Lawrence Livermore National Laboratory

Managing for the Winds of Change

International Wind Forecasting Techniques & Methodologies,

Portland, OR   July 24-25, 2008

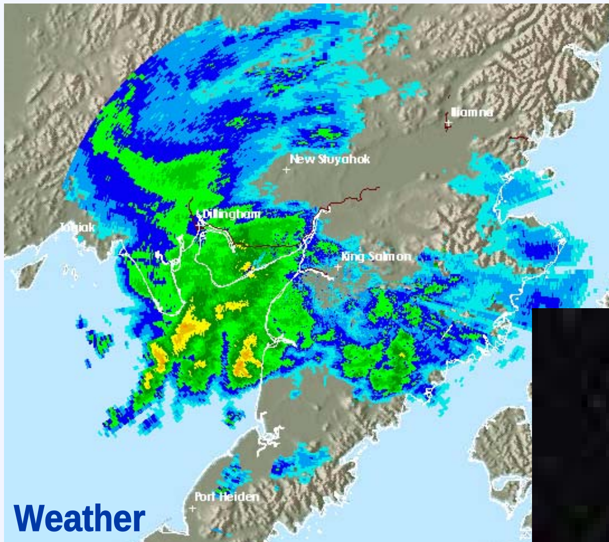
Dora Yen-Nakafuji

nakafuji2@LLNL.gov

Support for BPA and CalSO's Utility/Balancing Authority Focused USA/European Wind Forecasting Workshop

Lawrence Livermore National Laboratory, P. O. Box 808, Livermore, CA 94551

Forecasts vs Predictions



Wind Forecasts vs Wind Predictions

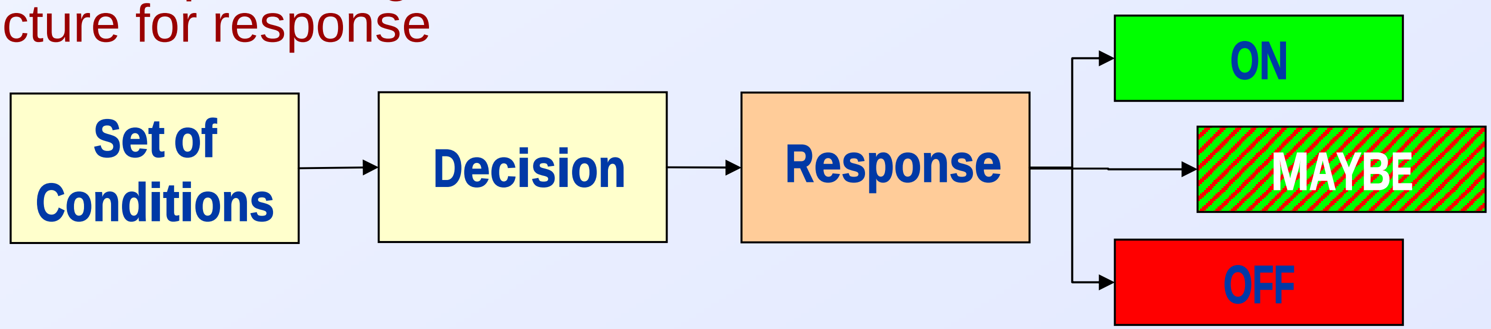
WHAT's THE DIFFERENCE?

Subtle but Critical Distinction
(even from the psychic experts)

- **Forecasts**
  - Offers a set of conditions that can reasonably be assured to come to pass based on reading information or impressions
  - Focuses on prevailing conditions and come to a clear and worthwhile picture of what conditions to expect
  - Acknowledges the possibility of changing conditions
  - Typically have some % certainty or skill depending on the interpreter in reading data - charts, signals or impressions
- **Predictions**
  - Goes one step farther than forecasts and attempts to tell the person how that set of conditions or impression will *manifest.*
  - Based in part on the forecast, and in part on an educated guess of how that energy will play out in the real world
  - A prediction focuses on one potential outcome and tends to be more fatalistic
  - Accuracy is difficult to rate – highly dependent on interpretation of set of conditions

Managing the Electrical Grid

- Decisions are based on a set of conditions
  - Unit commitment of MW based on projected loads given existing use conditions and expertise of scheduler
  - Dispatch of energy is based on existing system and market signals Conditions (demand) determines dispatch, expertise determines resources committed and response
  - Desired resource response is deterministic – ON or OFF
  - If resources do not respond or are insufficient…alternatives are dispatched
- Wind adds additional variability to the set of conditions used in informing decisions
  - Forecasts aid in reducing the variability that wind adds *but may never eliminate the variability*
  - 100% forecast is obtainable when wind is zero
- Decision makers (i.e. operators) need "a read" on the new system's prevailing conditions and come to a clear and worthwhile picture for response



Managing the "Maybe"

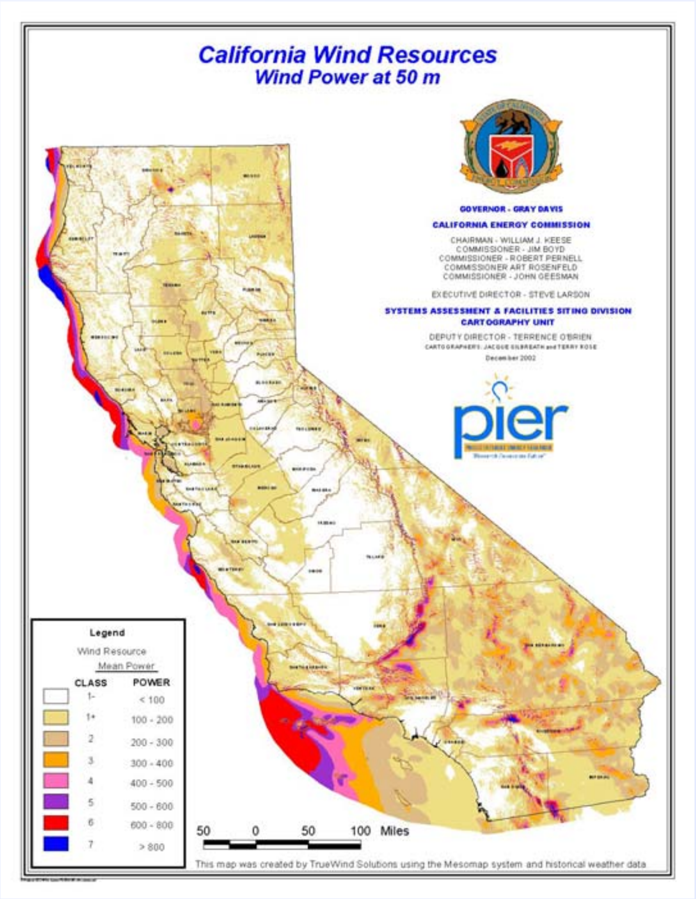
- Overview of Early Efforts in California
- Current Applications for Forecasting
  - Support market and operations (regional & real-time forecasts)
  - Assess impacts of climate change on renewable energy generation
  - Use of modeled forecasts to inform expansion studies (i.e. RPS, climate change)
- Perspective on Implementation Challenges & Continuing R&D

Pre-RPS Motivators for Wind Forecasting

- Early 1990s, California was one of the first states in the nation to have significant utility-scale wind energy on the grid (1600MW)
- State environmental objectives and early policy leadership provided public-interest funds to research advance renewable technologies and to diversify the electricity portfolio
- Desire to improve wind energy market competitiveness drove the need to
  - Improve wind turbine efficiencies,
  - Reduce capital costs
  - Improve wind predictability to optimize system benefits

Two Major Research Thrusts

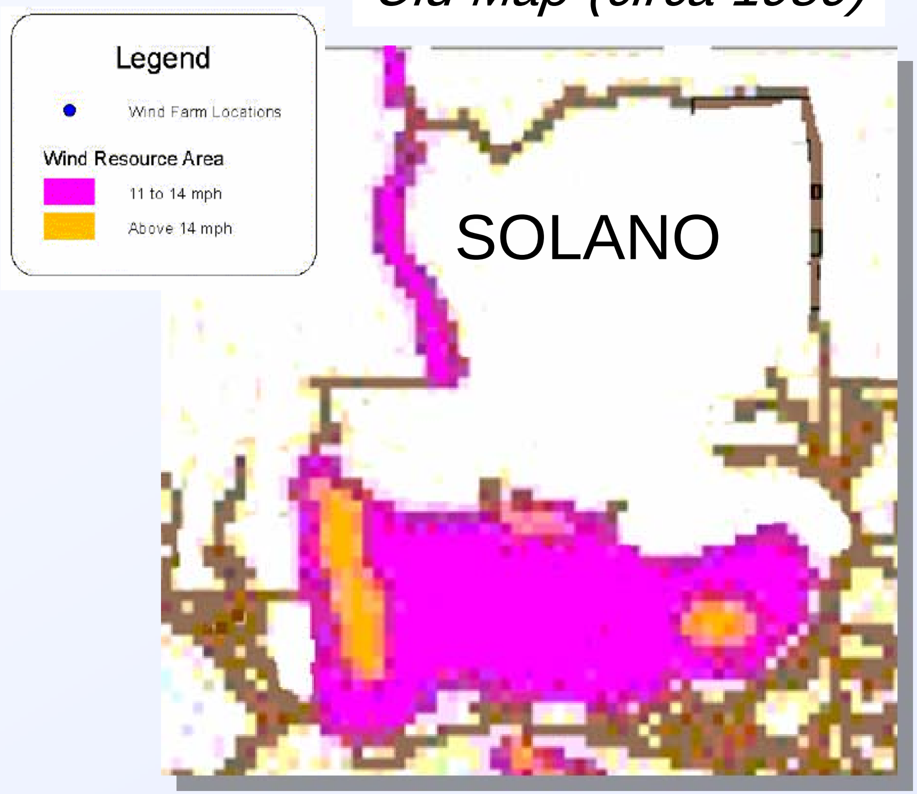
- In 2000, the California Energy Commission's Public Interest Energy Research (PIER) program supported the redevelopment of wind resource assessments for CA befitting state-of-the-art turbines
  - High resolution maps for multi-elevations (30m, 50m, 70m, 100m) of statewide wind resources
- PIER Wind Energy Development program identified wind energy forecasting as a critical component for improving wind energy competitiveness in the electricity market and worked with industry to research tools for leveraging new state-of-the art physics-based models



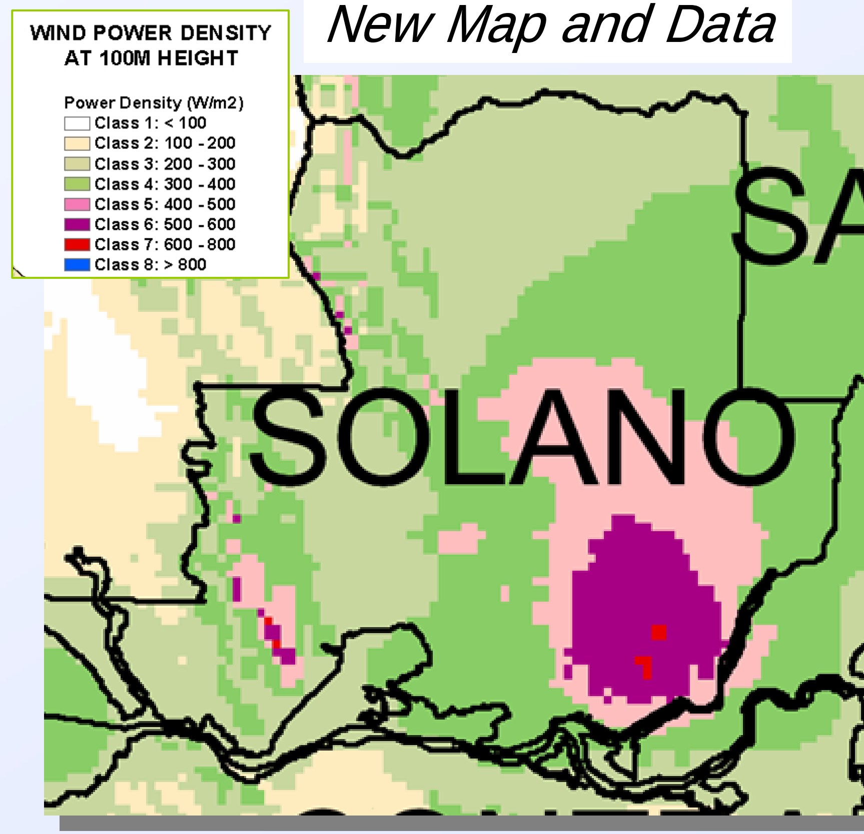
Source: www.energy.ca.gov/wind

Increased Data Access, Quality & Confidence

Old Map (circa 1980)



New Map and Data



- Refined wind resource locations and new development potential
- Identified new prospects for wind development

Wind Energy Forecasting Efforts

- Research phases
  - Phase I: Focused on developing forecast technologies capable of capturing CA's unique climate and topology to deliver 48hr forecasts
  - Phase II: Develop and test short-term regional wind forecasting algorithms (5min to 3hrs ahead) and improve forecast performance (1 to 48hrs)
- Wind Data Monitoring phases to support wind forecast model development & enhancements
- Resource support to CalSO and utilities
  - Wind Working Group
  - Participating Intermittency Resource Program (PIRP)
  - Intermittency impact and transmission studies (IAP)

Wind Energy Forecasting - Phase I (2001-2003)

Results led to additional questions related to forecasting skill scores, sources of error, types of input data, met tower locations, turbine availability, resolution of atmospheric and topological information

Participants

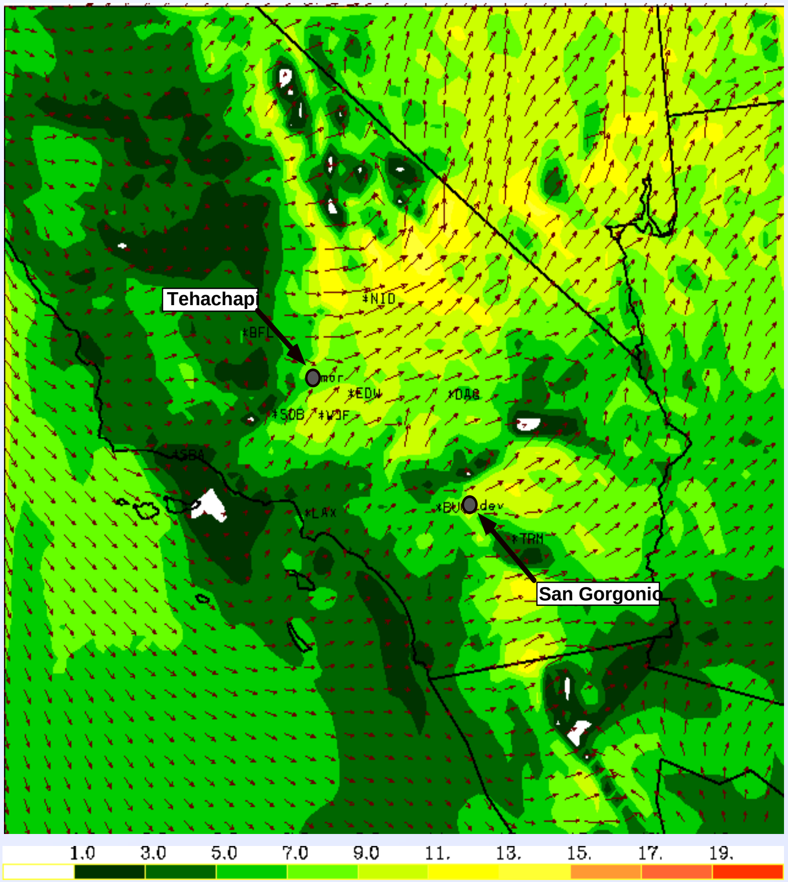
- **CEC/PIER**
- **EPRI**
- **AWS Truewind**
- **Risoe National Laboratory (RISOE)**
- **Applied Modeling, Inc**
- **UC Davis**
- **Wind Plant Operators**
- **DOE/NREL**

- Develop better understanding for capabilities of wind energy forecasting models and wind tunnel tests and EU lessons
- Used two different forecast technologies to generate twice-daily 48-hr forecasts
- Evaluate technologies for a range of site conditions (e.g. topography, wind resource, meteorology, wind turbine technologies)
- Validated forecasted results with actual data for wind projects in Southern CA (San Gorgonio) and Northern CA (Altamont Pass)
- Developed recommendations on how forecasts can be used by operations and resource managers – wind plant operator's perspective

EPRI-TR-1004038 (2003)

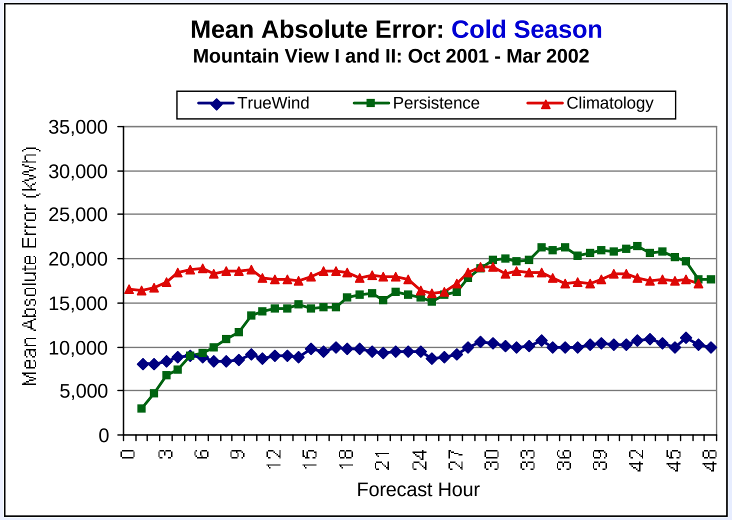
Basic Wind Energy Forecasting Model Approach

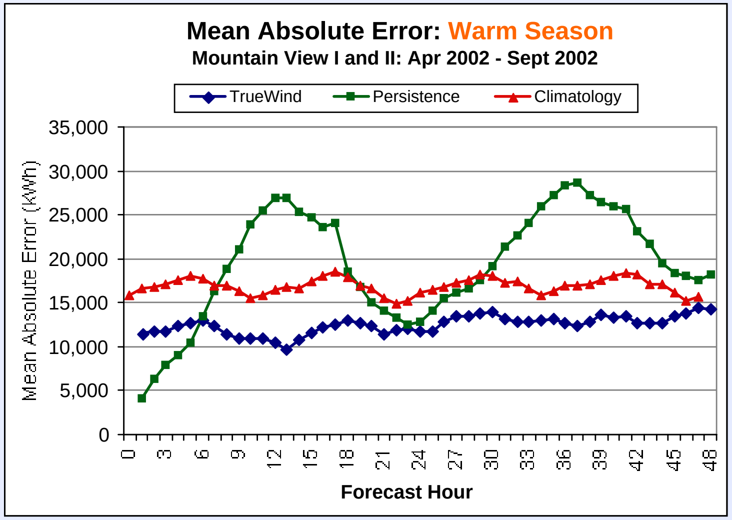
- Forecast models combine numerical weather forecasts, wind plant models and site data
- Download numerical weather forecast data (e.g. NCEP)
- Calculate wind flow around wind plant using model
- Apply model operating statistics (MOS) to estimate adjusted wind speed and direction at wind plant
- Estimate hourly power generation at percent (i.e. 100%) availability using wind plant model
- Apply MOS to estimate adjusted wind generation.
- Issue forecast



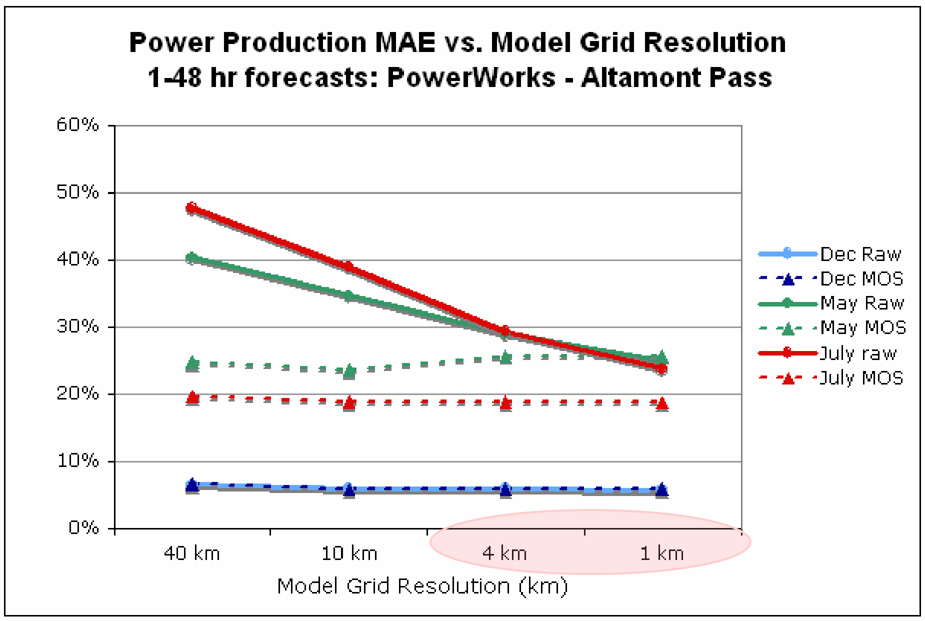
Phase I - Highlights

- Methods have considerable skill with respect to persistence and climatology at both California sites
  - Outperforms persistence after 4-6 hrs
  - Outperforms climatology for all hours (1-48)
- Substantial seasonal differences in performance
- Slow MAE growth during the 48-hr forecast period
- Considerable variation in wind forecast skill can be found over short distances (within a wind plant) as onsite meteorological towers do not necessarily represent wind at the turbine





Wind Energy Forecasting - Phase II (2003-2005)



Participants

- **EPRI**
- **AWS Truewind**
- **UC Davis**
- **LLNL**
- **SCE**
- **SMUD**
- **CalSO**

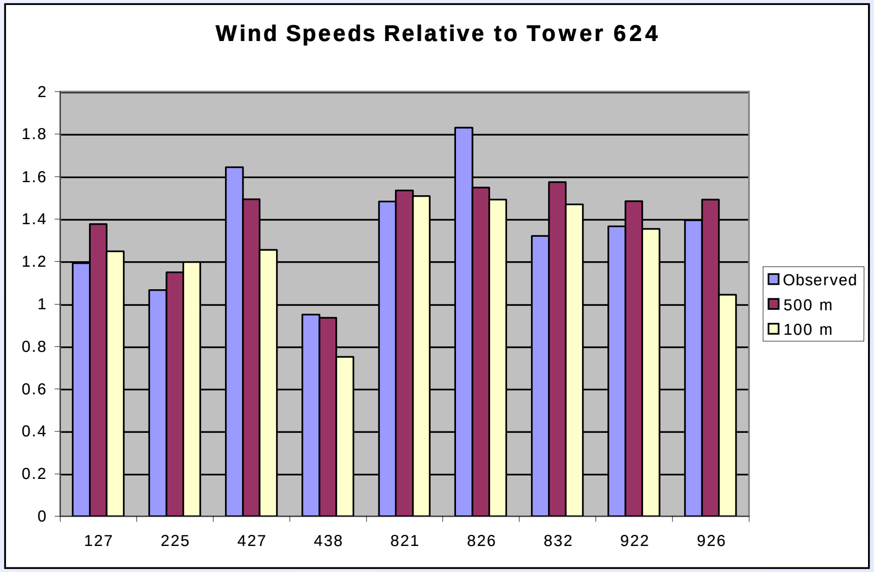
- Methods to reduce wind energy forecast errors and develop a deployment strategy for forecasting (control area perspective)
- Objectives included development and Testing of:
  - Rapid-Update Wind Speed and Direction Forecast Model
  - Short-Term Regional Forecast System (near real time 5min-3 hours)
  - Long-Term Regional Forecast System (day ahead, 1- 48 hours)
  - Forecasting model (CARD) research database, set of projected statewide input parameters and wind profiles
- Examined Short- and Long-Term forecast timeframes designed to help CalSO meet operating requirements

http://www.energy.ca.gov/2006publications/CEC-500-2006-089/CEC-500-2006-089-V1.PDF (1 of 4 volumes)

Phase II - Highlights

- Indentified forecast sensitivity to various input parameters (i.e met tower data, turbine output)
- Assessed forecast method variability to seasonal changes in CA (warm-season vs cold-season)
- Expanded forecasting study to 4 regions in CA (Tehachapi, Altamont, Solano and San Gorgonio)
- Targeted inputs for forecast enhancements
  - Detailed & accurate water surface temperature dataset (i.e. MODIS)
  - Higher horizontal grid resolution in physics-based models
  - Variation of MASS-6, WRF and COAMPS models
  - Importance of appropriate wind plant power curve modeling and availability
  - Use of ensemble forecasts over ANN or single statistical method
- Reduced MAE on average 3% (MAE 14.5%, 2.27m/sec)
- Additional physics-based model development, algorithm development accounting for seasonal and atmospheric impact on wind plant output

Focus Area	Forecast System Modification	MAE Reduction (%)
1	MODIS and Pathfinder Water Surface Temperature (WST) data (4 km) BASELINE: NCEP OI WST (110 km)	12.3%
2	1-km physics-based model grid BASELINE: 10-km physcis-based model grid	-4.7%
3	WRF with 40-km grid as the physics-based model BASELINE: MASS with 40-km grid	4.0%
4	Stratified 2-stage SMLR scheme BASELINE: Screening Multiple Linear Regression	15.8%
5	Model deviations from power curve BASELINE: Speed-based plant-scale power curve	4.6%
6	Mean of an ensemble of forecasts BASELINE: "Best" single forecast method	0.8%

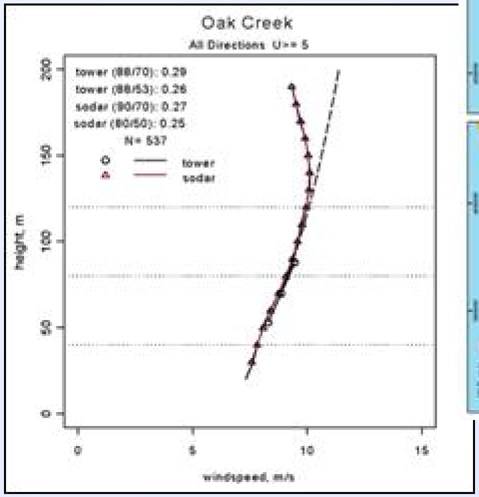


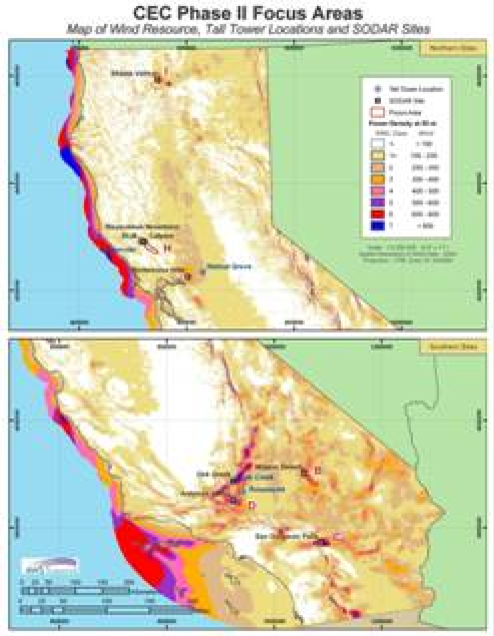
Variability of modeled and observed data

http://www.awstruewind.com/files/AWEA_Windpower_2006_CARegional.pdf.pdf

New Data: Sodar & Tall Tower Monitoring

- Responds to industry's need to acquire accurate, upper atmospheric wind data within the operating regime of current wind turbine technologies
- Enables wind data to be remotely measured at elevations of 50m to 200m – typical heights of new turbine technologies
- Reduces development risk at new sites with wind data measurements
- Improves wind plant power prediction for energy generation and wind energy forecasting
- Industry participation: Calpine, Oakcreek, Enxco





SODAR unit in the field

Wind Forecasting Expectations

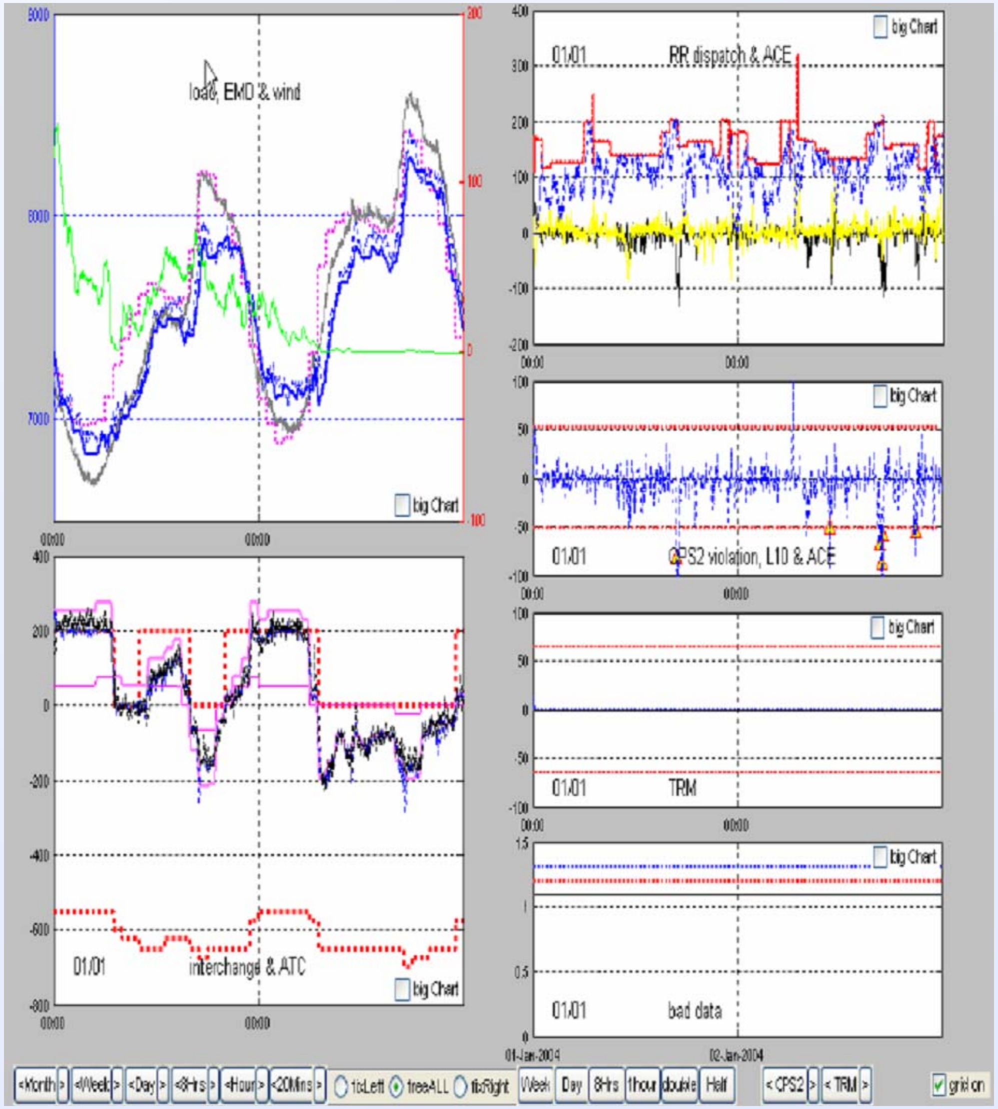
- Provide for the perfect forecast with imperfect or incomplete data
- Provide definitive information to controllers on whether to commit wind or other units
- Resolve the periods when there is no wind
- Use of wind forecasts (at high-penetration) to inform adaptation and mitigation strategies

Focus Areas for Wind Forecasting

- Control room integration and utilization (improve confidence)
- Continue to improve modeling and forecasting skills to decrease sources of error
  - Atmospheric modeling
  - Turbine performance characteristics
  - Identification of sensitivities/dependencies
- Field validation and reliable measurement data
  - Remote sensing data
  - Inflow/outflow monitoring
  - Improved horizontal and vertical resolution

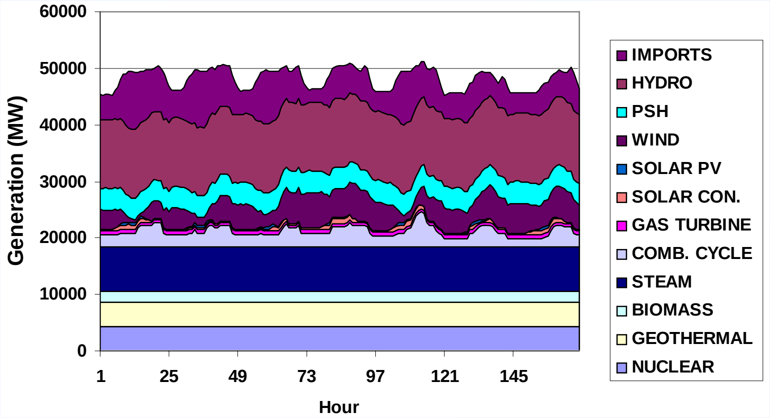
Control Room Challenge

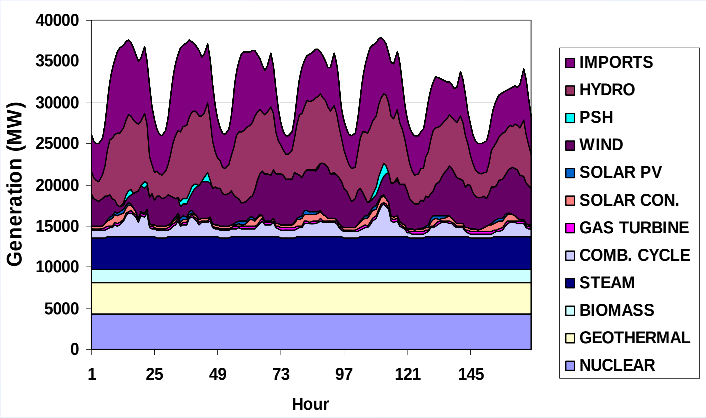
- Continue efforts to improve control room integration and for scheduling/dispatch
  - Visualization techniques
  - System-based cues or indicators (i.e. temp, press)
- Capture and track controller response to managing wind events
- Develop human factors-based cues for designing an informed environment (for various conditions)
- Continuing to improve confidence in models and forecasting skills



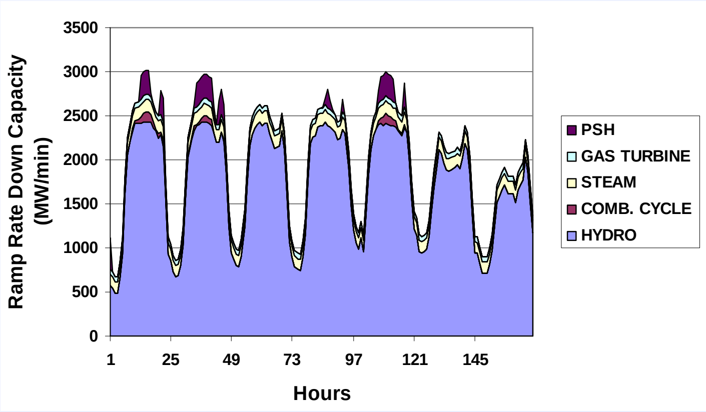
Ramping Capability

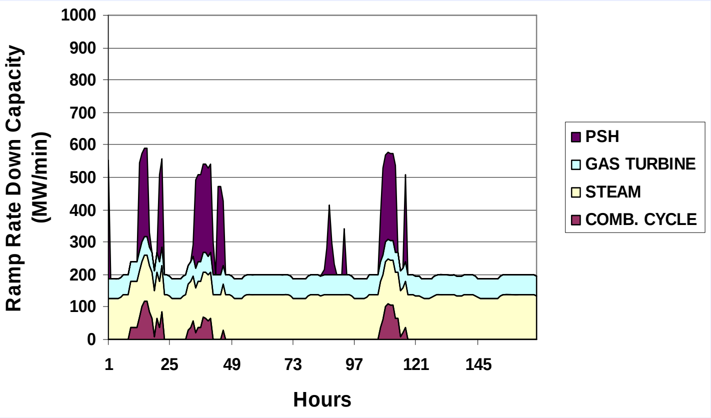
EX: May light load conditions (CEC IAP Study)





Review Unit Commitment and Dispatch (week of May)

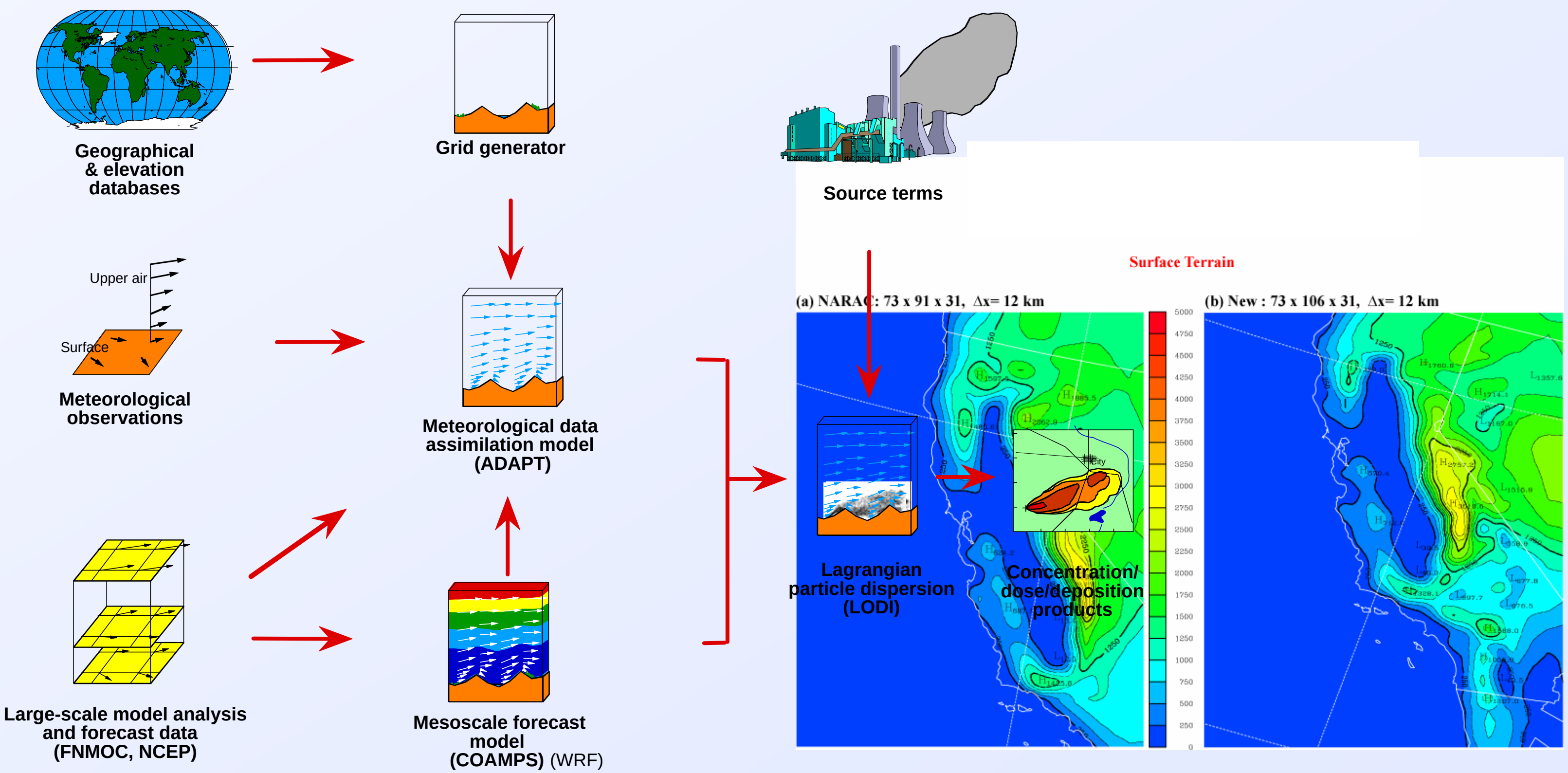




Begin characterizing system limits seasonally and year-round (i.e. 200MW/min capability with a few hours outside of this capability)

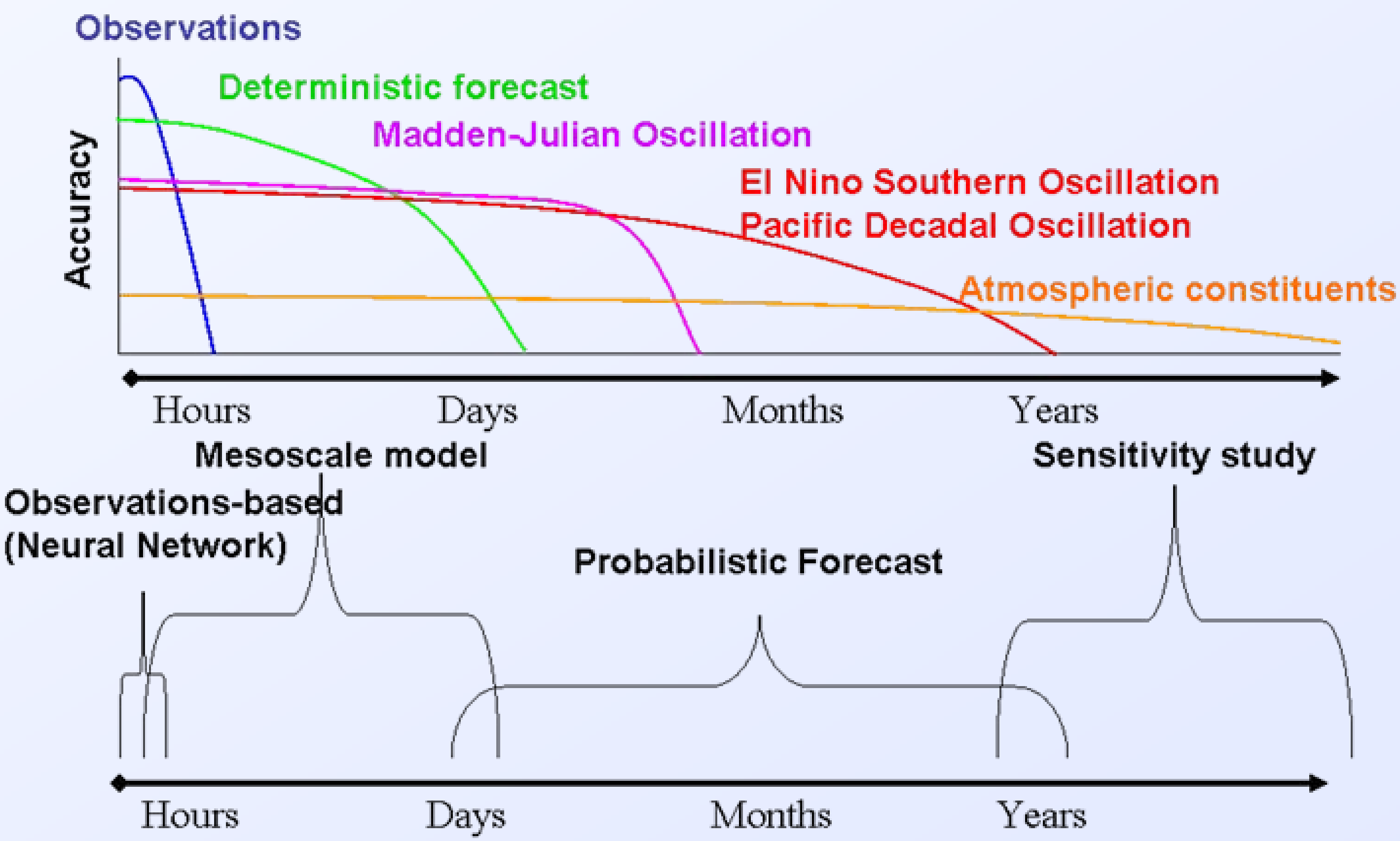
Improve Modeling Capabilities

- Working with industry to reduce wind forecasting errors
- Focus on improving data uncertainty and models to capture complex terrain issues unique to CA
- Couple climate and environment effects into electrical generation and planning paradigm



Algorithm Development

- Variety of models for design and simulations
- Real-time, high spatial resolution
- Errors minimized, improved confidence & reliability

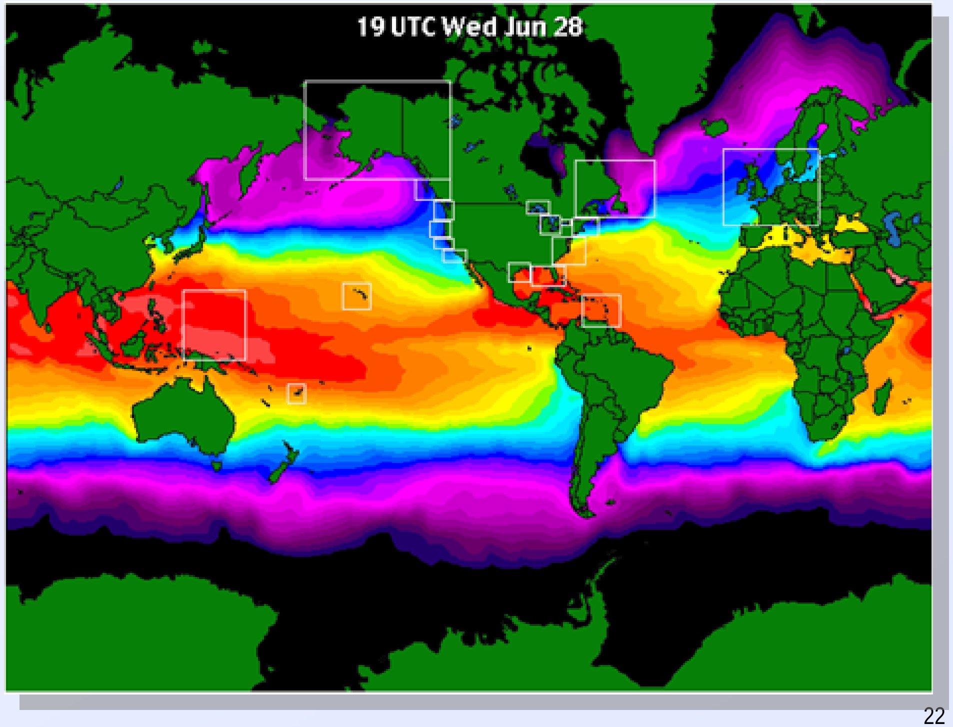


Assessing Climate Impacts

- Utilize wind forecasting models to support future planning scenarios and climate change considerations
- Study and use modern probabilistic weather and hydrological forecasts for the management of water reservoirs and other resources in the state.*
- Understand impact of climate on renewable resources

Connect Impacts to Electricity

- Generation
- Grid Operations
- Load



*Climate Action Team Recommendations

Ex. Bridging Communication Gaps

- **Project - Effects of Future Climate on Renewable Resources**
- Objectives:
  - Initial study to gauge potential climate impacts on generation and planning
  - Bring climate change considerations to the forefront of utility planning and longer-term electricity infrastructure planning
  - Work with industry to determine what is needed and how to best utilize climate change results to assess impacts on future planning and validation needs
  - Generate a set of climate-based indicators to better inform and guide transmission modeling efforts and longer-term investment considerations
  - Work with industries to improve forecasting tools and modeling capability

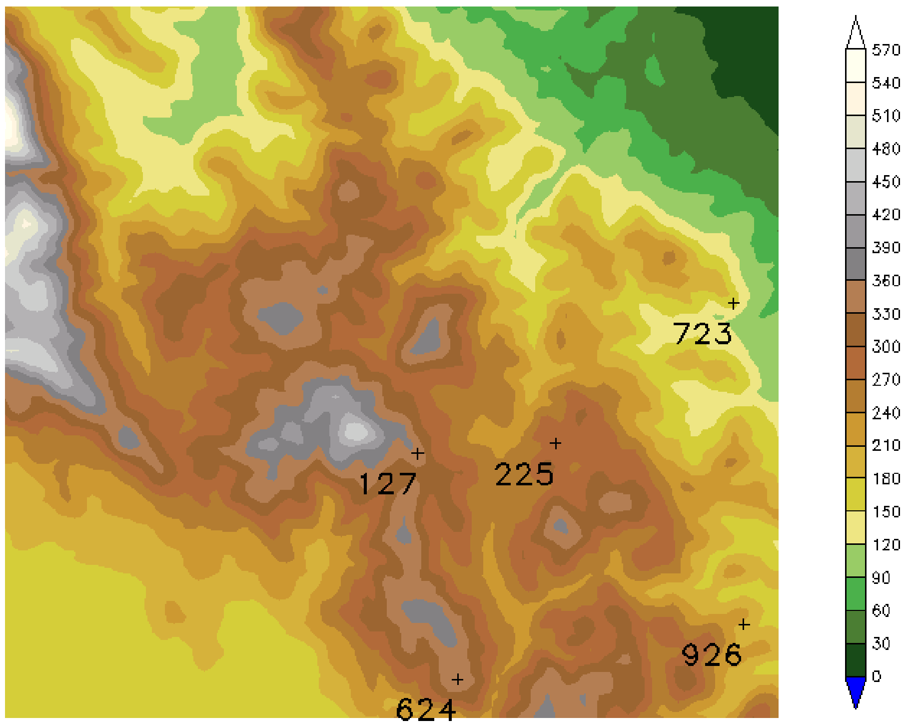
Bringing Different Perspectives Together

	Climate Change Community	**Utility Planning Community**
Planning Horizons	50-100 years	1-5 years
Geographic scale	Global, regional, multi-states	Utility service area, intra-state
Key Parameters	Temperature, pressure, precipitation, sea level	MWh, MW, load and generation attributes
Impacts	Modeling world, virtual	Real world, blackouts

<u>Research Team:</u>
LLNL, utilities, renewable industry, wind forecasters, academia, climate modelers
*** CEC/PIER funded effort**

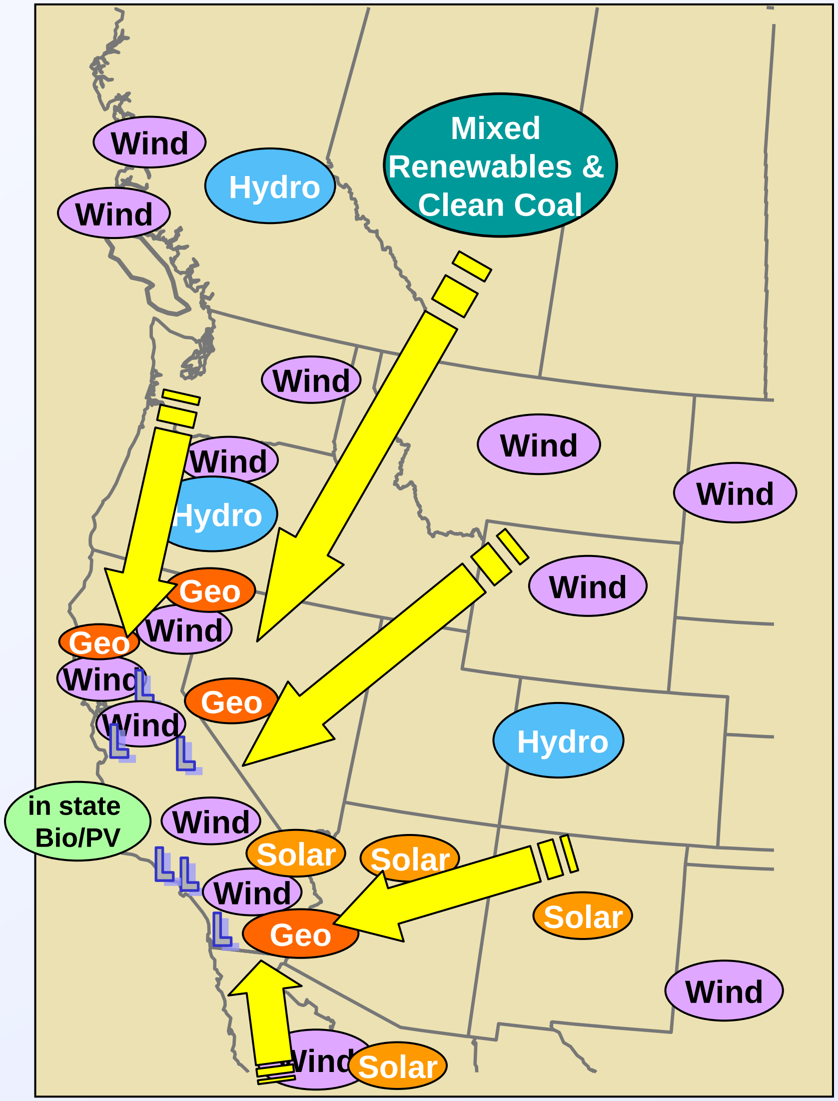
Develop Regional 3-D Flow Information

- Assimilate 3-D information around the wind resource area to improve Wind SENSE capability
- Assess remote sensing (sodar, doppler, lidar) in enhancing vertical boundary layer up to 500m-1km
- Optimize deployment of wind network
- Provide real-time indicators or signals for wind variability
- Couple wind tunnel methods and computational modeling



Pass scale resolution and surrounding flow (inflow/outflow)

Managing the Risks – Regional Interdependencies



- Vying for a CA market
- Expansion crossing multi-state & international borders
- Traditional single utility and single service area planning no longer adequate – *new modeling tools and technology specific information now needed*
- Increasing reliance on out-of-state and out-of-region renewable resources *makes CA dependent on conditions of that state or region (e.g., intermittency, storm conditions or droughts)*
- Transmission planning and energy forecasting capability must now include consideration of climate impacts on the combined output of all weather dependent resources - wind, solar, hydro versus only a single resource

Questions/Comments??

Contact Info:

Dora Yen-Nakafuji

Global Security NTERRA lead
National Security Engineering Division
Lawrence Livermore National Laboratory
nakafuji2@LLNL.gov