Energy Efficiency and
Renewable Energy

Public Interest
Energy Research

Geographic smoothing and forecasting RD&D for high PV penetration

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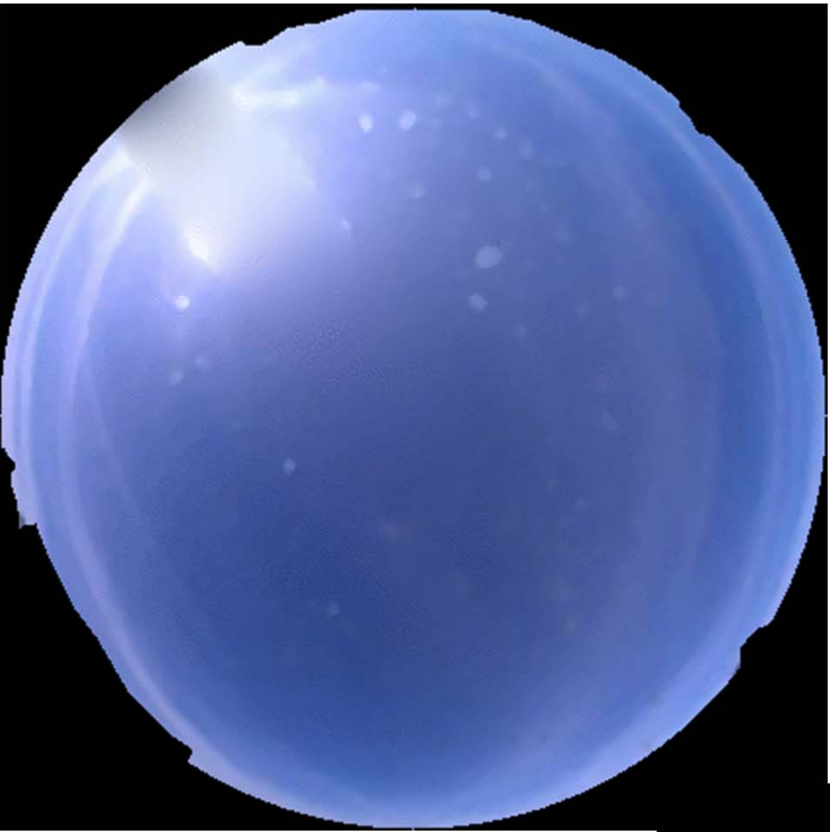
Variability of Solar Irradiance as an Impediment to High Solar Penetration

- Distribution system
  - Voltage changes; wear and tear on voltage regulation equipment
  - Reverse power flows
- Transmission system
  - Low penetration: forecast error leads to increase in reserve costs, inefficient transmission scheduling
  - Very high penetration: curtailment, storage

What causes PV variability?

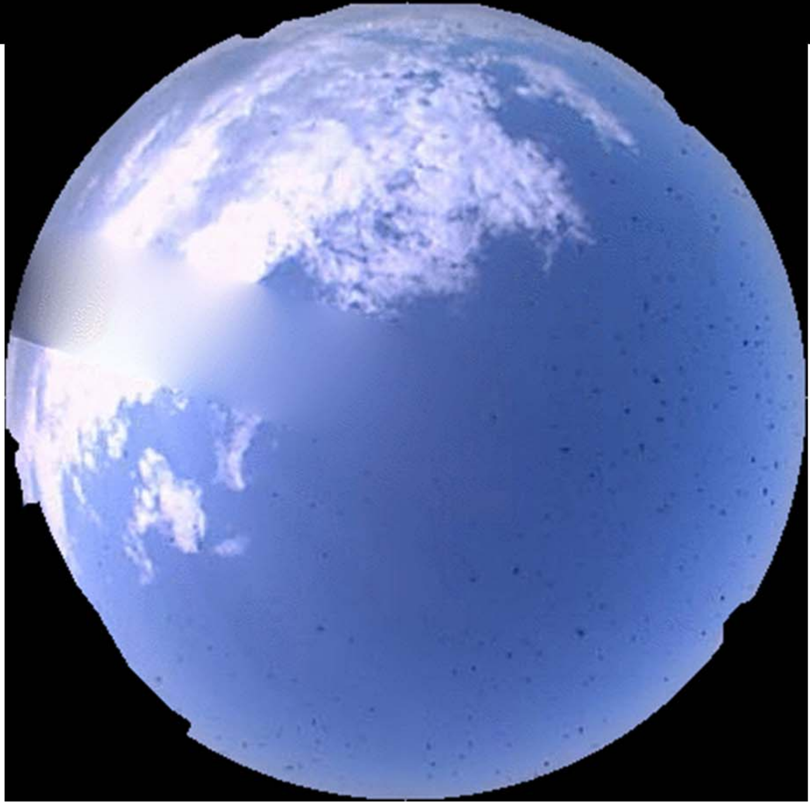
- Sun angles (predictable)
- Global solar irradiance
  - Variability due to clouds
  - Humidity / dust effects negligible for PV
- Cell Temperature: 0.5% / ^{o}C performance drop
  - Air temperature, wind speed
- Mounting / Operation
  - Shading, thermal properties

Cloud Types

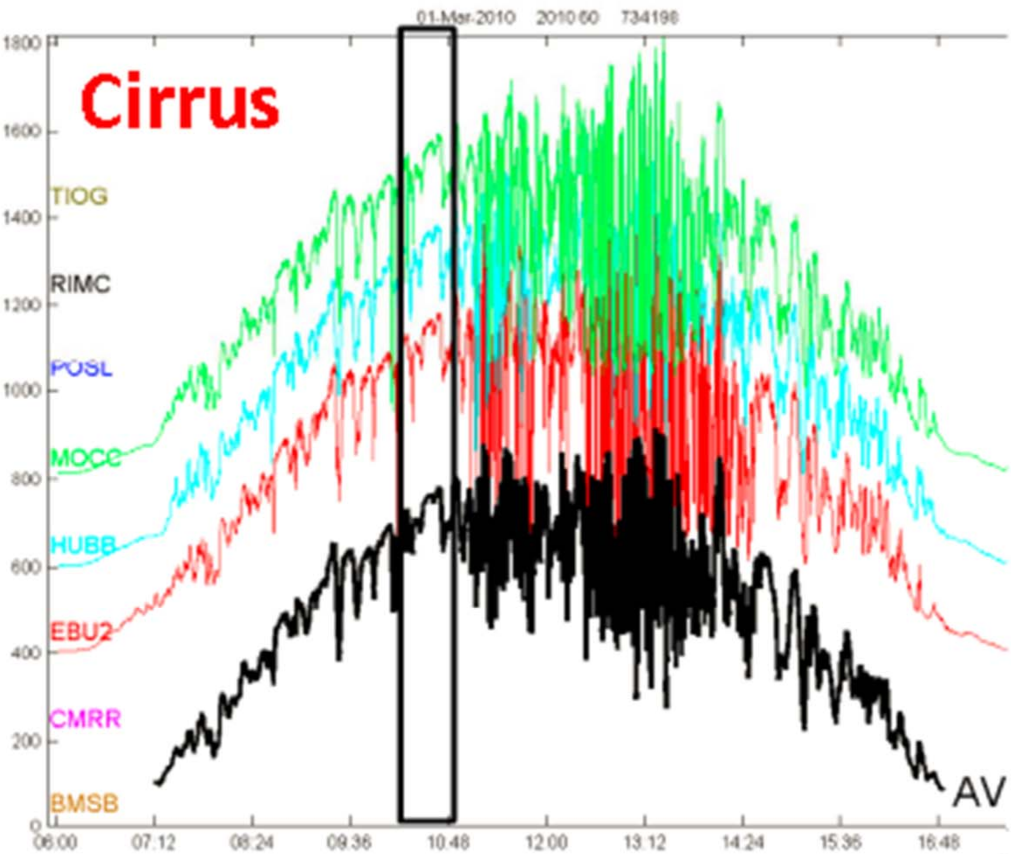


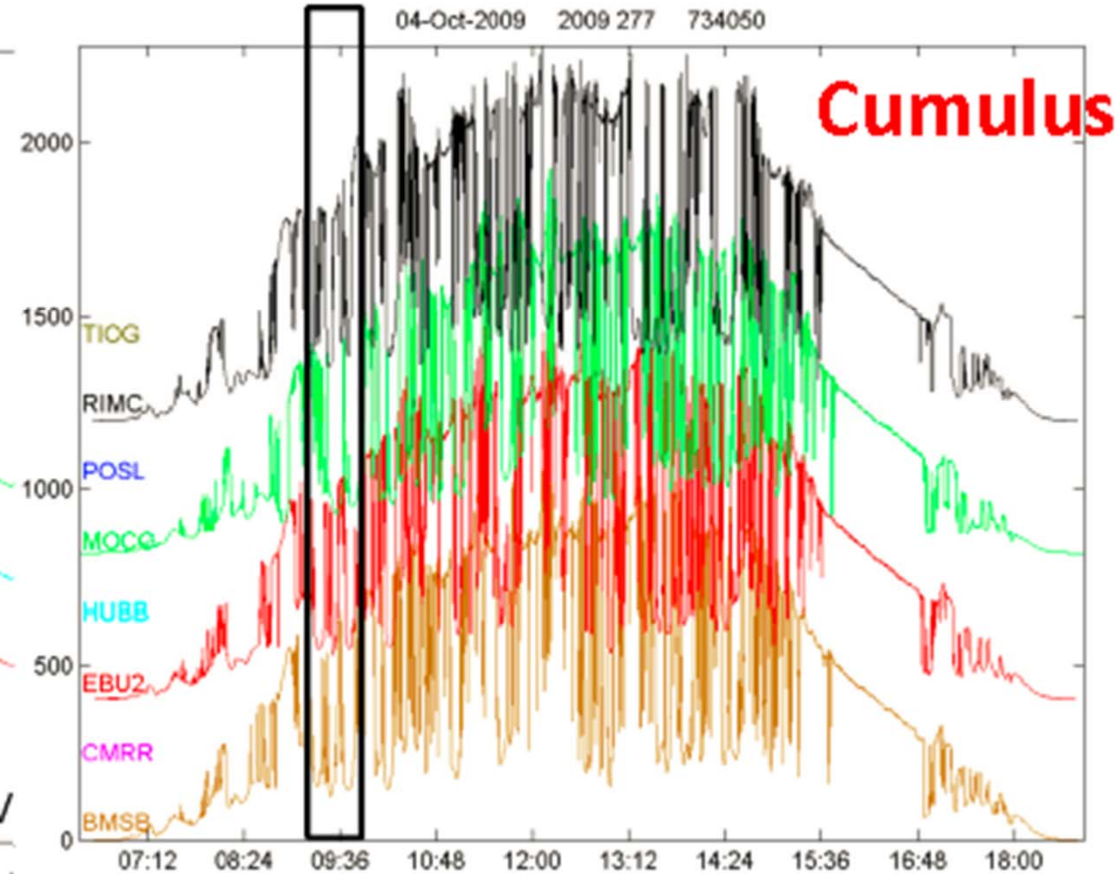
Cirrus

Cumulus



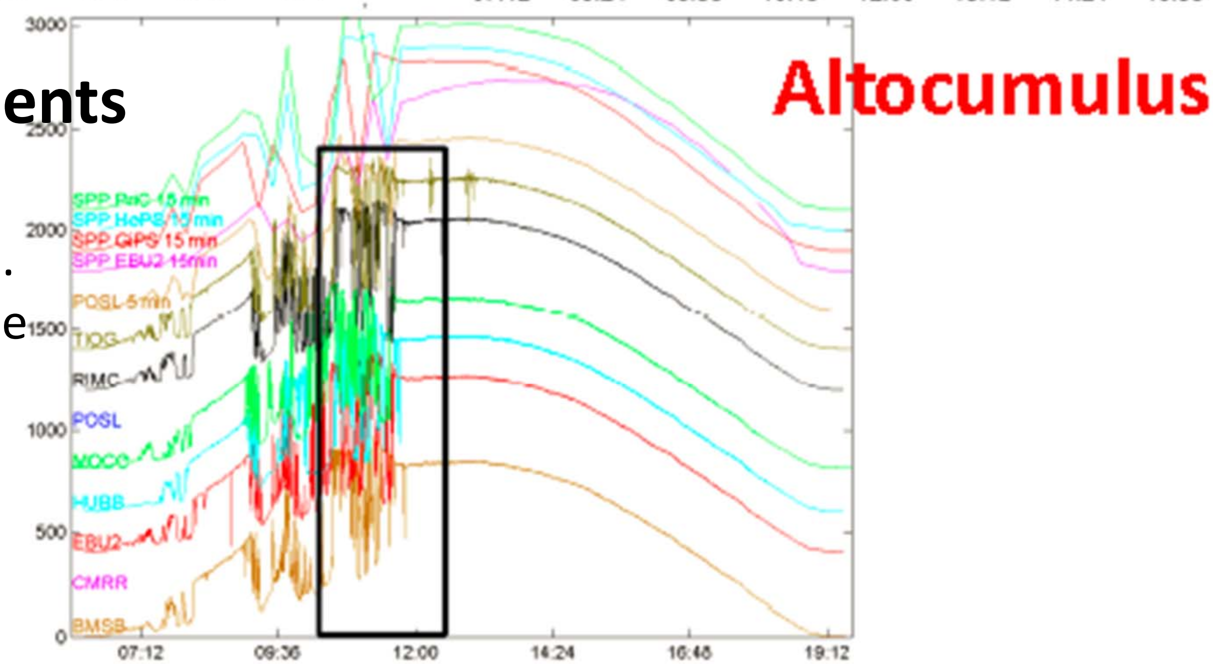
Altocumulus





Irradiance measurements on the same days

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

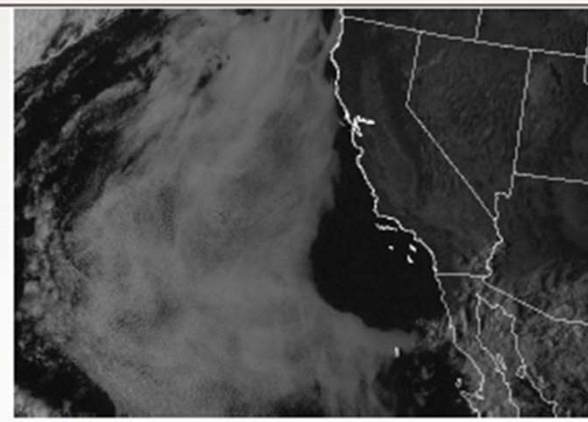


Challenges

The Challenge – Making the Best Forecast for Various Time Scales

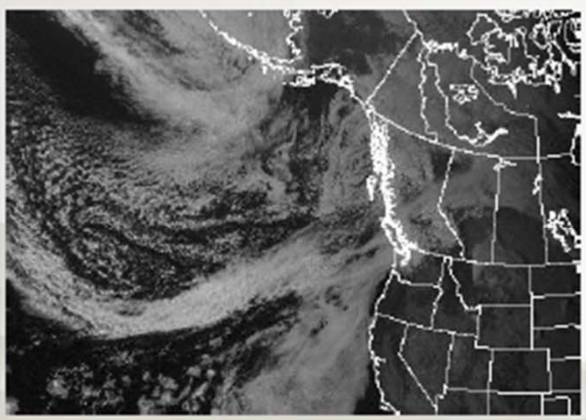
Minutes Ahead

- Cumulus clouds, small-scale cloud structures, fog
- Rapid and erratic evolution; very short lifetimes
- Mostly not observed by current sensor network
- **Tools: persistence, skycams, local irradiance trends**
- Very difficult to beat a persistence forecast
- Need: Data & tools to handle development & dissipation



Hours Ahead

- Frontal bands, mesoscale bands, fog, thunderstorms
- Rapidly changing, short lifetimes
- Current sensors detect existence but not structure
- **Tools: satellite-based cloud advection and NWP**
- Need: Better forecasts of development & dissipation



Days Ahead

- "Lows and Highs", frontal systems
- Slowly evolving, long lifetimes
- Well observed with current sensor network
- **Tools: NWP with statistical adjustments**
- **> ~ 10 days-** climatology and climate trends
- Need: better NWP performance & improved MOS

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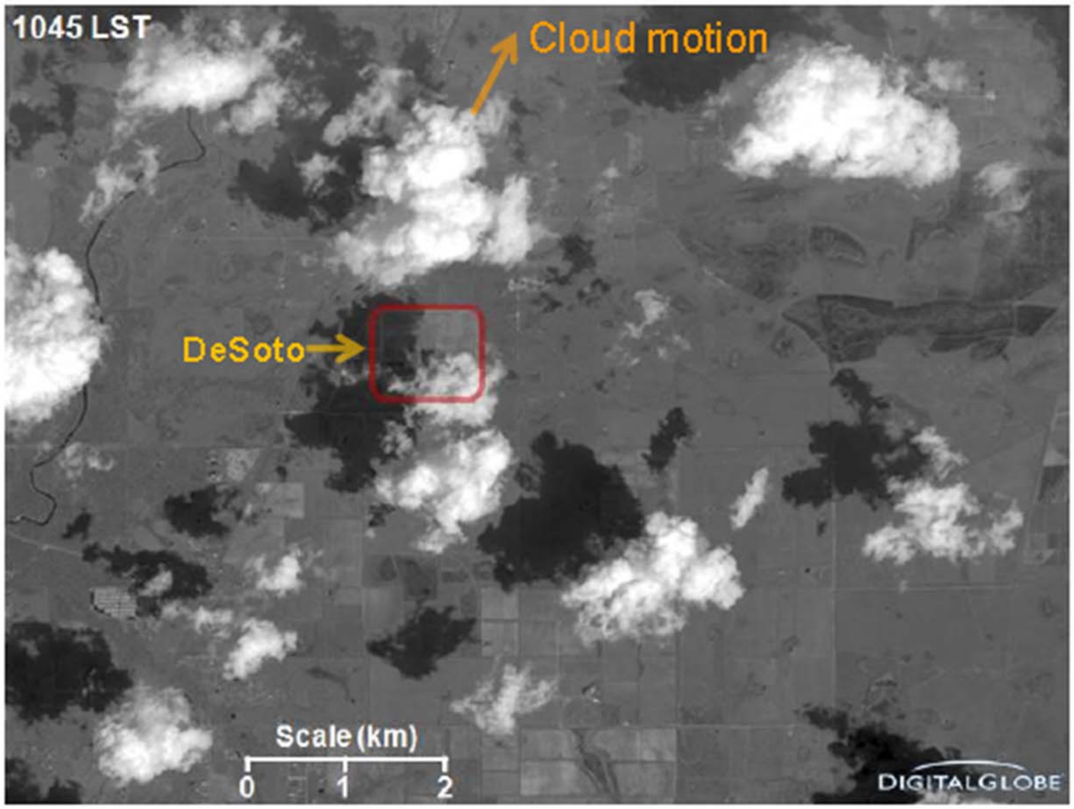
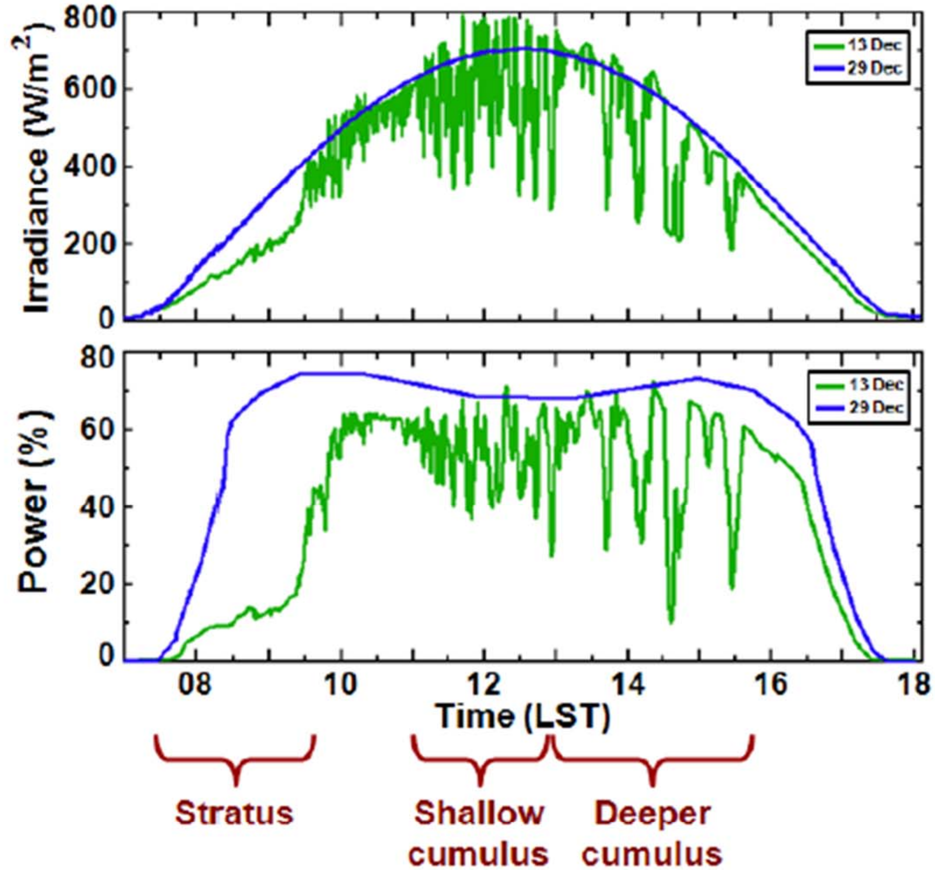
Clouds come in many types, with varying impacts on power. May be easier to forecast range of variability than schedule.

Cloud Impact Example



Example of clouds over the DeSoto PV site



Solar energy ramp events are influenced by cloud type, size and speed

Mark Ahlstrom, Windlogics

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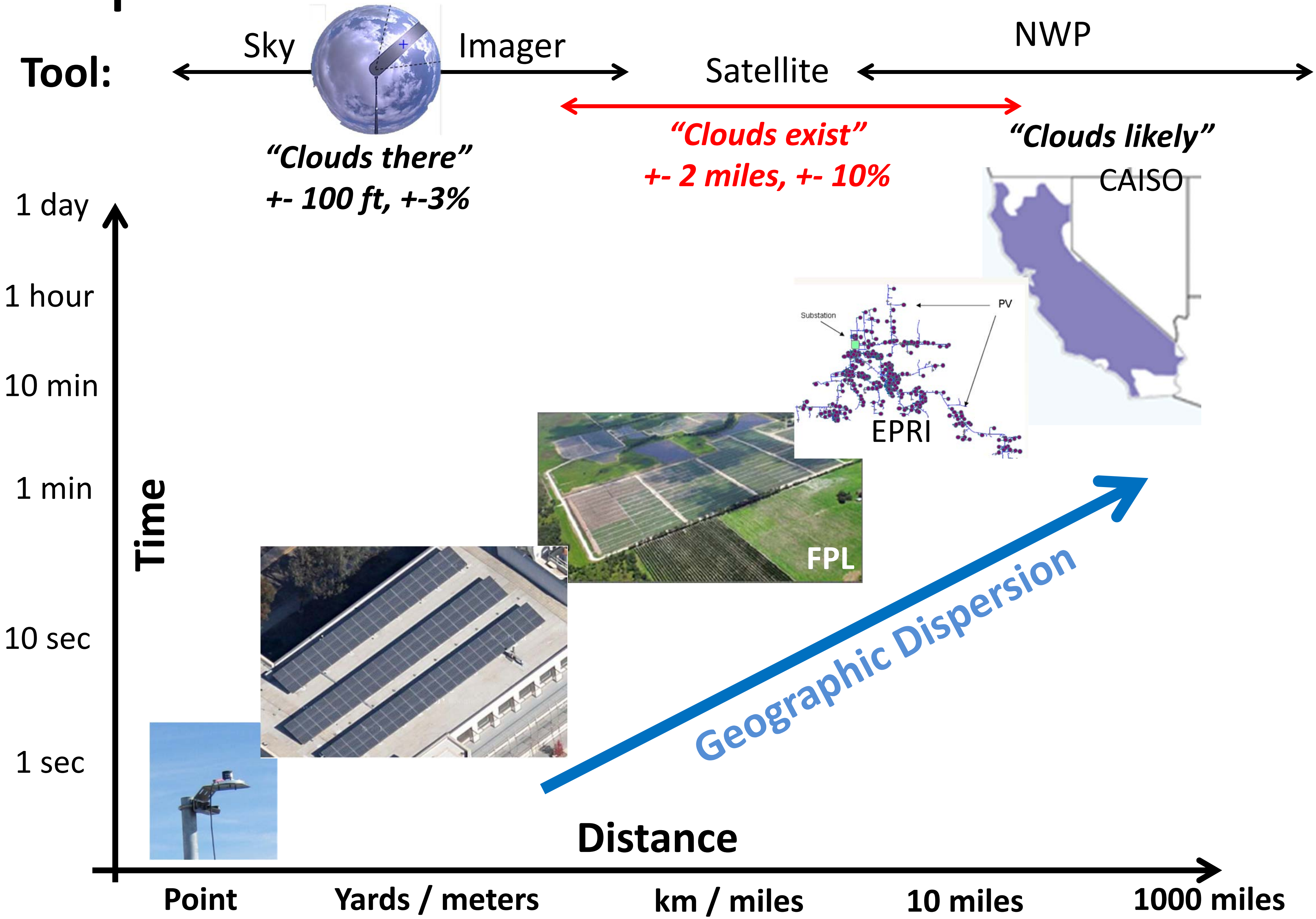
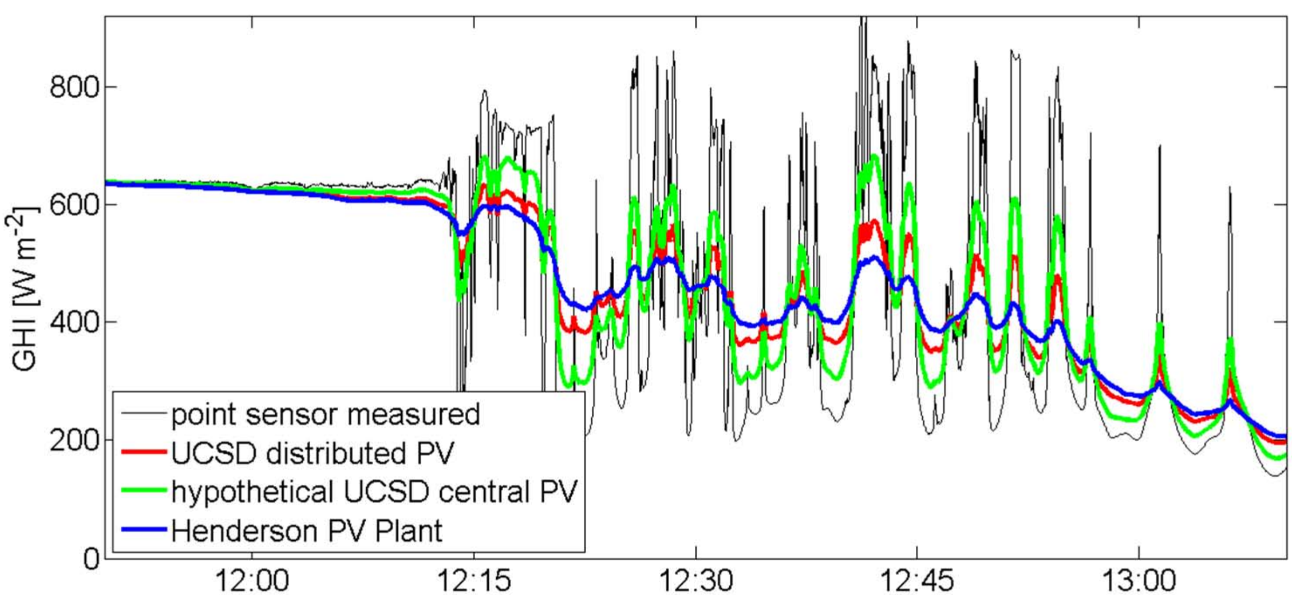
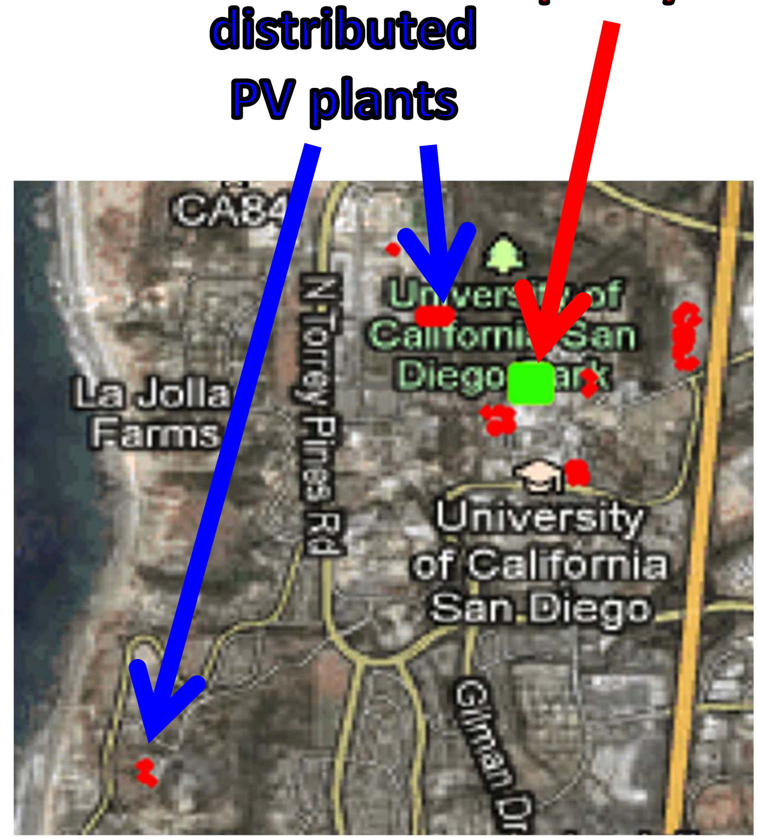
Space and Time Scales of Forecasts



Simulating Geographic Smoothing

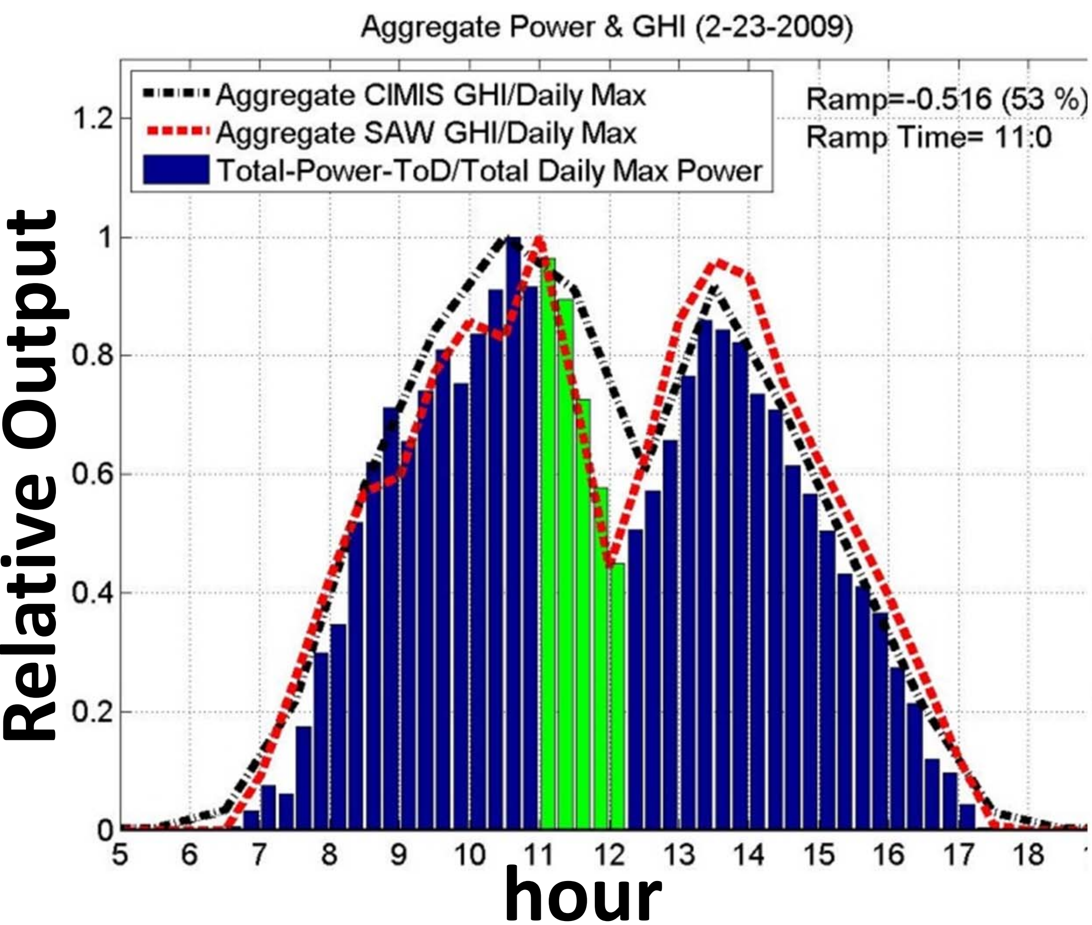
- Example: UC San Diego Campus.
- Distributed PV shows largest additional reduction in variability at 1 to 5 minute ramps.
- It is now possible to simulate geographic smoothing.
  - Lave and Kleissl (ASES), Hoff (DOE/CPUC workshop)



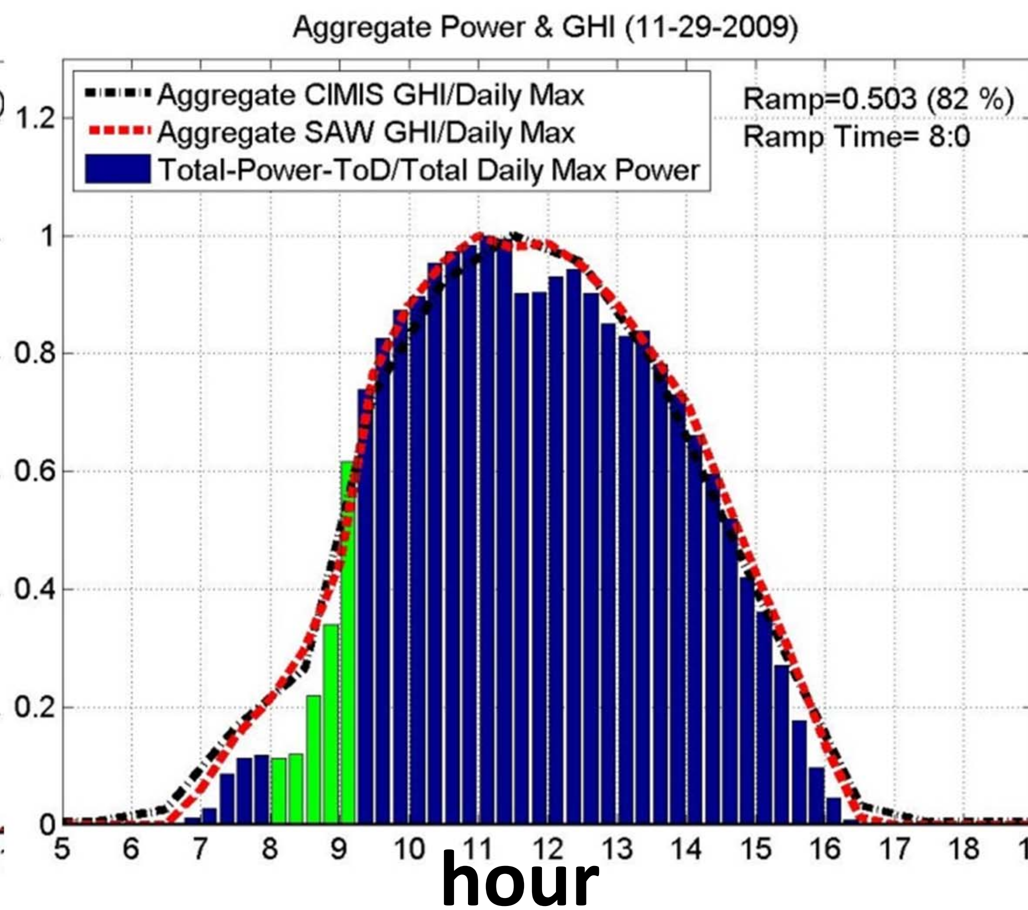


How well do ground and satellite data match PV generation?

Largest up-ramp: 60% of P_{max} in 1 hour



Largest down-ramp: 43% of P_{max} in 1 hour



Large ramps are detectable real-time by satellite and ground stations

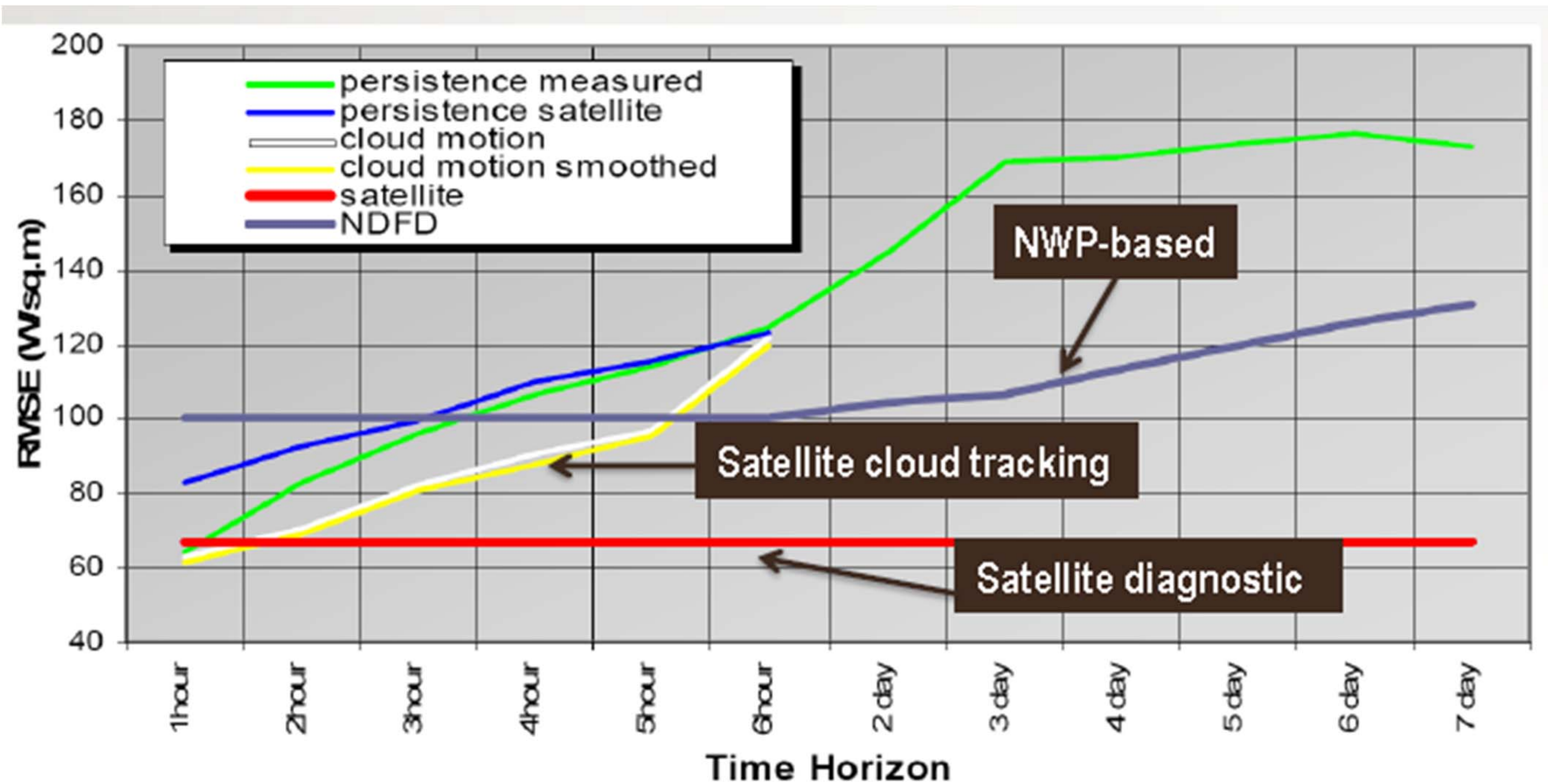
Are largest ramps *predictable* – day ahead, hour ahead? Under what conditions are ramps more likely?

Summary of Forecast Needs

- Geographic smoothing avoids the need for high resolution forecasts for large areas (e.g. for ISOs)
- Limited need for ground station networks due to high accuracy of satellite.
  - Reserved for very high PV penetration
- Required spatial and temporal resolution depends on application. Applications:
  - Currently: Balancing areas to estimate net demand. Solar generation insignificant.
  - Future:
    - Large solar generation. Balancing areas need accurate forecasts
    - Solar power plant operators
    - Transmission scheduling, Intra-hour markets.
- Address regulatory requirements: FERC NOPR

Forecast Tools / Error

- Numerical Weather Prediction
- Satellite Cloud Tracking
- Persistence



Richard Perez, ASRC

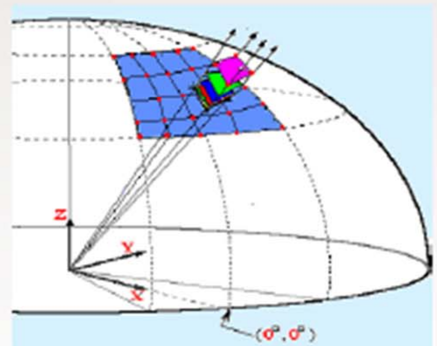
Methods

Forecasting Techniques - Days Ahead

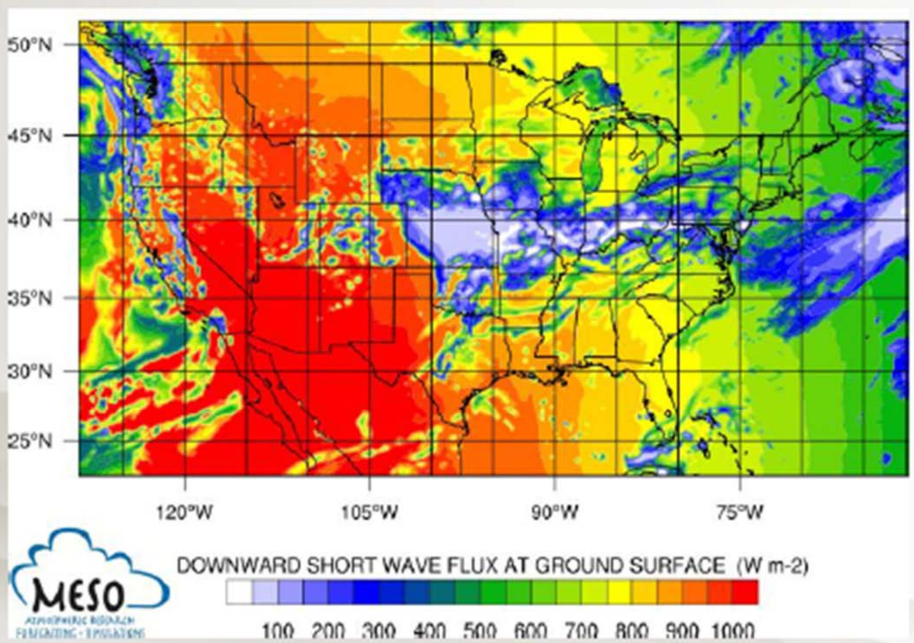
Physics-based Numerical Weather Prediction (NWP) Models

- Differential equations for basic physical principles (conservation laws) are solved on a 3-D grid
- Simulates the evolution of the atmosphere over a 3-D volume
  - explicitly predicts a time series of most atmospheric variables including solar irradiance at all grid points in the model domain

$$\frac{\partial u}{\partial t} = m\left(-u\frac{\partial u}{\partial x} - v\frac{\partial v}{\partial y} - \frac{\partial \Phi}{\partial x} - \sigma_p \alpha \frac{\partial p^*}{\partial x}\right) - \dot{\sigma}\frac{\partial u}{\partial \sigma_p} + fv$$



- Initial values for all variables must be specified for all grid cells.
- Boundary values must be specified for all boundary cells (usually from another model with a larger domain)



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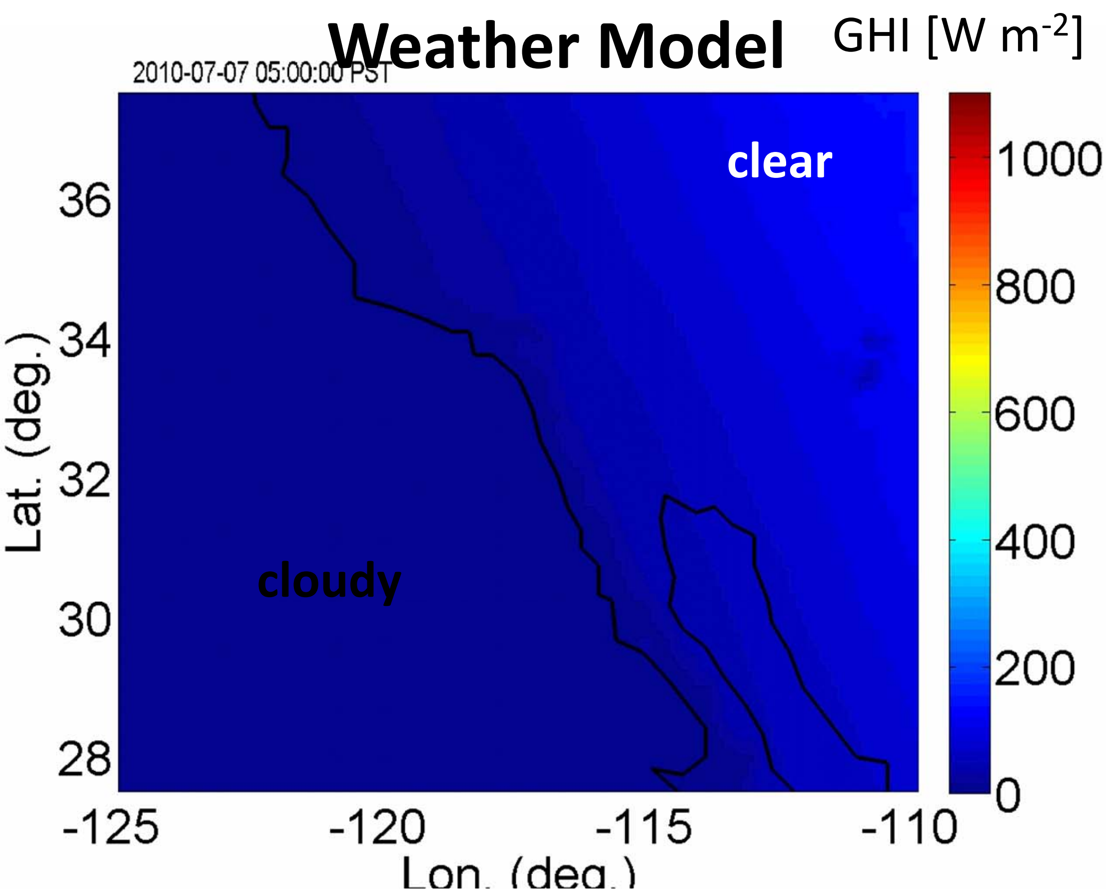
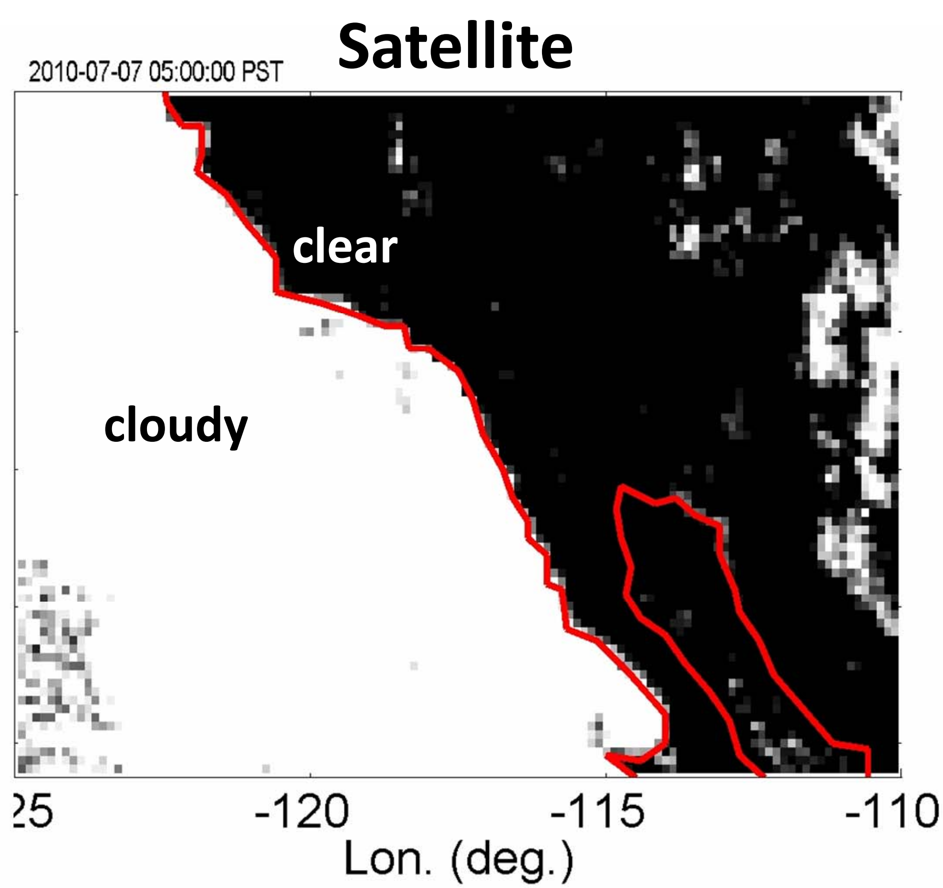
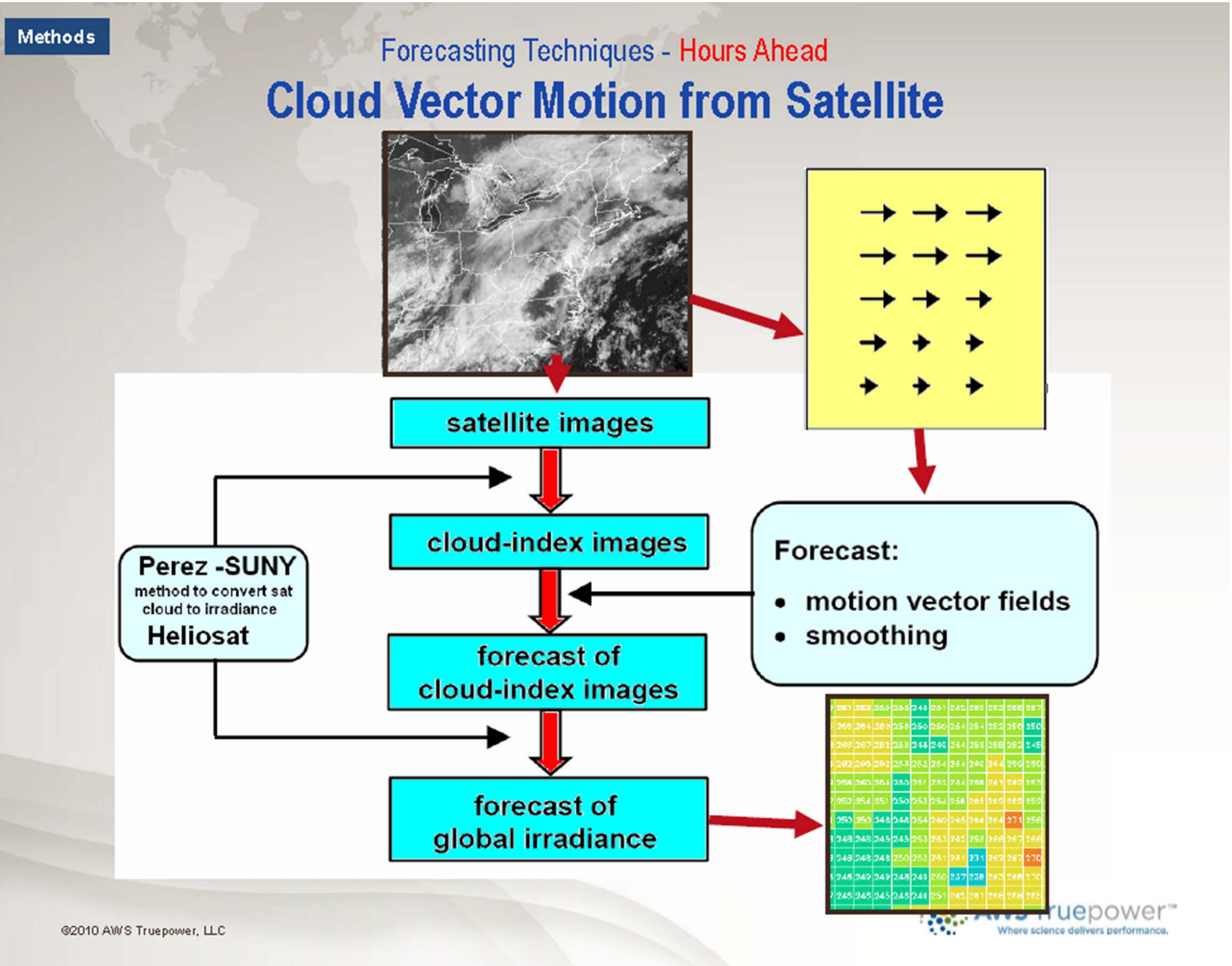
Example of NWP Forecast errors

- Small spatial error (10 to 100 miles), but big impact (80% of CA DG)
- Reducing error would require very high resolution NWP







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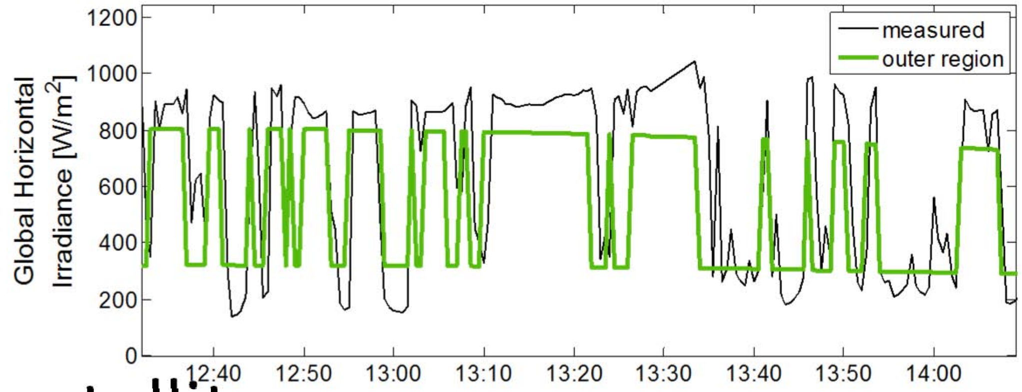
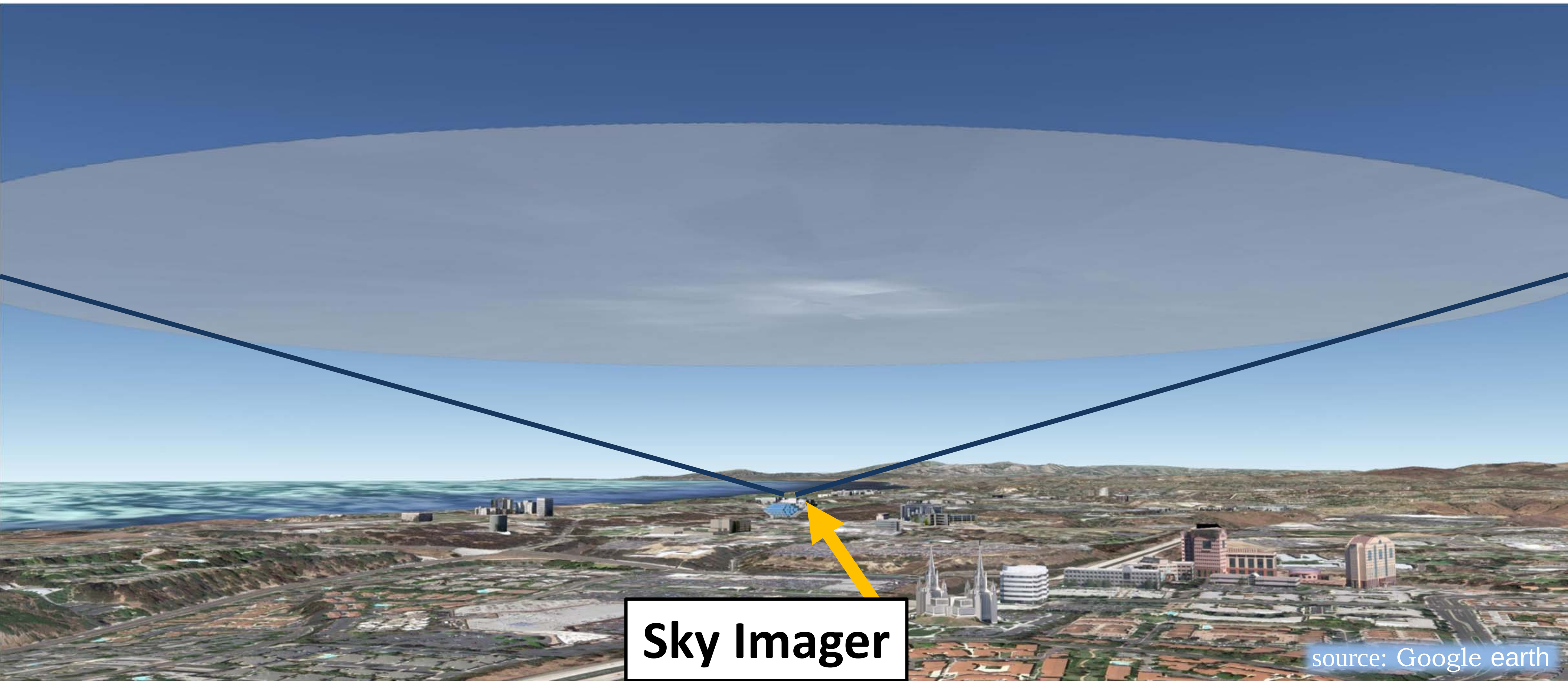
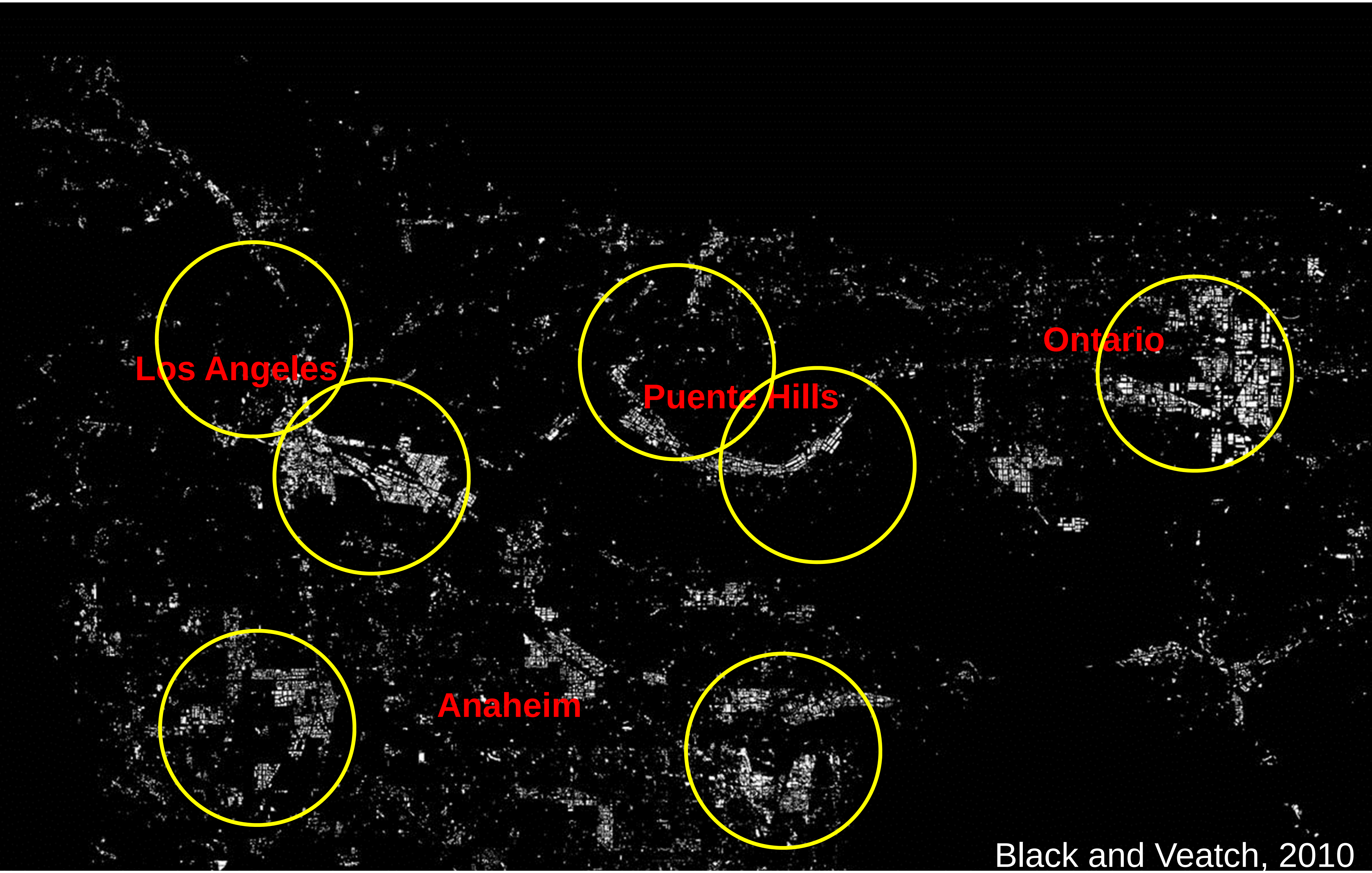
Total Sky Imagery



- Cloud projection
- Cloud advection similar to satellite
- High spatial and temporal resolution, but limited horizon



Los Angeles Warehouse Roof Market

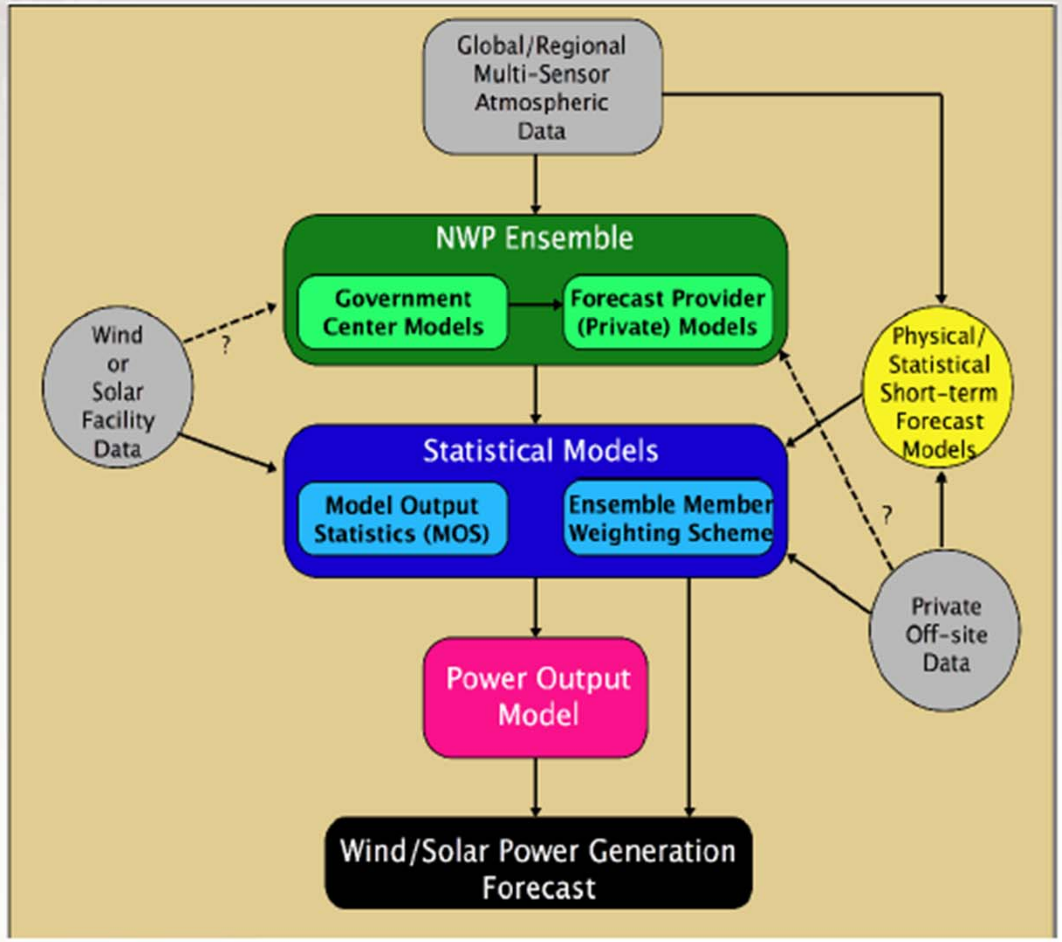


Black and Veatch, 2010

Methods

Integrated Solar Forecast System

- Combination of several methods and a variety of input data types
- Ideally: the system seamlessly switches from one technique to another as the look-ahead time increases
- Plant output model must consider the type of solar facility
  - PV, CSP etc
  - Could be a statistical or physics-based model



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The Role of RD&D in Solar Forecasting

The ultimate goal is for solar forecasts to

- reduce non-renewable peaker generation, spinning reserves and permanent load shifting.
- be 90% accurate (MAPE) in intra-hour solar forecasts for distribution circuits and 98% accurate over CAISO.
- raise the reliability for a spatially dispersed DG network to be characterized as a firm generation intra-hour resource on a distribution circuit and a wider regional area.
- be integrated with energy storage for intra-hour charge-discharge algorithms or voltage control equipment.

RD&D direction to advance High PV Pen

Day ahead Solar Forecasting (NWP)

- Improve statistical corrections (regime-based corrections), but soon diminishing returns
  - Specific meteorological events (marine layer clouds, Tule fog)
- More and better assimilation of ground or satellite data into NWP
- Improve NWP cloud and radiative transfer models
- Conduct high resolution rapid refresh simulations to improve cloud resolution

Timeline

RD&D direction, focus, strategies or initiatives to advance High PV Pen

- Intra-day Solar Forecasting (Satellite)
  - 2D radiative transfer models to model cloud effects (especially for concentrating solar power)
  - Enhance to account for cloud dissipation / development
- Intra-hour Solar Forecasting
  - Responsive to FERC NOPR RM10-11-000
  - Sky imager integration with satellite imagery
    - 3D radiative transfer models
  - Mathematical techniques (neural networks, estimators)

Integrating Solar Forecasting with the Smart Grid Solar Stakeholders

- Transformer, inverters, energy storage and PV manufacturers
- Distribution system operators, designers, and control software developers for mitigating variability
- ISOs for centralized solar, microgrids, virtual power plants and DG and the private sector stakeholders in these markets
- Tech transfer to regulators and professional standards for allowable limits of penetration
- A great start with the DOE-CPUC workshop site hosted by UCSD March 2011

Future

Future Prospects:
How can forecast value be increased?

- **Develop Distributed Solar Generation Forecast Tools**
  - Inventory of solar generation sites
    - System attributes
    - Operating condition
  - Data from the sites?
  - NWP and satellite-based methods can be easily adapted for this application
  - Statistical schemes need site data (power output or irradiance)
- **Make more effective use of forecast information**
  - Use of probabilistic forecasts
    - Substantial amount of information is discarded when ONLY deterministic information is provided
    - Research studies in other (non-energy) applications have indicated that trained users make better application decisions when using a probabilistic forecast
  - Better forecast integration with decision-maker's procedures

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Vendors will vary on how they combine methods to best advantage, and how NWP models are enhanced in the future

Technical Issues

- **Optimal "blending" of methods**
  - Bridging the gaps smoothly across time
- **Various methods not only work best in certain timeframes, but also work best with certain cloud types**
  - Rapid Update Cycle models may work better than satellite tracking during convective events
  - Certain cloud types (e.g. shallow cumulus) will have predictable impact patterns on solar energy production (depth & frequency)
- **Optimizing power forecasts for time steps that matter to the power system**
  - Average power versus intra-period variability
  - The operating and market rules matter!

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Acknowledgement of Funding Sources

- $1.9M DOE grant and $0.5M CEC matching for Modeling for High PV Penetration
- $1M of CEC RESCO to $1M of UCSD match
- $0.2M from CEC Solar Collaborative
- $0.5M of CSI Round I
- $0.7M from Sanyo for Battery Storage Integration
- $0.5M from CEC for Forecast Model Integration

- Jan Kleissl, University of California, San Diego, 858-534-8087, jkleissl@ucsd.edu

- http://solar.ucsd.edu
- UCSD Portal on DOE website: https://solarhighpen.energy.gov/project/university_of_california_san_diego