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SOLAR FORECASTING AND GRID INTEGRATION

Project Sponsors and Partners

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U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

SunShot U.S. Department of Energy

Costshare:

Key Deliverables

- Solar variability model for distributed or utility scale solar power plants
- Marine Layer Forecast Models
- Sky imager forecast model
- Solar inverter model for dynamic simulations
- Gadgets:
  - > Topographic horizon data for California
  - > Downscaled 1 sec PV output data from 80 systems
  - > Cloud speed sensor

- For more details: March 2013 CPUC CSI I Webinar

Wavelet Variability Model (WVM)

Inputs

PV Plant Footprint

Density of PV

Point Sensor Timeseries

Location/Day Dependent "A" Coefficient

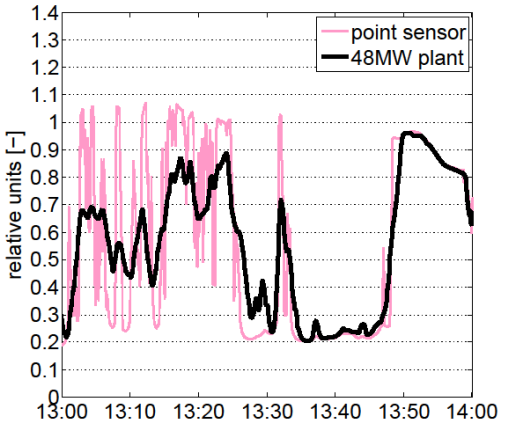
determine variability reduction (smoothing) at each wavelet timescale

Outputs

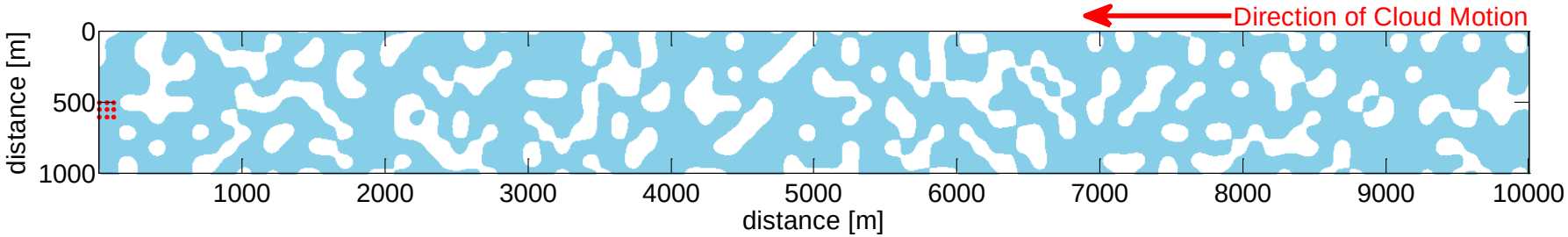
Plant Areal Average Irradiance

irradiance to power model

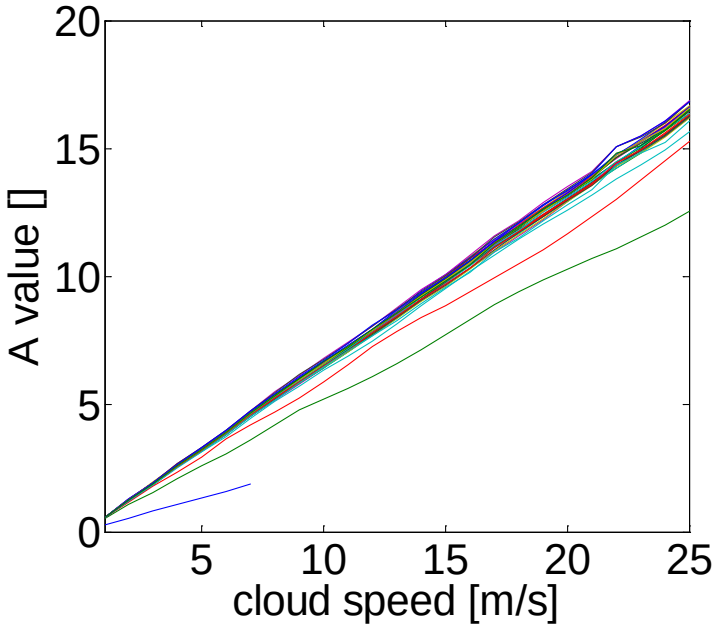
Plant Power Output



Cloud Simulator: Smoothing Depends on Cloud Speed



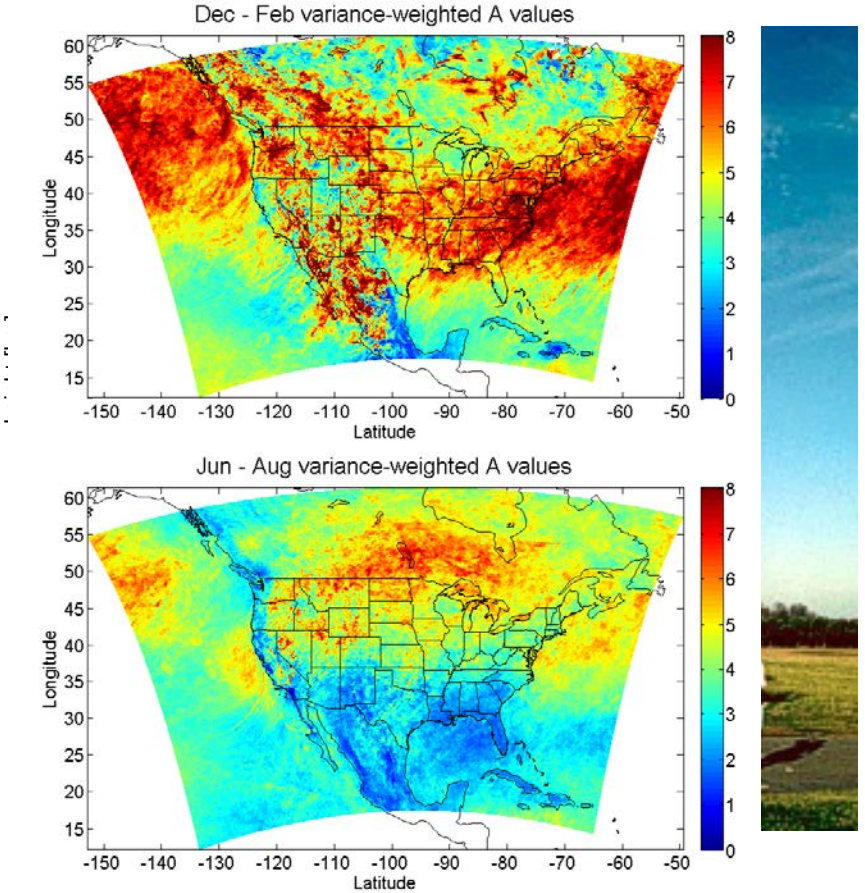
Scaling depends on cloud speed



For sufficiently large cloud speeds and sizes,

$$A = \frac{1}{2} * CS$$

Obtain Cloud Speed from Weather Forecasts

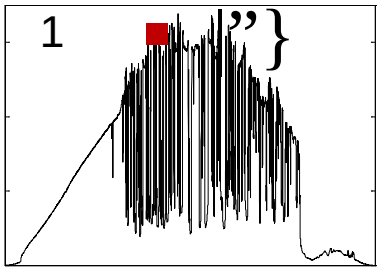


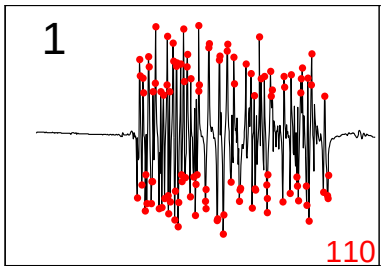
Puerto Rico 10% Ramp / Minute Rule

Collecting 1-second irradiance measurements at the University of Mayaguez, PR.

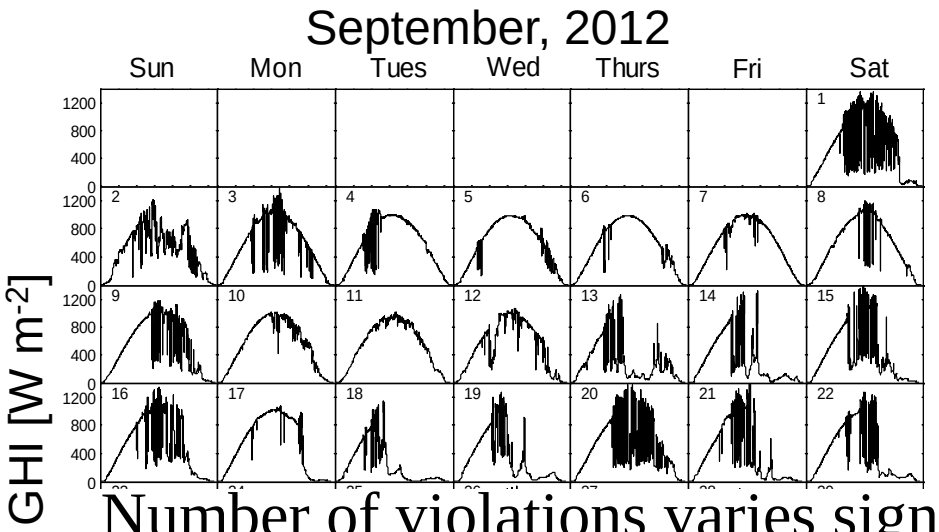
- Arrangement of 4 sensors allows for cloud speed measurement.
- Data input to WVM to simulate PV plant power output.

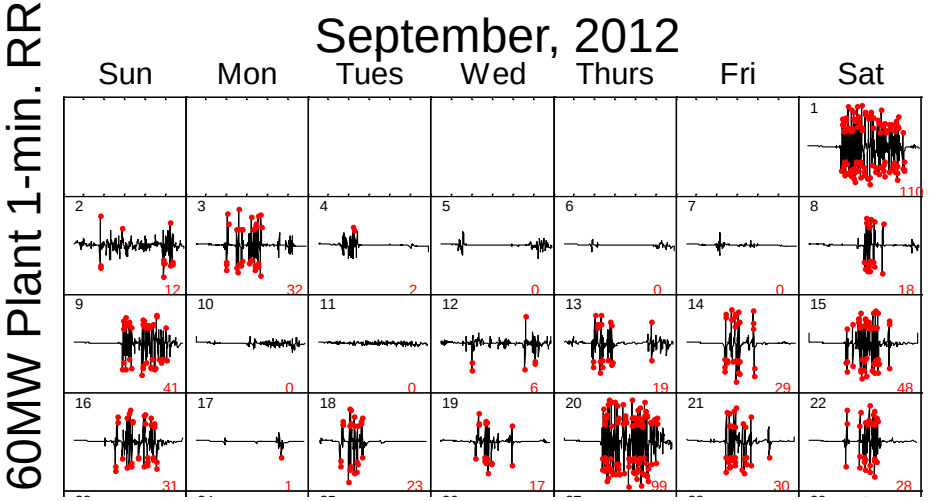
Daily Irradiance





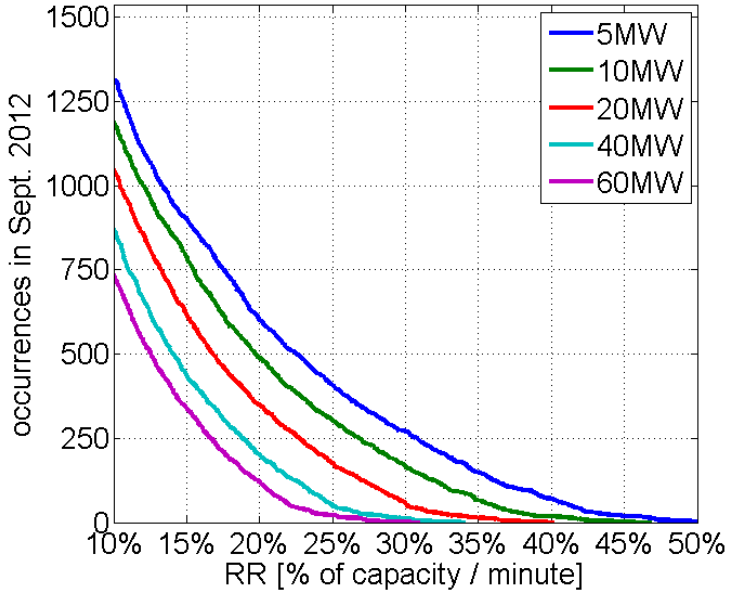
RRs and violations

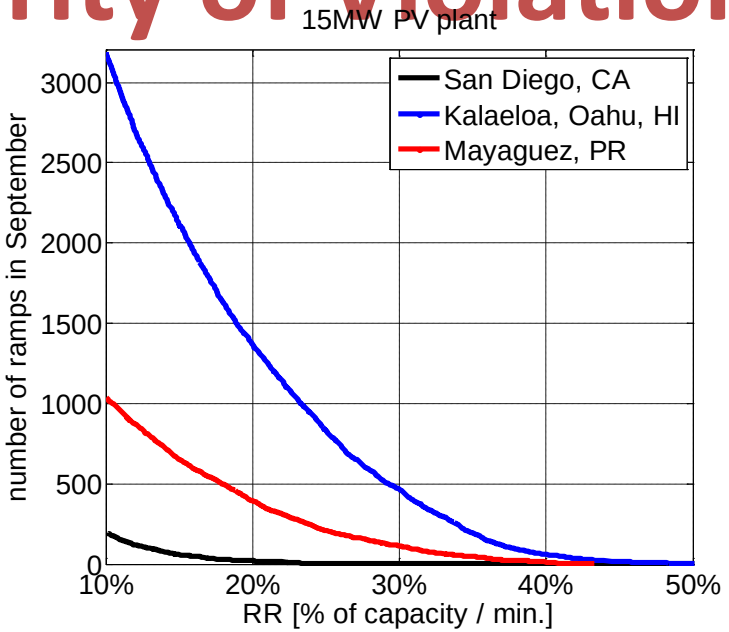




Number of violations varies significantly by day.

Occurrence and Severity of Violations





Plant Size	5MW	10MW	20MW	40MW	60MW
Violations of 10% rule in September 2012	1322	1192	1051	873	737

- Large number of violations
- WVM allows simulating PV ramp rates, but also the impact of mitigation measures such as solar forecasting and battery storage.
- WVM run for >10 developers during prospecting.

How do Extreme Ramps Scale with System Size?

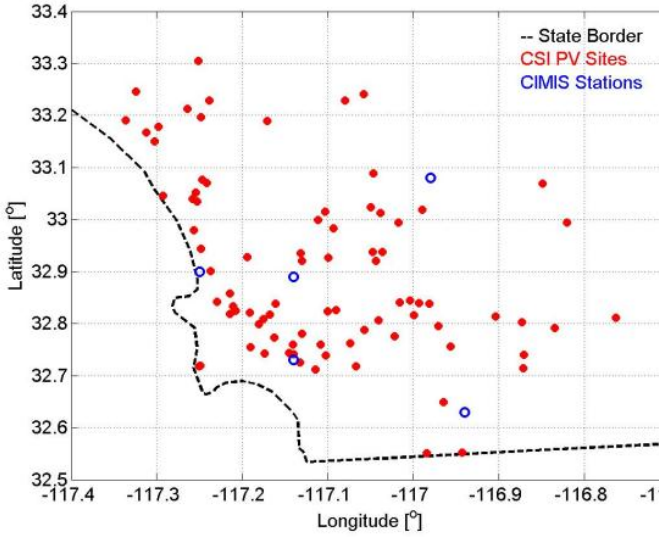
Maximum Aggregate Solar Ramp Rates for California IOUs

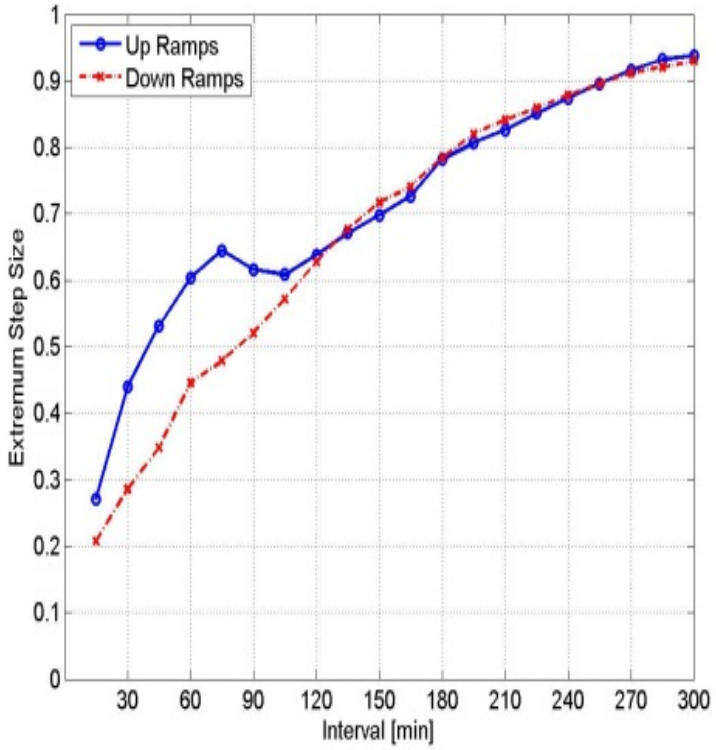
Objective: Analysis of aggregated distributed PV power output in SDG&E, SCE, PG&E, CAISO territory

- Ramp rates of aggregate measured power output of the PV systems
  - > Implications for intra-hour load following / balancing
- Compare PV power output against ground measured and satellite-derived irradiation
  - > What metering for PV systems is necessary to be able to follow output in real time?

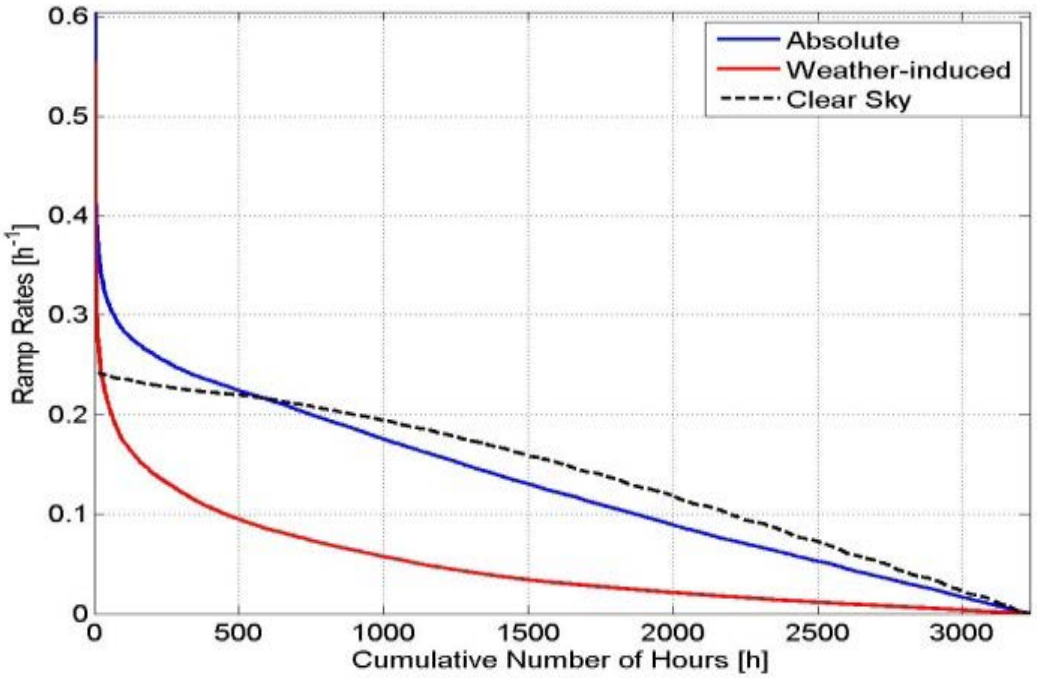
Ramp Rates for SDG&E

- Weather-induced RRs are wrt 30 day average daily cycle
- Largest ramp events are weather-induced



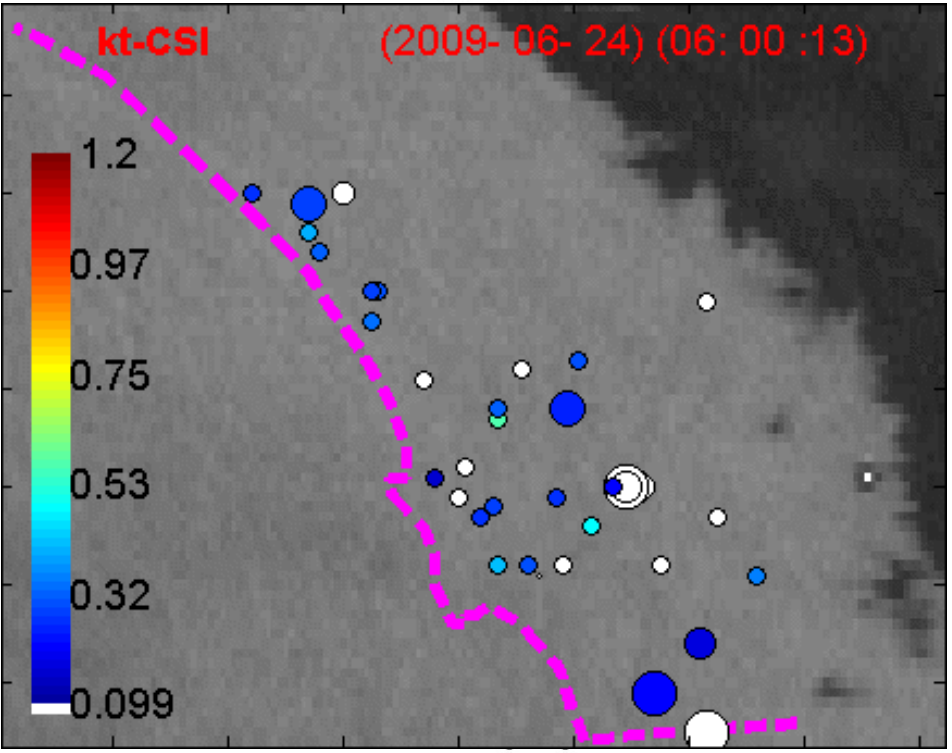


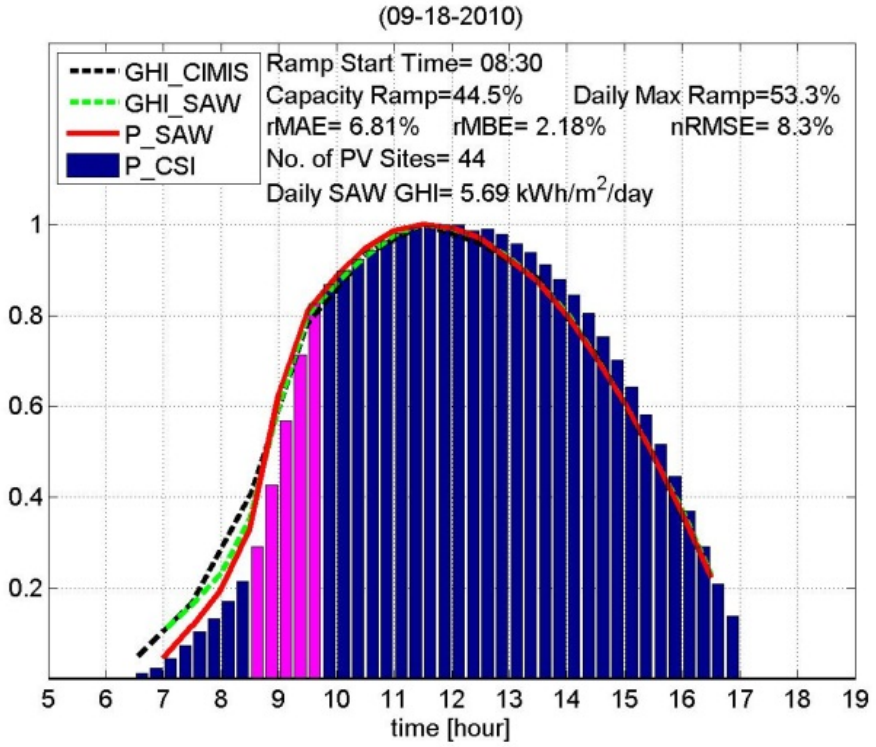
Largest step size of normalized aggregate PV output versus time interval



Cumulative distribution of absolute value of 1-hour ramp rates of normalized aggregate PV output

Two Days with the Largest Ramp Rates





Aggregate modeled & measured power of all 45 PV sites and Aggregate GHI of 5 CIMIS stations for the day with the largest 1-hour ramp rate in 2010

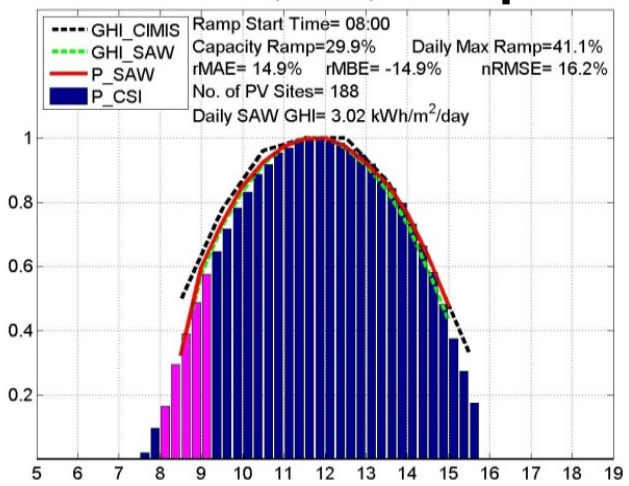
- Largest aggregated hourly ramp: 60.4% of PV PTC capacity
- 2nd largest ramp: 44.5%.
  - Marine layer cloud “burn-off”, like many other large ramps.

Largest Ramps for all California IOUs

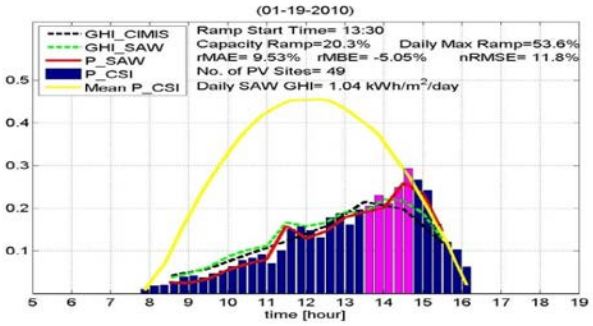
	SDG&E	SCE	PG&E	CAISO
Average distance between sites	28 km	101 km	186 km	332 km
Largest absolute hourly ramp	60.4%	30.7%	29.9%	29.9%
Largest weather induced ramp	55.5%	29.8%	27.6%	20.3%

- Largest ramps in SCE, PG&E, CAISO driven by changing sun angle in early morning and late afternoon during clear skies.
  - Highly predictable.
  - Anti-correlated to evening load peak.
- Relative Ramp rates do not decrease for areas beyond 60 miles.
- Weather-induced ramp rates decrease with area (56% for SDG&E versus 20% for CAISO).

Absolute Ramp

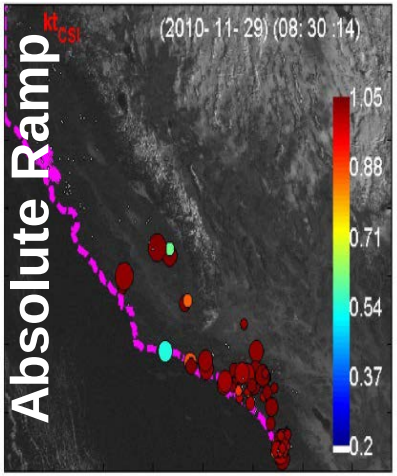


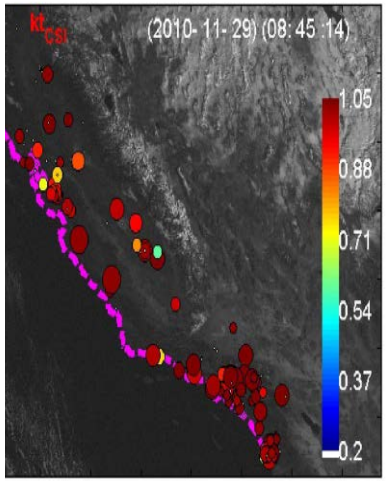
Weather-induced

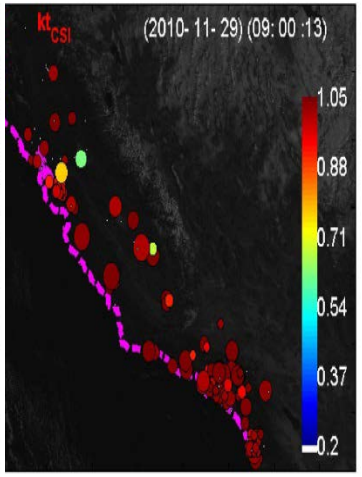


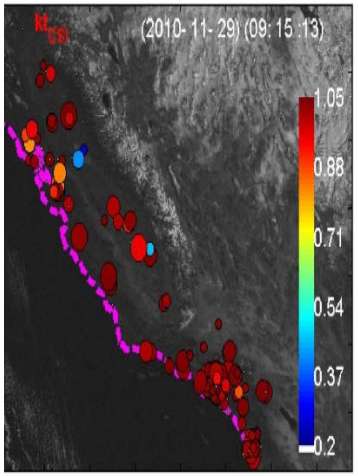
Largest Ramps in CAISO

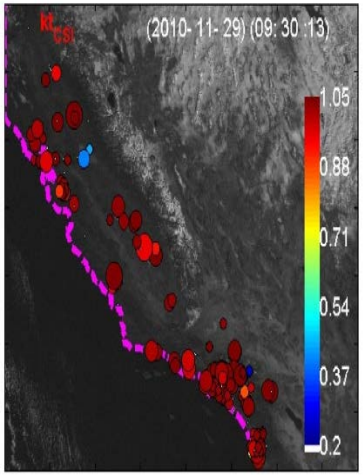
Absolute Ramp



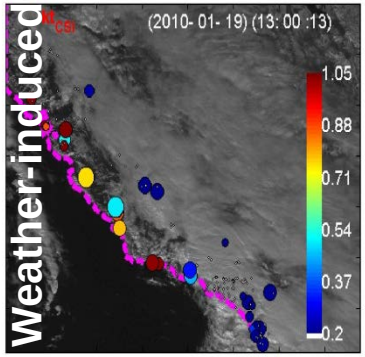


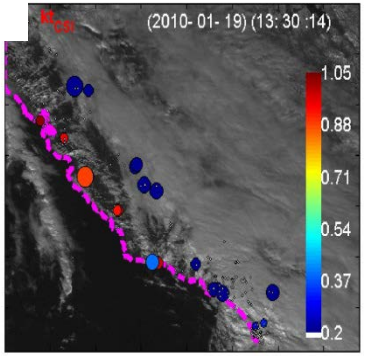


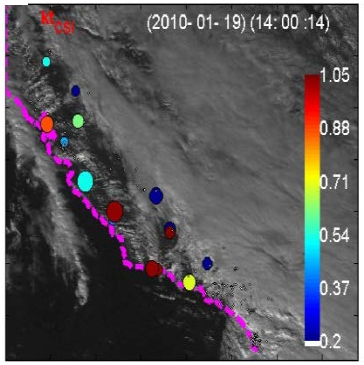


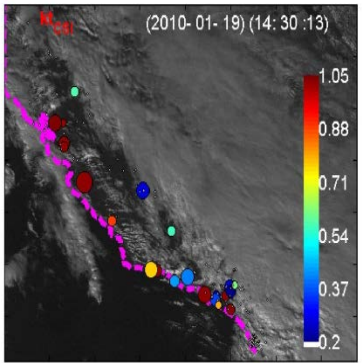


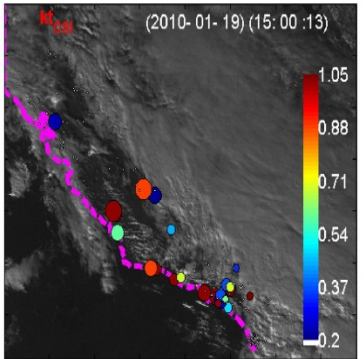
Weather-induced

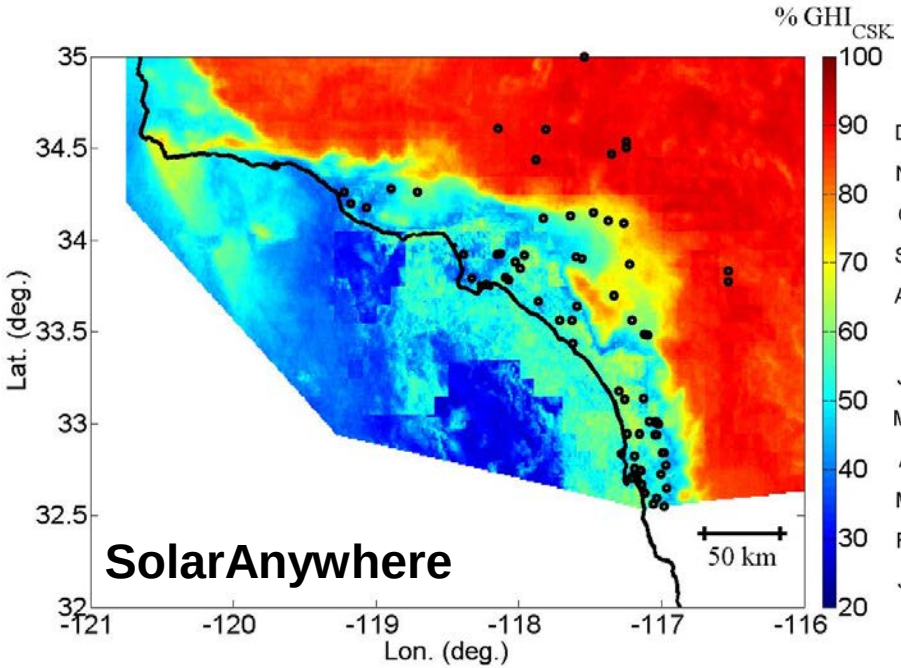


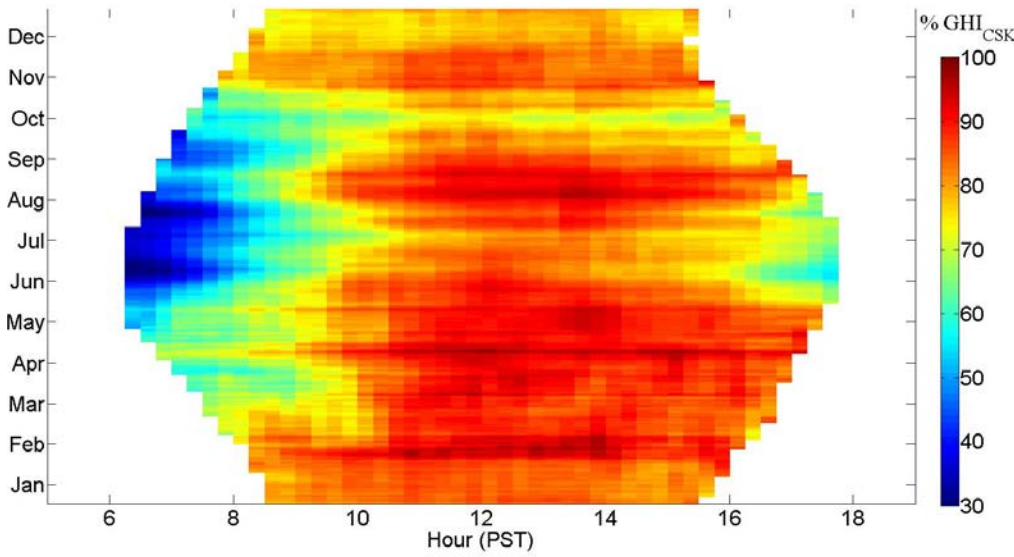










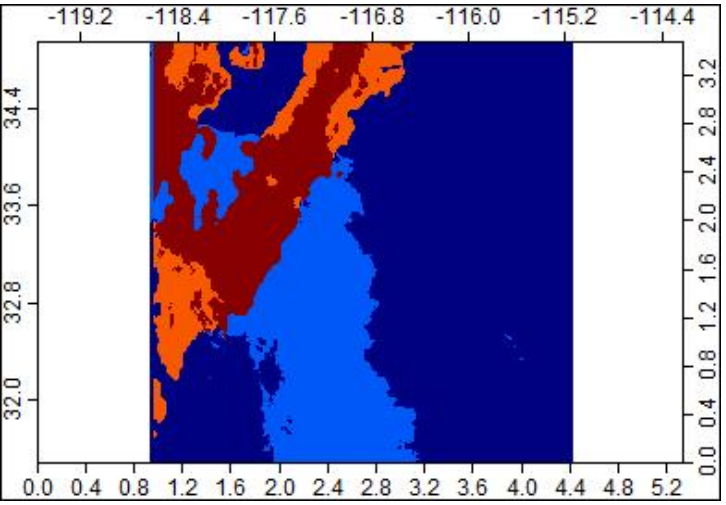


Marine Layer Solar Forecasting

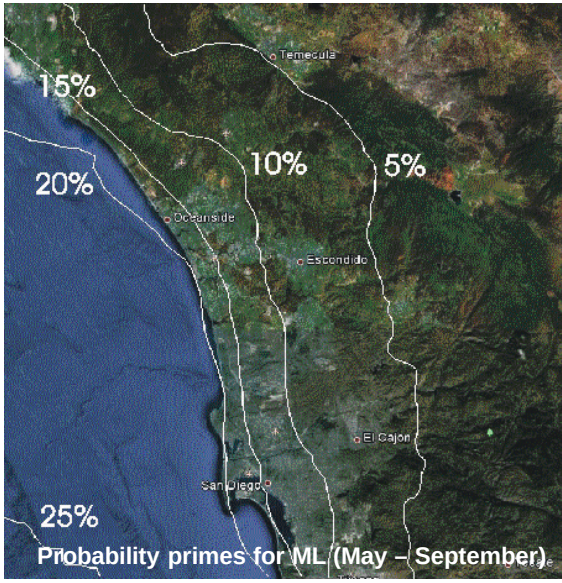
- Logistic Regression (GPLI)
- High Resolution Numerical Weather Prediction (UCSD)
- Evaluation period May – October 2013

Statistical Marine Layer Forecast Model

- Goal: Predicting the likelihood of marine layer (ML) development along the southern California coast.
- ML Classification: Automatic ML classification algorithm from satellite data.
- Multivariate logistic day-ahead ML forecast given real time weather observations and NWP.

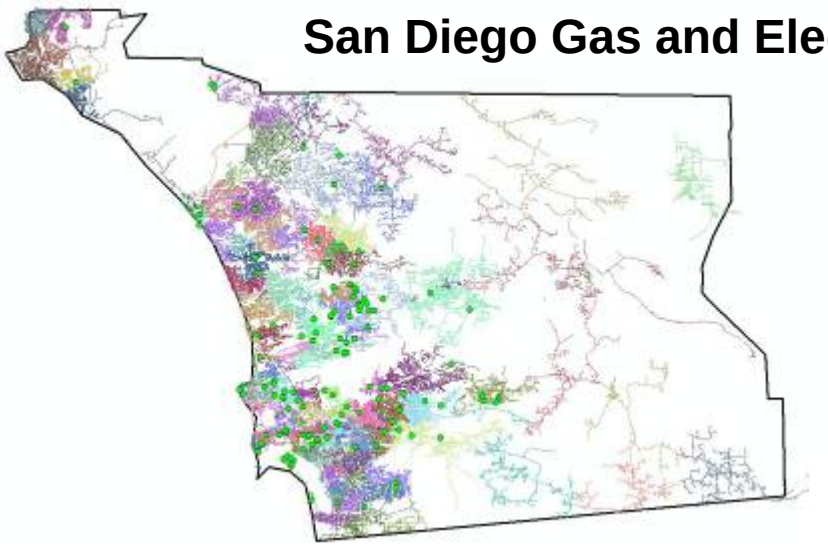


Satellite Classification:
Marine layer: light blue
ML + cloud: purple
Cloud: orange
Clear sky: dark blue



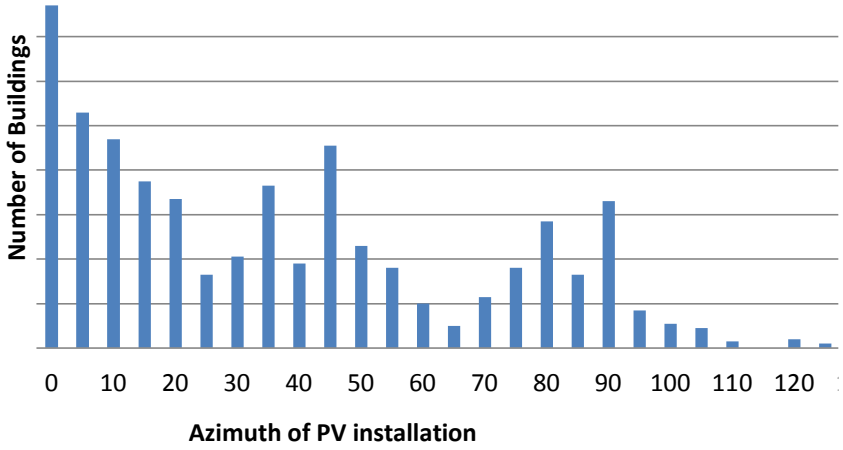
Probability primes for ML (May – September)

Net Load Forecasting – distributed PV generation:

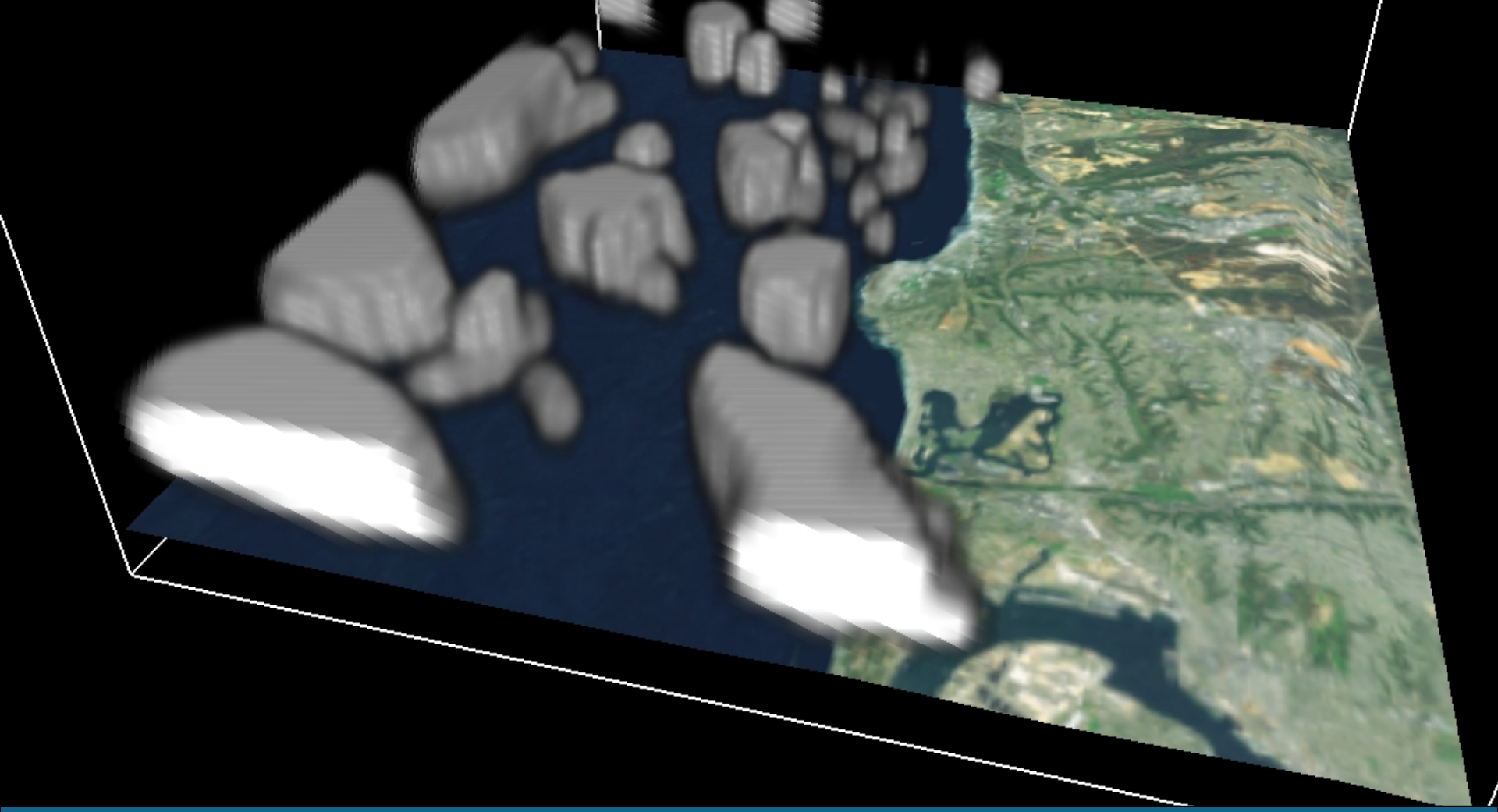


San Diego Gas and Electric:

- **20,000+ distributed PV generation sites**
- **300+ substations**
- **Impact of distributed PV sites on grid performance?**

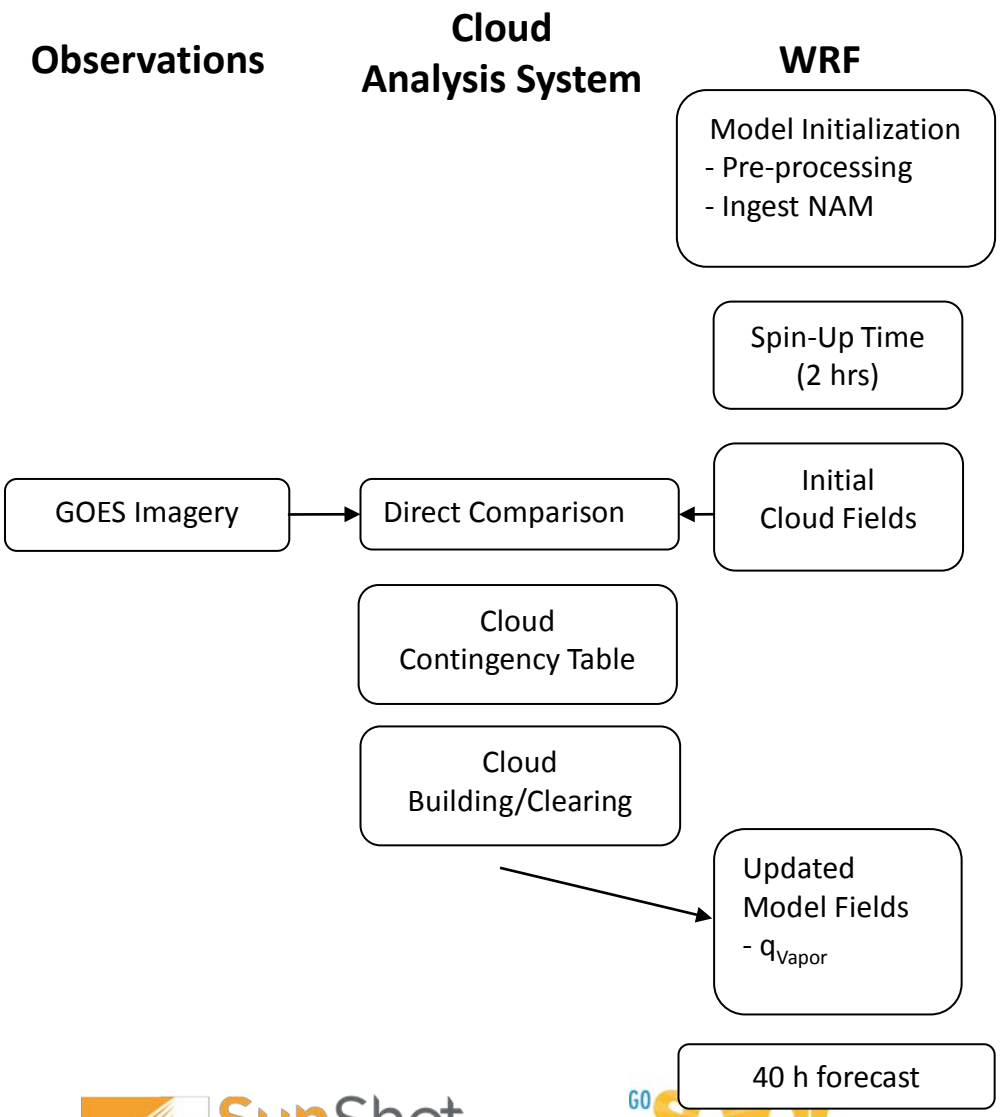


- ✓ Develop distributed generation cluster profiles
- ✓ Develop load forecast parameters for clusters
- Operational PV forecasting
- Testing and calibration



High-resolution, cloud-assimilating NWP at UCSD: day-ahead (40 h) solar forecasts across Southern California. 1.3 km and 5 min resolution.

Model and Cloud Data Assimilation



To improve accuracy, clouds are populated in initial conditions

Direct Cloud Assimilation

- Cloud hydrometeors are modified in initial conditions

WRF model simulates cloud evolution

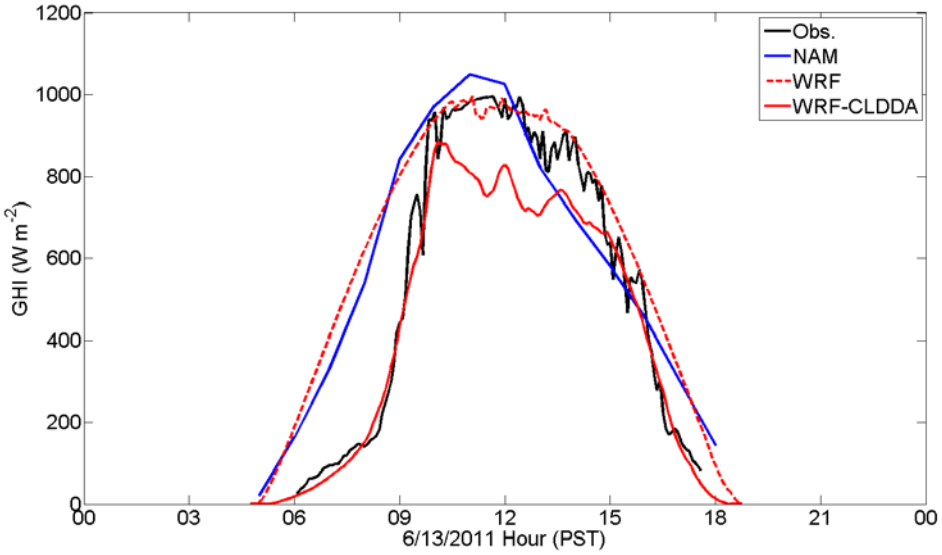
- Evaporation
- Deformation
- Condensation

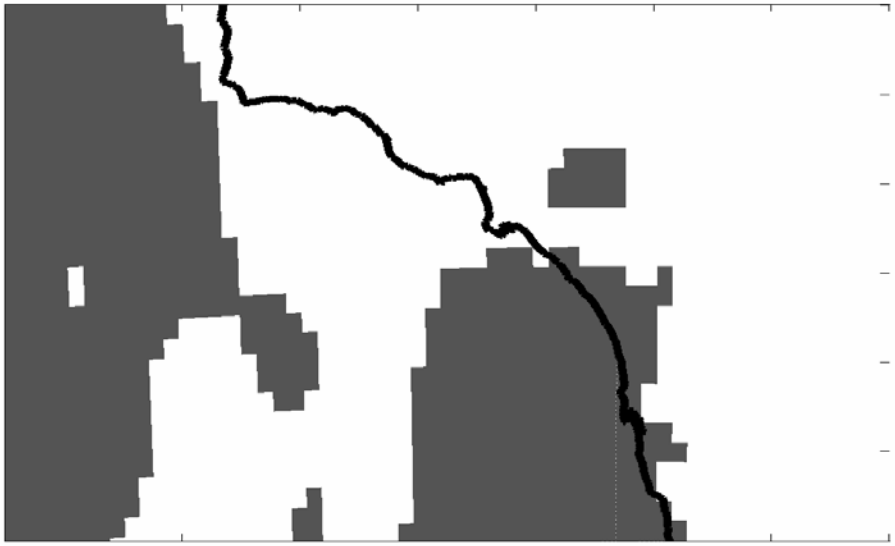
RUC methodology

- Benjamin, *et al.,* 2004, 2007, etc.

WRF-CLDDA Simulation of Marine Layer Dissipation

6/13/2011



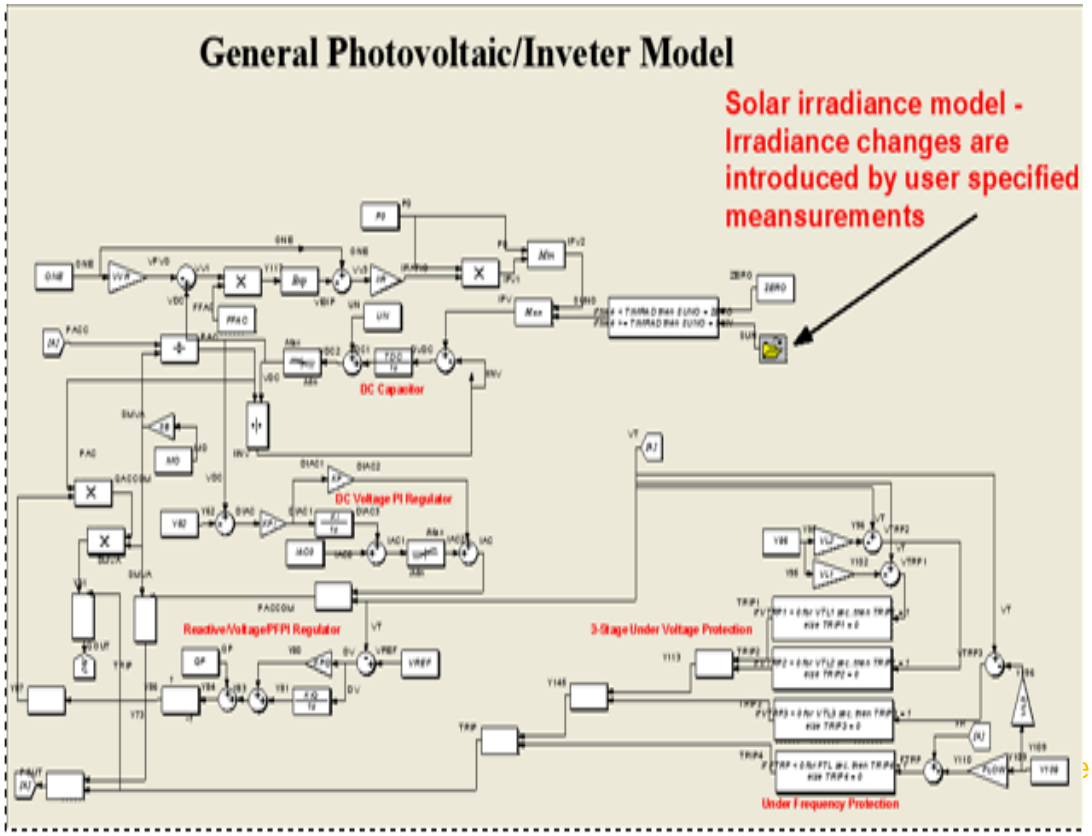


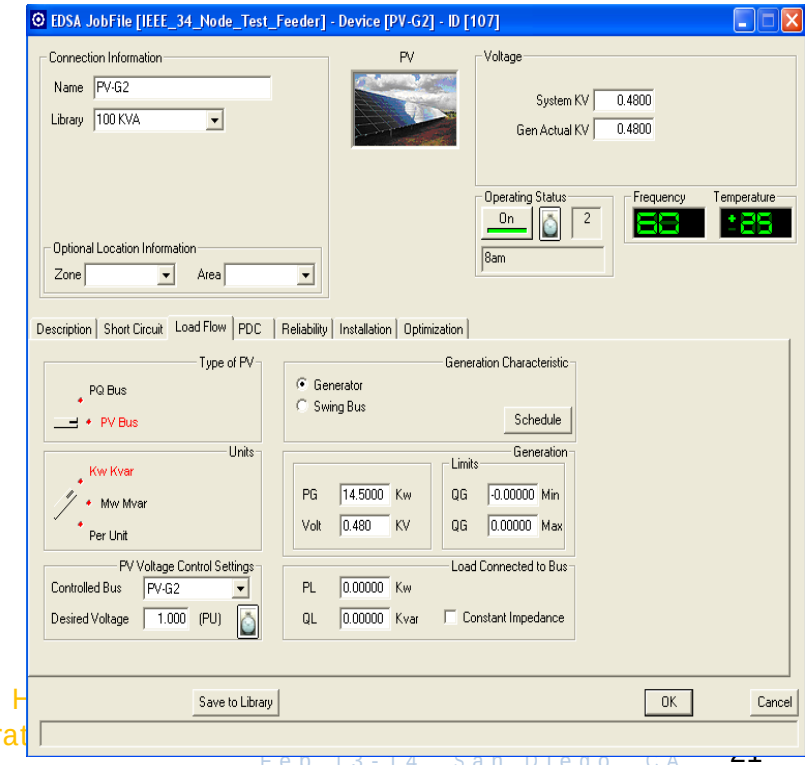
Integration with Utility Models

- Dynamic system modeling
- Energy storage dispatch for demand charge reduction
- Sky imager forecasting for feeder voltage control

Power Modeling

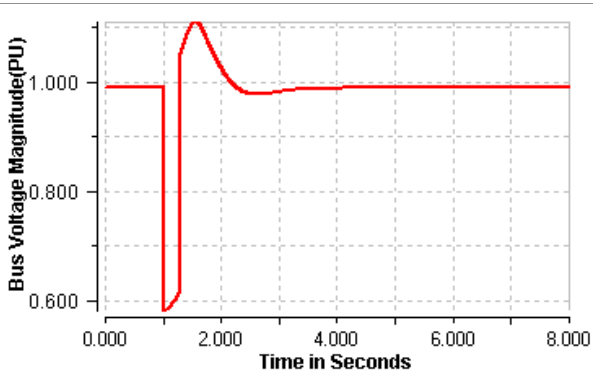
1. Static and dynamic modeling determines allowable power circuit penetration levels, performance constraints and cost.
2. Specific inverter designs are implemented as hardware options. These inverter modeling capabilities are essential to power system modeling and analysis.
3. Generic inverter attributes are also defined facilitating broad based modeling and analysis.

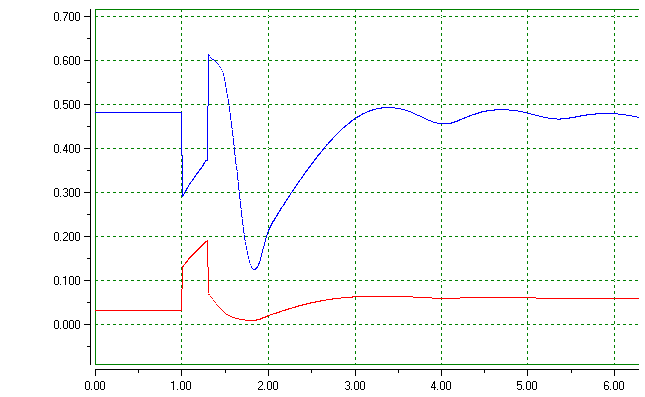




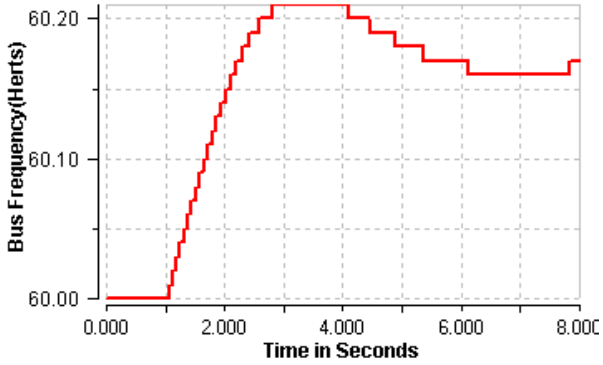
Power Systems Simulations

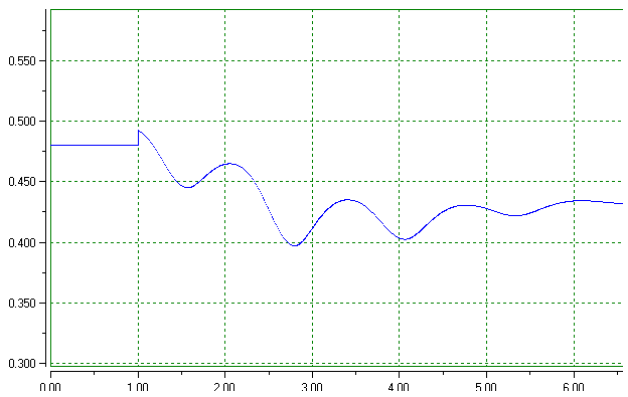
Voltage Support.



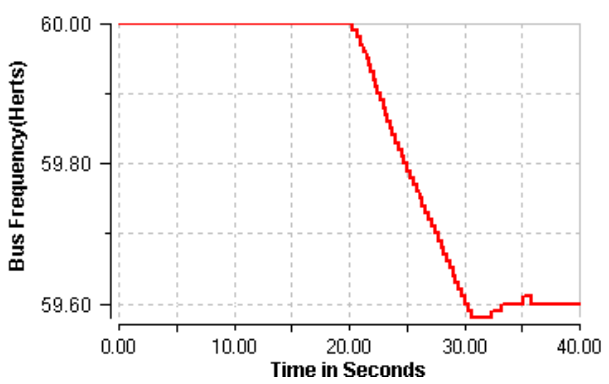


Frequency Support



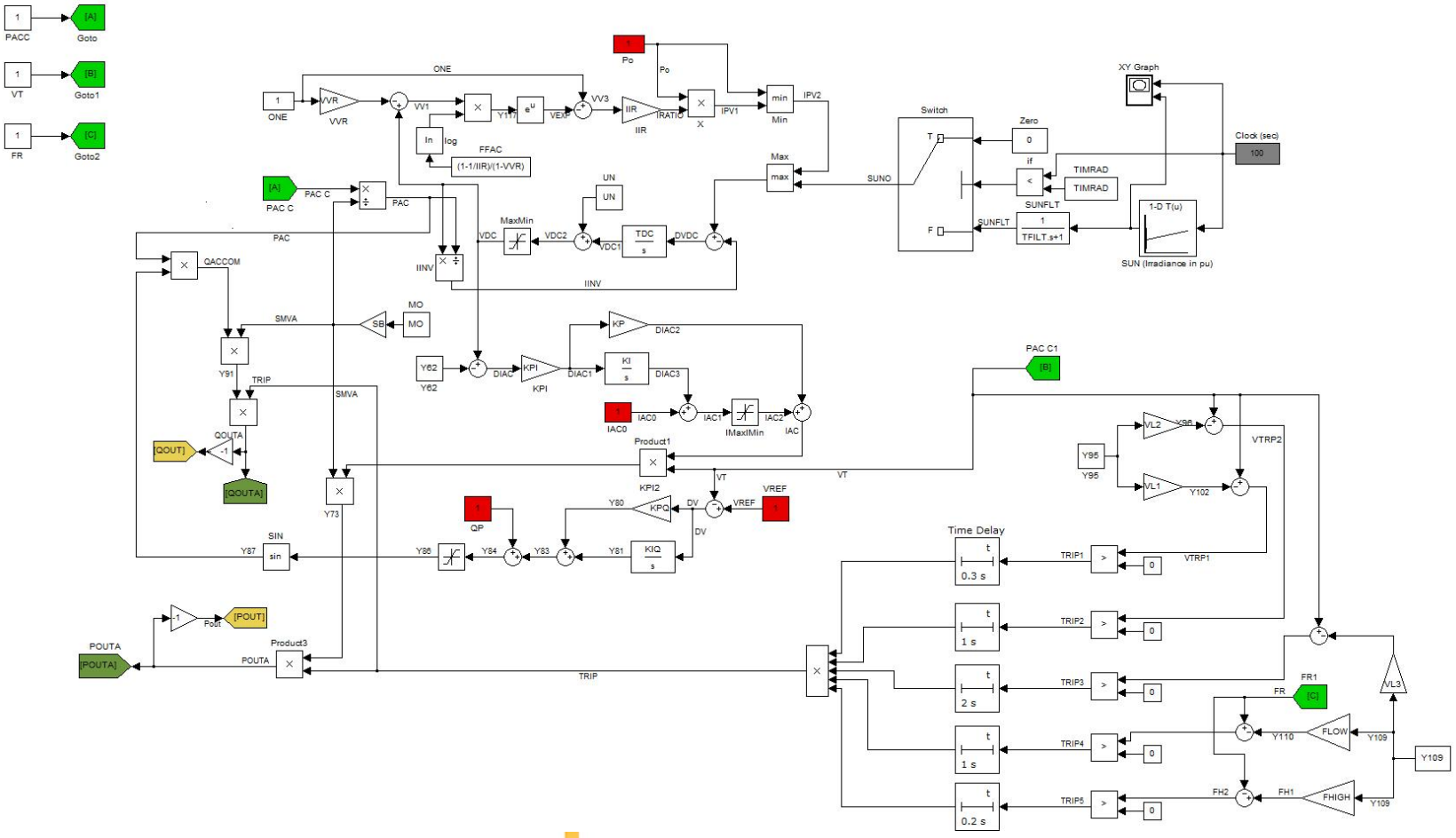


Ramp-down



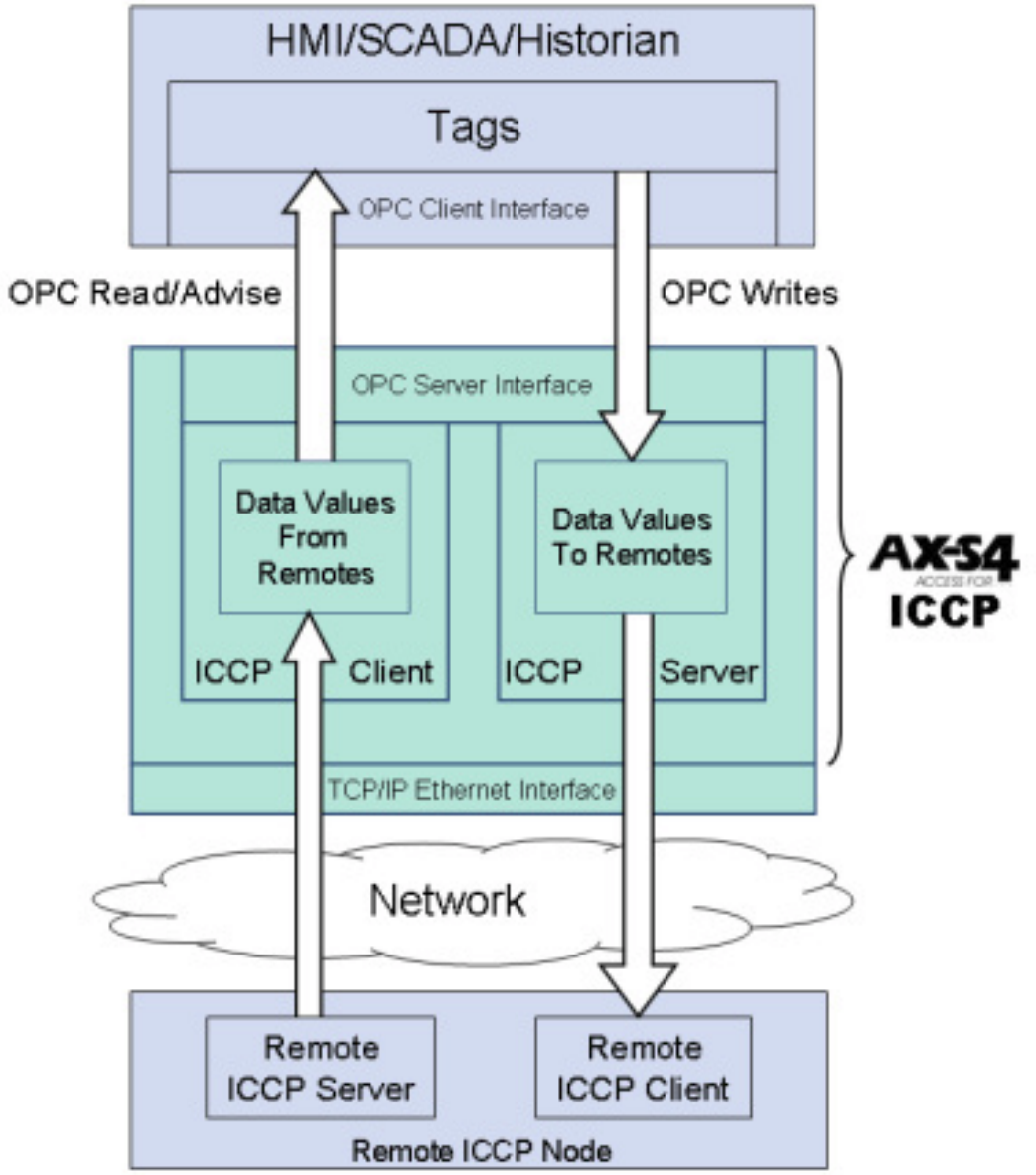
Power Systems Simulations

Dynamic simulations using Power Analytics model in Simulink



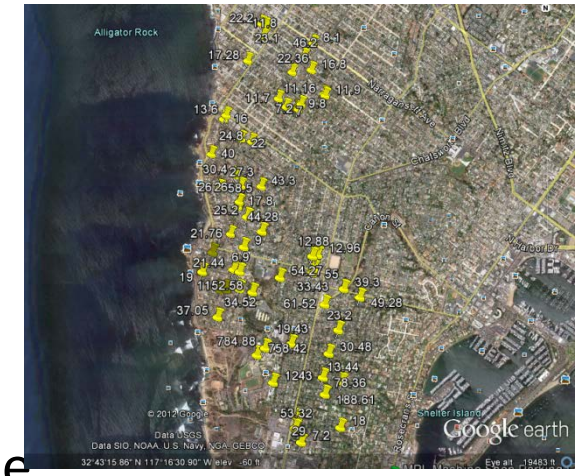
Secure Bi-Directional Communication - ICCP

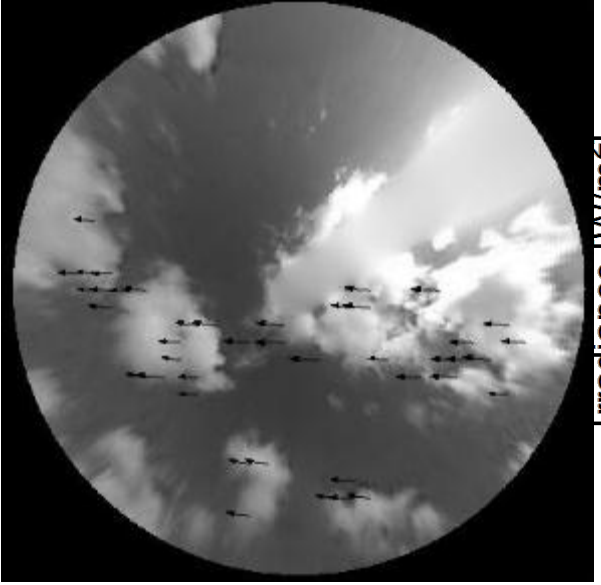
- ICCP (IEC 60870)
  - > Inter-control Center Communications Protocol
  - > OSI structured
  - > Mature and accepted bi-directional communications standard
  - > Currently supported by SDG&E
- Currently in production Power Analytics
- In certification with ERCOT

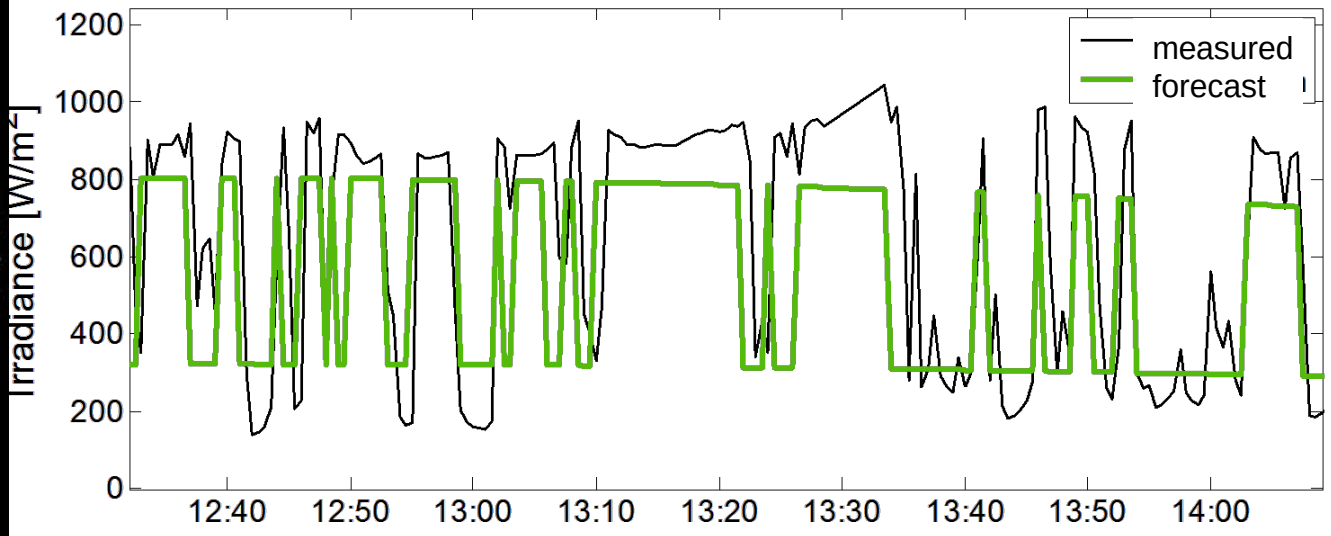


5 SDG&E Feeders with High PV Penetration

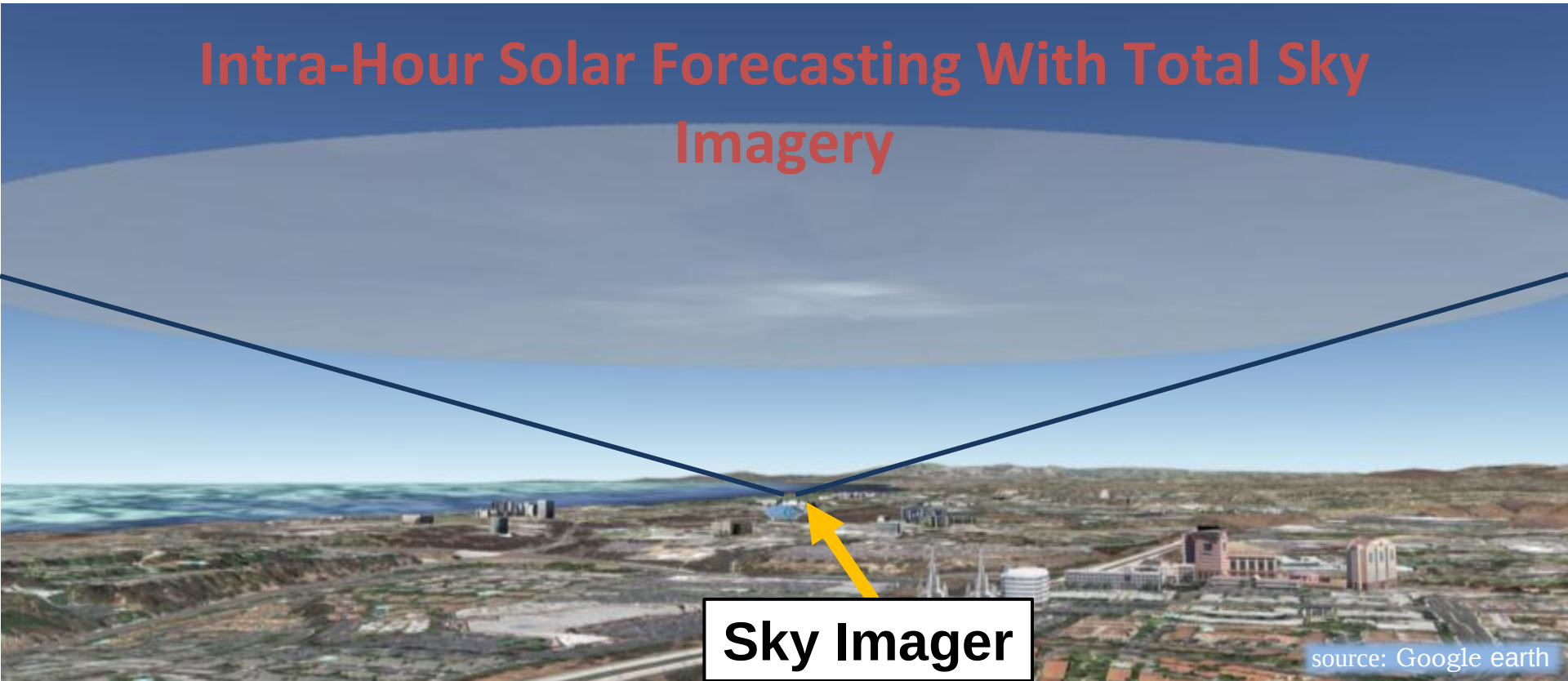
- Climate Zones (coastal to desert)
- Urban and Rural
- 1 mile to 10 mile size
- Goals
  - > Examine ramp rates by site and in aggregate
  - > Evaluate feeder impacts (losses and voltage regulation)
  - > Evaluate mitigation measures enabled through forecasting







Intra-Hour Solar Forecasting With Total Sky Imagery



Sky Imager Movies Go Here

Feeder Modeling and Control

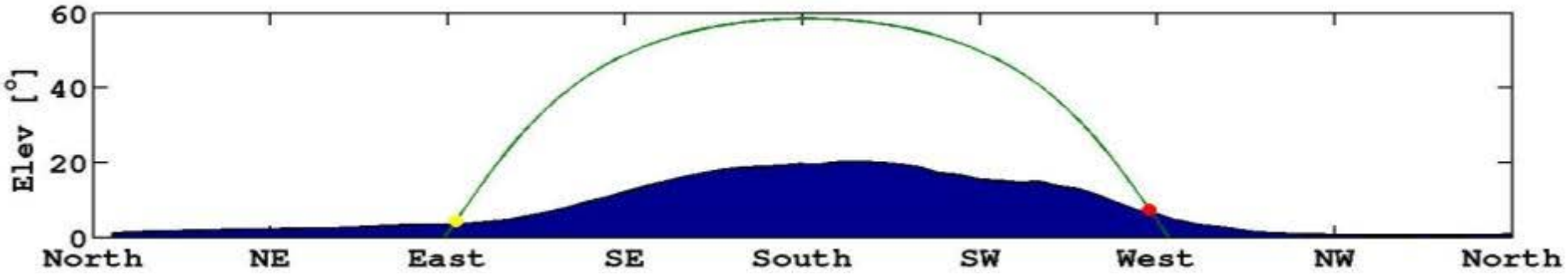
- Develop highly spatially and temporally resolved solar resource data for the feeders
  - > Apply to all PV systems on feeder
  - > Also simulate highly resolved load data
- Simulate feeder voltages and voltage regulator actions
- Investigate use of forecasting to reduce potential voltage regulator actions associated with PV

“Gadgets”

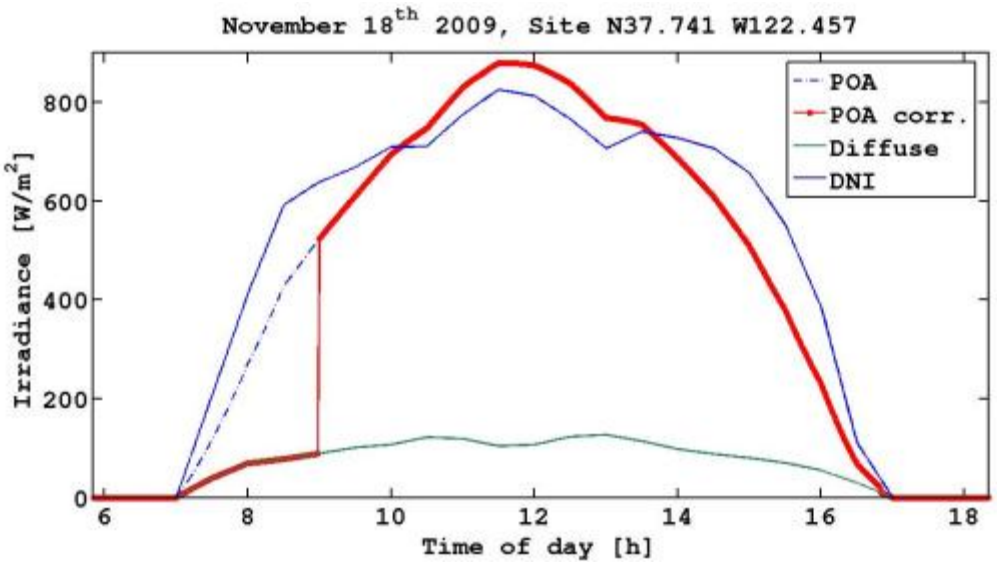
- Topographic Horizon Database
- Downscaled 1 sec PV Output Data
- Cloud Speed Sensor

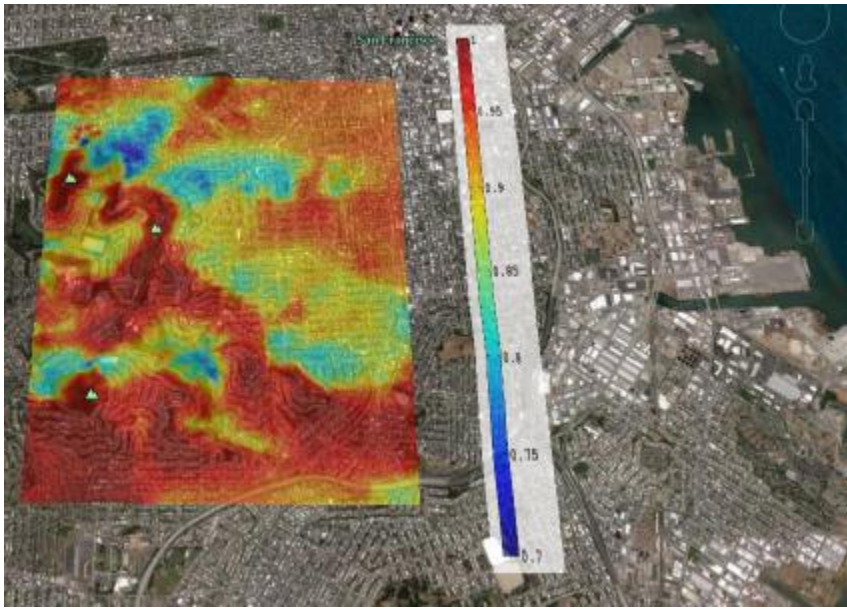
Topographic Horizon Database

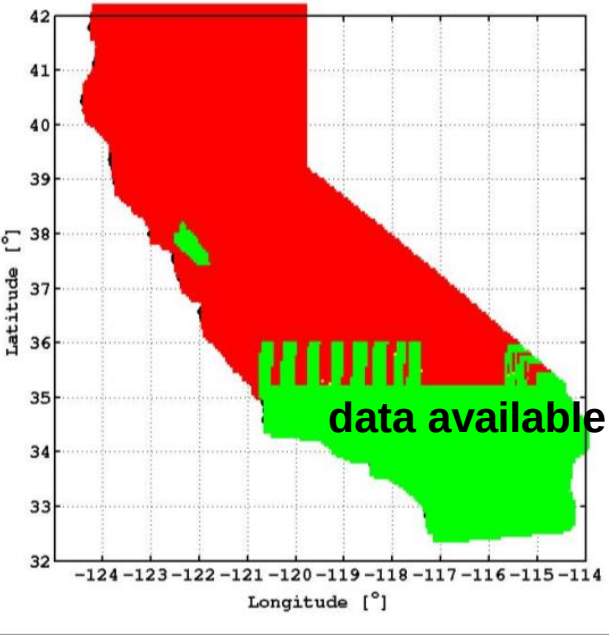
- Topographic shading reduces PV output and is commonly not considered by satellite or NWP solar resource models.
- Impact on PV generation generally benign, but can be a few % in mountainous areas.



Case Study – Twin Peaks





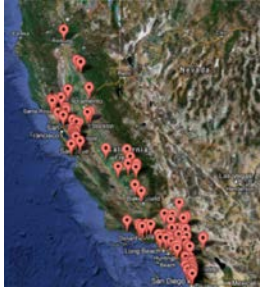


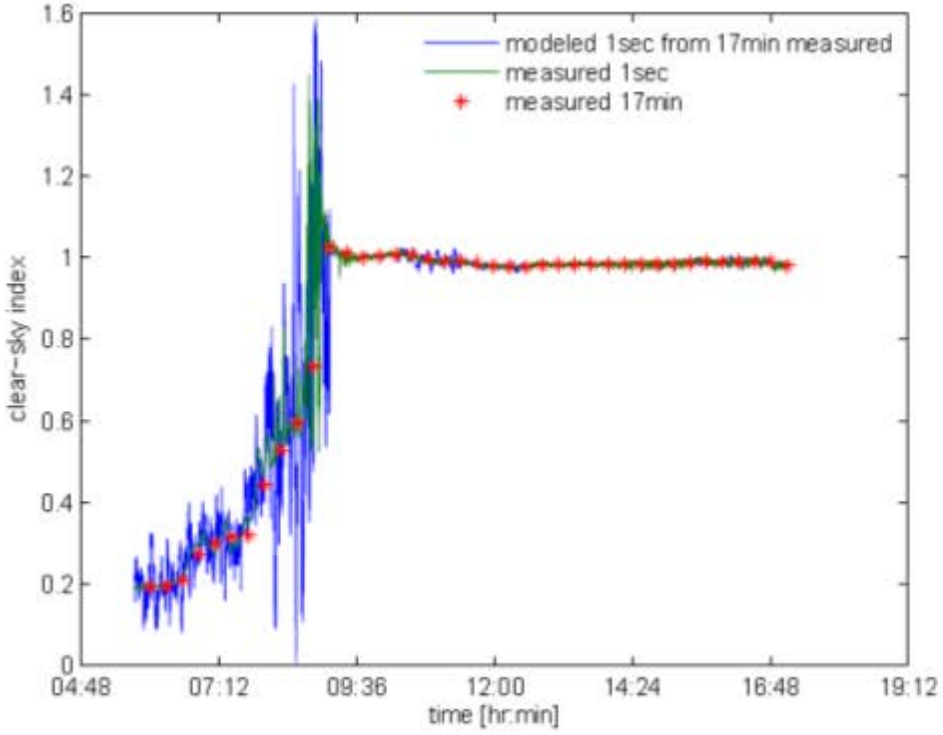
- Day length up to 30% shorter than unobstructed
- Annual losses usually less than 1%
- Data available for all high PV penetration regions with topography

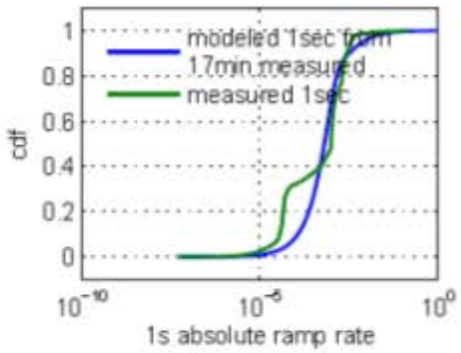
Downscaled CA PV Data to 1 sec

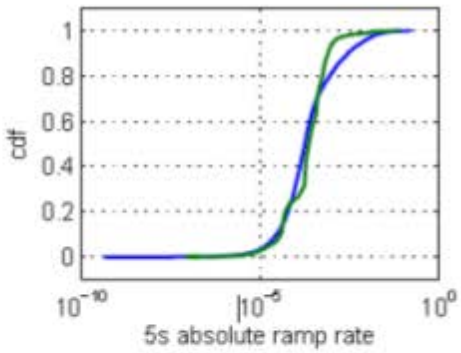
- High resolution PV data required for integration studies
  - > Voltage variability impacts of PV exacerbated when assuming uniform output profiles for all sites on a feeder
- CSI performance based incentive (PBI) data only available as 15 min average
- Statistical downscaling uses properties of resolved data (e.g. clear versus cloudy) to dynamically introduce fluctuations

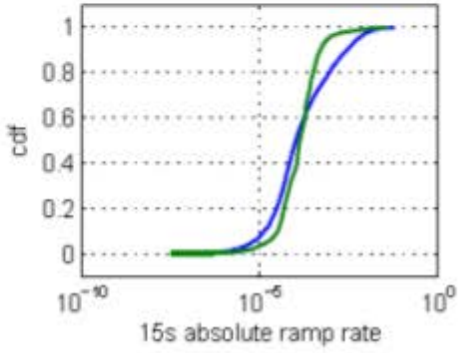
Downscaling Example

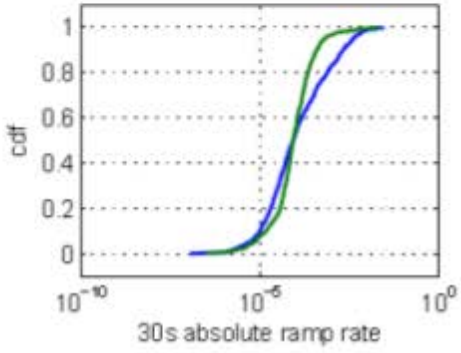






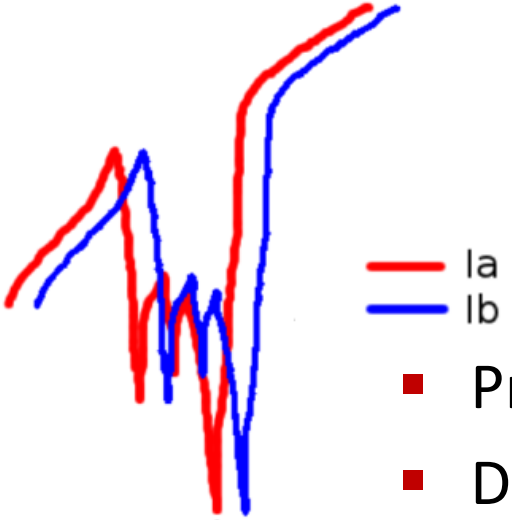


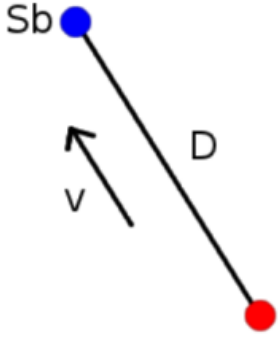


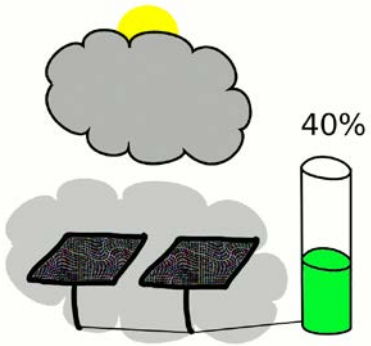


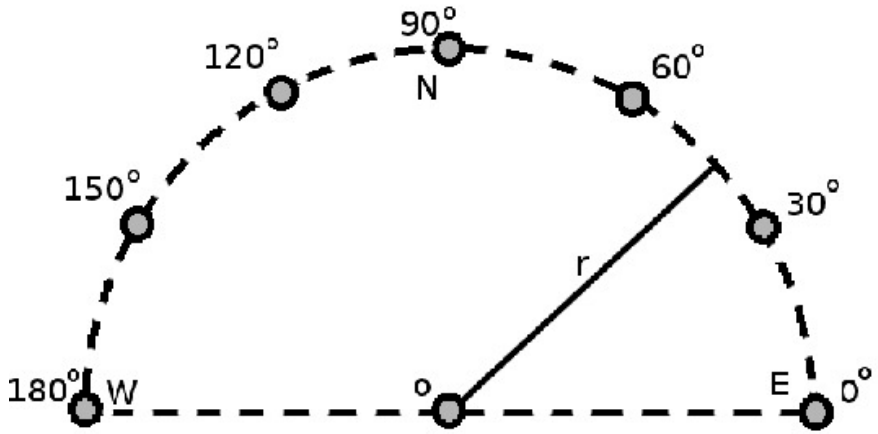
- Request at http://solar.ucsd.edu/datasharing/
- 365 days of 1 sec data per site
- 115 sites in California

Cloud Speed from Pairs of Solar Irradiance Measurements









- Provisional patent filed
- Developing commercializable product
- Integration into meteorological measurement systems at utility scale solar power plants

Pair #	Direction [°]	Regression Coef.	Time gap [s]	Speed [m s^{-1}]
1	0	0.7140	1.65	3.6
2	30	0.7062	1.70	3.5
3	60	0.7433	1.35	4.4
4	90	0.8123	0.80	7.5
5	**120**	**0.8483**	**1.05**	**5.7**
6	150	0.8268	0.85	7.1
7	180	0.7629	0.30	20

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Q&A AND DISCUSSION