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Development of a Multiple Look-ahead Time Scale Solar Generation Forecast System

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Presentation Overview

- Project Background and Objectives
- The Challenge of Multiple Time Scale Solar Forecasting
- Forecasting Tools for Each Time Scale
- Integration of Methods
- Forecast Performance Evaluation

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Project Overview

- **OBJECTIVE**: To refine, integrate, test and validate a set of existing forecasting tools that can provide the highest possible performance for frequently updated predictions of solar power production in California over a broad range of look-ahead time periods from minutes to many days ahead.
- **APPROACH**:
  - Refine most promising existing tools for specific look-ahead time scales
  - Develop an algorithm that optimally blends methods for each look ahead period
  - Iteratively evaluate and refine the individual and integrated methods
- **TEST VENUE**: Sempra solar generation facility in Henderson, NV as the forecast target and evaluation site.
- **SUPPORT**: CEC Agreement # 500-10-057

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Project Team

- **AWST** will be leading and managing all aspects of the project including sub-awards to the other team members.
- **MESO** will develop the NWP and other modeling components in the creation of multiple time scale forecasts.
- **UC-San Diego (UCSD**) will oversee equipment installation and data collection at the Copper Mountain 48-MW PV plant in Henderson, NV.
- **Clean Power Research (CPWR)** will provide satellite derived intra-hour and hour ahead solar forecasts and work with MESO and UCSD to integrate them into the instrument-based and NWP forecast.
- **CAISO** will be assisting AWST and UCSD by providing expertise and resources for data, testing, and evaluation of work performed.
- **Servitek Solutions** will review project design plans, technical reports and assist with QC automation of existing meteorological data networks and site instrumentation.

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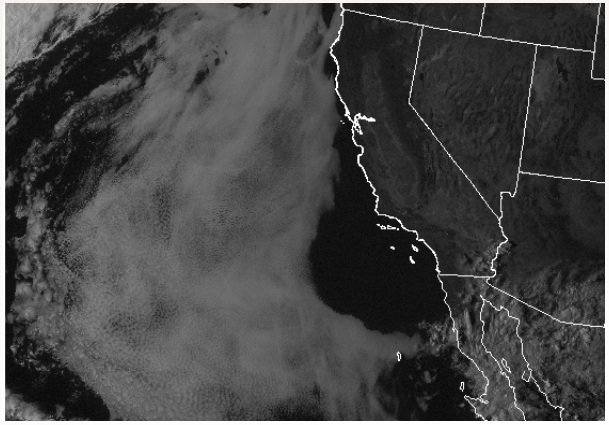
The Challenge – Making the Best Forecast for Various Time Scales

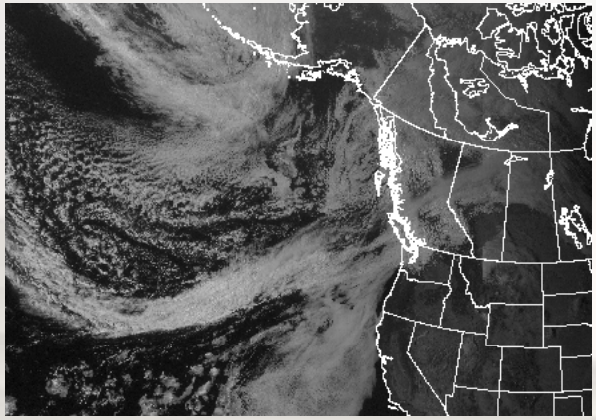
Minutes Ahead

- 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**
- 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 motion 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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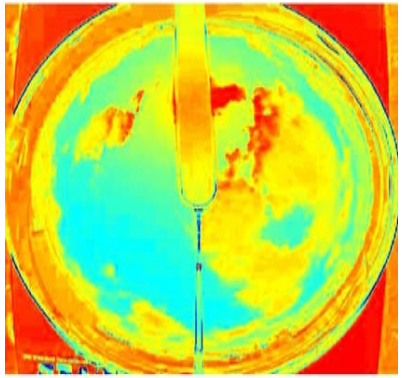
Intra-hour Forecasts: Total Sky Imager Cloud Motion Extrapolation

- Based on pattern recognition techniques applied to cloud images
- Estimates motion vector of cloud elements from sequential images
- Projects future cloud patterns from the motion vector
- Greatest value for 0 to 30 minute ahead forecasts
- Limitations
  - Total Sky Imager's (TSI) field of view limits forecast look ahead times
  - Development or dissipation of clouds or cloud patterns
  - Multiple layer cloud patterns with different motion vectors



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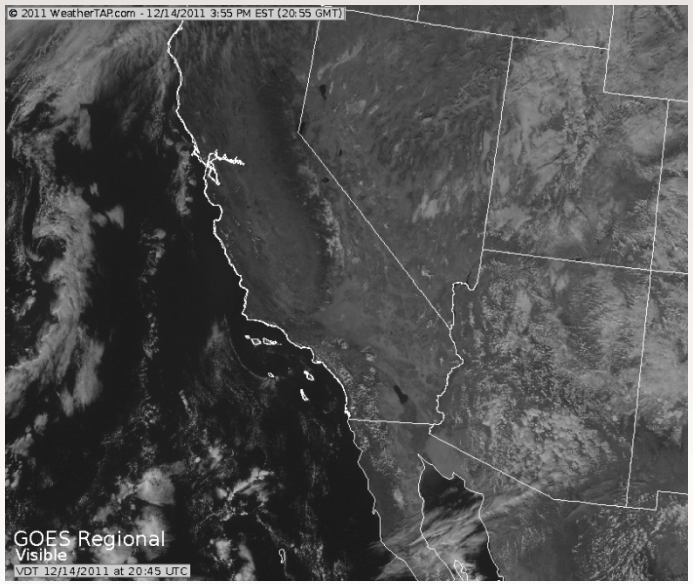
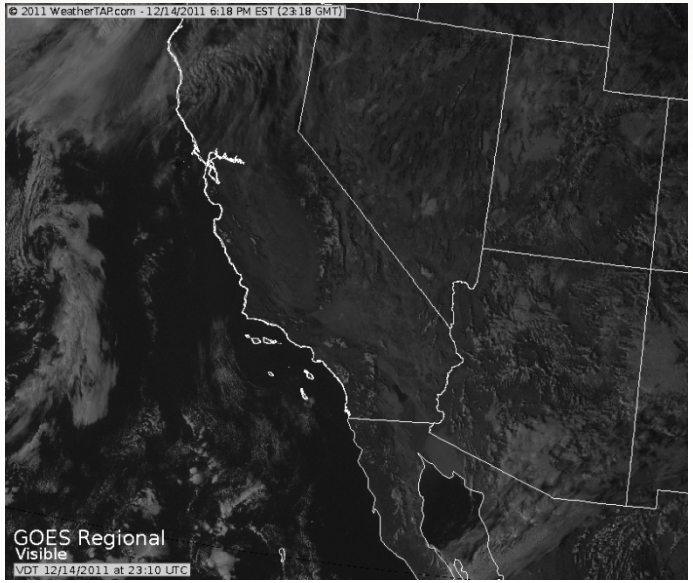
1-6 Hour Ahead Forecasts: Satellite-Based Cloud Motion Extrapolation

- Similar to the sky image method except current cloud patterns are detected through the use of images from satellite-based sensors.
- Advantage: much larger area of coverage (1000s km^2) means that the motion of the cloud field can be projected forward over longer time periods (several hours)
- Limitations:
  - The spatial resolution (~ 1 km) is much less than TSI images
  - Difficult to anticipate cloud development or dissipation
  - Hard to diagnose motion of multiple layer cloud patterns





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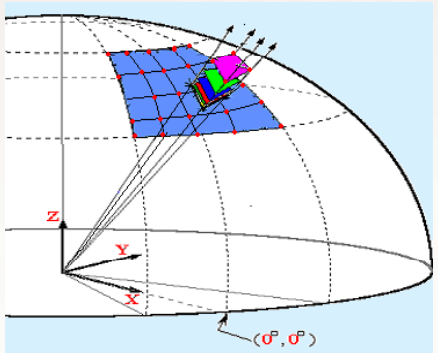
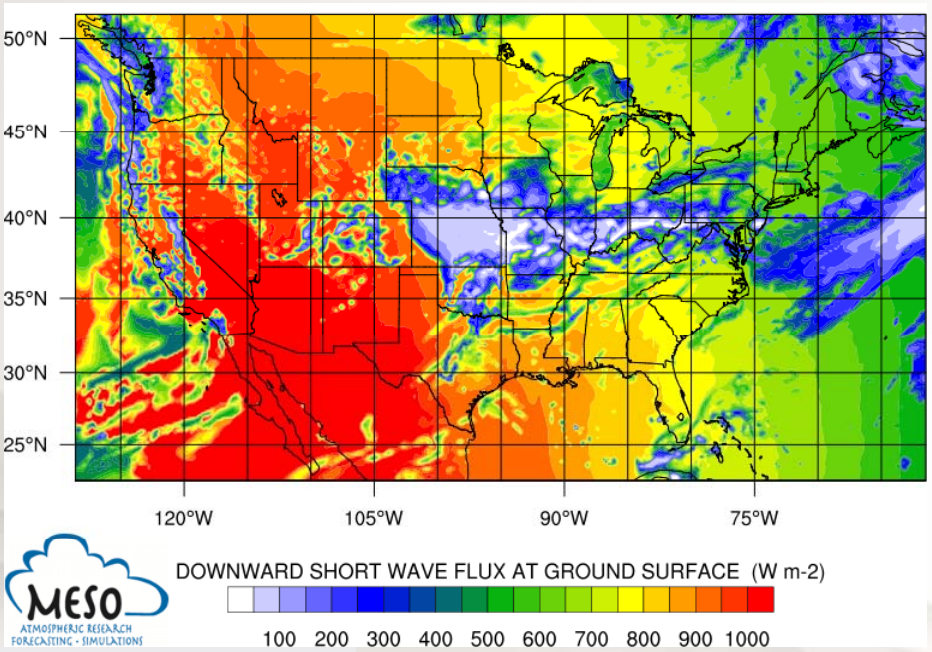
Physics-based Numerical Weather Prediction (NWP) Models

- Differential equations for basic physical principles (conservation laws) are solved on a 3-D grid

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



- 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



- 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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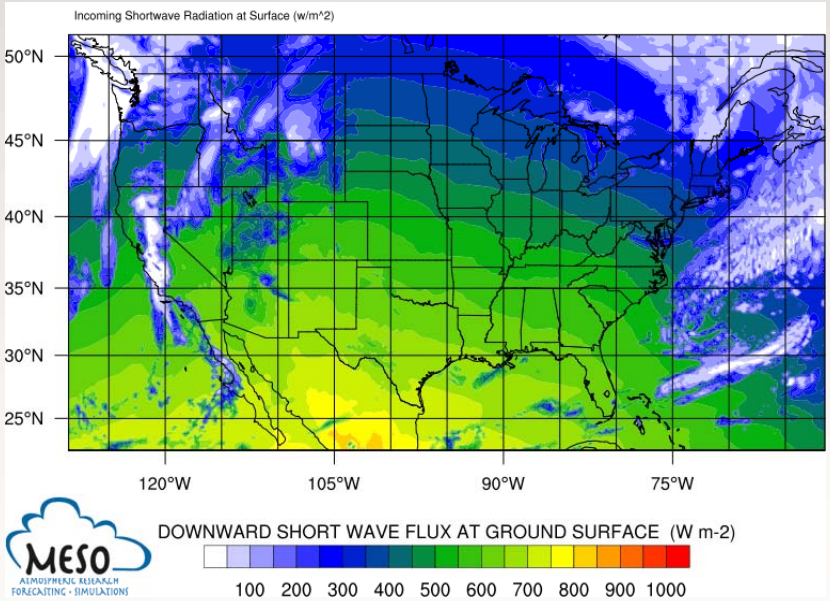
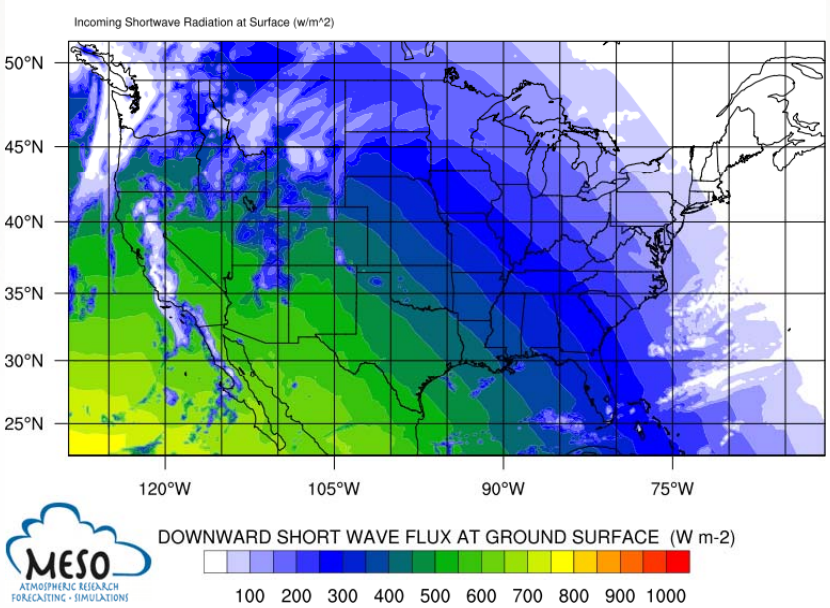
Methods

6 hours to Many Days Ahead Forecasts Standard Cycle NWP

- Regional and global scale models initialized every 6 hours at government forecast centers
- Initial state specification from a blend of data from many sources
- Higher resolution regional or local NWP models can be used to “downscale” forecasts from larger scale models.
- Limitations:
  - Can’t resolve atmospheric features small than the scale of the grid cells
  - Errors in the initial state, especially for clouds
  - Systematic errors due to limitations in model or data assimilation formulation
  - Infrequent updates; doesn’t include most recent data





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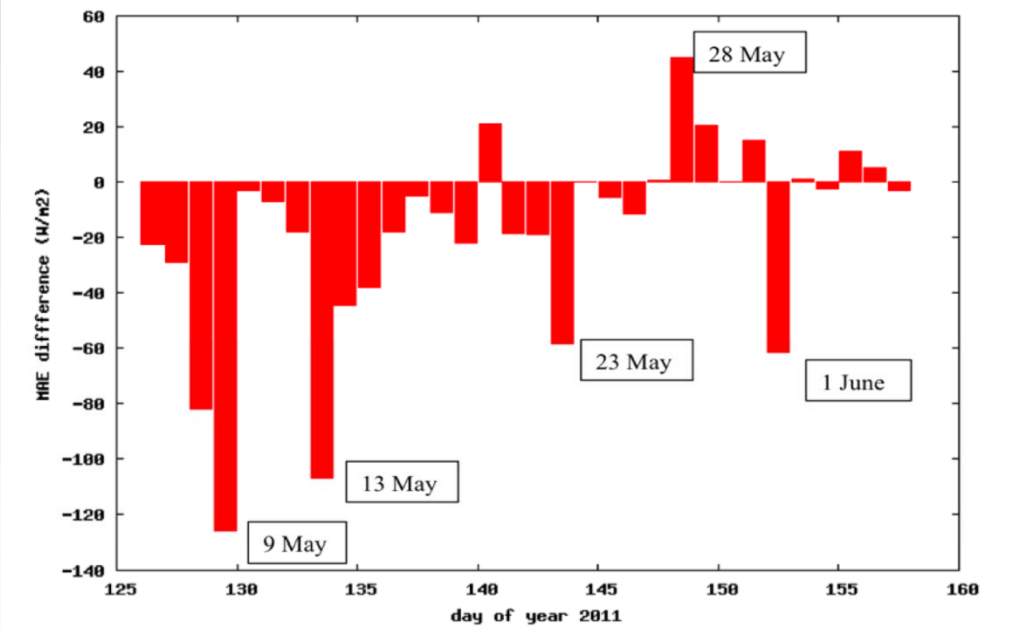
Methods

1-6 hours Ahead Forecasts Rapid Update NWP

- Customized very high res NWP models initialized every 1 or 2 hours
  - Techniques to optimize this approach undergoing significant development
- Can use cloud data from local sensors and satellite-based images to improve the initialization of clouds
- Can improve upon standard cycle NWP for very short-term forecasts
- Alternative (or complement) to satellite cloud vector technique
  - Should be better at predicting cloud development & dissipation
  - Takes longer to generate forecasts so impact of most recent data not available as quickly
  - More sensitive to input data limitations



Reduction in 1-12 hour ahead irradiance forecast MAE (watts/m^2) for each forecast cycle for a site on the southern California coast when satellite-cloud image data is assimilated into a rapid update NWP model relative to that produced by the same system with no input of satellite-based cloud data

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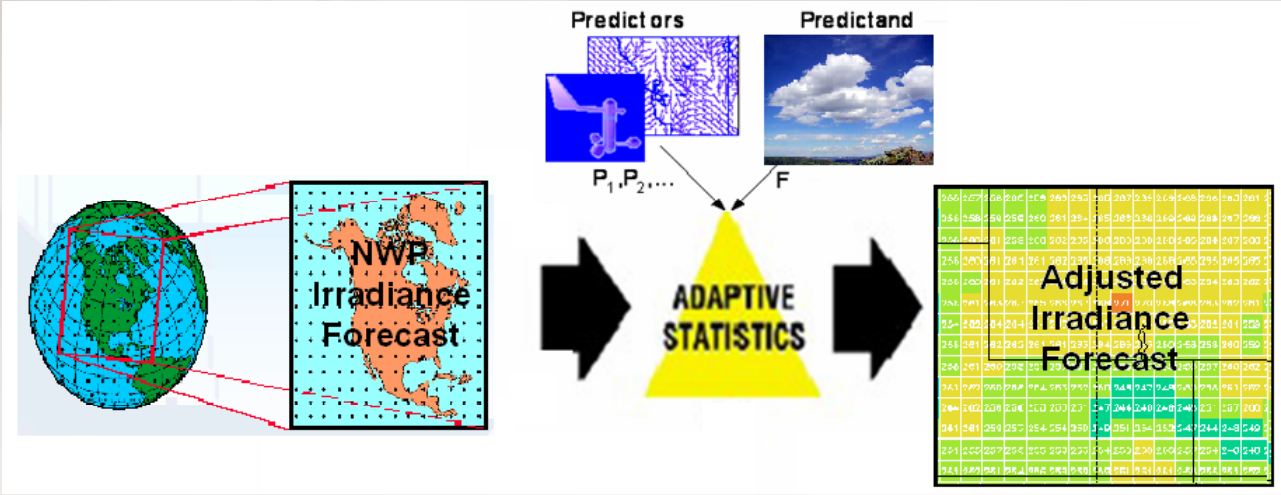
Model Output Statistics (MOS)



- Statistical adjustment to individual model predictions
  - Account for processes below the scales resolved by each method
  - Correct for systematic errors caused by the limitations of each method
- Requires a training sample of concurrent model forecasted and measured values of the forecast variable
- Many statistical approaches can be used
  - Statistical models: linear regression, artificial neural networks etc.
  - Training sample strategies: fixed, rolling, regime-based etc.

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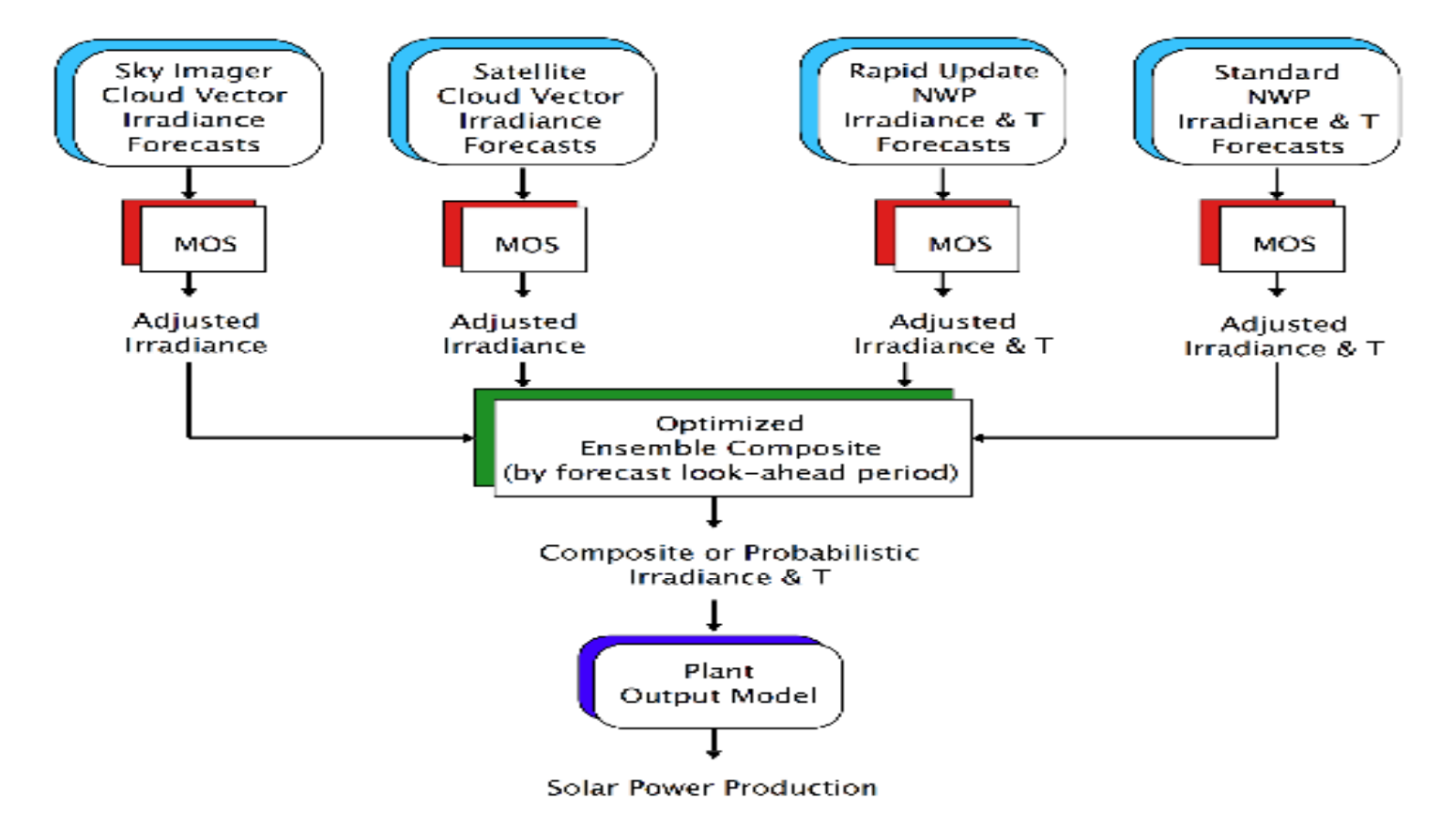
Integrated Forecast System

- A statistical adjustment (MOS) will be applied to each method to minimize systematic errors
- Composite forecast from weighting individual forecasts based on historical performance for each look-ahead time frame
  - Weather regime-based weights



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Forecast Evaluation and Refinement

- Evaluation Venue and Data: Sempra's Henderson, NV PV plant. Available data:
  - 2 Total Sky Imagers (TSIs)
  - 7 meteorological stations with irradiance measurements
  - 18 NREL calibrated panel modules
  - Power output [kW] from 96 inverters with 300 kW of PV each
  - existing solar networks stations
- Method Refinement Cycle
  - Diagnose error patterns in components methods and forecast integration algorithms
  - Formulate and implement modifications and repeat diagnostic cycle

- Forecast Evaluation.
  - Standard metrics (MAE, RMSE, bias etc.)
  - Metrics to focus on performance during periods of ramp events and high temporal variability
  - Stratified by a variety of factors such as season, cloud regime etc.

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Summary

- Objective: Develop, test, refine and validate a solar power generation forecast system that will produce optimal and seamless performance over a wide range of time scales ranging from minutes to many days ahead by effectively integrating multiple existing forecast tools that have performance advantages for specific look-ahead time scales
- Development and Evaluation Venue: Sempra PV facility in Henderson, Nevada
- Project Team: AWS Truepower, MESO, Inc., UCSD, CPWR, CAISO, Servitek Solutions

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