Improving Economics of Solar Power Through Resource Analysis, Forecasting, and Dynamic System Modeling

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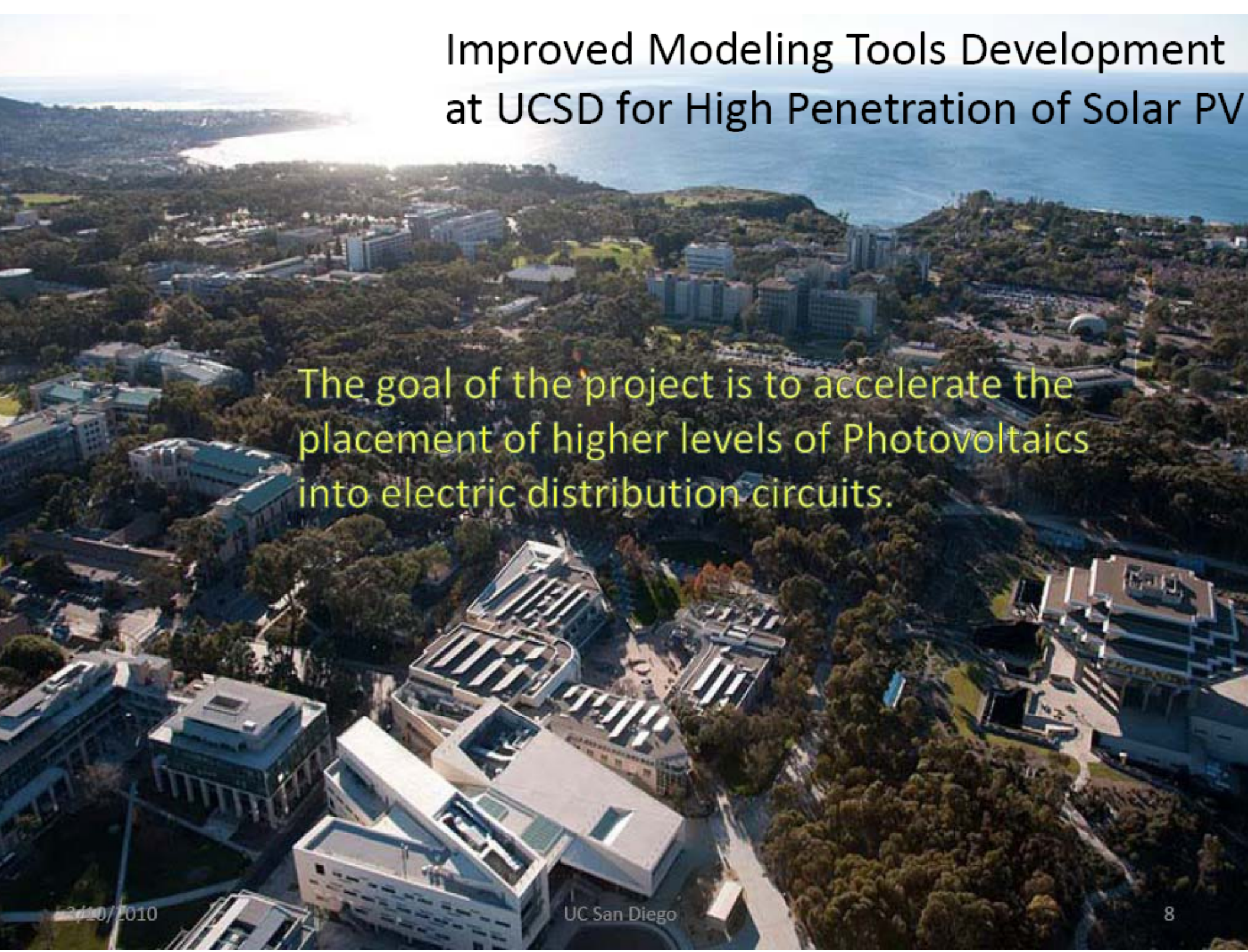
CAISO: Jim Blatchford

Improved Modeling Tools Development at UCSD for High Penetration of Solar PV



The goal of the project is to accelerate the placement of higher levels of Photovoltaics into electric distribution circuits.

Overview

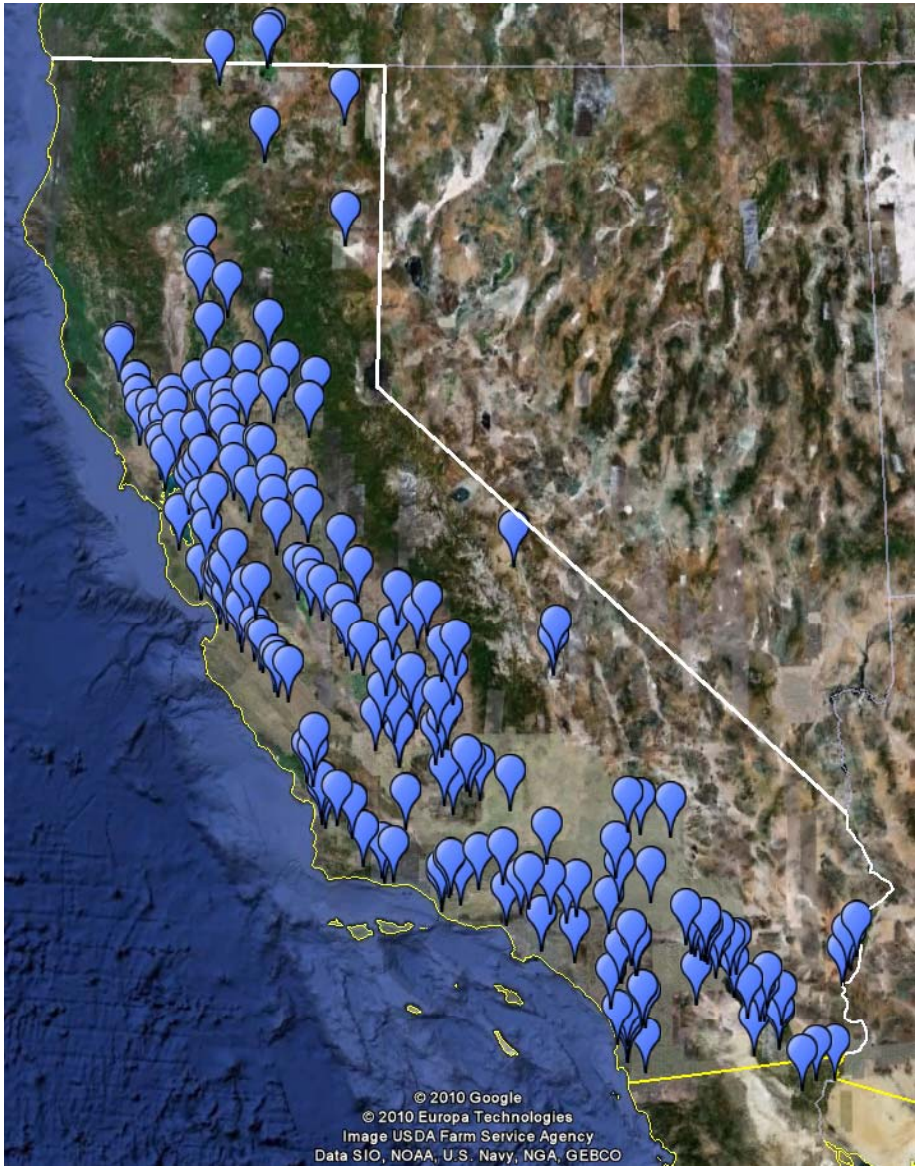
- Prior work
  - Solar Resource Mapping
  - UC San Diego microgrid
  - Solar resource and PV output monitoring
- Improve Solar Resource Models and PV performance modeling
- Solar Forecasting
- Integration with utility models

Prior Work

- Testing National Solar Radiation Database for California
- Online solar maps in Google Earth
-High frequency ramp rates
- UCSD Microgrid

CIMIS Network

- California Irrigation and Management Information System (CIMIS), California Department of Water Resources (DWR)
- Statewide coordinated network of weather stations designed for ET measurements
- Quality controlled global horizontal irradiance data, sensors recalibrated annually
- Data from 26 CIMIS stations was used to validate NSRDB-SUNY dataset

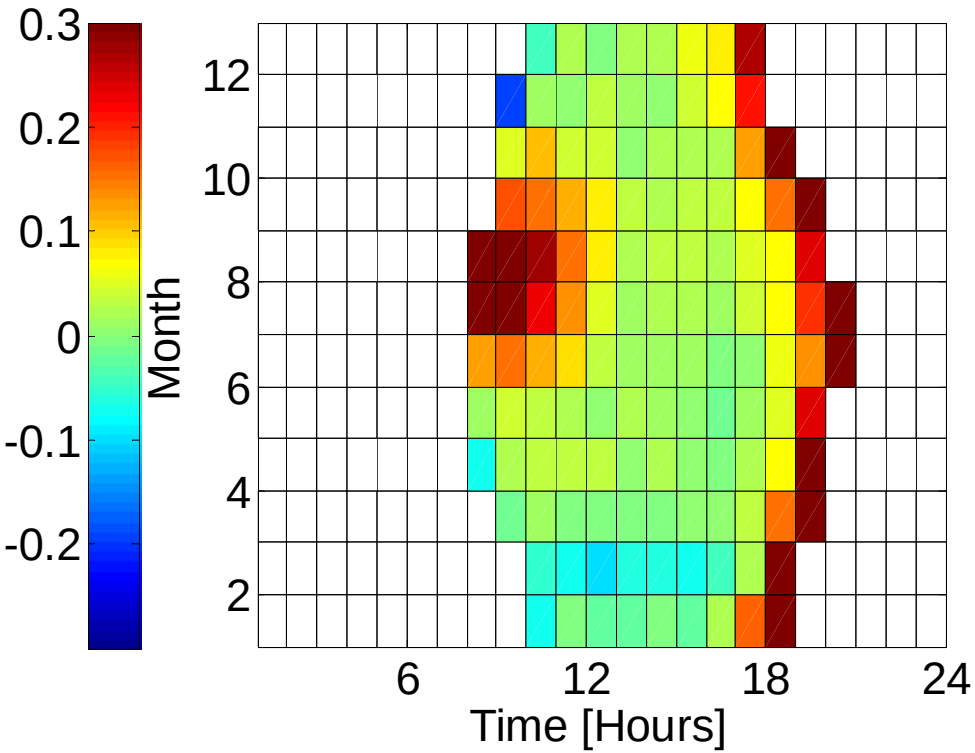


Station Map courtesy of Anders Notrott. © 2010 Google

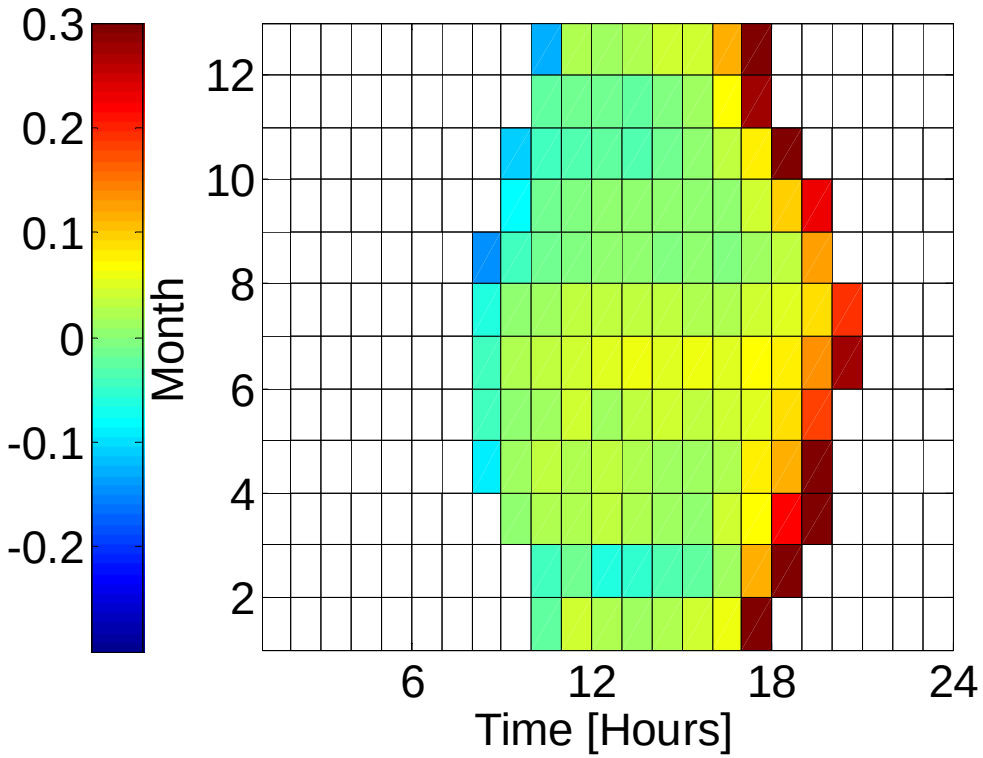
NSRDB Overpredicts GHI near Coast

MBE between SUNY model and CIMIS GHI measurements

CIMIS #111 – Green Valley, Santa Cruz Co.
7.5 km from the coast



CIMIS #008 – Gerber, Tehama Co.
93.0 km from the coast



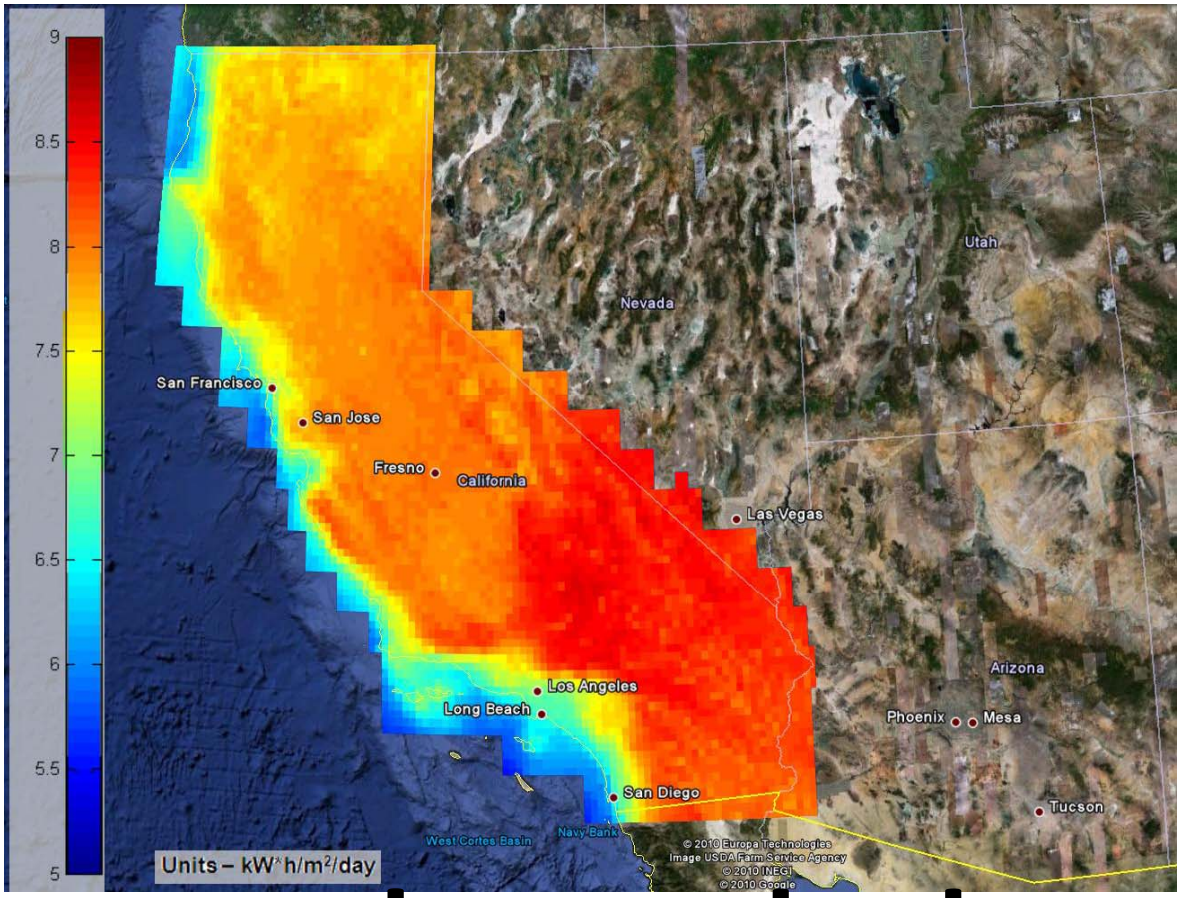
(SUNY – CIMIS) / CIMIS

Units →[%·10^{-2}]

Nottrott & Kleissl (2010)

Corrected Solar Maps for CA

- Applied correction algorithm to generate a corrected GHI data set for California
- Visualized using Google Earth (free software)
- GIS tool facilitates accurate solar resource assessment and economic analysis



Corrected NSRDB SUNY mean irradiation during June for California. © Google, 2010

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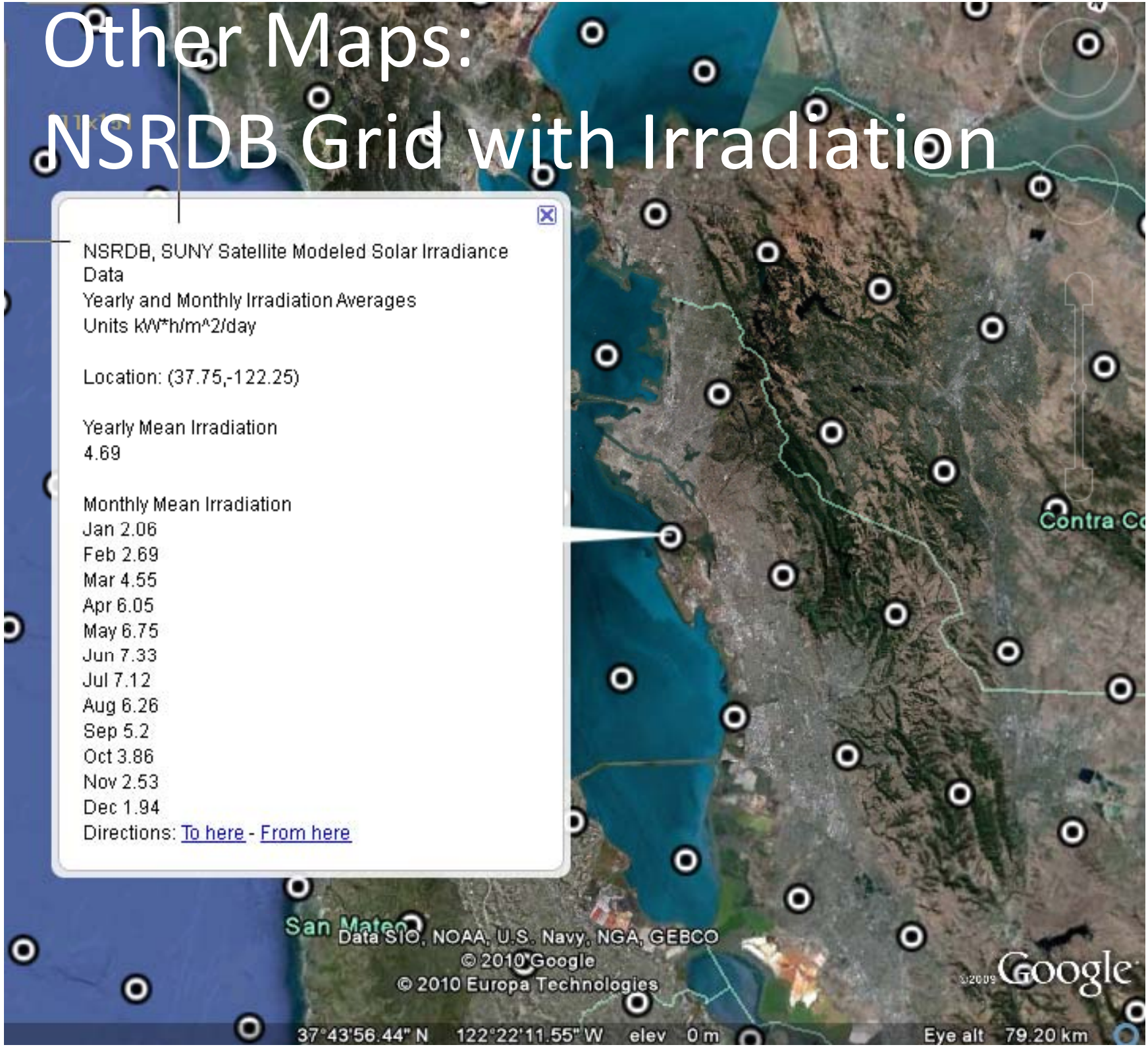
Other Maps: NSRDB Grid with Irradiation



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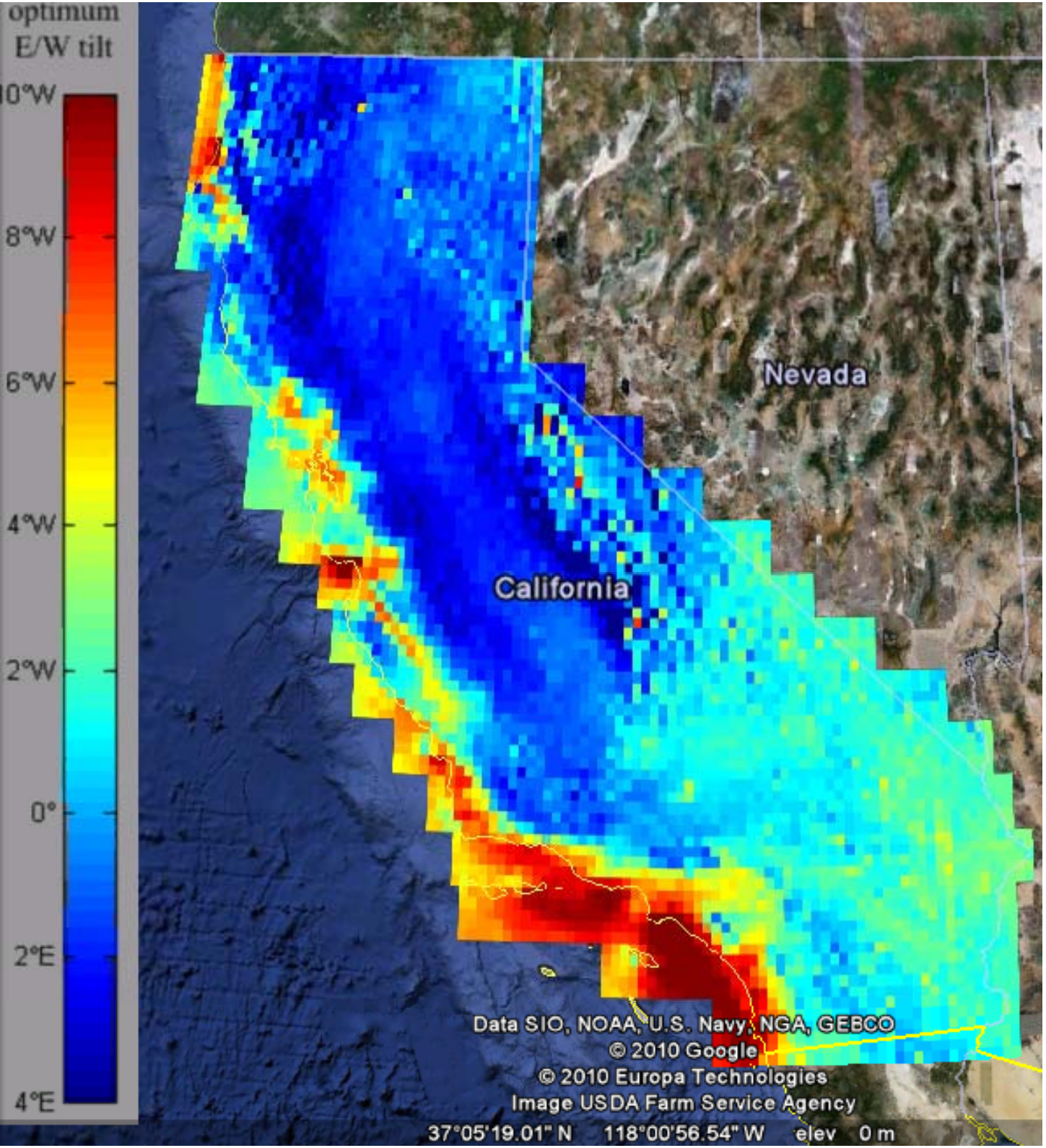


Optimum azimuth angles for PV

© Google, 2010

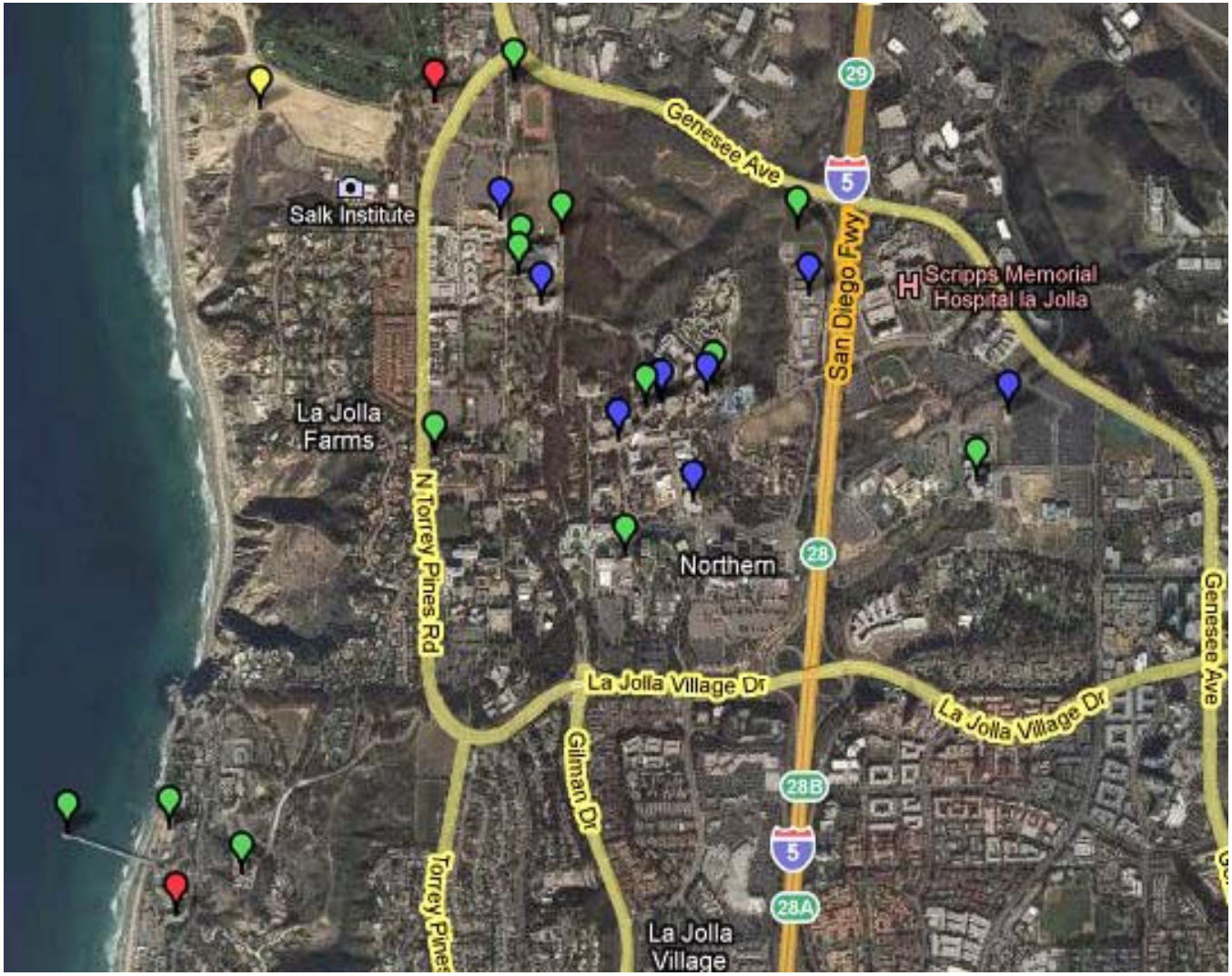
UCSD Microgrid

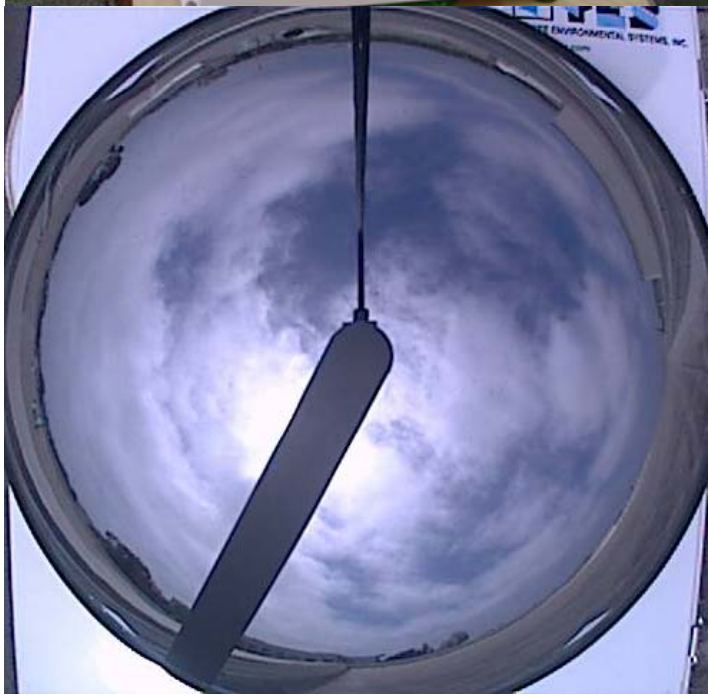
- Generation:
  - 42 MW peak load
  - 30 MW NG CCHP plant generates 80% of annual demand
  - 1.2 MW of PV
  - 40,000 ton hr thermal energy storage
- Distribution:
  - Owns 69 kV substation
  - 96x 12kV underground feeder circuits 4x 12kV distribution substations
  - Meters 50,000 energy data points
- Committed to install:
  - EDSA Microcorp. / Viridity Scheduler / Optimizer
  - 2.8 MW fuel cell using methane gas
  - 1.8 MW / 11.2 MWh electric energy storage
  - 1.9 MW expansion of PV with CREBs financing
  - 2.0 MW / 8 MWh of PV integrated storage with CA SGIP incentives
  - $250M/yr building expansion and $72M, 3 Yr EE program

Legacy Infrastructure

Planned Expansions

UCSD: Dense metering



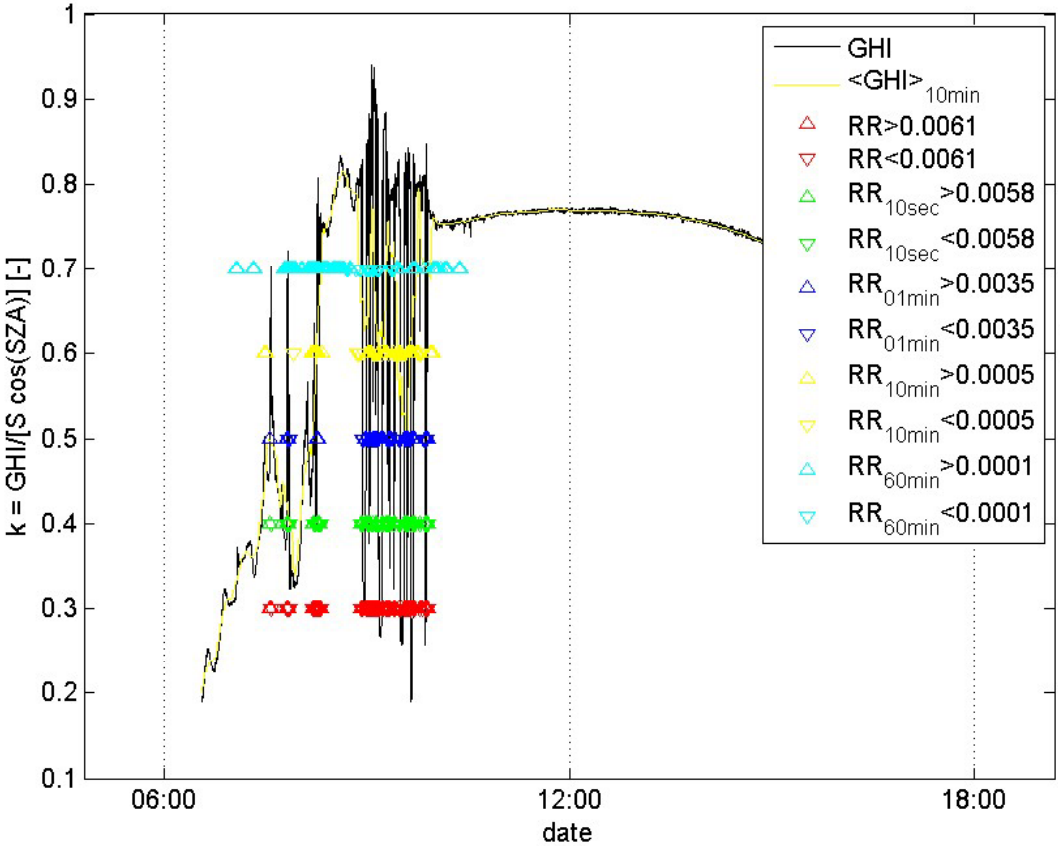


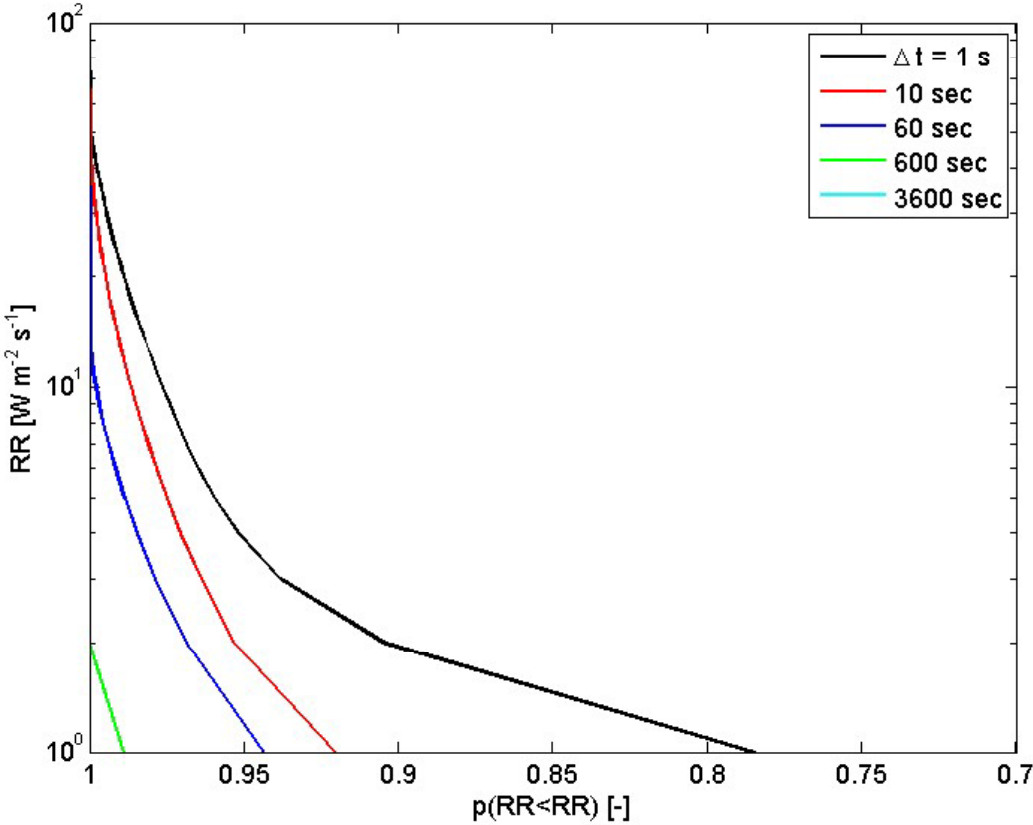
9 PV sites, 16 weather stations, 1 sky imager and ceilometer

© Google, 2010

Ramp Rates from 1 sec Irradiance

- Identifying high ramp rate events over 1 sec – 1 h
- Computing 'load duration curves'





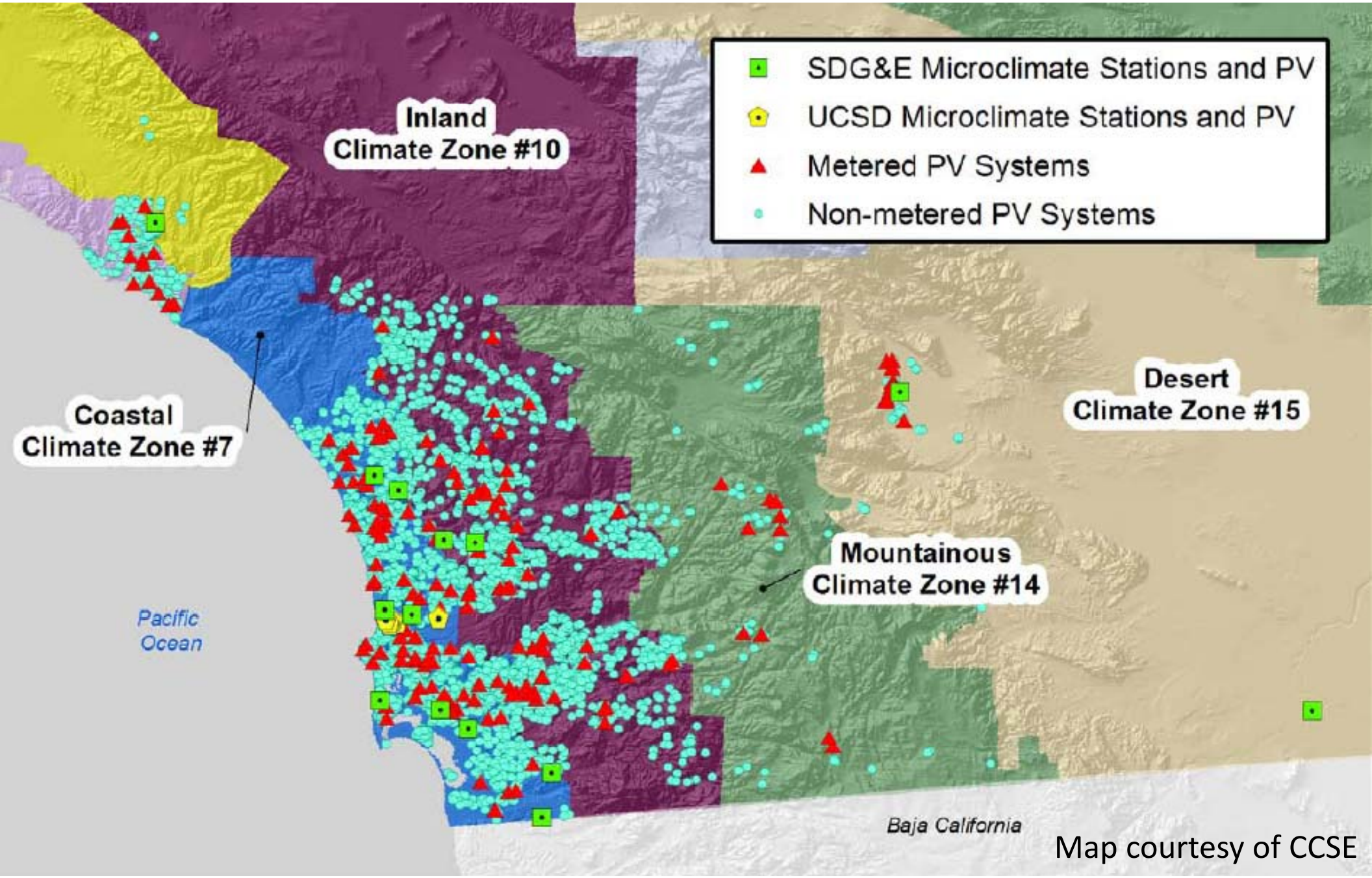
CSI RD&D
Solar Resources and PV Modeling

-Metered PV systems as pseudo-radiometers

- PV performance model

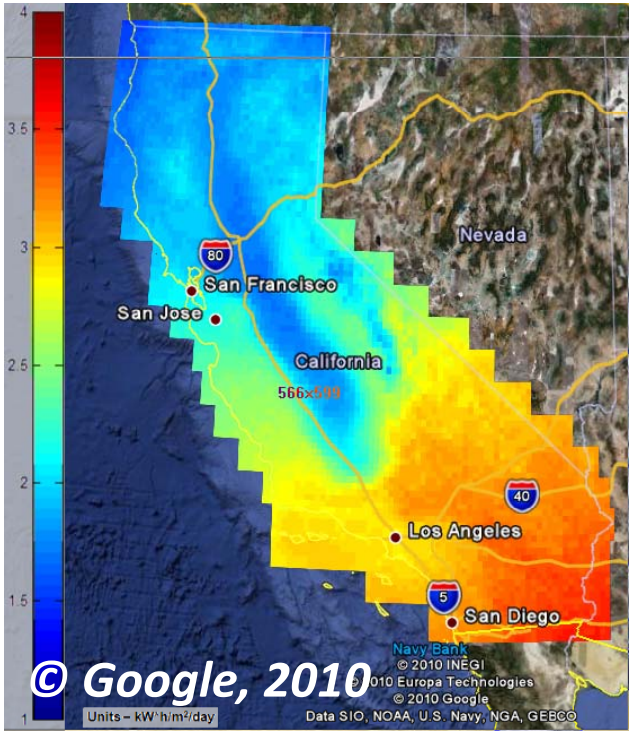
- Improve accuracy, temporal, and spatial resolution of NSRDB

PV Systems in San Diego County

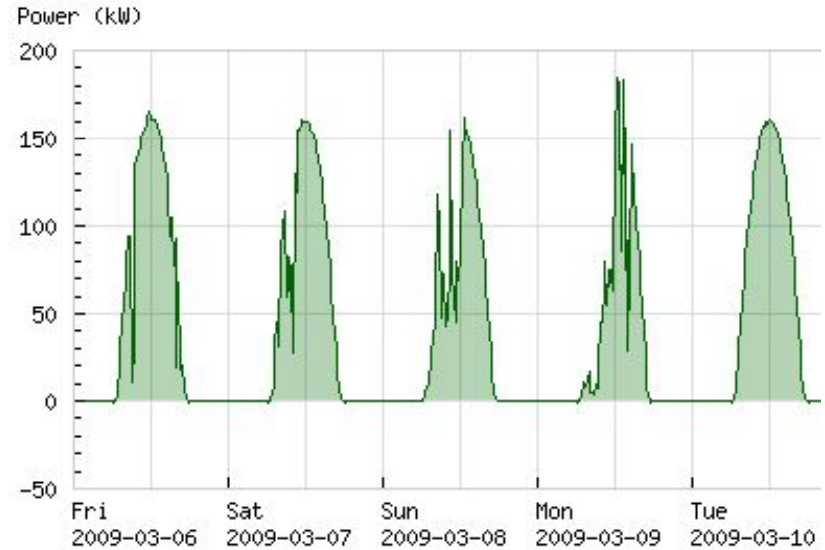


Map courtesy of CCSE

Working the Magic



15 minute PV AC output data



azimuth, tilt, rated efficiency, shading, location

DJI

GHI, DNI

clearness index

PV temperature

tilt

azimuth

Improve NSRDB

- Accuracy (similar to CIMIS analysis, now with 1000s of systems)
- Spatial scale: detect fine spatial gradients in areas of high PV penetration to get 5 km resolution
- Temporal scale:
  - 1 hour → 15 minutes using PV data
  - Given clearness index, develop probabilistic timeseries down to 5 minutes. Calibrate model using UCSD 1 second data
- Publish in Google Earth, other formats on demand

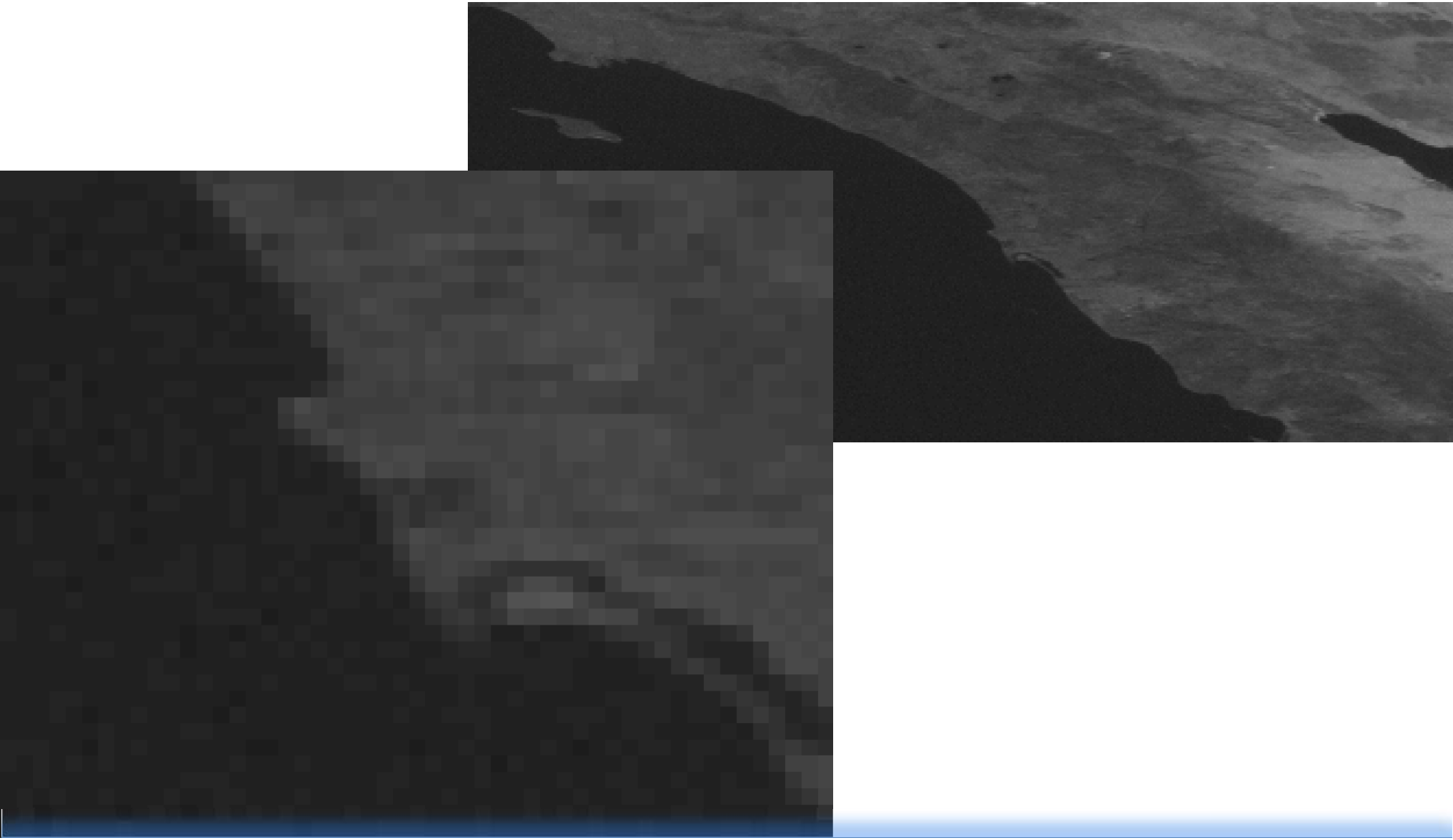
Conduct Dynamic System Modeling

- Examine instabilities associated with voltage sags, upset conditions leading to islanding, and reverse power flows on the distribution system

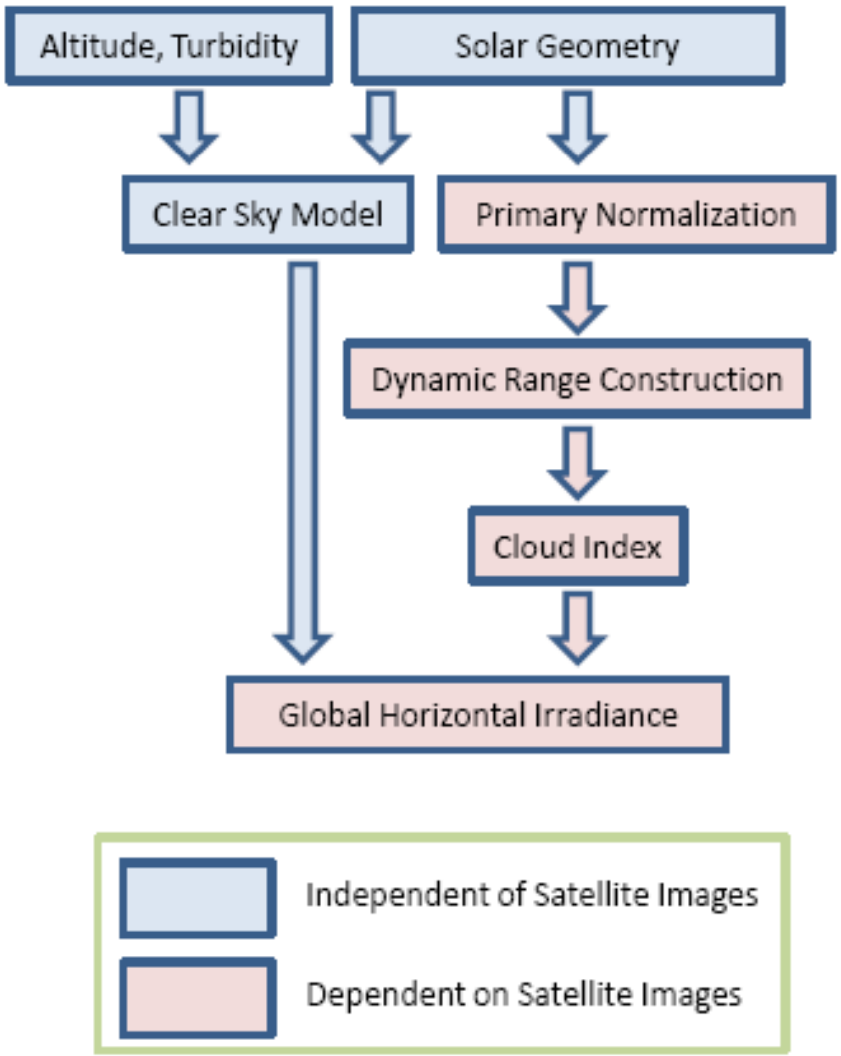
EDSA
POWER ANALYTICS

Solar Forecasting

GOES West Images



Obtaining GHI from GOES data

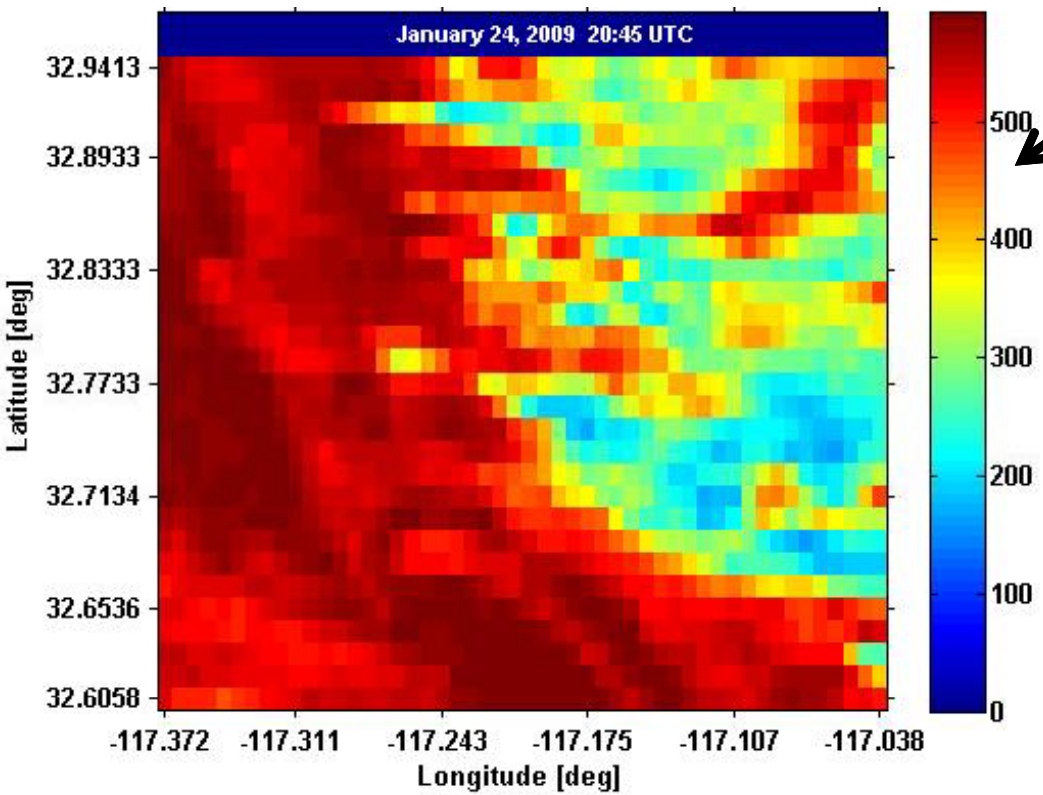


Formulation of global horizontal irradiance:

$$GHI = \sum_{i=0}^{2} a_i \left[\underbrace{k(n)}_{\text{Determined from processing satellite images}} \; \underbrace{GHI_{csk}(\theta_s, h, T_L)}_{\text{Empirically modeled using computed solar angle, and databases of altitude and turbidity}} \right]^i$$

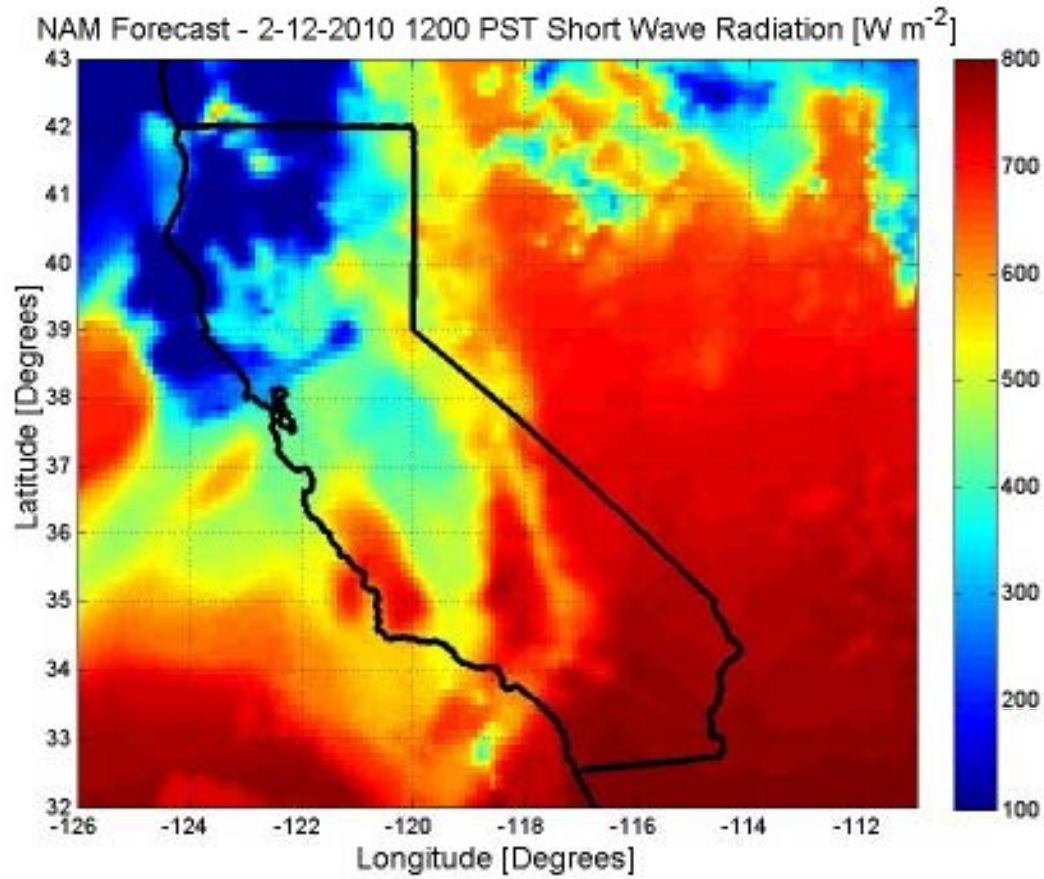
GHI	Global horizontal irradiance
k	Clear sky index
n	Cloud Index
θ_s	Solar zenith angle
GHI_{csk}	Clear sky global horizontal irradiance
h	Altitude
T_L	Linke Turbidity
a_i	Regression constant

Forecast Products



Satellite cloud maps

Numerical weather forecast



Typical errors (RMSE) for hourly GHI forecasts: 20-40%

Integration with utility models

- California Solar Energy Collaborative
- Surveys
- Workshop with draft products
- Informal information exchange