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Current Status and Challenges of Solar Power Production Forecasting

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Overview

- The Solar Power Forecasting Challenge
- Current Forecasting Tools
  - Weeks and Months Ahead
  - Days Ahead
  - Minutes and Hours Ahead
  - Types of Forecast Products
- Forecast Performance Benchmarks
  - Performance metrics
  - Days Ahead
  - Hours Ahead
  - Solar vs. Wind Power Forecasts
- The Road to Improved Forecasts

Solar Power Forecast Challenge

Factors that Affect Solar Power

- **Global Solar Irradiance (~90%),**
- **Temperature (~10%),**
- **Wind (<1%)**
- **Type of Plant**
  - Determines exact impact of all three factors
  - Categories of plants: (1) PV, (2) Concentrating PV, (3) Solar thermal (also concentrating)
  - PV is sensitive to Global Irradiance
  - Concentrating types (thermal and PV) are sensitive to Direct Normal Irradiance
  - Also significant sensitivity variations within basic categories

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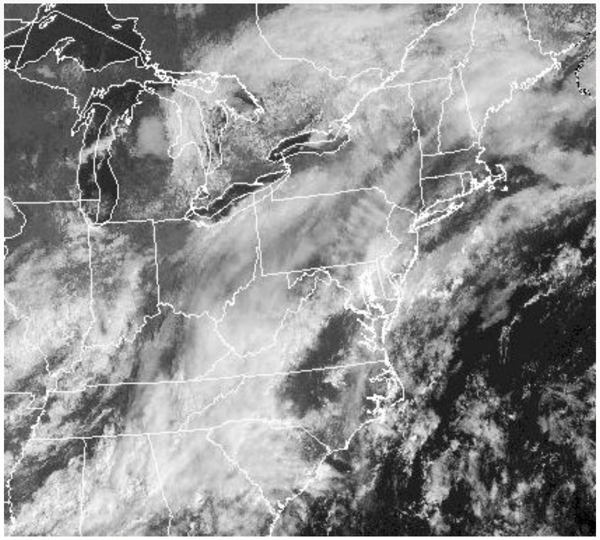
Solar Power Forecast Challenge

Environmental Factors that Affect Solar Irradiance

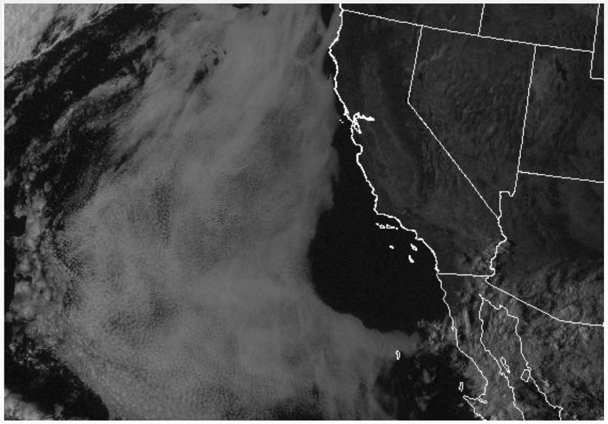
- **Sun Angle**
  - most significant but completely predictable
- **Cloud Cover**
  - cause of the most variance (~90%)
  - largest meteorological challenge to forecasts
- **Haze, Dust and Smoke Particles**
  - up to 10 % of variance
- **Humidity levels (Water Vapor)**
  - about 1 % of variability
- **Components of Irradiance (diffuse, direct) are affected differently by these factors**



The Challenge – Making the Best Forecast for Various Time Scales

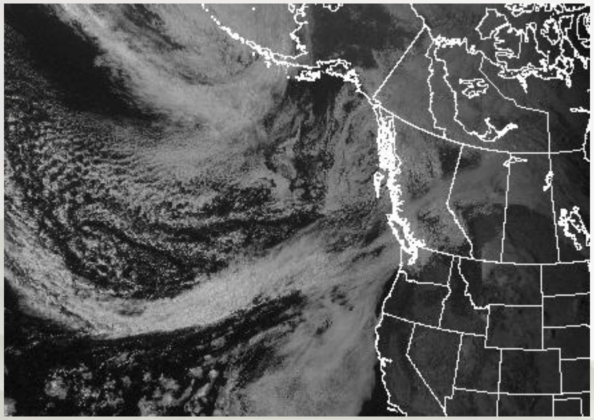
Minutes Ahead

- 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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Solar Irradiance Forecasting Tools

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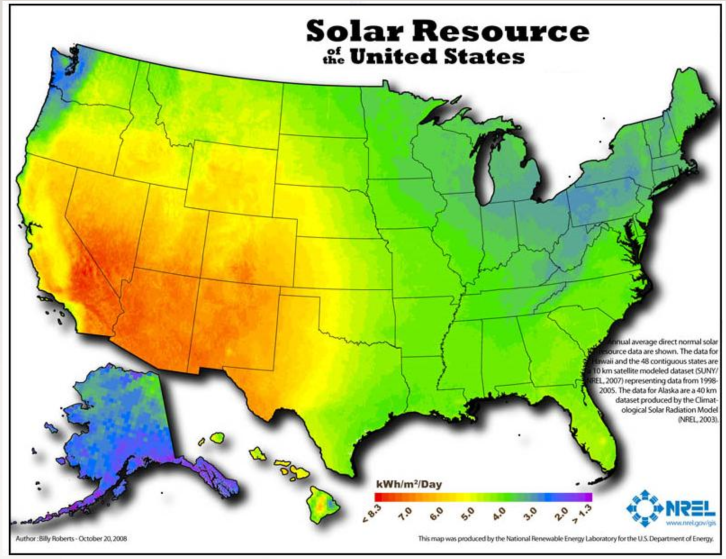
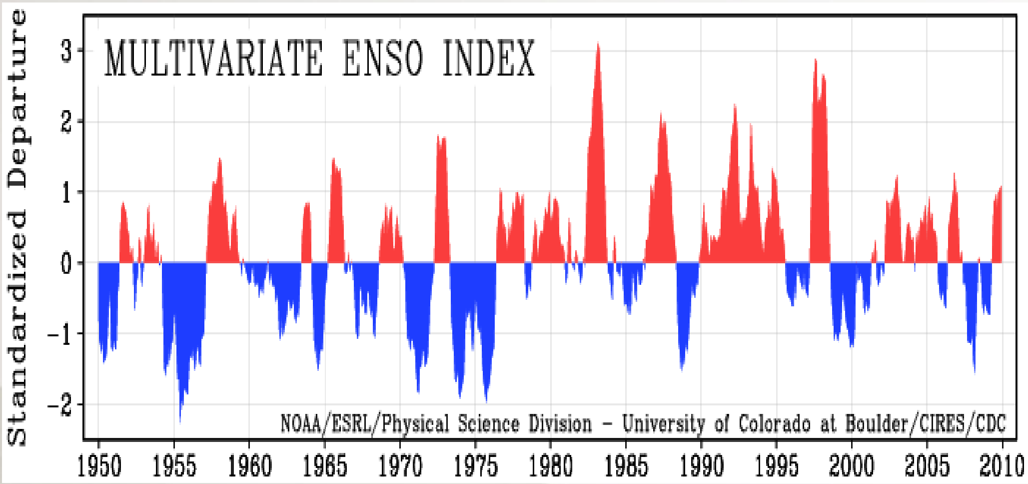
Methods

Forecasting Techniques – Weeks & Months Ahead

Climatology and Global Circulation Indices

- Climatology
  - Long term characteristics of solar resources by time of day and day of year
  - Often the best forecast for look-ahead periods >10 days





- Statistical links to Global Circulation Indices
  - El Nino (ENSO)
    - Cloudiness and precipitation have significant correlations with ENSO in some areas
  - Madden-Julian Oscillation
  - North Atlantic Oscillation (NAO)
  - Pacific Decadal Oscillation (PDO)

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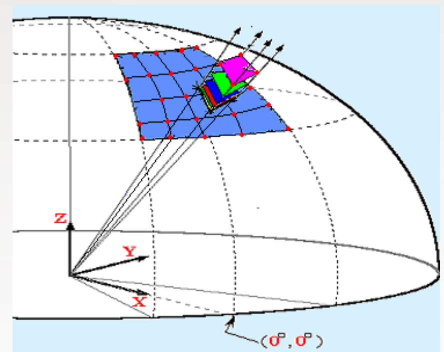
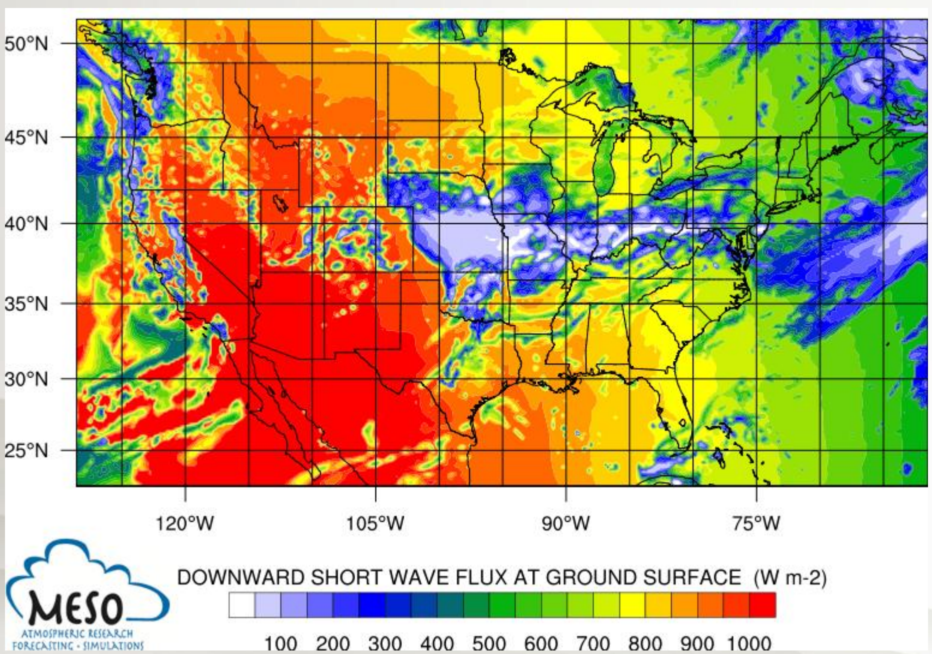
Forecasting Techniques - Days Ahead

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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