Energy Efficiency and
Renewable Energy

Public Interest
Energy Research

Solar Forecasting Concepts and Summary of Research Projects

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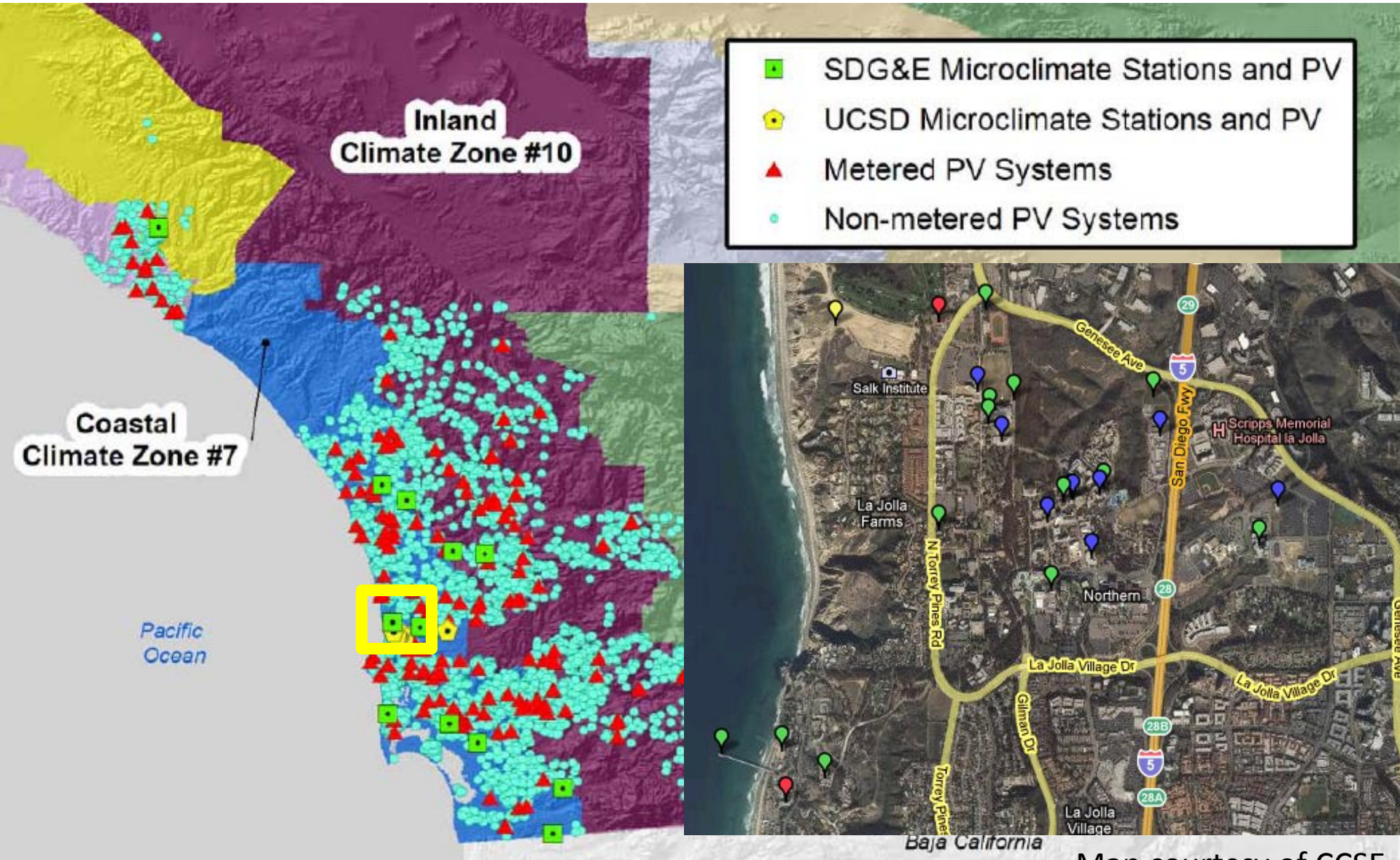
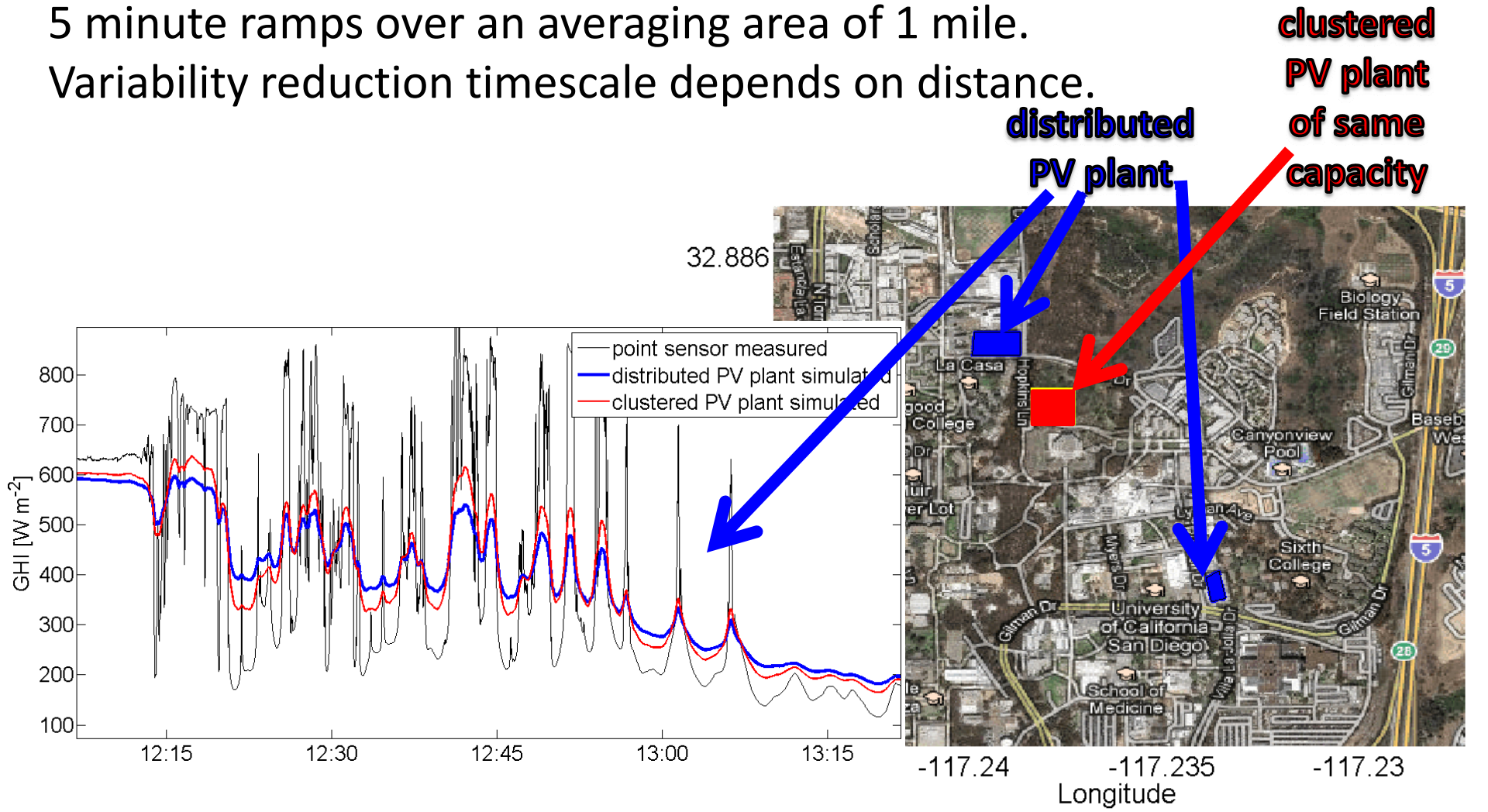
PV Systems in San Diego County and UC San Diego: Testbed for Solar Variability



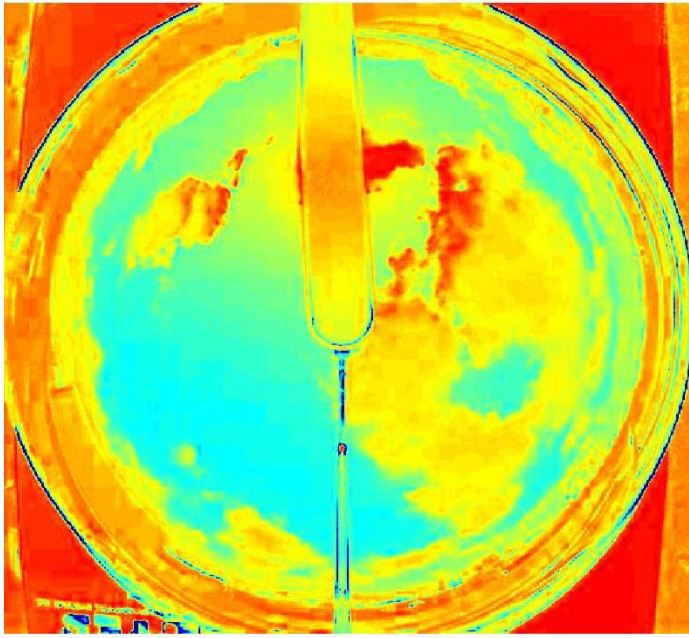
Map courtesy of CCSE

Simulating Geographic Smoothing

Distributed PV shows largest reduction in variability at 1 to 5 minute ramps over an averaging area of 1 mile.
Variability reduction timescale depends on distance.



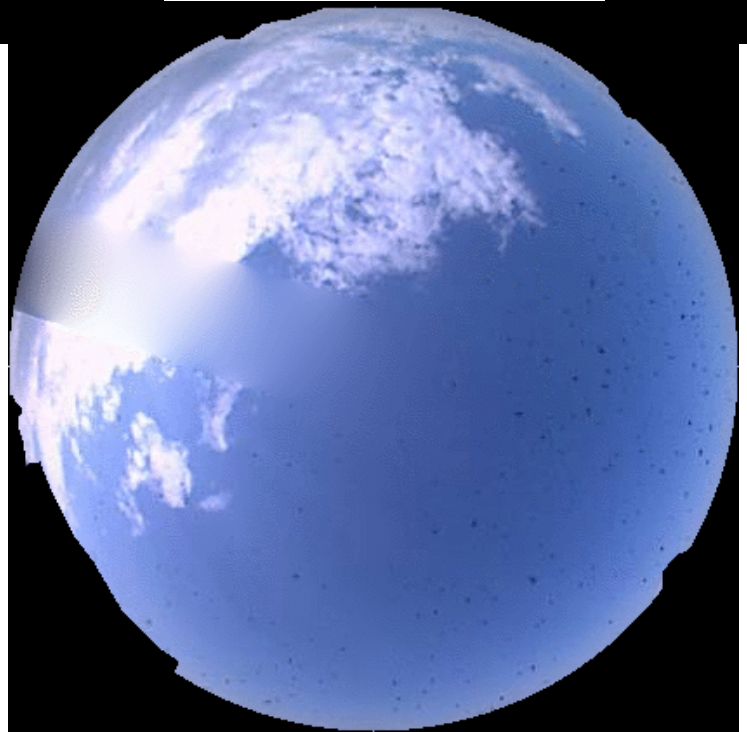
Intra-hour Solar Forecasting with a Total Sky Imager



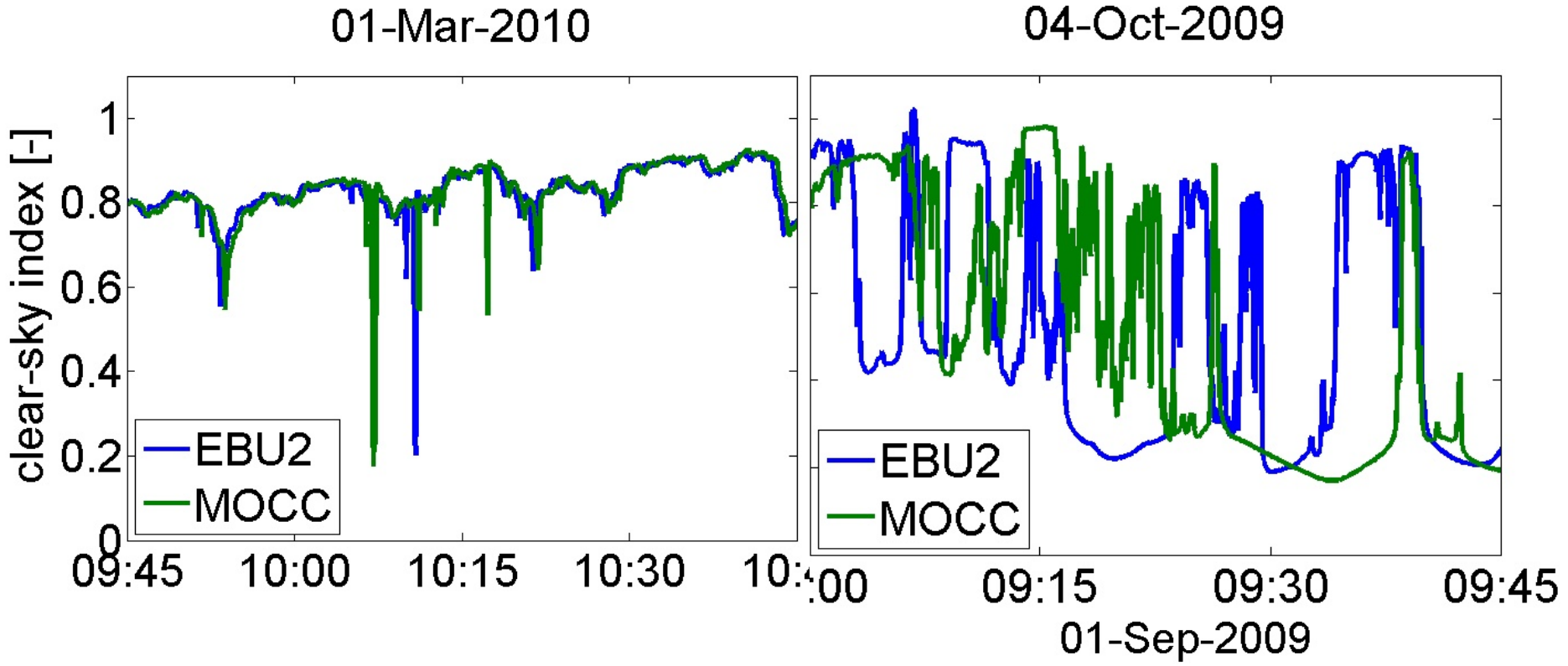
Cloud Types

Cirrus

Cumulus

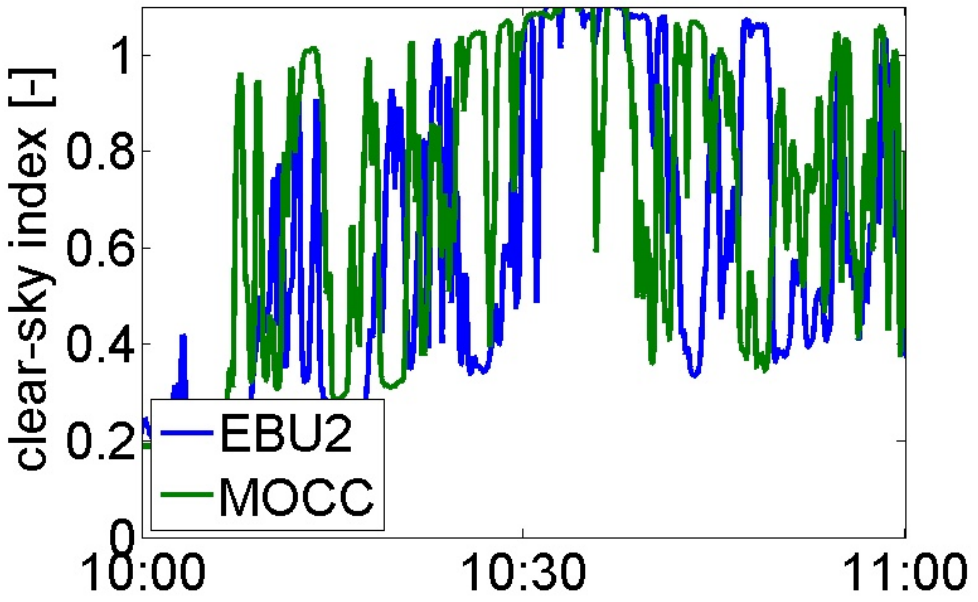


Altocumulus



Irradiance measurements on the same days

Offset to show different sites.
Black box corresponds to time period from sky imager.

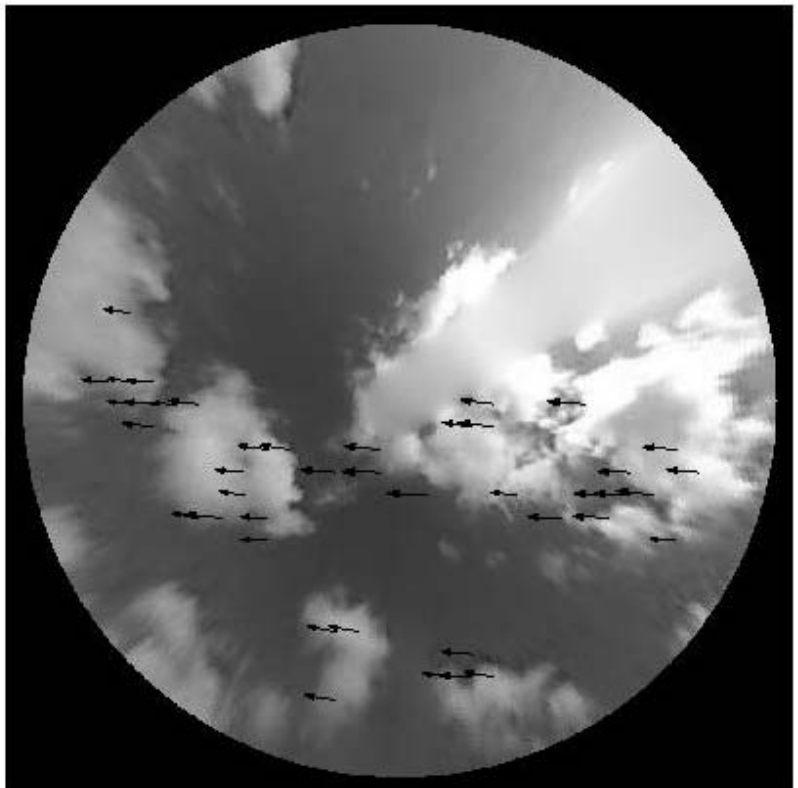


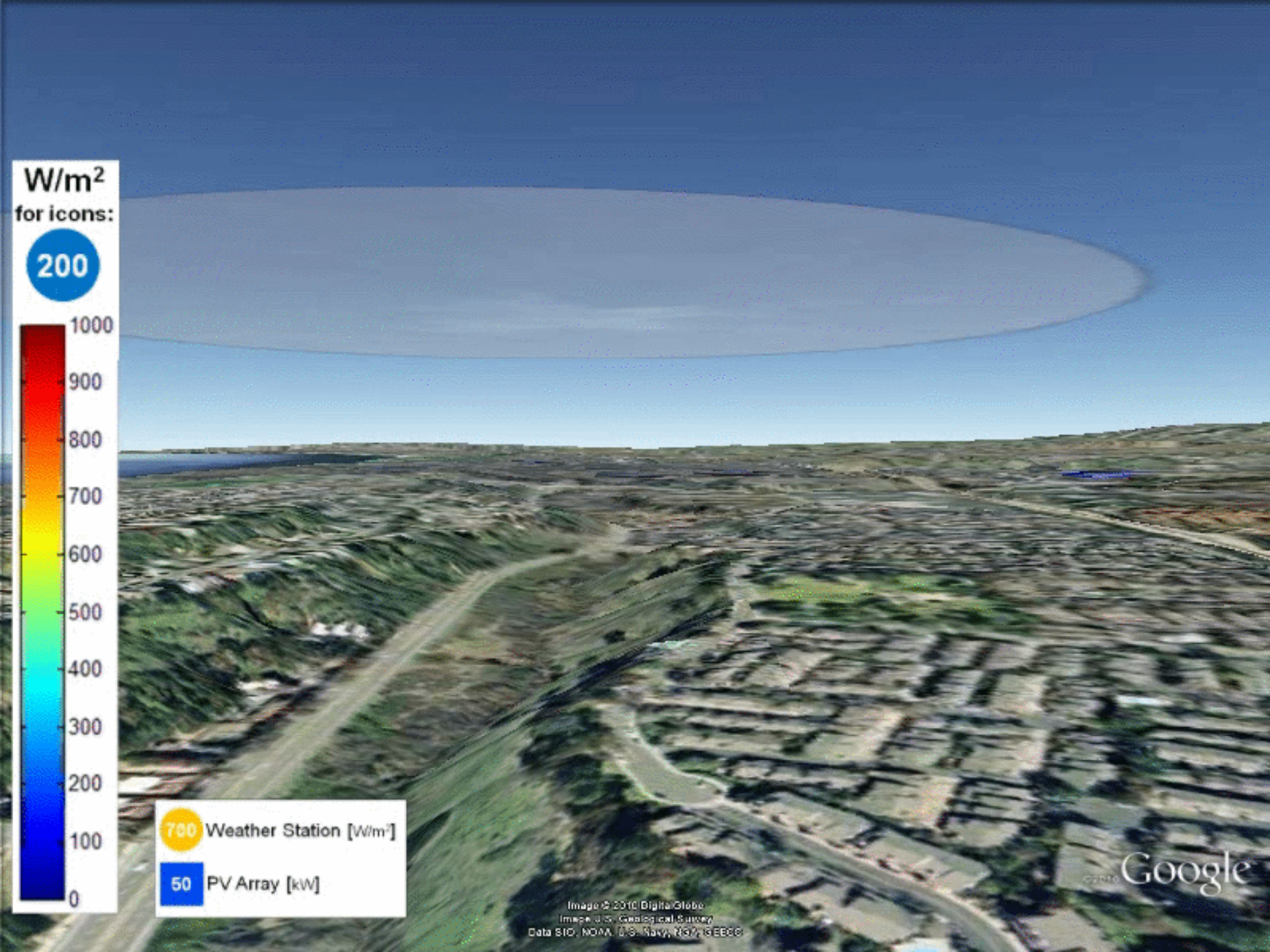
Cloud Motion Vectors

- Apply cross-correlation method to coordinate-transformed sky image.
- Retain only vectors for which high correlation is obtained
- Assume homogeneous cloud velocity

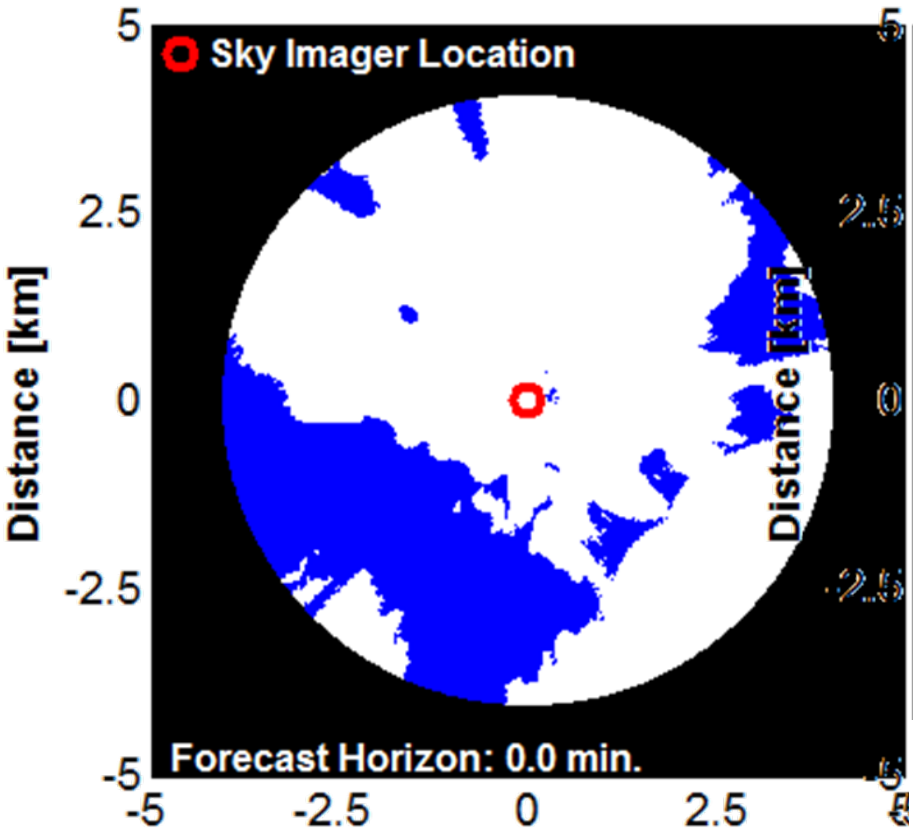
2009-10-04 16:26:30.000

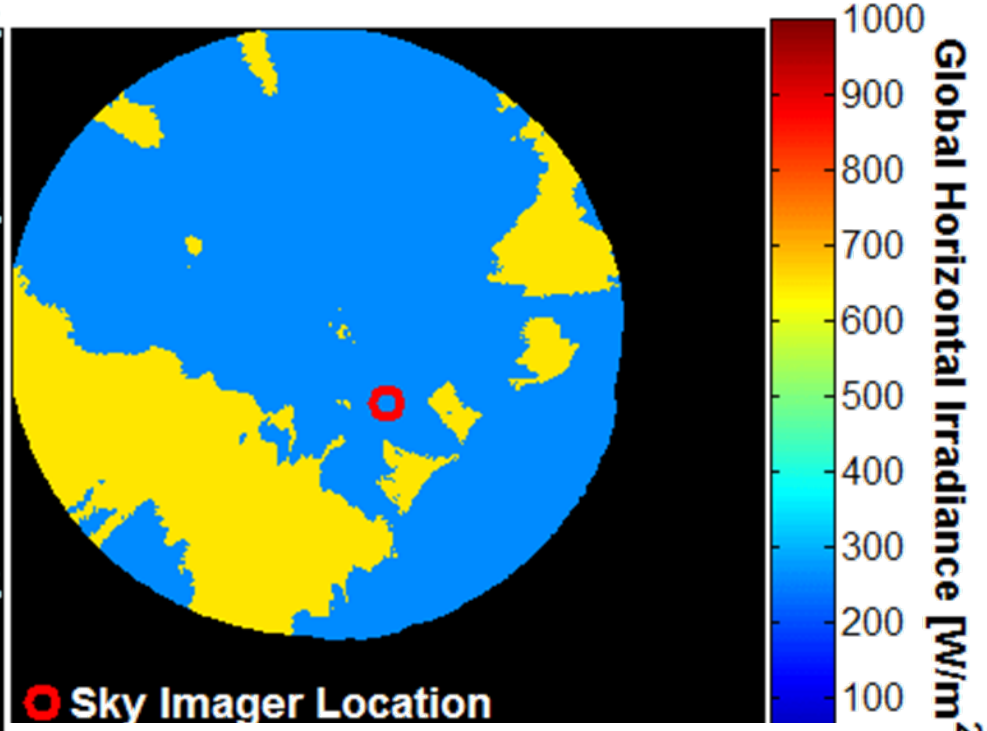
U: -5.8532m/s V: 0.54762m/s



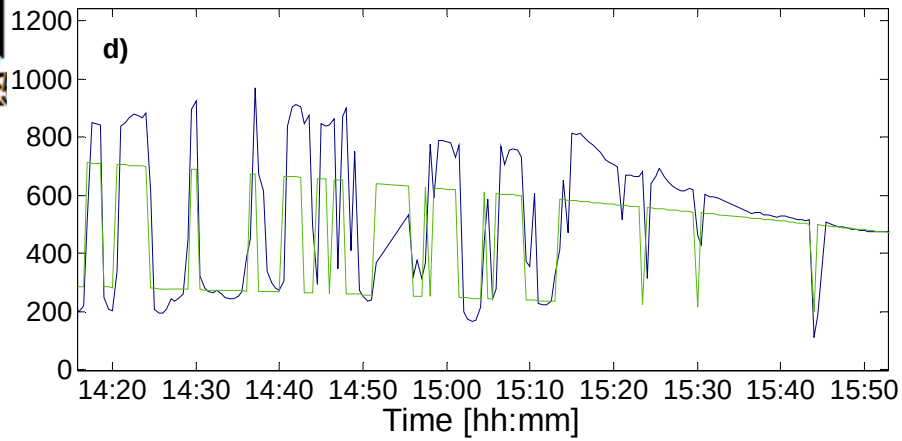

W/m2
for icons:
200
1000
900
800
700
600
500
400
300
200
100
0
700 Weather Station [W/m2]
50 PV Array [kW]
Image © 2010 DigitalGlobe
Image U.S. Geological Survey
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google

Advection of Frozen Clouds to Obtain Irradiance Forecast

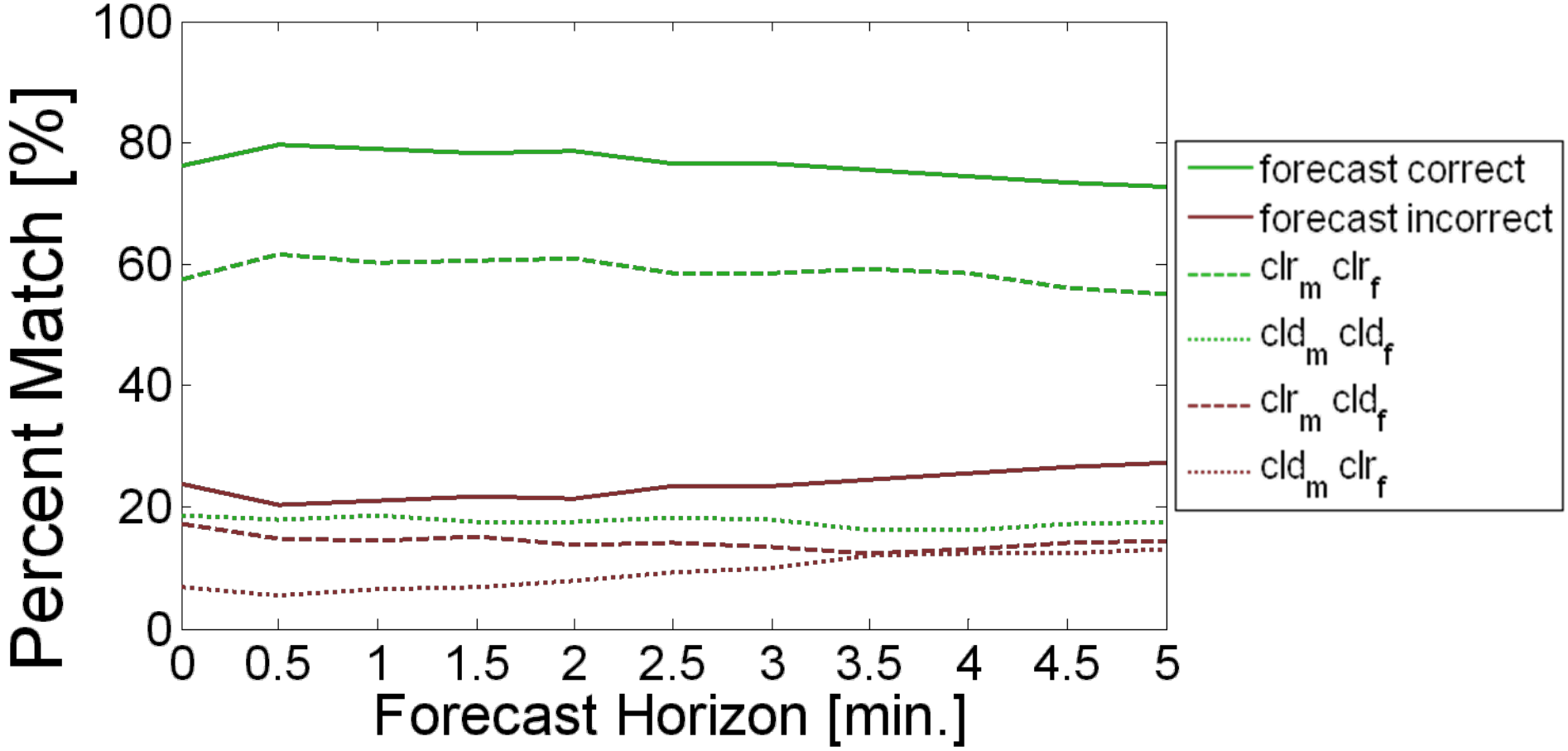




Irradiance Forecast [W m^{-2}]



Cloudy / Clear Forecast Results

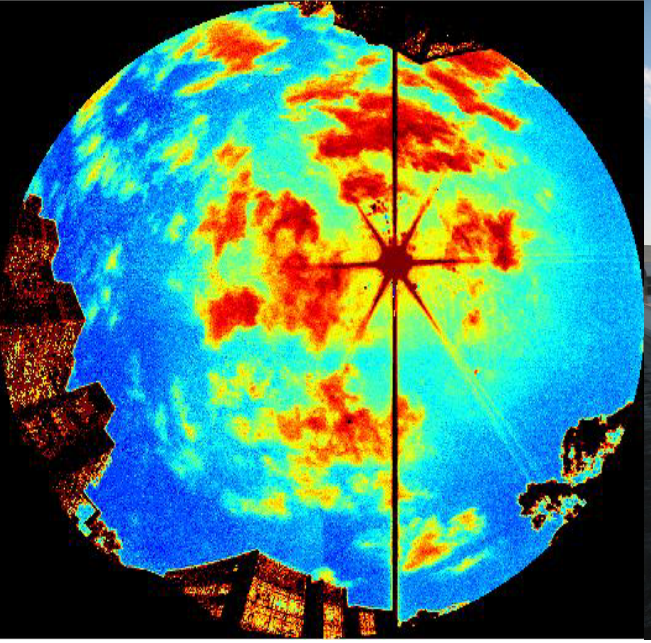


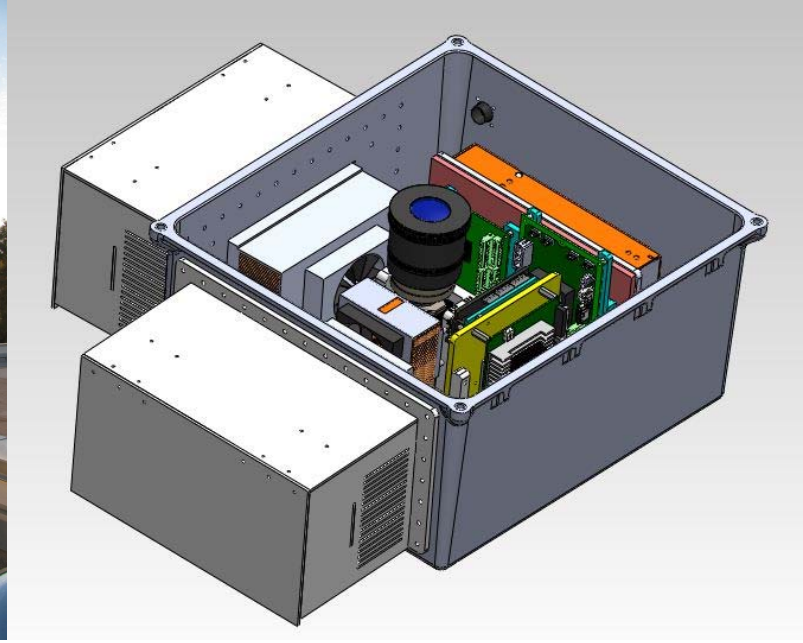
Evaluated method on four days with partly cloudy conditions.

70-80% forecast accuracy based on cloudy / clear pixel count.

Forecast Results at UCSD Testbed

- Error increases with forecast horizon, but still 25% better than persistence after 5 minutes.
- After 10 to 25 min scene exits the field-of-view
  - Sky Imager provides situational awareness to CAISO over this timescale
- Demonstration studies with Sempra Energy at 48 MW PV and SCE for rooftop PV
- If we can achieve the forecasting breakthroughs, 7 sky trackers would provide intra-hour forecasts for the majority of the LA/OC market



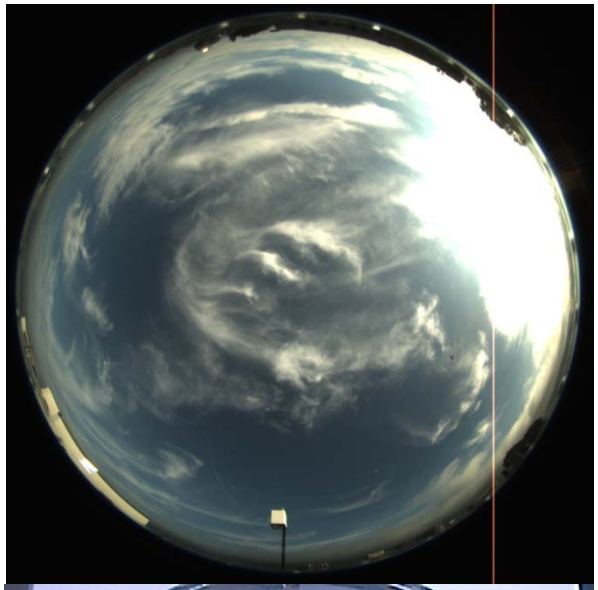


Advanced Sky Imagers Hardware Development

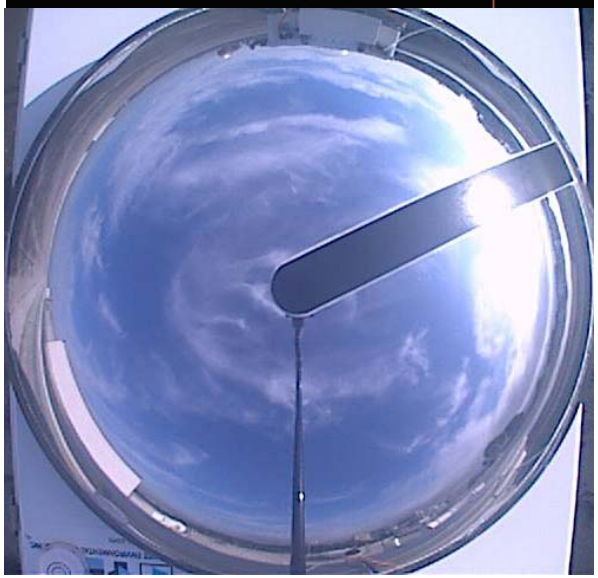
SANYO

UCSD-Sanyo prototype produces **high-quality** sky imagery

UCSD-Sanyo Technology



Current Technology



Major Improvements

- High dynamic range
  - More accurate cloud fields
  - Allows for more reliable thin cloud detection
- No shadowband necessary
  - 10% more imagery available
  - Interpolation errors eliminated
- Controllable image capture process
  - Multiple exposures to create composite reduces data loss to sun saturation

Forecasting Irradiance

- More accurately capturing the cloud field will result in better irradiance forecast performance

SANYO

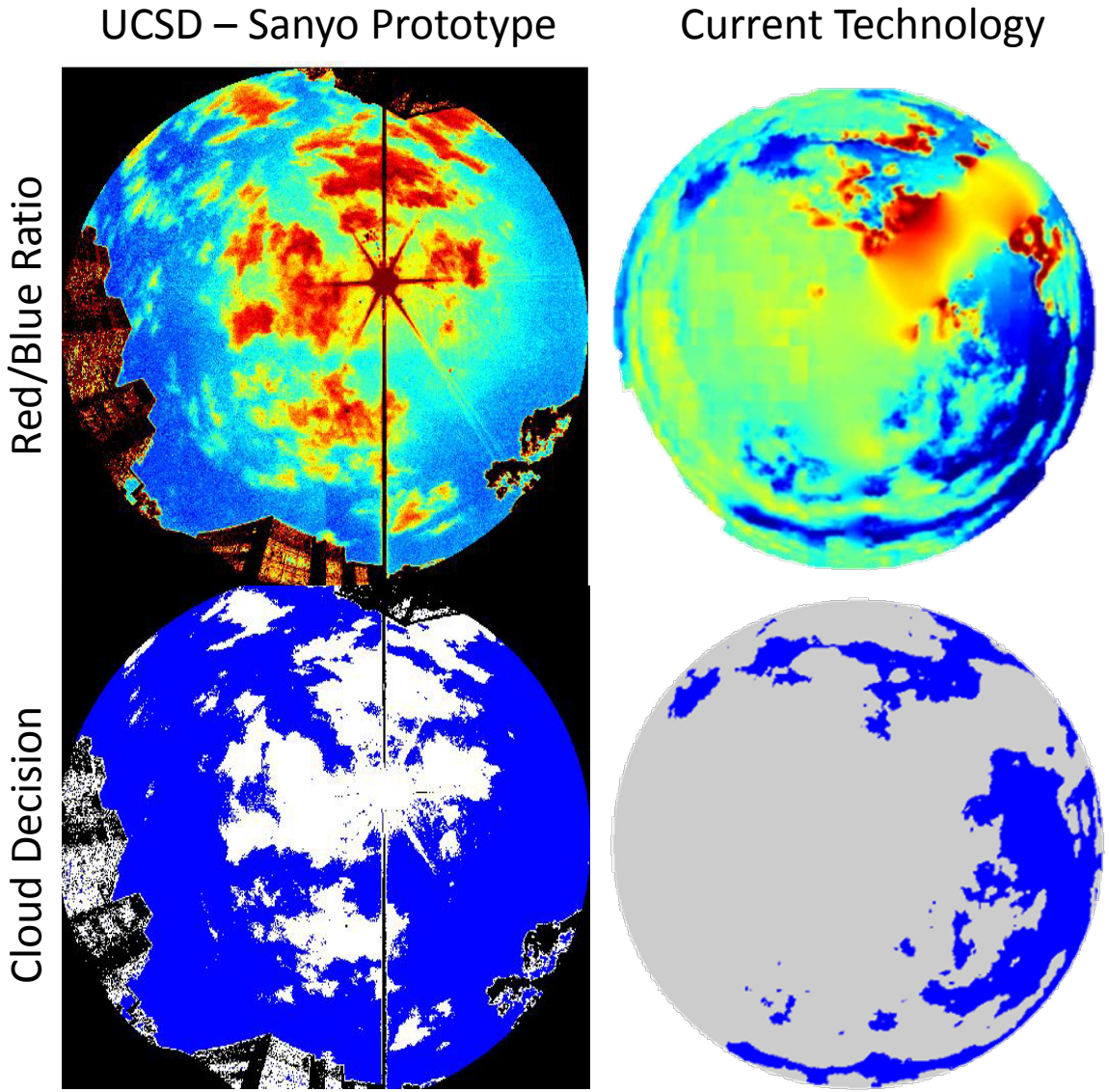
Improved imagery enhances cloud decision accuracy

Improved Red/Blue Ratio (RBR) calculations

- Precise gain control to prevent RBR fluctuations
- No compression tiling

Improved Cloud Decision Images

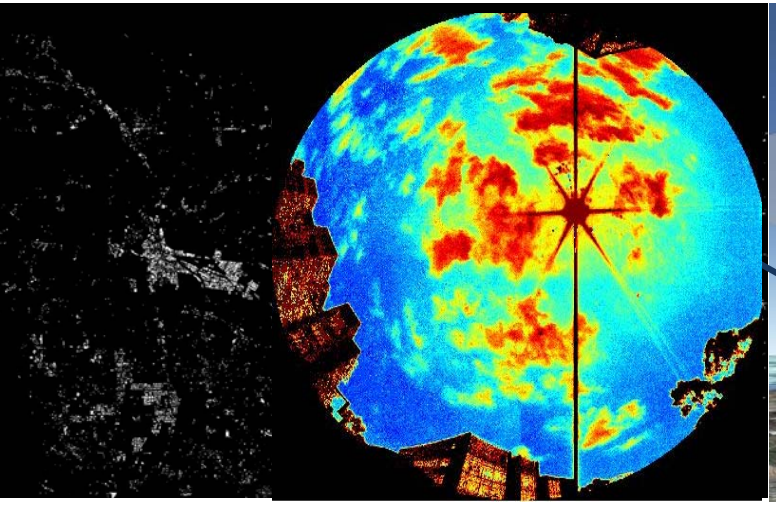
- Saturation near sun will be removed by using composite images from multiple exposures, providing nearly 100% sky coverage.

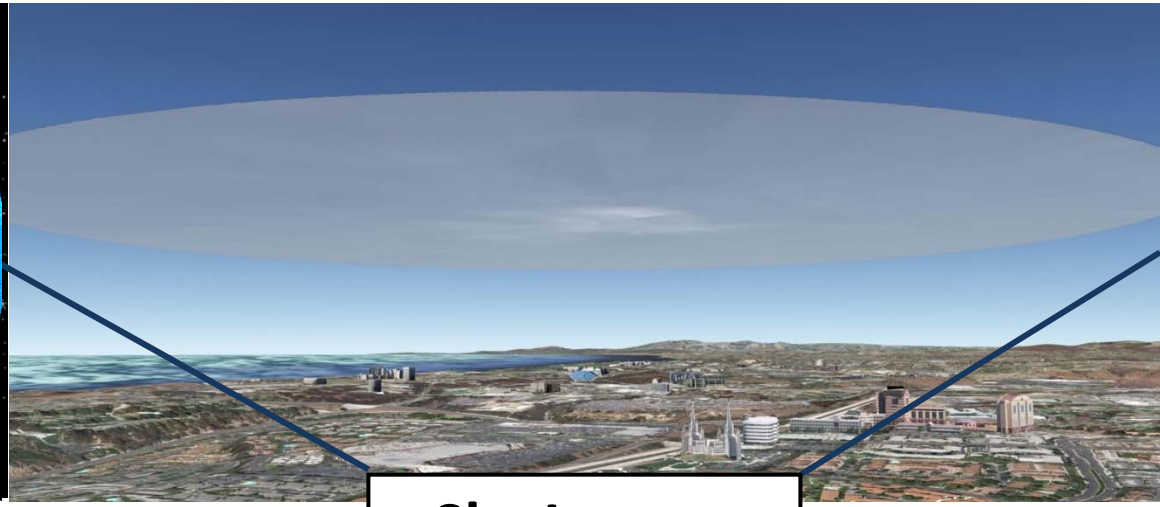


SANYO

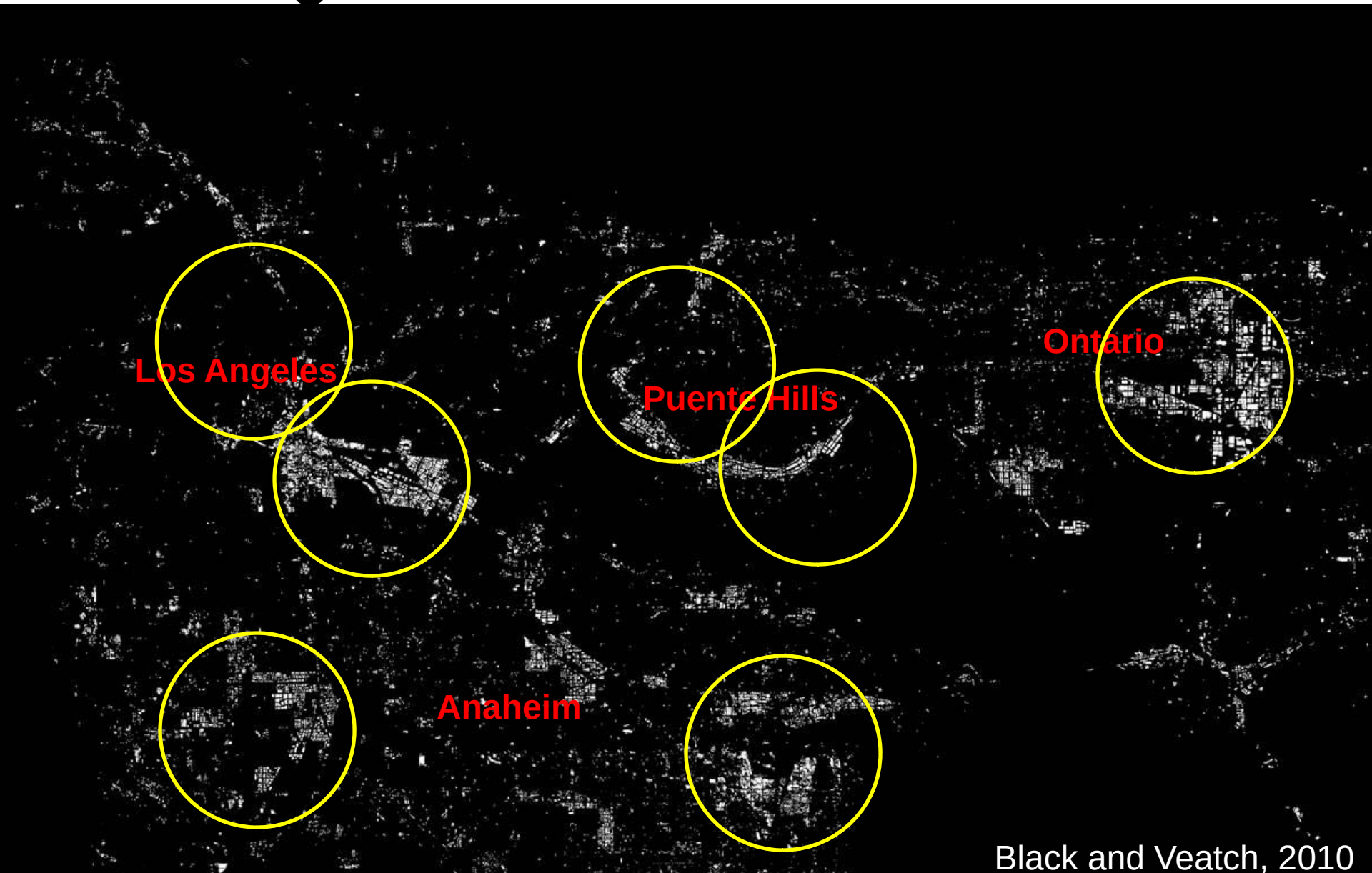
Solar Forecasting for Utility-Scale Distributed Generation in SCE Territory

500-10-060, PI: Enernex





Los Angeles Warehouse Roof Market

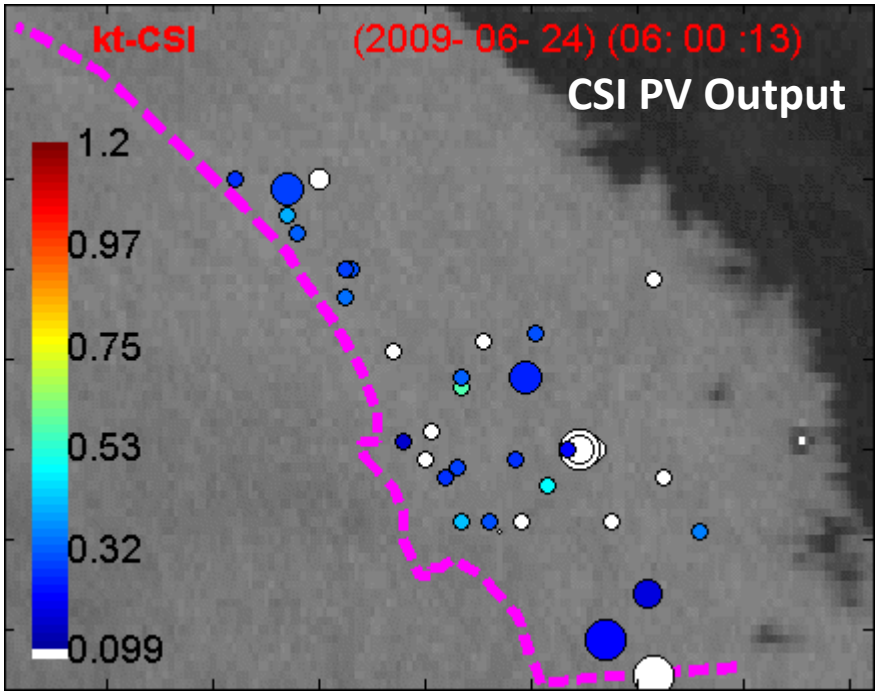


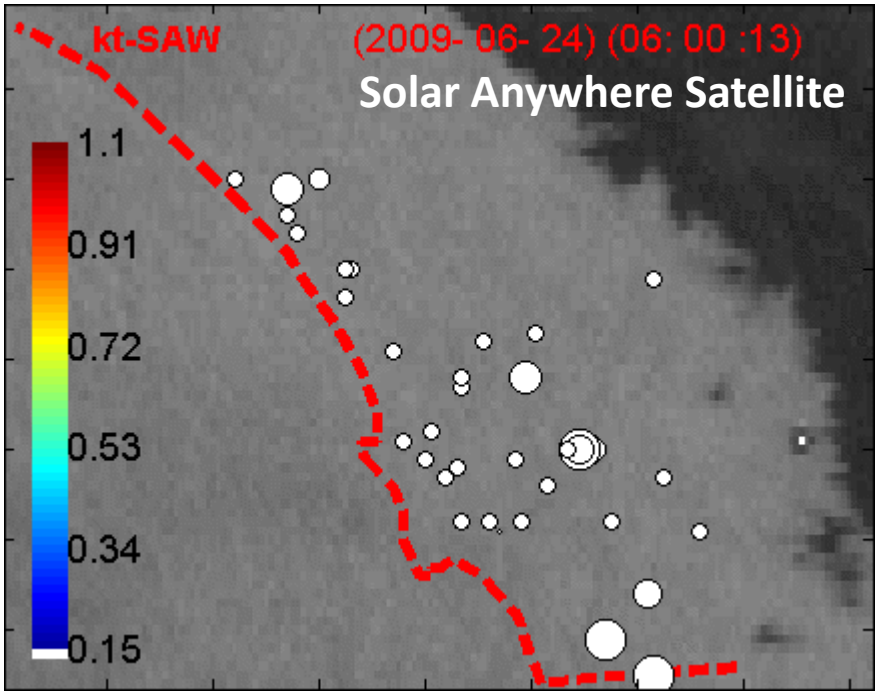
Black and Veatch, 2010

Contingency Scenario: Marine layer burn-off

June 24, 2009: GOES Satellite Imagery Animation

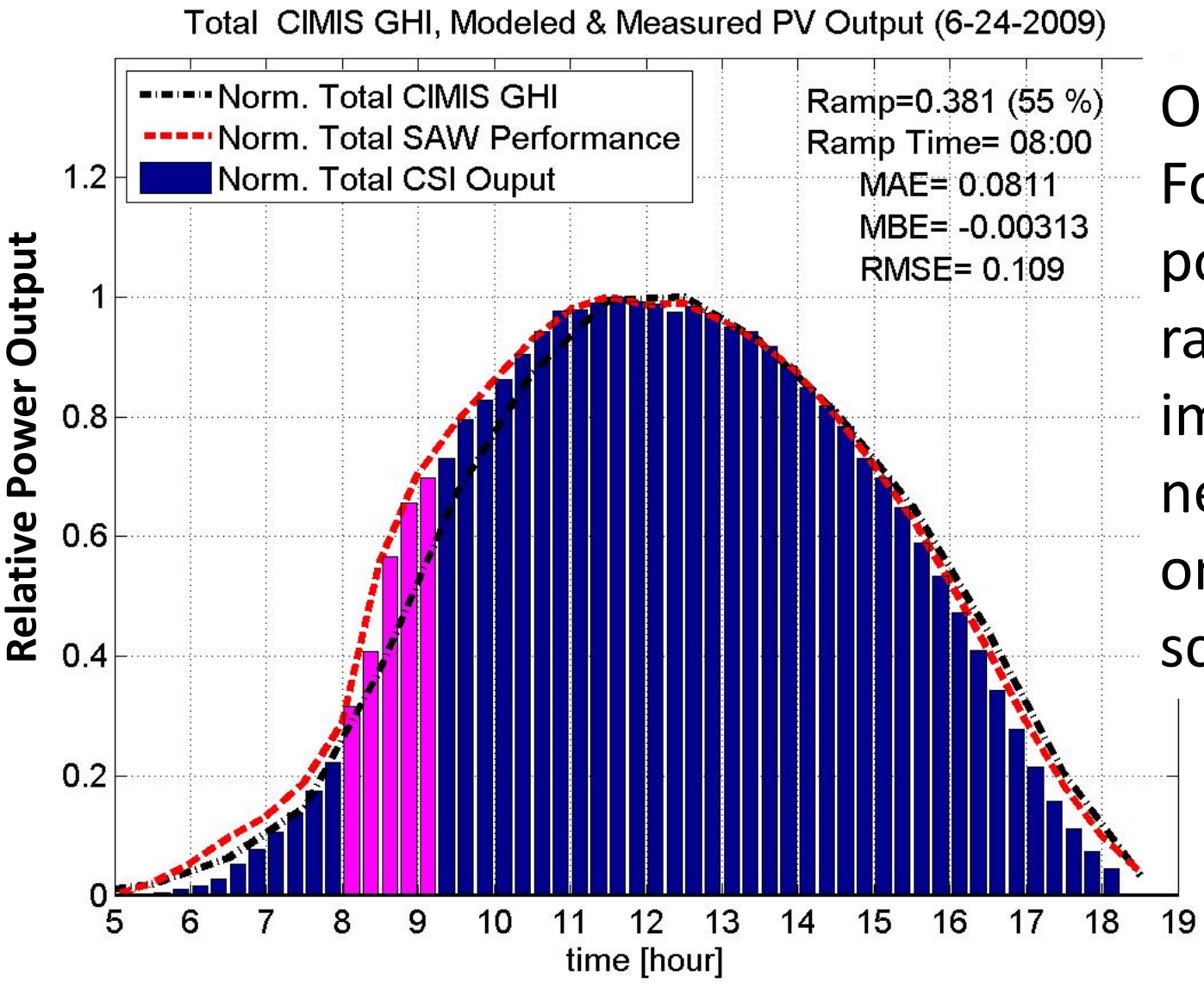
The size of the circles is proportional to the rated power of the solar power plant.





Color: clear sky index = fraction of possible power output. kt = 1: maximum power output (red)

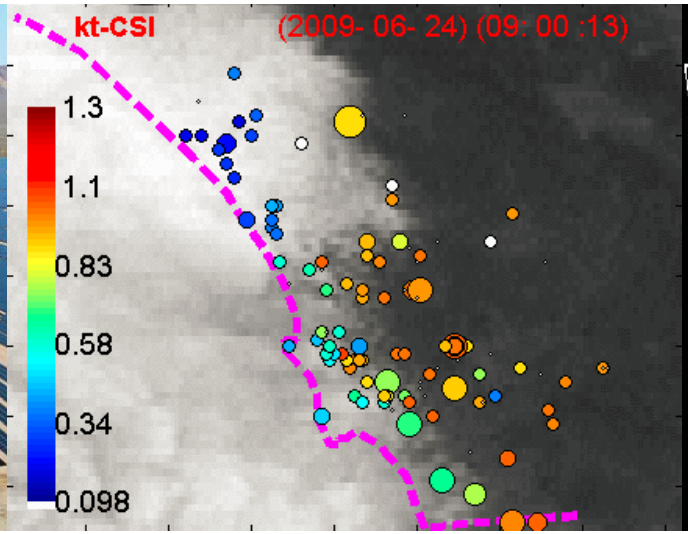
Aggregate power output of 39 PV sites, satellite data, and 5 CIMIS stations

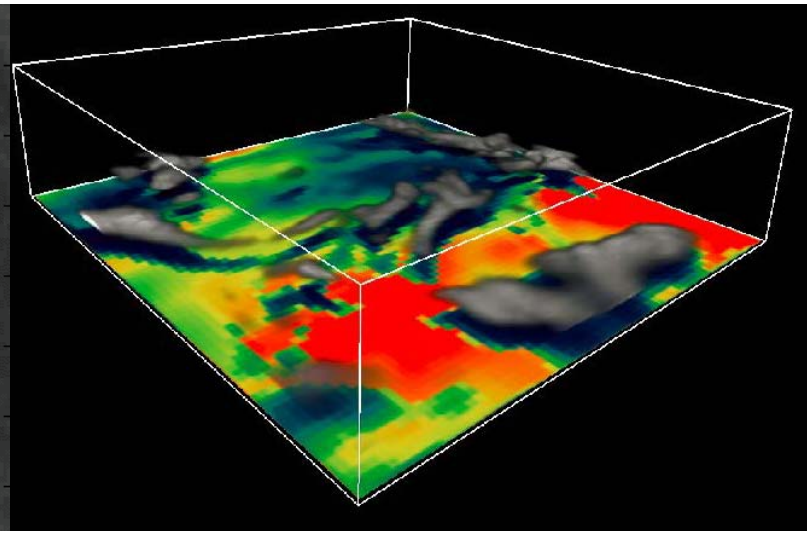


Objective: Forecast fleet power output ramps with sky imager networks. Focus on contingency scenarios.

Renewable Resource Management at UCSD

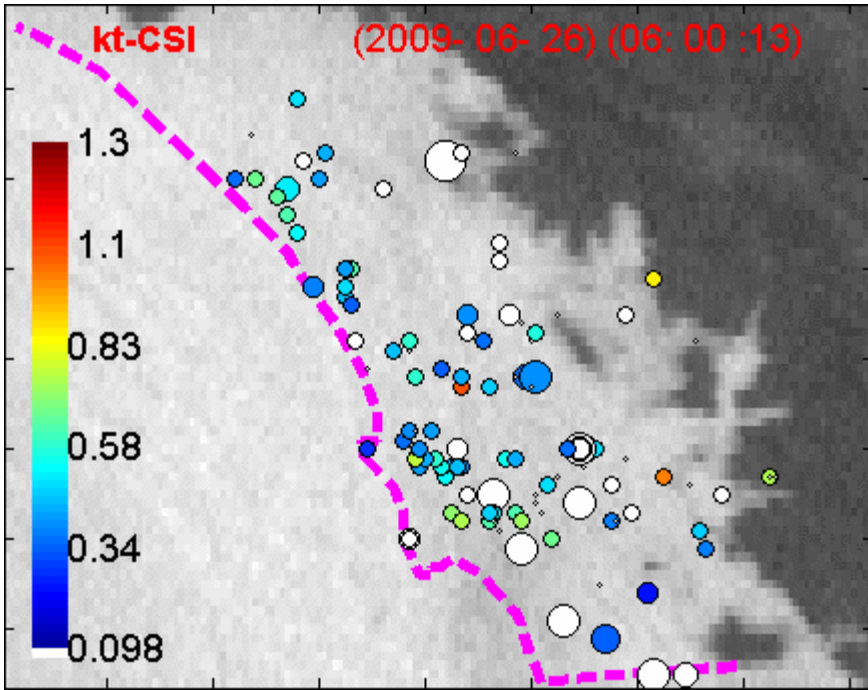
500-10-043





Solar Forecasting Through Ground Data

- Solar forecasts from dense network of ground stations (PV systems)
  - Quality control ground data
  - Compare satellite and ground cloud motion
- Evaluate forecast accuracy

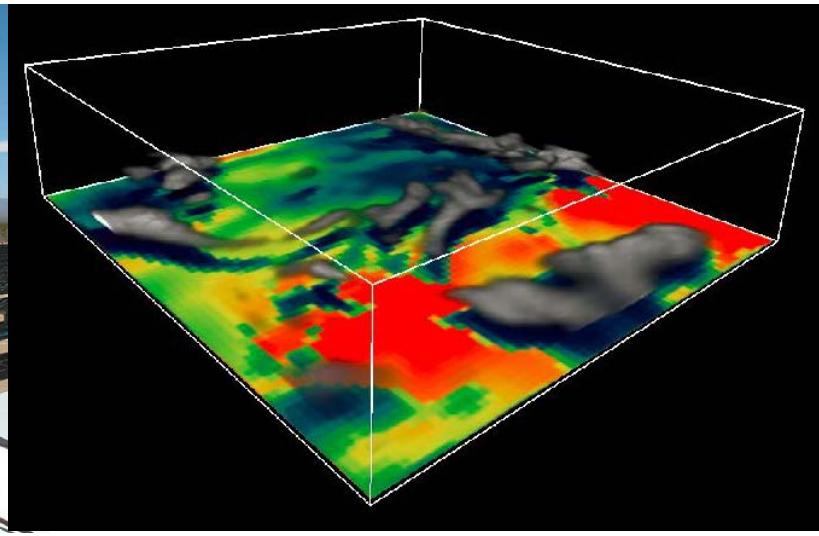


Optimal Forecasting Using Ground / Satellite / NWP

- Evaluate models for different synoptic conditions
- High-resolution numerical weather prediction using Weather Research and Forecasting (WRF) model
  - Assimilate satellite and sky imager data
- Probabilistic forecasting using multi-model ensembles

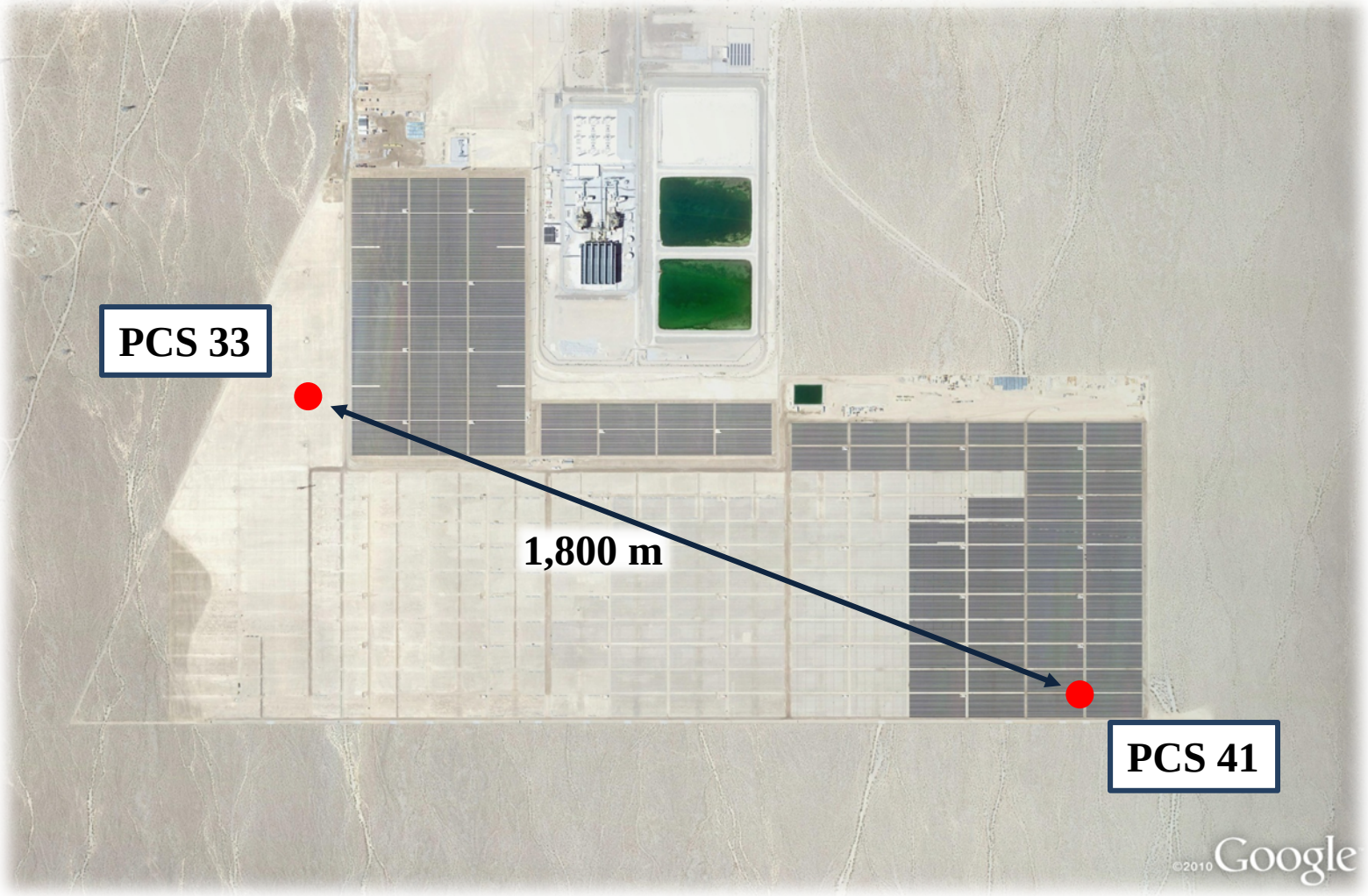
Solar Forecasting for Utility-Scale Centralized PV at Sempra Gen 48 MW PV

500-10-057, PI: AWS Truepower



Sempra Generation Copper Mountain

48 MW Thin Film PV Plant, Largest in the U.S.



● **TSI deployment site**

Total Sky Imager Installation

Forecast Integration

- Integrate sky imager, satellite (Clean Power Research), and NWP (AWS Truepower)
- Evaluate and improve forecast products
  - Regime-based temporal ‘switch-over’ from TSI to satellite to NWP
  - Assimilate detailed TSI cloud information into satellite, and satellite into NWP
  - Enhance cloud motion vectors

Technology Transfer

- Engage Technical Advisory Committee
  - Jim Blatchford, CAISO
  - Bill Torre, SDG&E
  - George Rodriguez, SCE
  - Dan Pearson, PG&E
- Present at SEPA, EPRI webinars
- Conduct workshop
- Engage industry for implementation: Clean Power Research, AWS TruePower, Garrad Hassan

Contact Information

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http://solar.ucsd.edu

UCSD Portal on DOE website: https://solarhighpen.energy.gov/project/university_of_california_san_diego