NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Stochastic Modeling at Multiple Timescales

FERC Technical Conference:

Increasing Real-Time And Day-Ahead Market Efficiency Through Improved Software

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Outline

- **Terminology check and project overview**
- **Multiple timescale modeling framework**
  - Stochastic model
  - Robust model
- **Constrained ordinal optimization (COO)**
- **Probabilistic forecasts**
- **Future work**

Terminology

Multi-scenario-based, expected cost minimized

Stochastic SCUC/ED

L. Wu et al. 2007;
F. Bouffard et al. 2008;
J. Morales et al. 2009;
J. Ruiz et al. 2009;
P. Meibom et al. 2011

Feasibility satisfied by predetermined probability level

Chance-Constrained SCUC/ED

U. Ozturk et al. 2004;
Q. Wang et al. 2012;
H. Wu et al. 2014

Single-scenario-based

Robust SCUC/ED

Immunity against all realization, worst-case cost minimized

D. Birtsimas et al. 2013;
J. Zhao et al. 2013

Interval SCUC/ED

Upper- and lower-bound feasible, not-expected cost minimized

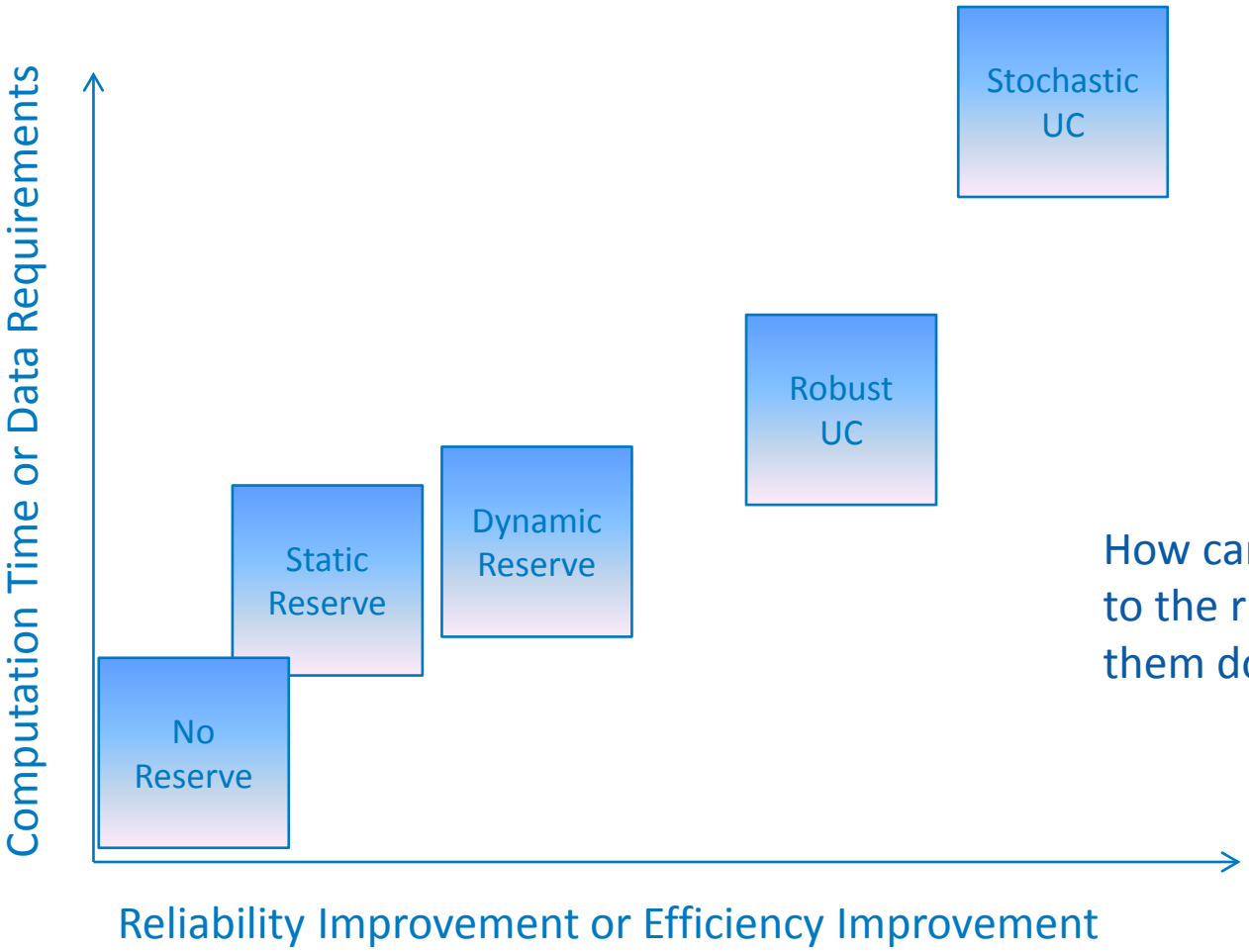
J. Wang et al. 2007;
Y. Wang et al. 2011;
L. Wu et al. 2012

Scenarios define exogenous deterministic constraints

Dynamic Reserve

M. Ortega-Vazquez et al. 2007;
R. Matos et al. 2011;
E. Ela et al. 2011 (summary);
E. Ibanez et al. 2013

How to Prepare for Uncertainty

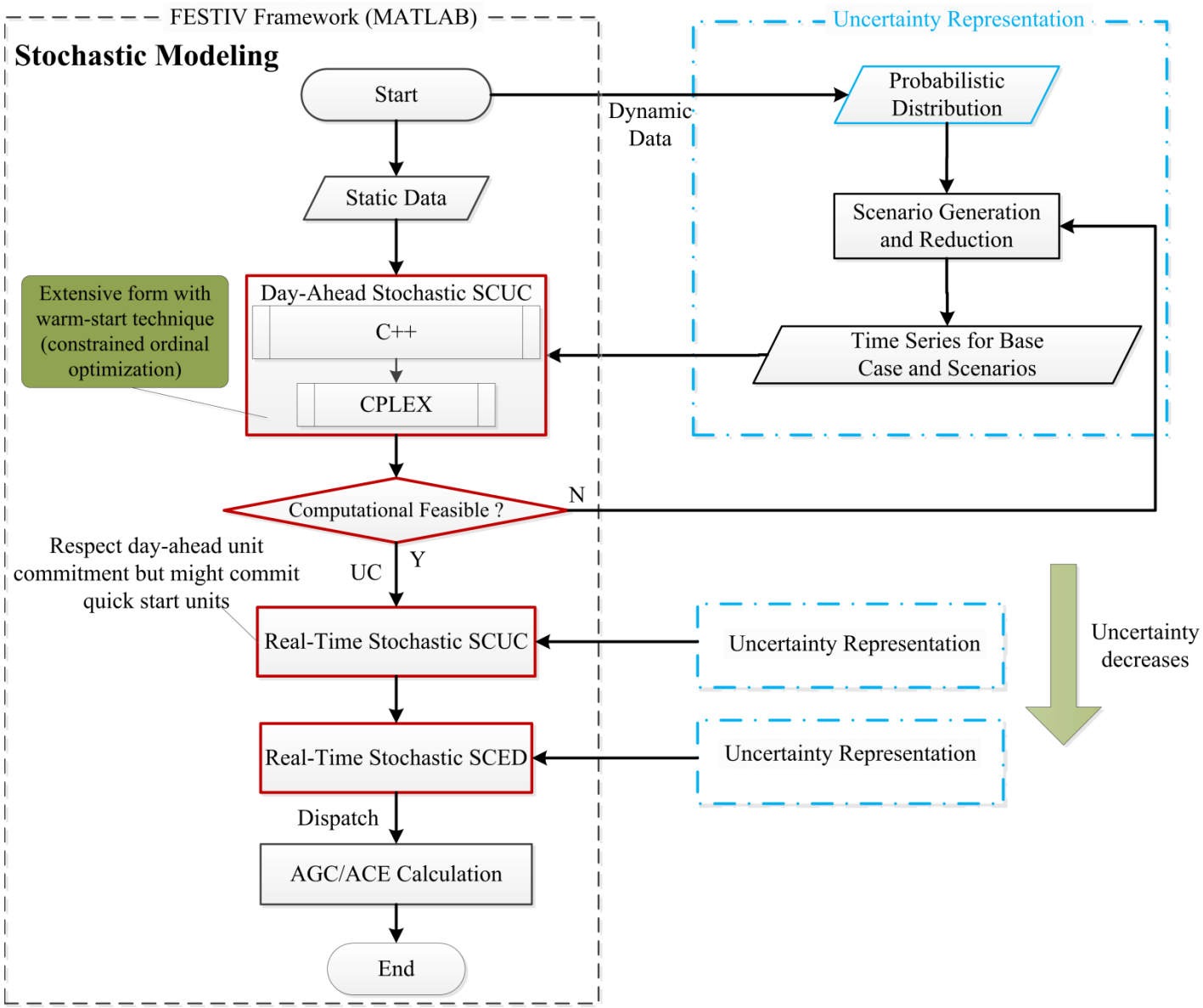


How can we move the boxes to the right? Or can we move them down?

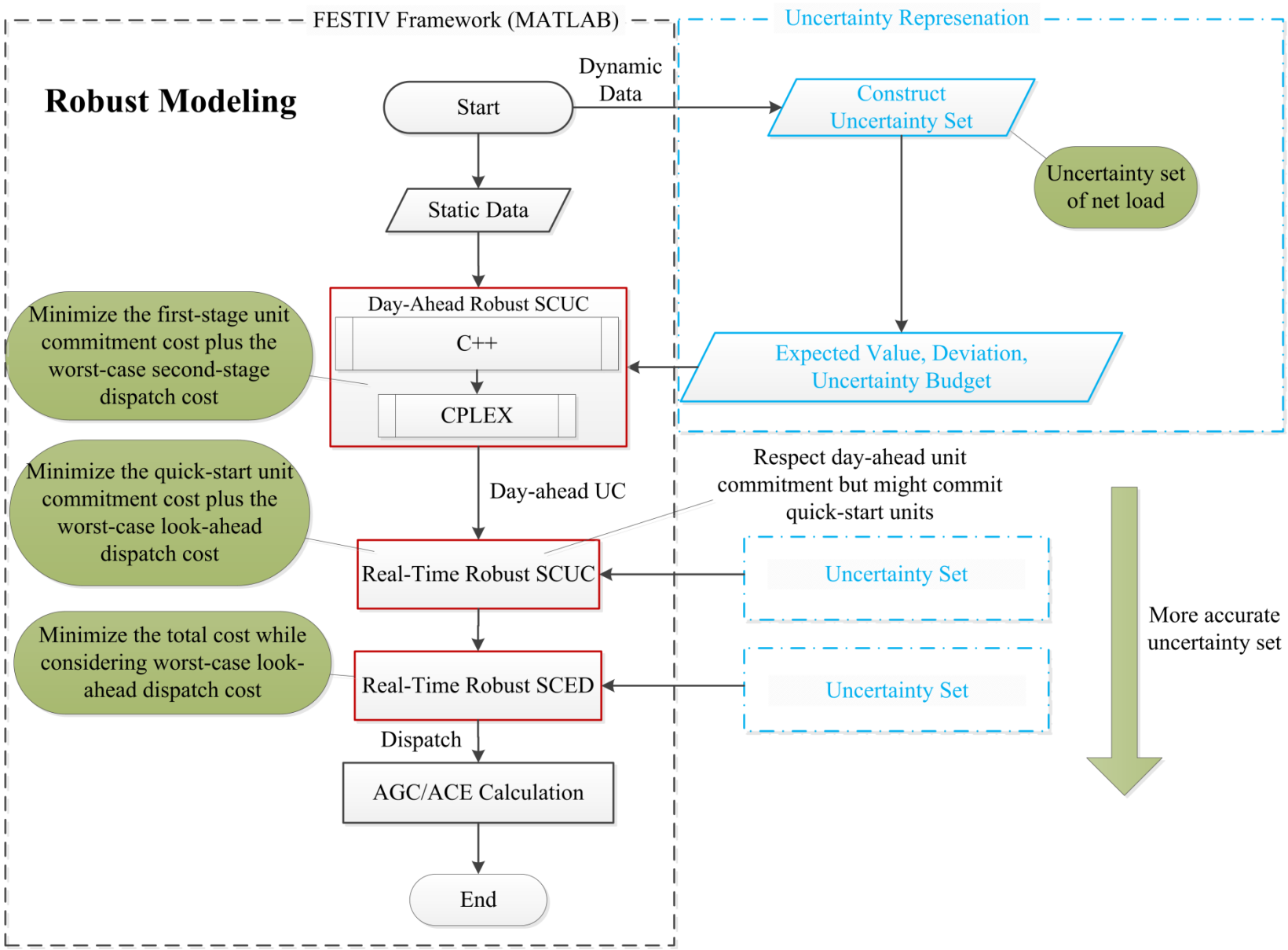
Project Goals

- **Use renewable resource and load forecasting error characteristics representing probabilistic forecasts with correlations across time, space, and each other (e.g., load and solar)**
- **Develop stochastic model, operating at multiple time resolutions and time horizons**
  - Merge with DASCUC, RTSCUC, RTSCED
- **Develop robust model, operating at multiple time resolutions and time horizons**
  - Merge with DASCUC, RTSCUC, RTSCED
- **Understand how each strategy (along with intelligent dynamic reserve) reduces the imbalance (improves reliability) due to increased variable generation**
- **Understand how each strategy affects the incentive structure (pricing scheme) such that enhancements can be incorporated into market design, if necessary**
- **Perform a direct comparison and plain word assessment of the efficiency (production cost) from each strategy**

Multiple Timescale Stochastic Model



Multiple Timescale Robust Model



COO for Stochastic SCUC

- **Scenario-based method in terms of Monte-Carlo Simulation is one of the major solutions of stochastic SCUC**
- **Scenario-based method characteristics**
  - The accuracy of MCS is at best $1/(N)^{1/2}$
  - A non-convex, NP-hard SCUC in each scenario
  - Hard-coupling constraints link all scenarios

  Multiplicative impacts!
- **Drawbacks**
  - Computationally infeasible when considering a large number of scenarios

COO for Stochastic SCUC (Cont.)

- **Goal: Finding good enough solutions with high probability instead of searching for the best solution with certainty**
- **Two tenets**
  - Ordinal comparison
  - Goal softening

  Intuitively reasonable, mathematically proven*
- **Advantages**
  - Saves computation efforts by at least one order of magnitude
  - Convergence rate of COO is exponential, which is much faster than $O(1/(N)^{1/2})$ of MCS

*Y. C. Ho, Q. Zhao, and Q. Jia. (2007). *Ordinal Optimization: Soft Optimization for Hard Problems*. New York: Springer.

COO for Stochastic SCUC (Cont.)

Generalized S-SCUC

$$\min_{\mathbf{I},\mathbf{P}^s} J(\mathbf{I},\mathbf{P}^s) = \min_{\mathbf{I},\mathbf{P}^s} \lim_{NS\to\infty} \sum_{s=1}^{NS} \mu_s \cdot L(\mathbf{I},\mathbf{P}^s,\xi^s)$$

$$s.t. \quad h(\mathbf{I},\mathbf{P}^s) \le 0,$$

$$\mathbf{I} \in \Theta,$$

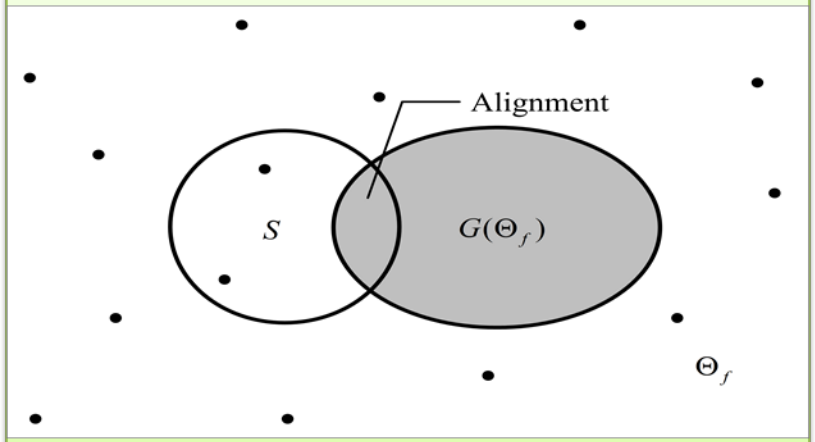
Feasibility Model

$$\sum_{i\in E_{1,t}} P_i^{\max} + \sum_{w\in E_{2,t}} P_{w,t}^{\mathrm{f},\max} \ge D_t^s, \forall t, \forall s$$

$$\sum_{i\in E_{1,t}} P_i^{\min} \le D_t^s, \forall t, \forall s$$

$$\sum_{n=1}^{k-1} (a_{l,i_n} - a_{l,i_k})\overline{P}_{i_n} + \sum_{n=k+1}^{N} (a_{l,i_n} - a_{l,i_k})\underline{P}_{i_n} + a_{l,i_k} D_t^s \le B_{l,t}, \forall l, \forall t, \forall s$$

Alignment Probability



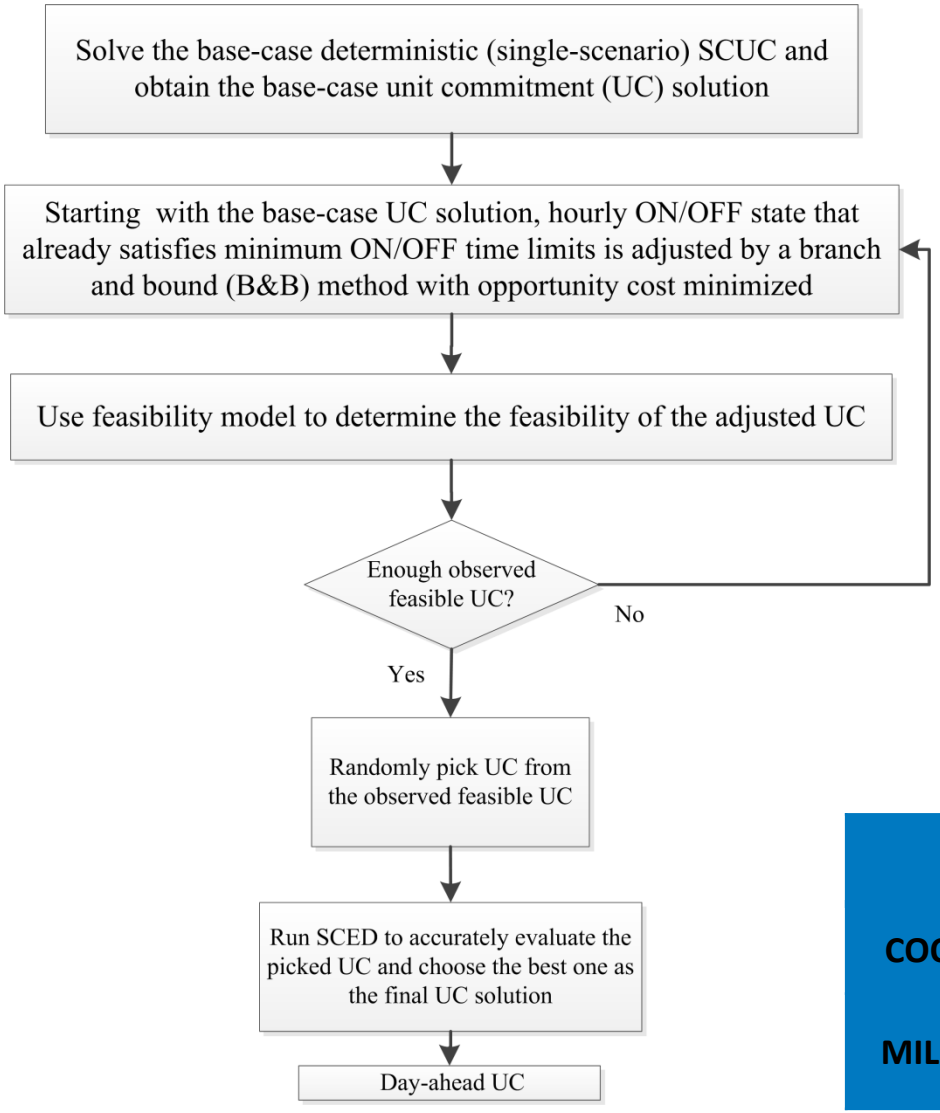
$$\mathrm{Prob}(|G(\Theta_f) \cap S| \ge k) \ge a$$

BPFM

$$\mathrm{Prob}(|G(\Theta_f) \cap S| \ge k)$$

$$= \sum_{j=k}^{\min(g,S_N)} \sum_{i=0}^{S_N-j} \frac{\binom{g}{j}\binom{M-g}{S_N-i-j}}{\binom{M}{S_N-i}} \binom{S_N}{i} q^{S_N-i}(1-q)^i \ge a$$

COO for Stochastic SCUC (Cont.)



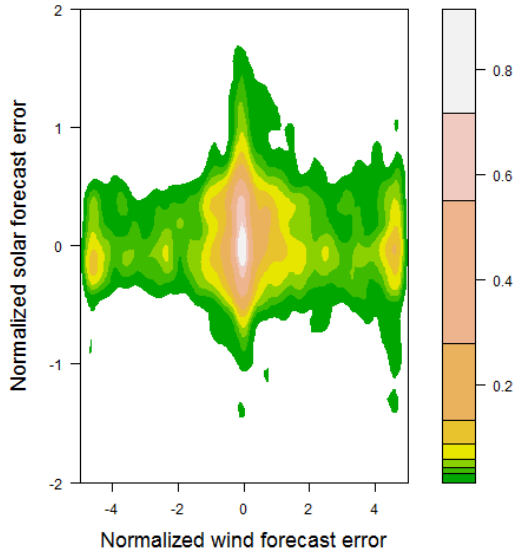
- Consider a wind penetration level of 21.7% in IEEE 118-bus system
- Uncertainties: Forecast errors of wind speed and hourly load as well as random outages of generating units and transmission lines
- Compare the COO to the CPLEX solution with default settings for solving the extensive form with the reduced 16 scenarios

	Operation Cost ($)	EENS (MWh)	CPU Time (s)
COO	1,431,840 ±65,330	6.11	1612
MILP	1,437,110 ±162,760	6.03	47359

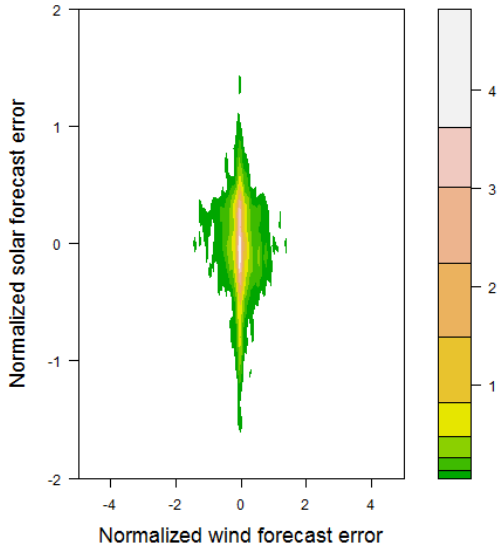
90% savings

H. Wu and M. Shahidehpour. (2014). "Stochastic SCUC Solution with Variable Wind Energy Using Constrained Ordinal Optimization." *IEEE Trans. Sustainable Energy* (5:2) April; pp: 379–388.

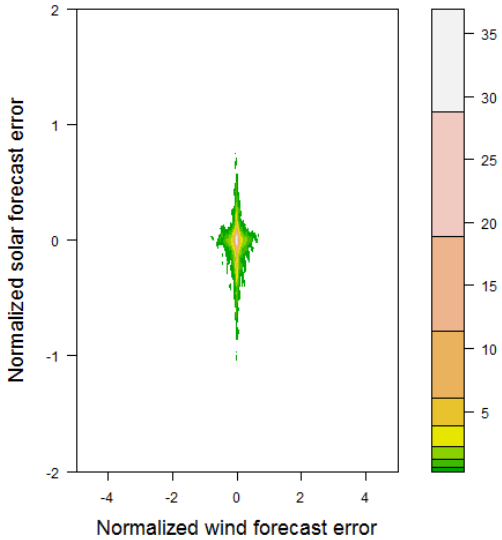
Forecast Errors of Different Timescales



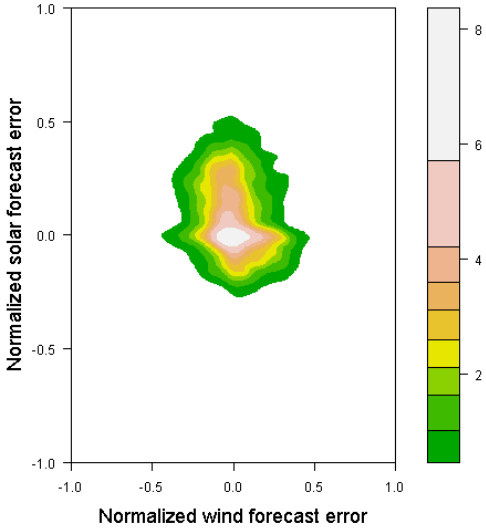
(a) Day-ahead joint distribution

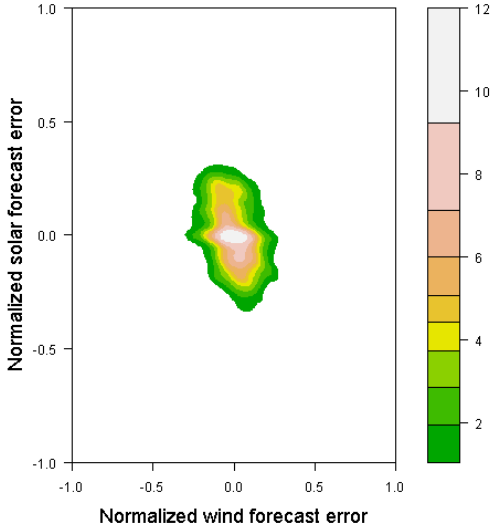


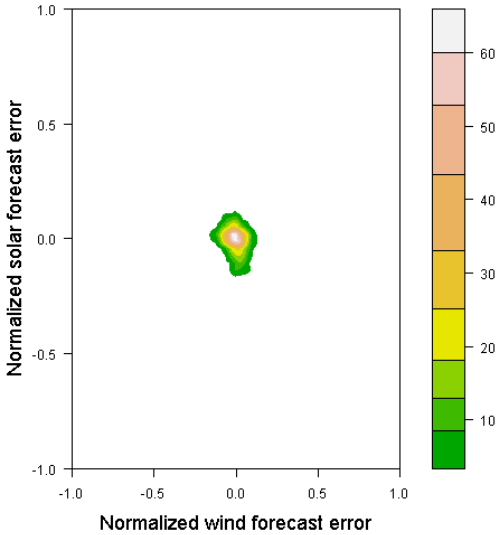
(b) Four-hour-ahead joint distribution



(c) One-hour-ahead joint distribution







J. Zhang, B.M. Hodge, A. Florita. (2014). "Joint Probability Distribution and Correlation Analysis of Wind and Solar Power Forecast Errors in WWSIS." *J. of Energy Eng.*

Correlation Analysis of Different Timescales

Pearson's Correlation Coefficients[1]

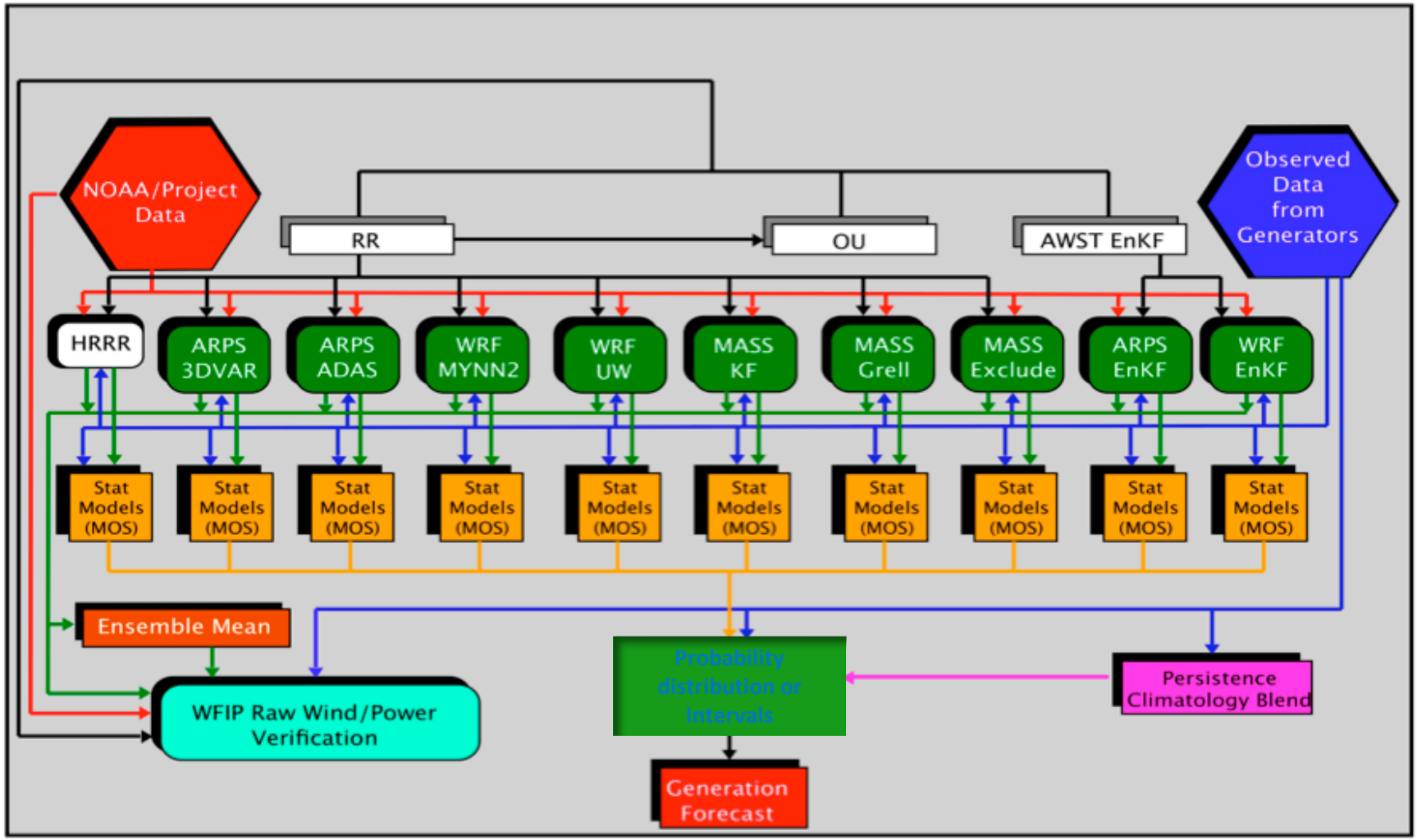
	Day-Ahead			Four-Hour-Ahead			One-Hour-Ahead		
	Year	Jan.	July	Year	Jan.	July	Year	Jan.	July
WWSIS*	-0.19	-0.21	-0.30	-0.34	-0.18	-0.63	-0.13	-0.06	-0.34

- **Wind and solar generation forecast errors are inversely correlated**
- **A larger inverse correlation would be preferable, because a large positive wind forecasting error would be more likely to be offset by a negative solar forecasting error**
- **Future work will investigate the impact of the inverse correlation on the reliability and efficiency of each model**

*Western Wind and Solar Integration Study

J. Zhang, B.-M. Hodge, A. Florita. (2014). "Joint Probability Distribution and Correlation Analysis of Wind and Solar Power Forecast Errors in WWSIS." *J. of Energy Eng.*

Wind Generation Forecast*



Probabilistic wind generation forecasts for the next 6 hours with 15-minute time resolution

*J. Zhang, A. Florita, B.M. Hodge, et al. (2014). "Ramp Forecasting Performance From Improved Short-Term Wind Power Forecasting." *IDETC/CIE*.

Future Work

- **Direct comparison of SSCUC, RoSCUC, and Dynamic Operating Reserve in terms of reliability (imbalance), efficiency (production cost), and incentive structure (profit)**
- **Integration into market designs**
  - New advanced models schedule operating reserve inherently within the model without dual value for reserve constraint
  - DAM SCUC and reliability SCUC interaction and evolution
  - Is it plausible for an ISO to receive probabilistic bids from market participants?
- **Stochastic energy (vs. power) scheduling**

Questions

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- http://www.nrel.gov/electricity/transmission