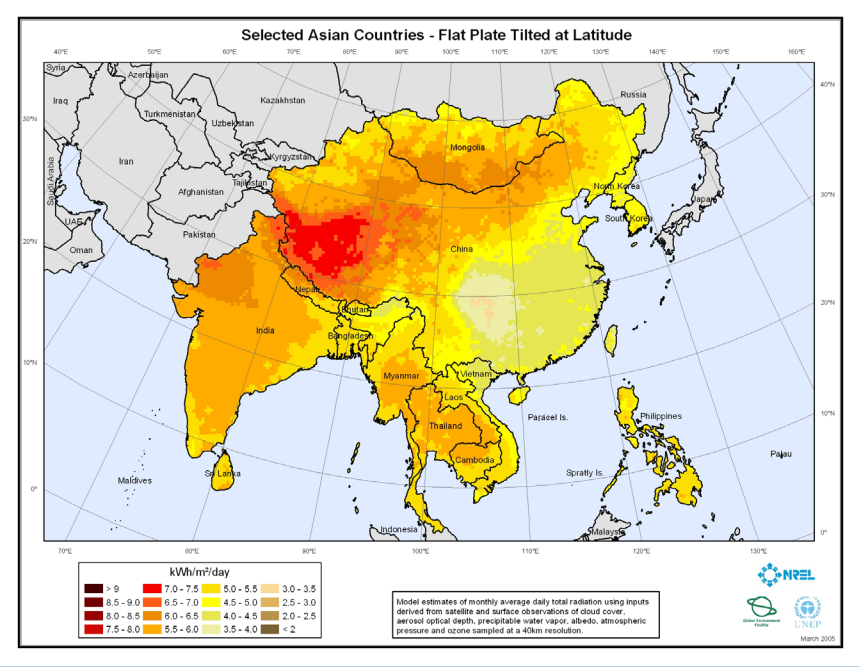
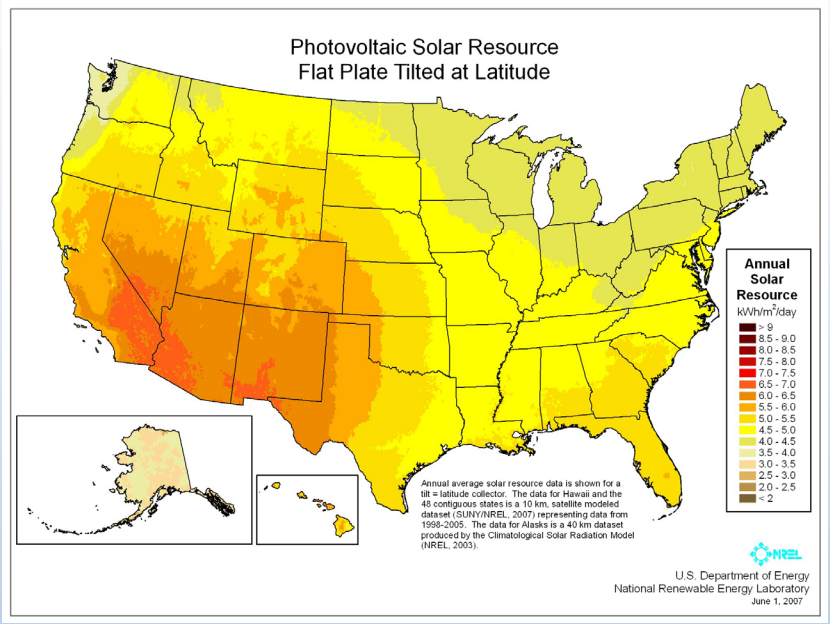
Globally, solar resources significantly outweigh energy use





Global electricity consumption, 2005: 17,300 TW-hr/yr
Source: USDOE/EIA, "International Energy Outlook 2008"

PV can generate this on ~95,000 km^2 of sunny land!

Accurate Knowledge of Solar Resource is Key to Understanding PV Performance

- Large-area modeling approaches
- On-site measurements and instrument metrology
- Forecasting solar resources
- Tools for accessing and analyzing resource data
- Resource variability

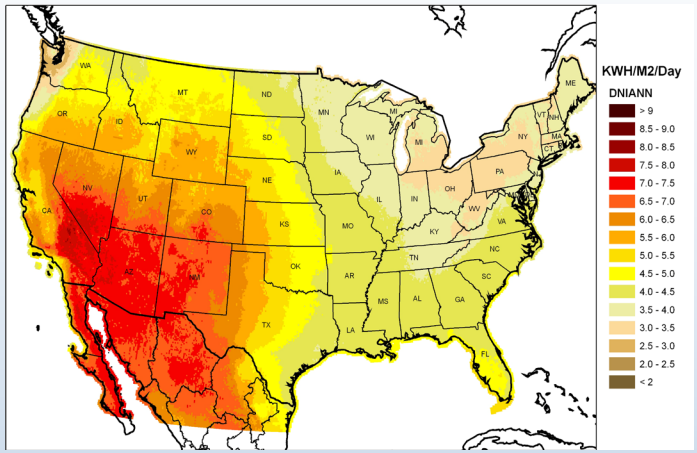
What is Resource Assessment?

A *characterization* of the magnitude and variability of the resource (Wind, Hydro, Ocean, Geothermal, Biomass, Solar) with regard to:

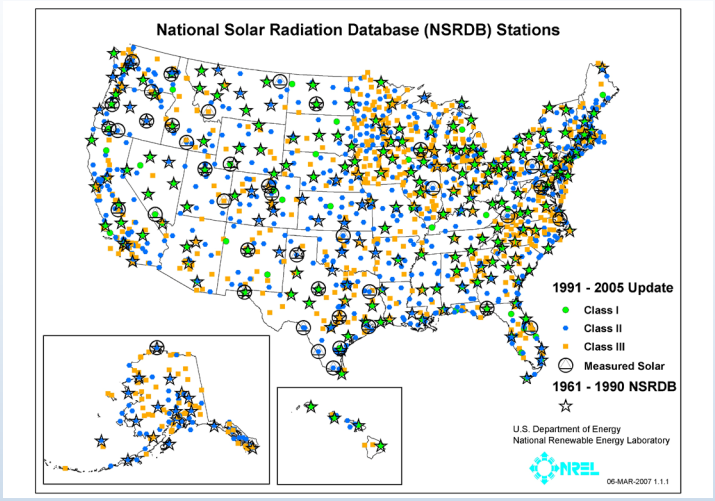
- Changes with **time**
  - short-term (minutes, hours)
  - long-term (seasons, years, decades)
- Changes with **location**

Resource Assessment underlies all analysis and technology decisions

National Solar Radiation Data Base – 1991-2005 Update

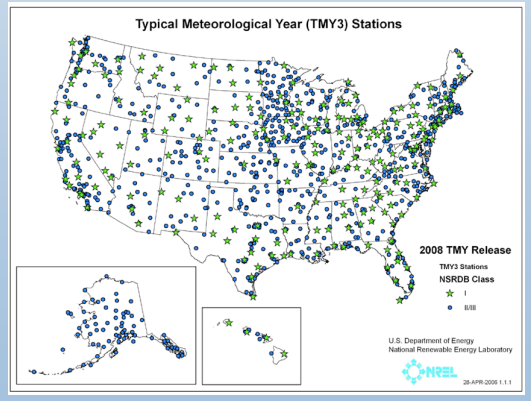


Gridded satellite data (SUNY/Albany)



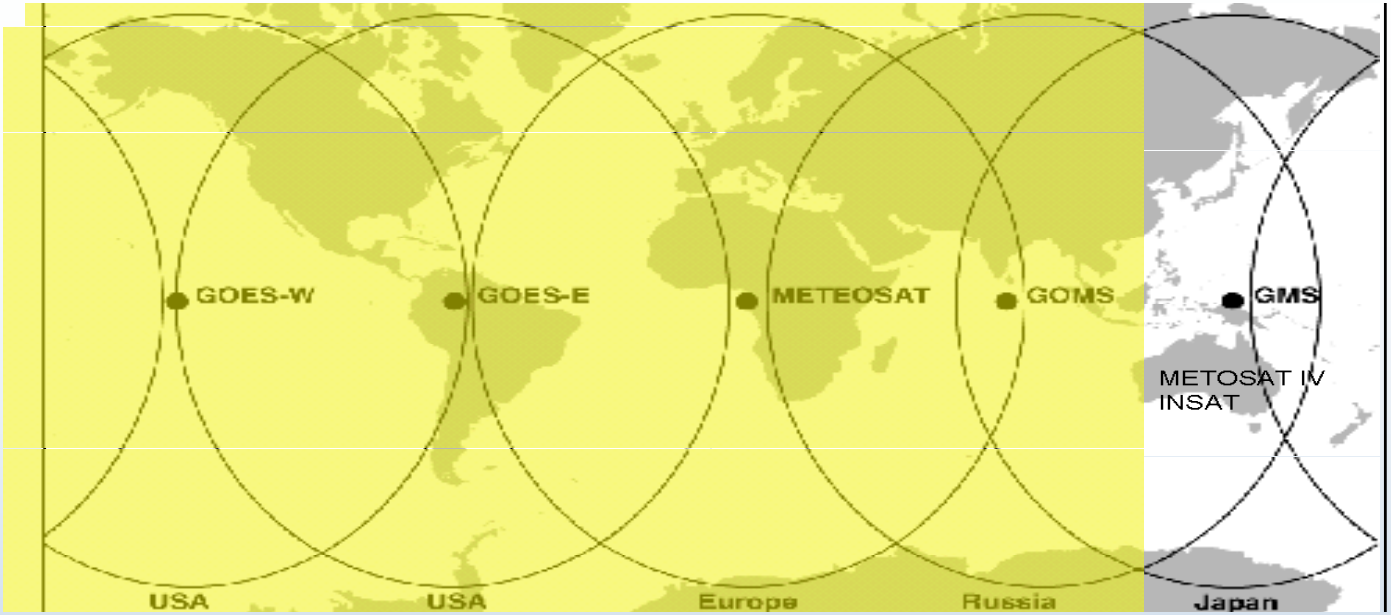
Surface stations

TMY3 Stations



Data Access

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	[At the time of this writing, this data set is planned for a late 2007 release] 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)

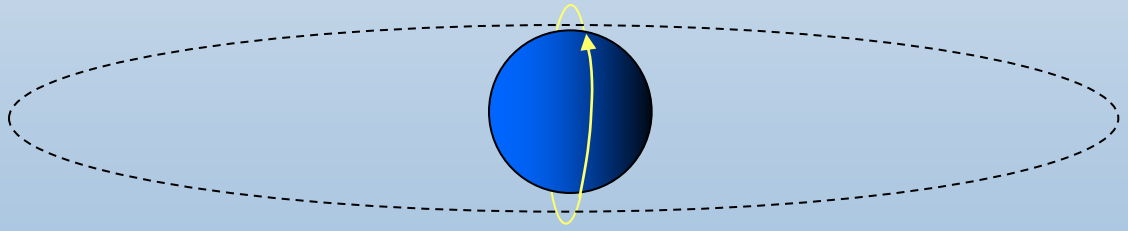


Geostationary Weather Satellites

- High resolution
(decaying at high latitudes)
- Continuous in time

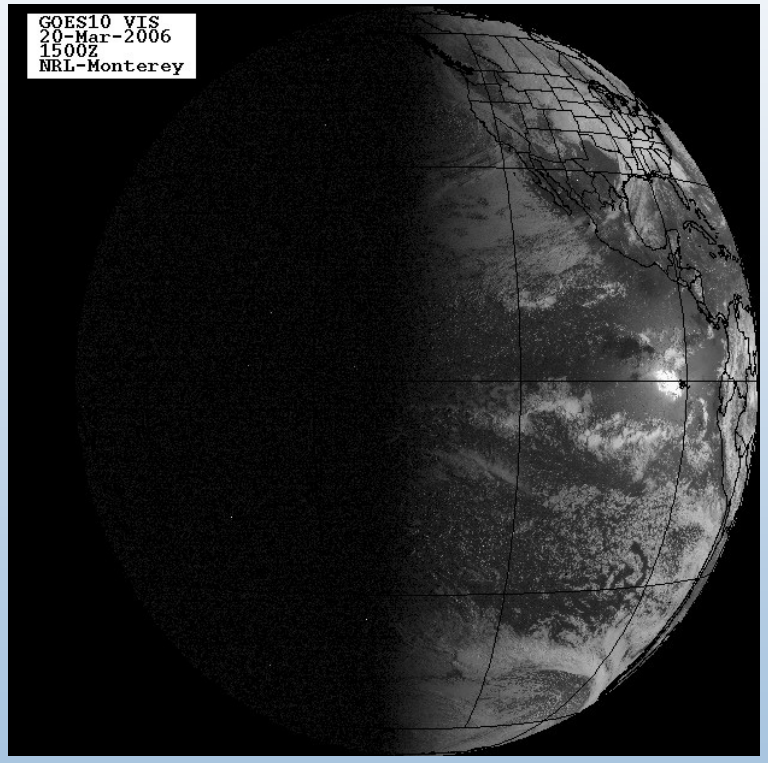
Polar Orbiters

- Very High resolution
at all latitudes
- Twice a day only

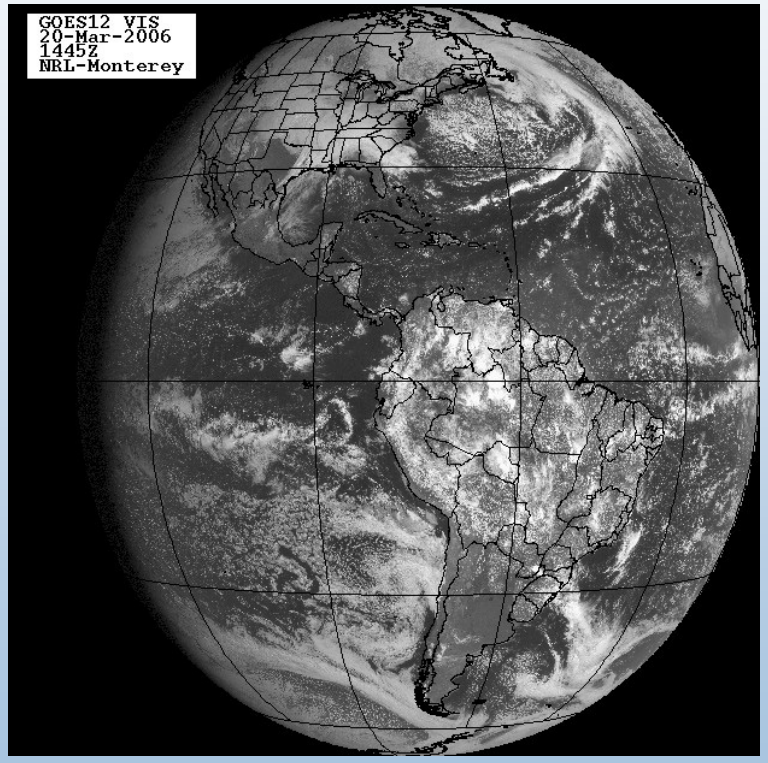


Source: Dr. Richard Perez, SUNY/Albany

High-Res (10-km) Method of Dr. Richard Perez State University of New York, Albany

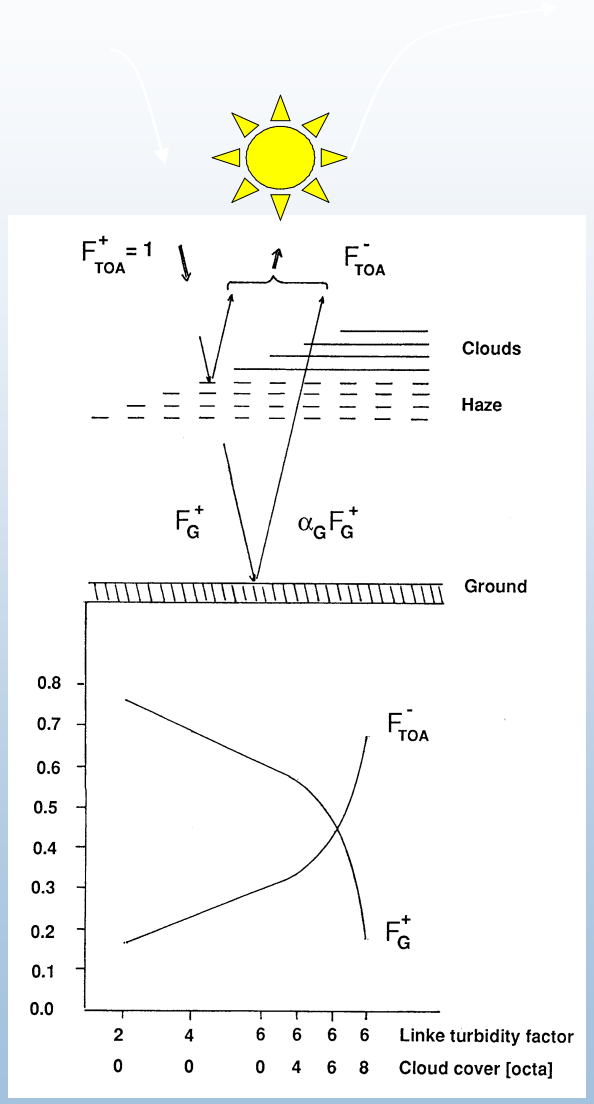


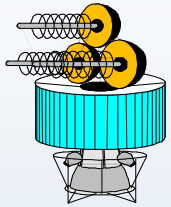
GOES-9/10

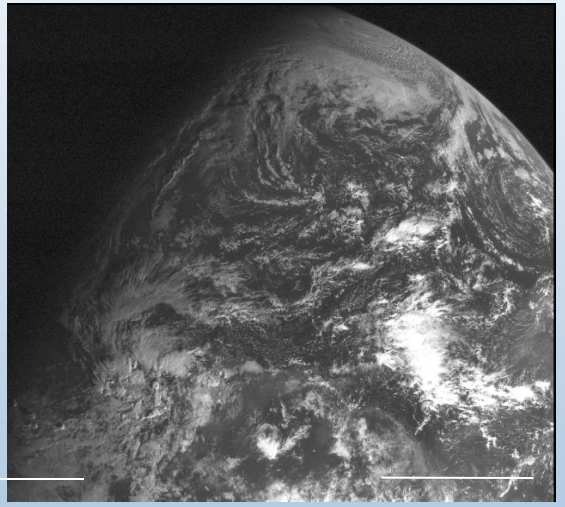


GOES-8/12

Basic Principle



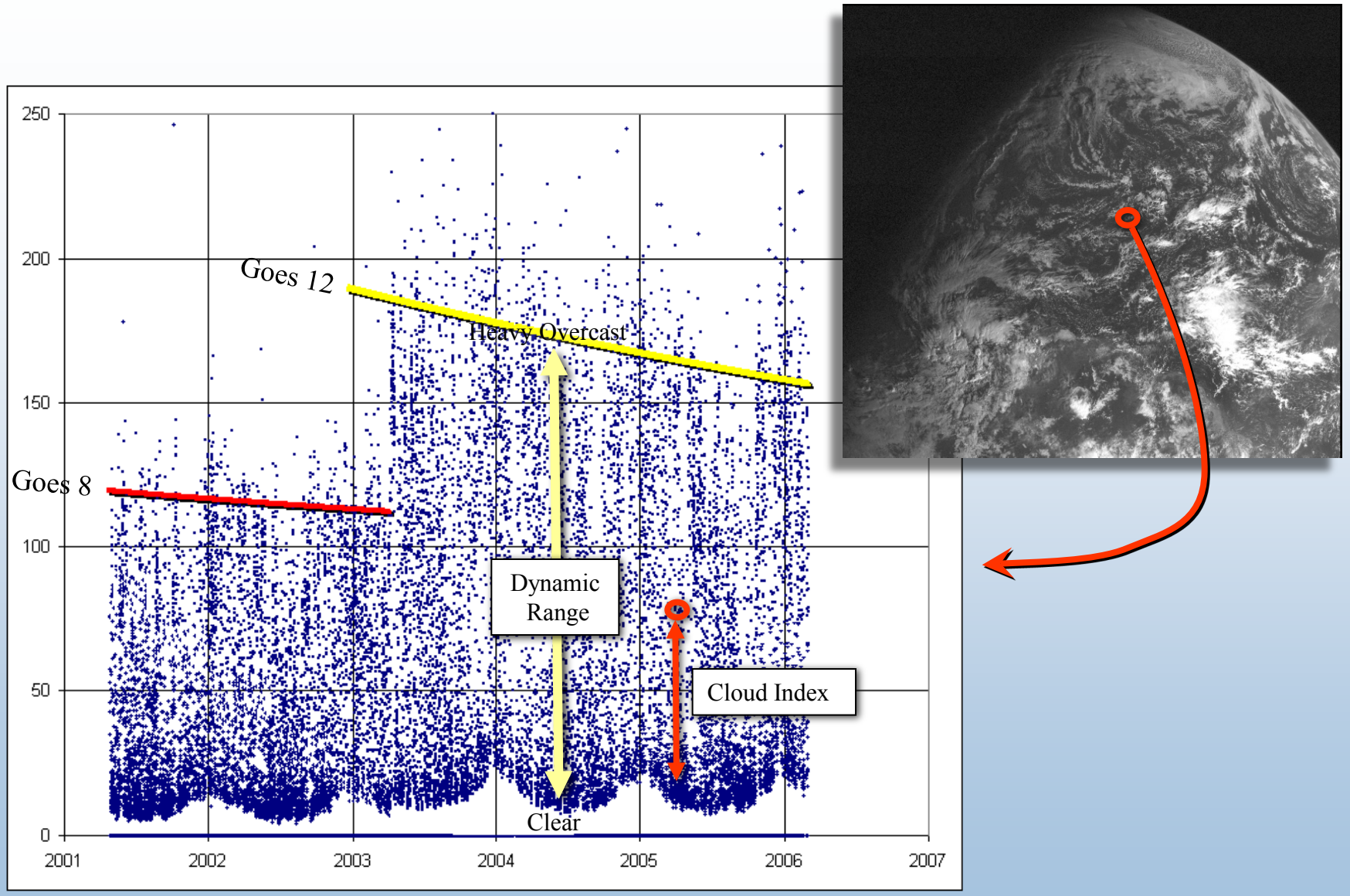




$$T = \frac{F^+_G}{F^+_{TOA}} = a - b\left(\frac{F^-_{TOA}}{F^+_{TOA}}\right)$$

Source: Dr. Richard Perez, SUNY/Albany

Richard Perez, et al.



Source: Dr. Richard Perez, SUNY/Albany

Operational Model

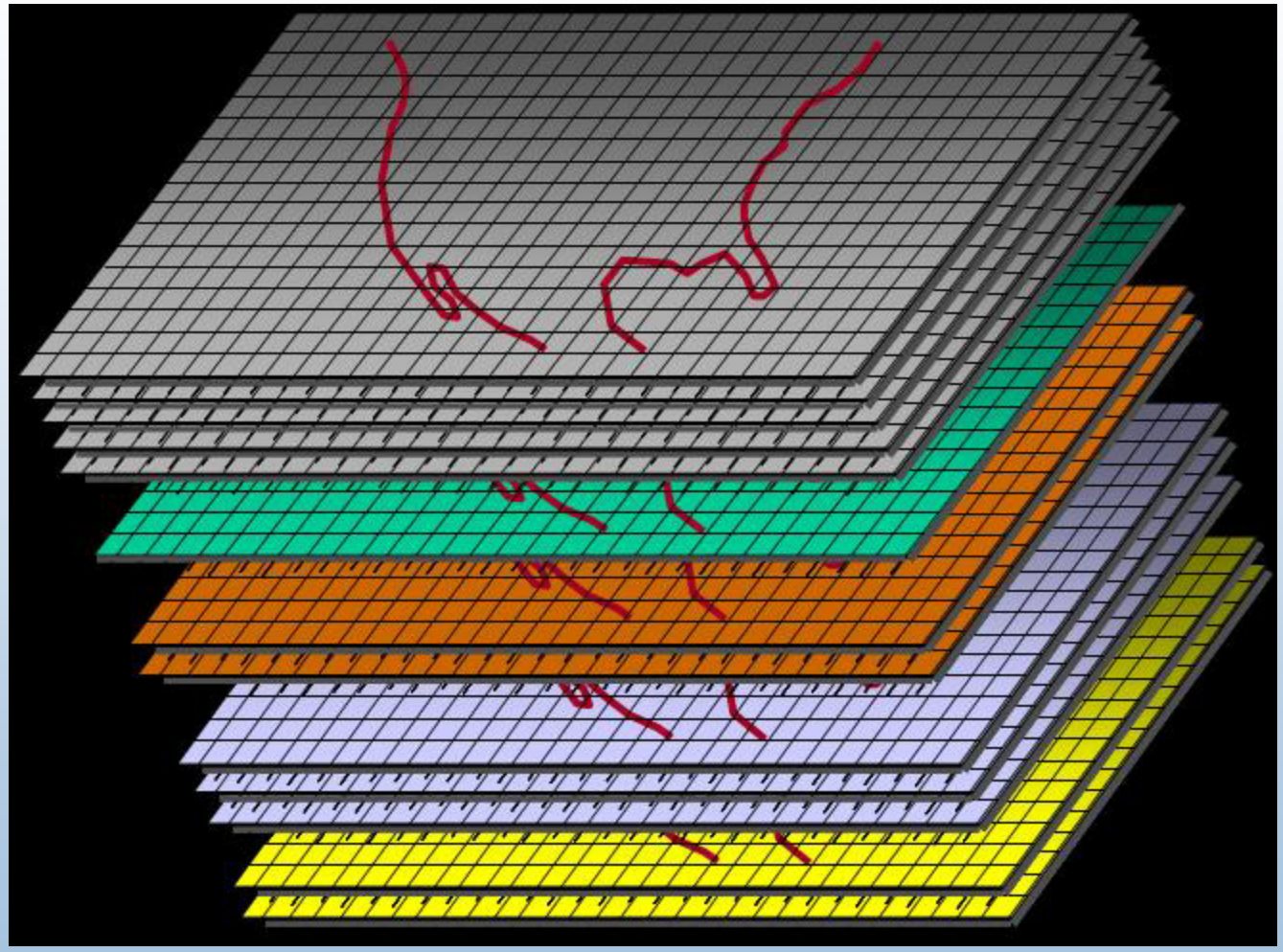
Hourly pixels

Terrain elevation

Turbidity, H_2O, O_3 (12 months)

Snow cover (daily)

Specular correction (month-hour)



Source: Dr. Richard Perez, SUNY/Albany

Composite of
GOES-E and GOES-W
images showing
coverage available
To NREL

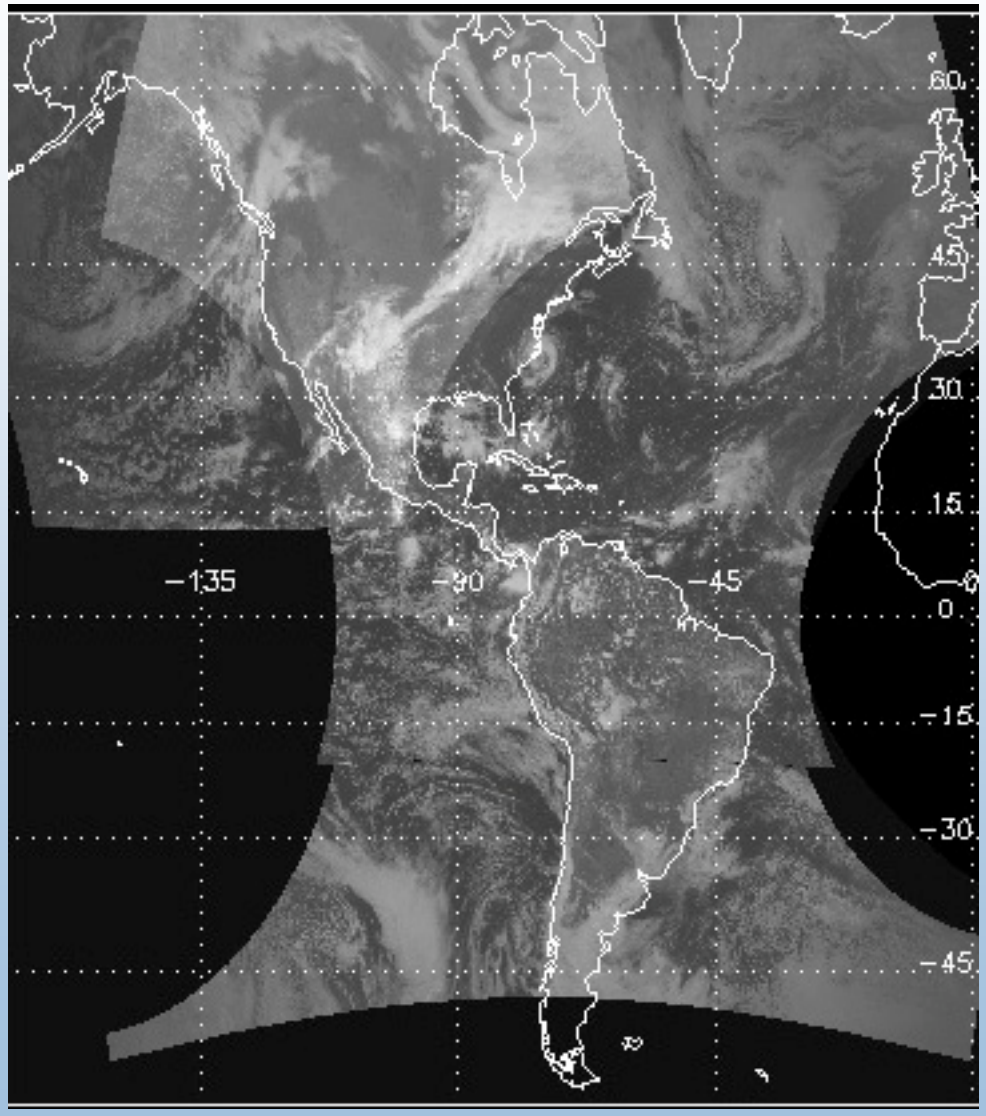


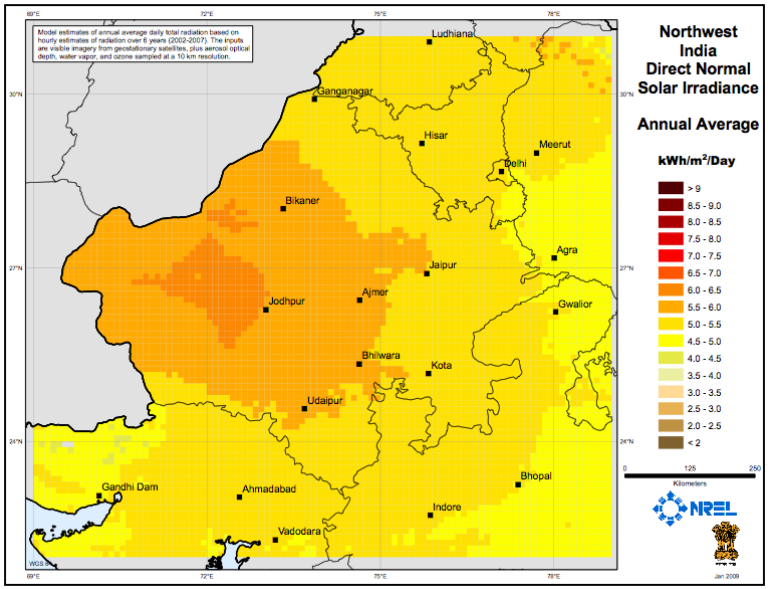
Image provided by Bernard
Walter Consulting

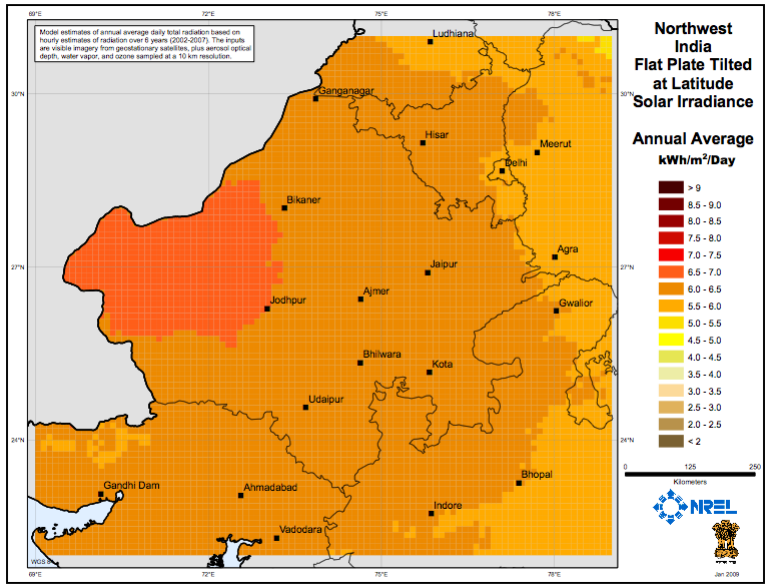
Solar Maps for Rajastan, India

- Satellite-based solar resource maps for NW India
- Developed by SUNY/Albany, USA
  - Meteosat weather satellite
  - GHI, DNI, Latitude Tilt
  - Geospatial Toolkit
  - Documentation
  - CD's available in March 2009
- Validation support provided by MNRE and IMD
- Training course with MNRE at NREL, September 2008
- Products available at:

- http://www.nrel.gov/applying_technologies/ra_india.html

- Maps are of significant value to industry and planners





Solar Radiation Research Lab

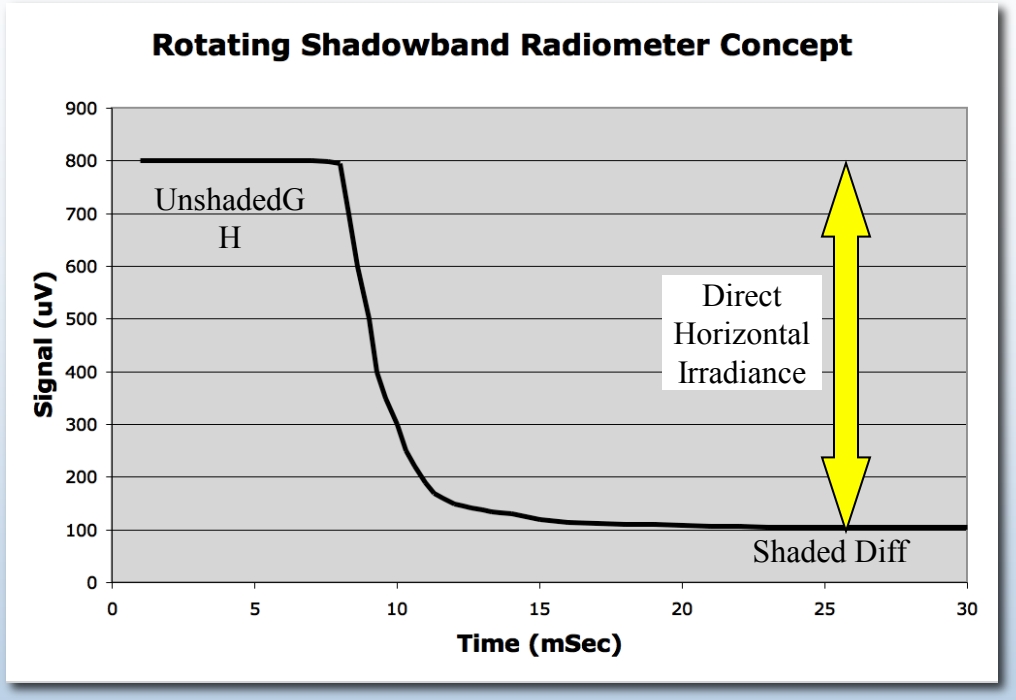
Solar Radiation Research Lab

- **Resource Measurements**
- **Instrument Calibrations**
- **Measurement Research &Training**

Outdoor Radiometer Calibrations

www.nrel.gov/solar_radiation

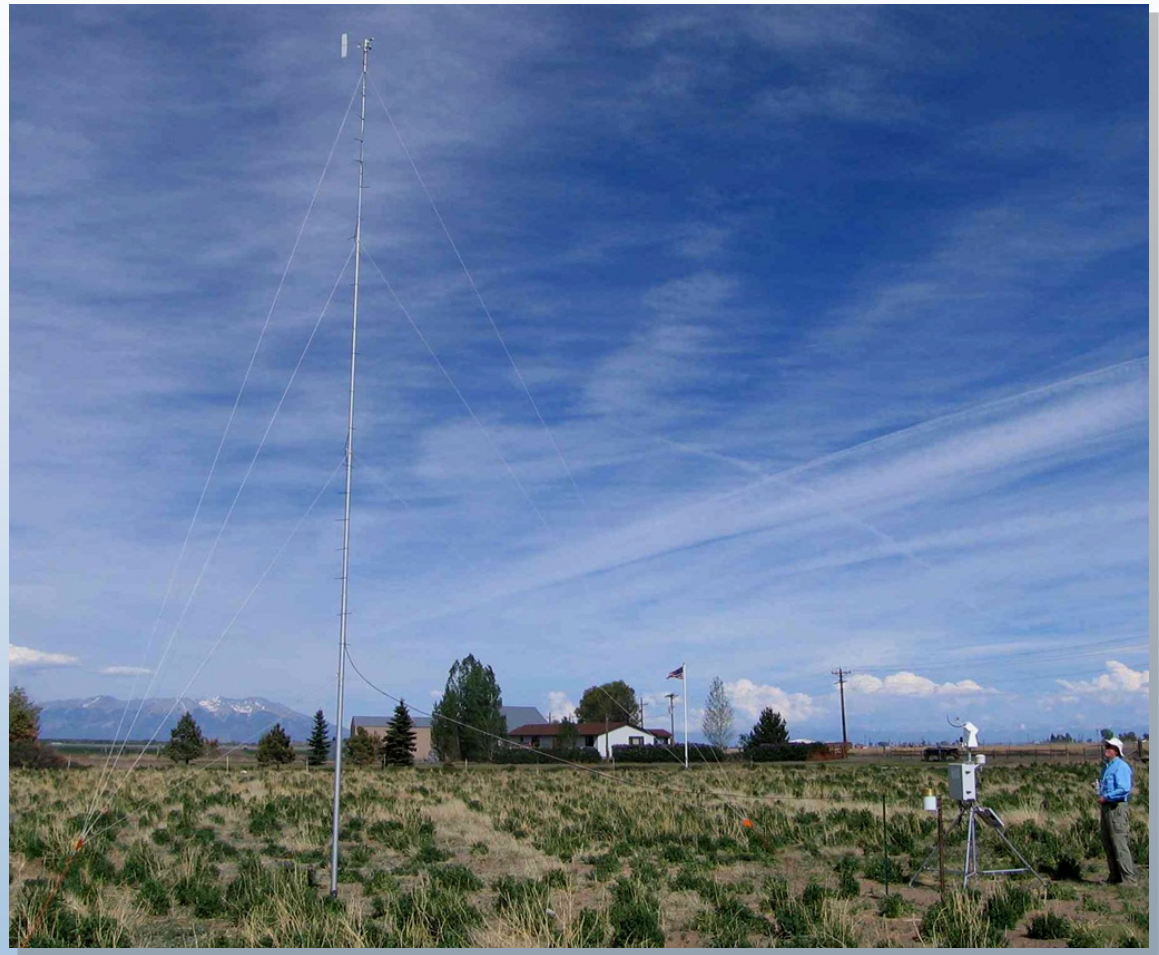
Measurement Research



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

Low-Cost Solar Monitoring

Rotating Shadowband Radiometers Provide DNI



RSR Station in Monte Vista, Colorado: A low-cost Weather Station
1-min Data Available from http://www.nrel.gov/midc/ss1

SOLRMAP (Solar Resource and Meteorological Assessment Project)

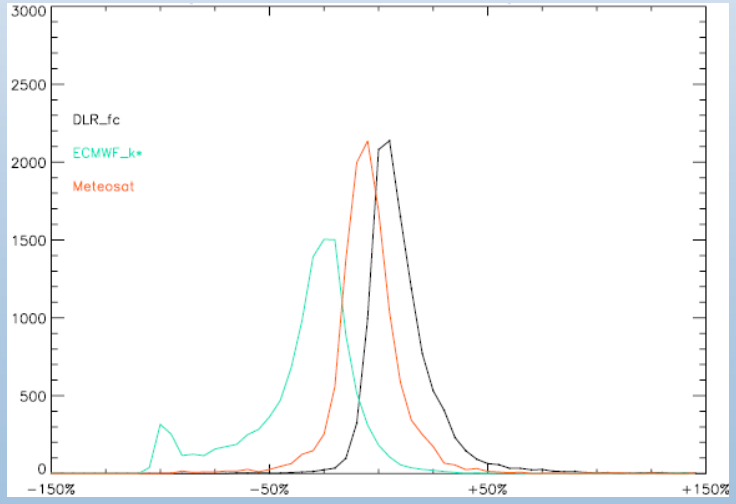
- High-Quality ground-based solar monitoring stations (12, or more if enhanced funding becomes available)
- Installed in cooperation with utilities and developers using NREL CRADAs through the CSP Program
- Supports development activities of stakeholders; provides NREL with critical research data sets
- Stations are operated by the utility; NREL supervises installation, oversees data quality assessment, makes data available via web (public or secured)
- Six stations currently installed in AZ, CO

Solar Resource Forecasting Requirements

- Daily plant operations (load following)
  - Hourly, 15-minute “look ahead”
  - 105-minute (CAISO, PERP)
- Storage/Dispatch Scheduling (day ahead, 2-3 days)
  - Determined by value of power (storage vs. grid)
- System maintenance (7-day)
- System performance
  - Seasonal (lower priority)
  - Outages
- RE Standards (RPS); long-term cash flow analyses
  - Annual predictions (based on energy)
  - Interannual variability and long-term trends
  - Banking of REC’s

Solar Forecasting in IEA/SHC Task 36: Solar Resource Knowledge Management

- Perez (U.S.), in collaboration with NASA
  - NDFD evaluations
  - GMAO (NASA) evaluations
  - Collaboration with Oldenberg
  - Cloud vector motion analysis (with NREL)
- DLR (Germany)
  - AFSOL Irradiance Forecasting System
  - Comparison of AFSOL with ECMWF
  - Comparisons with MM5

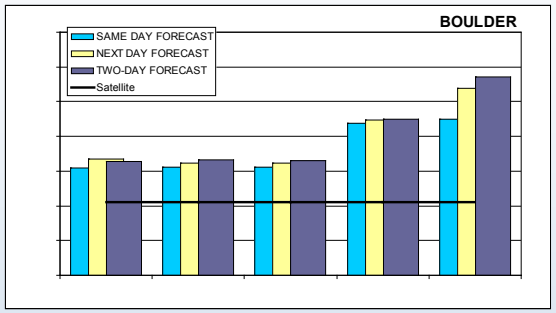


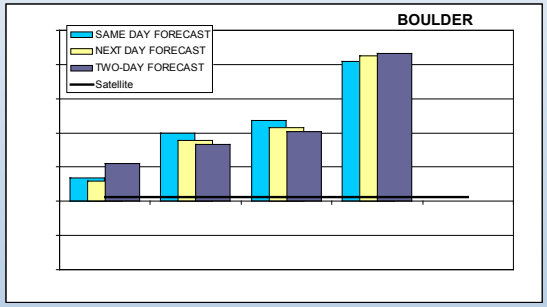
DNI Relative Difference, %

AFSOL direct
ECMWF direct
Meteosat-7 direct

Source: Breitkreuz, et. al

Performance of GHI forecasting schemes (top: RMSE, bottom: MBE)

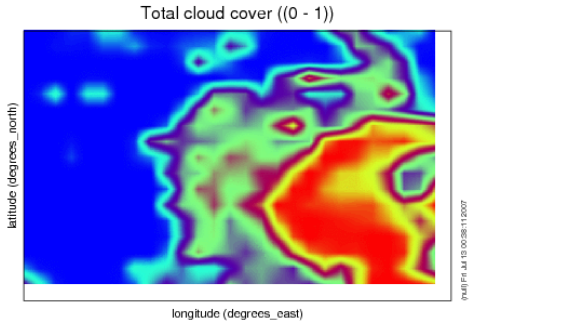


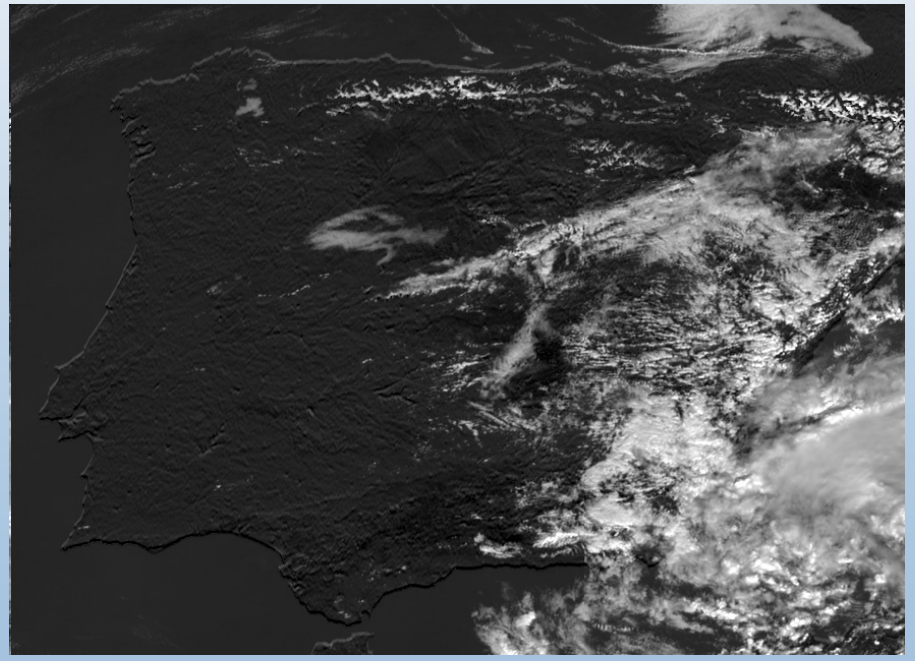


Source: Perez et. al

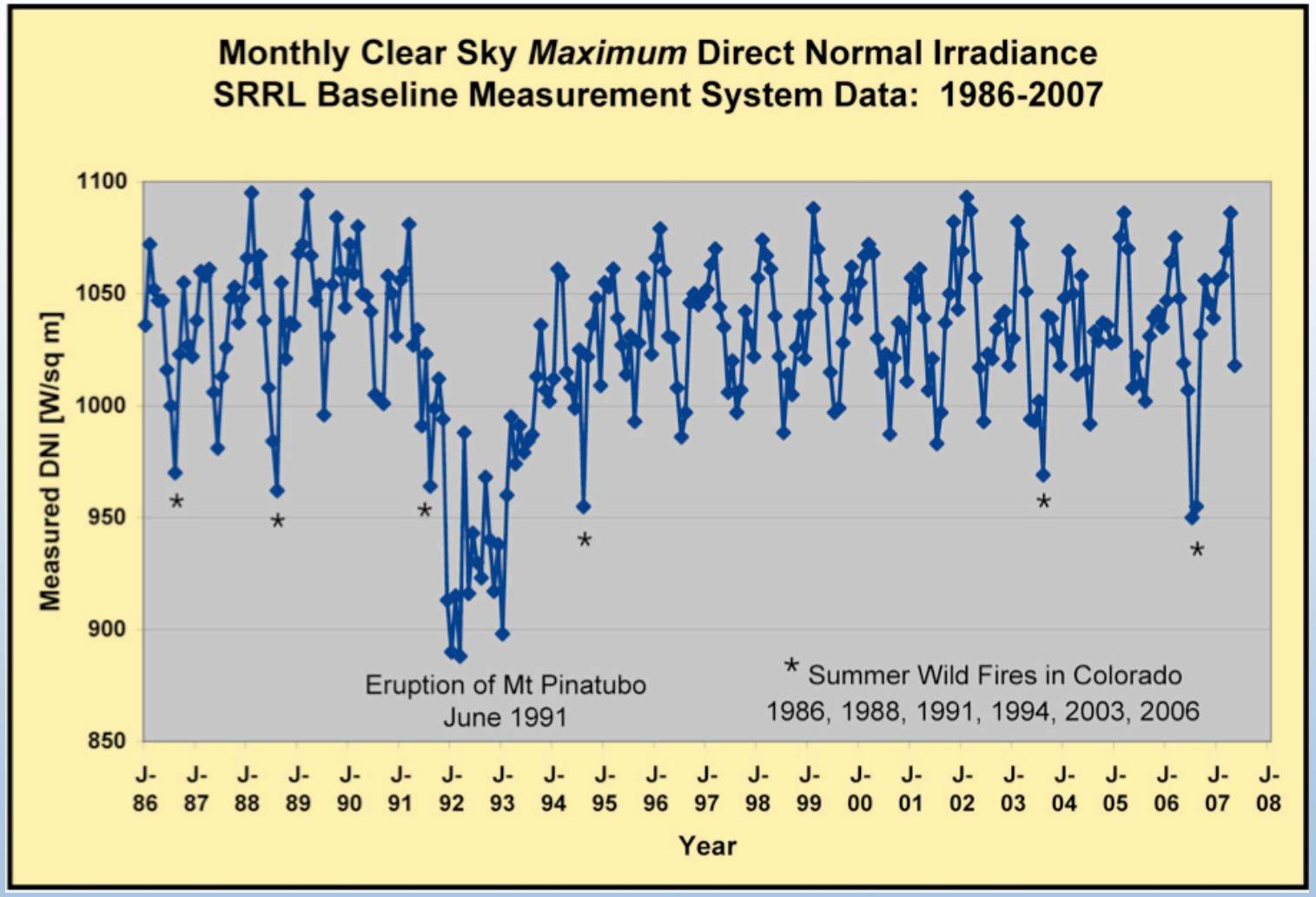
Solar Forecasting in IEA/SHC Task 36

- University of Oldenburg
  - Power prediction for PV systems
  - Benchmarking of forecast procedures
  - ECMWF Accuracies





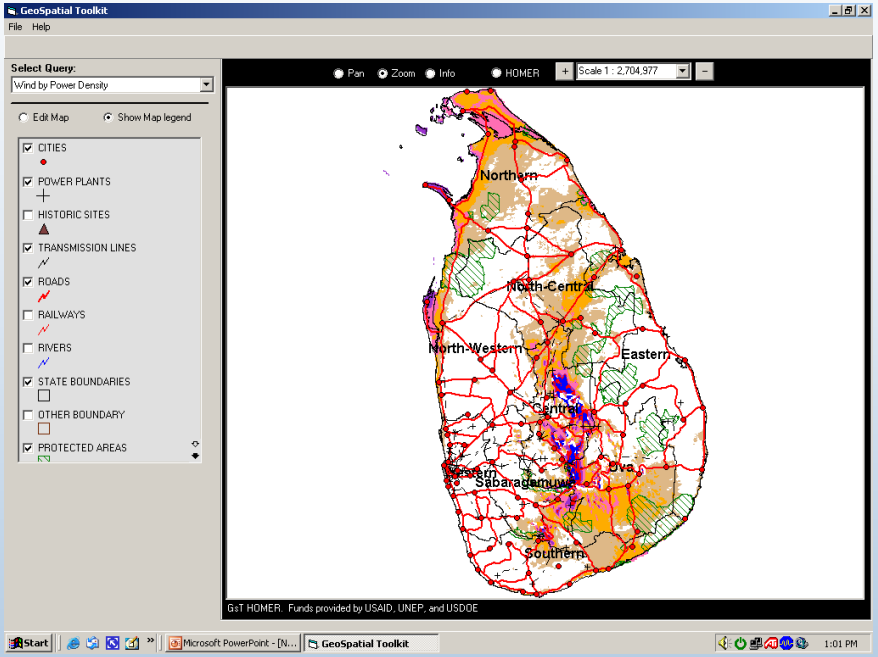
Interannual Variability



Source: Tom Stoffel, NREL

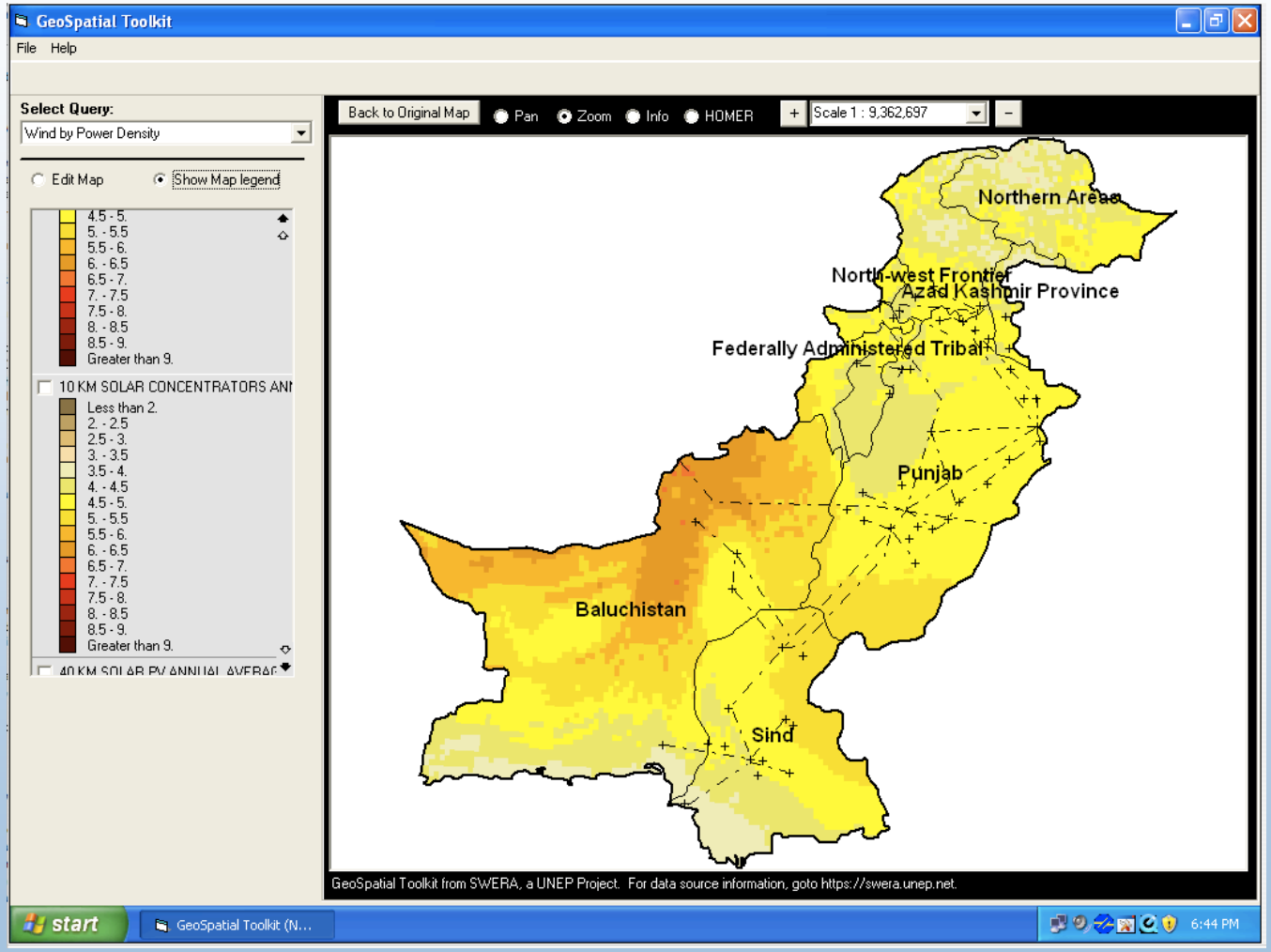
GeoSpatial Toolkits

- Allows users to overlay geospatial data sets
  - Resource data
  - Transmission lines
  - Transportation networks
  - Excluded land areas
  - Etc.
- Simple queries allow renewable potential analysis
  - How much high resource land areas within x km of transmission network?
  - How much resource available on non-excluded land?
  - Etc.



Example of geospatial toolkit interface for Sri Lanka wind resource map

Solar Example: Pakistan



Includes solar, wind, MSW, geothermal resources

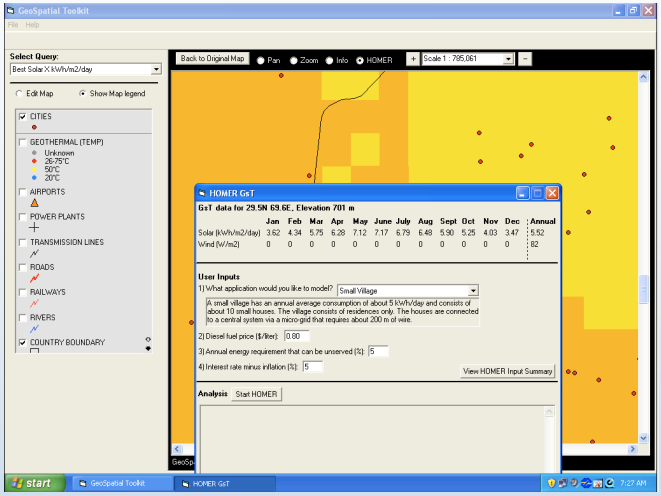
Geospatial data from partners, countries and global data sets (elevation, land use, transmission lines, roads and railroads, cities, power stations)

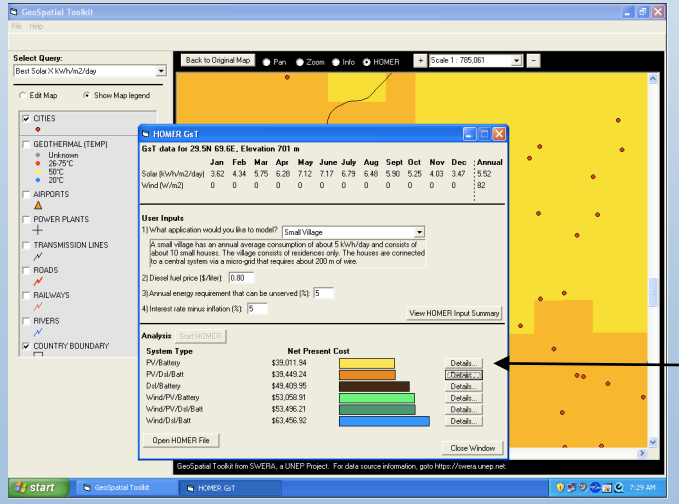
Menu-driven, parameterized queries

Displays multiple layers in geographic format

Pakistan GsT Example: Link to HOMER

- HOMER is NREL's Micropower optimization model
- Provides least cost hybrid system alternatives
- Resource data is passed from the GsT to HOMER
- Includes applications e.g "small village" with logical assumptions and defaults
- Analyzes thousands of system options
- Results ranked by least cost
- User can modify assumptions and re-run





Click on "Details"

Issues for PV Reliability

- Bankable data sets
- Short-term variability associated with clouds (ramp rates)
- Impact of clouds on distributed systems
- Solar resource forecasting
- Best practices for use of solar data
- Benchmarking of different solar data sets and forecasting schemes

Thank You!