FY12 DOE/CERTS Internal Program Review

Real-Time Wide-Area Monitoring Tool Based on Characteristic Ellipsoid Method (CELL)

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- Jian Ma, Burns & McDonnell, Former Project Lead

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Project Objectives and Quick Overview

- **Objective:**
  - Develop a relatively simple, easy-to-implement and easy-to-use tool to monitor, predict and control the dynamic behavior of power systems for wide-area situational awareness, prediction and decision making support for operators
- **Specific Objectives:**
  - Monitor dynamic behaviors of power systems
  - Identify system disturbances
  - Provide wide-area situation awareness far beyond a single control area
  - Supply predictive and actionable information (in progress)
- **Support:**
  - Initially by PNNL-LDRD; and then by U.S. DOE's Office of Electricity Delivery and Energy Reliability through the Consortium for Electric Reliability Technology Solutions (CERTS)
- **Demonstration and Testing:**
  - Tested in PNNL Electricity Infrastructure Operations Center (EIOC)

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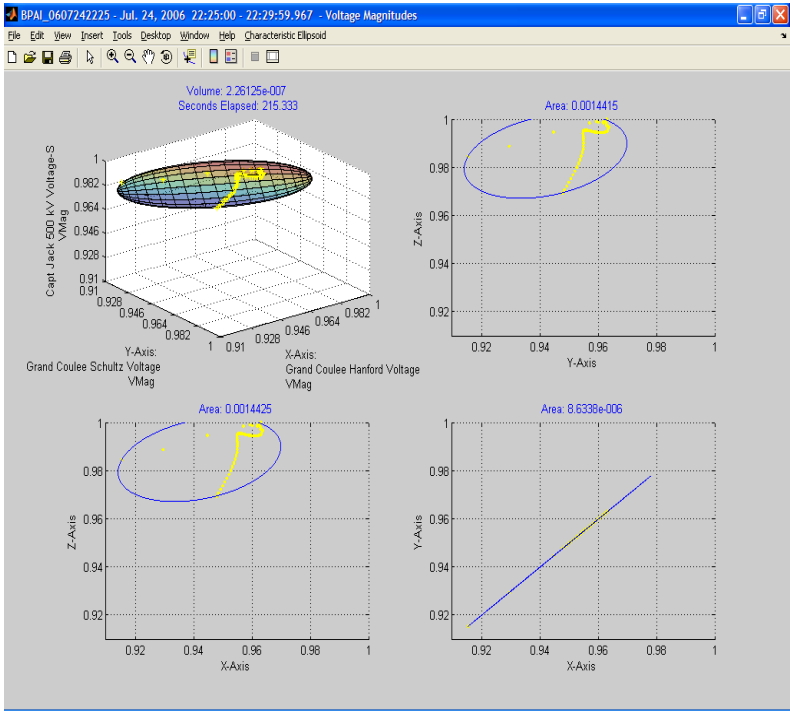
The Idea of CELL: Minimum Volume Inclusive Ellipsoid

- System trajectory ➡ Simple quadratic algebraic equation

$$\begin{cases} \dfrac{dx_1}{dt} = F_1(x_1, x_2, \ldots, x_n) \\ \dfrac{dx_2}{dt} = F_2(x_1, x_2, \ldots, x_n) \\ \quad\ldots \\ \dfrac{dx_n}{dt} = F_n(x_1, x_2, \ldots, x_n) \end{cases} \Rightarrow a_1 y_1^2 + a_2 y_2^2 + \ldots + a_n y_n^2 = c$$



- An optimization procedure minimizes the volume of CELL
- CELL *encloses* all recent points of system trajectory
- Key characteristics of CELL:
  - *volume*
  - *eccentricity*
  - *orientation of axes*
  - *derivative of the volume*
  - *characteristic sizes*
  - *projection of axes*
- Physically meaningful system Information:
  - *disturbances (type, location, size, etc)*
  - *damping*
  - *coherency of oscillations*

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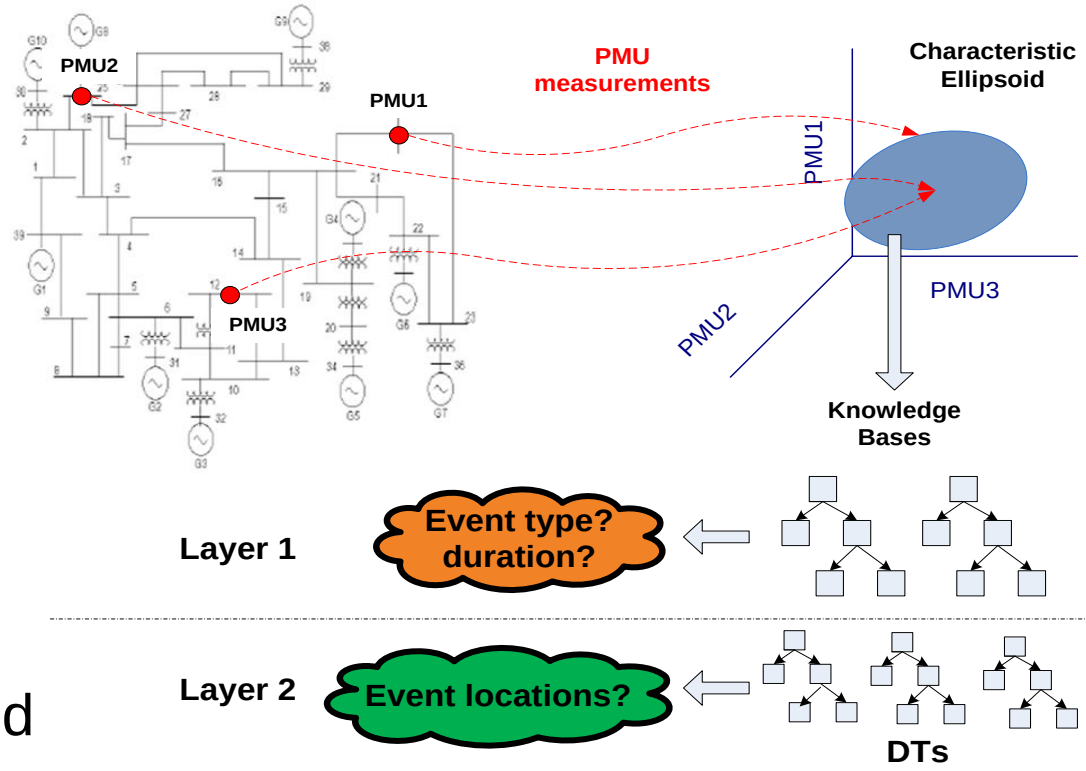
The Idea of CELL: Decision Tree Analysis

- Sudden volume change
  - ➡ *System disturbance*
- Volume and shape
  - ➡ *Spread of disturbance*
- Orientation
  - ➡ *Disturbance location*
- Shape and orientation
  - ➡ *System motion*
- Speed of volume change
  - ➡ *Generalized "damping"*
- Use *decision trees* to recognize disturbances and their characteristics



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Overall Technical Accomplishments

- **CELL mathematics:**
  - Developed advanced mathematical apparatus for *multi-dimensional* CELL calculations
  - Solved degenerated (dimension deficient) ellipsoid problems
- **Event detection and identification (type, location, etc.):**
  - Developed a methodology for interpreting CELL indices based on decision trees
  - Robustly revealed event types and locations
  - Tested on the New England 39-bus model and the *full WECC model*
  - Used *real phasor measurement data* and *actual system events*
- **A demonstration tool:**
  - Based on *full WECC model*
  - Provide multiple communication approaches for operators (text, voice, graph, map and GUI)
- **Google Earth application:**
  - Buses, transmission lines, and PMU locations
  - Disturbance locations

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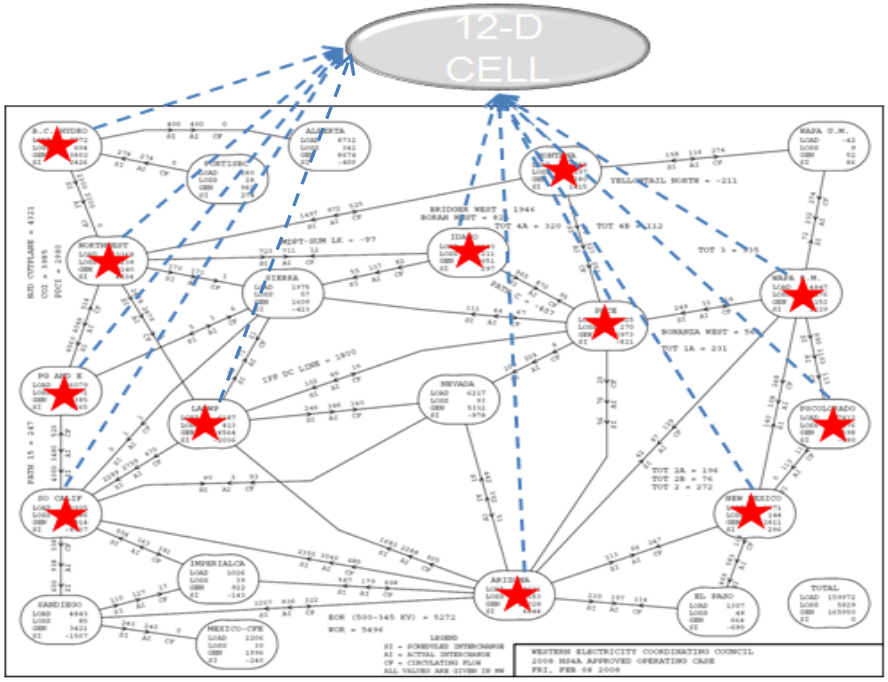
Case Study: Full WECC Model

- **Overview of the full WECC operational model:**
  - 16,031 buses
  - 3,993 transmission lines
  - 3,216 generators
  - 6,330 transformers
- **Operating conditions:**
  - 2009 heavy summer base case
  - 25 operating conditions
- **Simulated five types of events at various locations:**
  - Generator trips: 112 machines
  - Line trips: 117 transmission lines
  - Three-phase faults: 111 bus locations
  - Load loss: 34 loads
  - Shunt switching: 23 locations
  - Over 19,000 simulations
- **Selected only 12 PMUs across WECC to identify types and locations of various events**



- **Performance (Success rate, %):**
  - Generator trip locations (13 zones): *97.86%*
  - Load loss locations (3 zones): *98.24%*
  - Line trip locations (9 zones): *95.21%*
  - Fault locations (9 zones): *99.01%*
  - Event types (5 types): *97.48%*;

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Major Technical Accomplishments That Will be Completed This Year (FY12)

- Install CELL in the Electricity Infrastructure Operation Center (EIOC) **- DONE**
- Develop predictive capability to detect system insecurities ahead of time **– SOME PROGRESS**
  - Develop CELL-S approach (statistical ellipsoid)
  - Separate slow/fast motions
  - Predict slow/fast motions
  - Determine the probability and time to possible violations
- Integrate Wide-area Multidimensional Nomogram (WAMN) and CELL applications to demonstrate the approach. . . **- ???**
- Demonstrate actionable decision support for operators. . **- ???**
- Work with the industry organizations on technology transfer

Priority Task under limited funding

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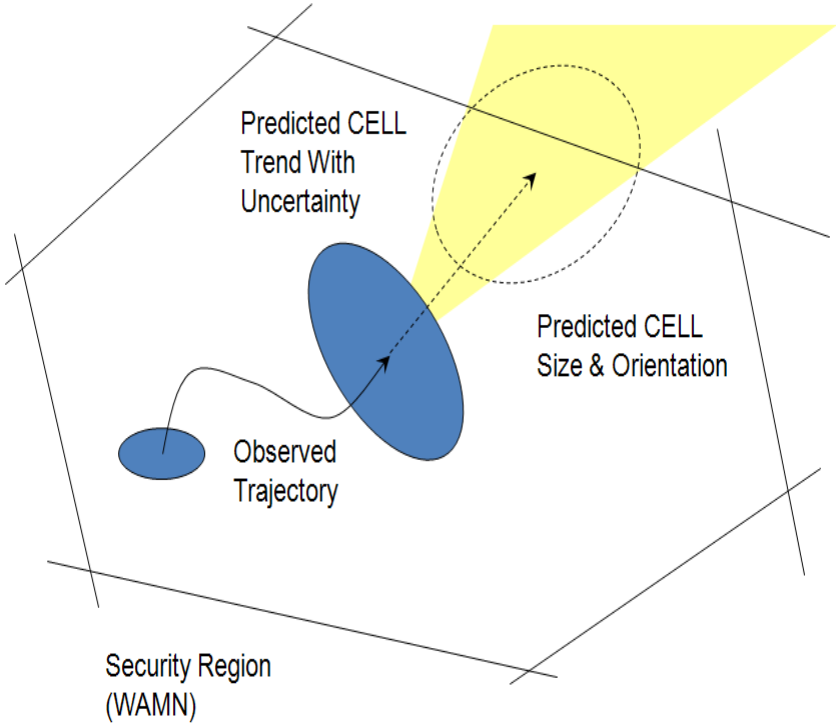
Deliverables and schedule for activities to be completed under FY12 funding

Tasks	Milestones	Timelines (beginning from work authorization)	Accomplishments	Deliverables
1	**Install CELL in the Electricity Infrastructure Operation Center (EIOC)**	---	DONE using FY11 money	A demonstration tool has been installed at PNNL's EIOC
2	Develop predictive capability to detect potential system insecurities ahead of time.	3 months	Significant initial progress using FY11 money	Presentations for NASPI RITT and PITT task teams
3	Develop a probabilistic version of CELL approach (CELL-S).	6 months???	Some initial progress using FY11 money	???
4	Integrate WAMN and CELL applications to demonstrate the predictive approach.	4-8 months???	---	???
5	Demonstrate opportunities for actionable decision support for operators.	12 months???	---	???
6	**Work with the industry organizations on technology transfer**	6 months	Ongoing effort	Progress report

Predictive CELL

- **Evaluate available security margin:**
  - Build security region represented as wide area nomograms (PNNL's work previously funded by DOE)
  - Calculate shortest distance to security boundary
- **Build probabilistic CELL:**
  - Statistical analysis with different confiden levels
  - Calculate CELL's probabilistic characteris indices
- **Predict future CELL trace (center, shape and orientation):**
  - Violation type and probability
  - Where possible violation may occur
  - Time remaining to violation



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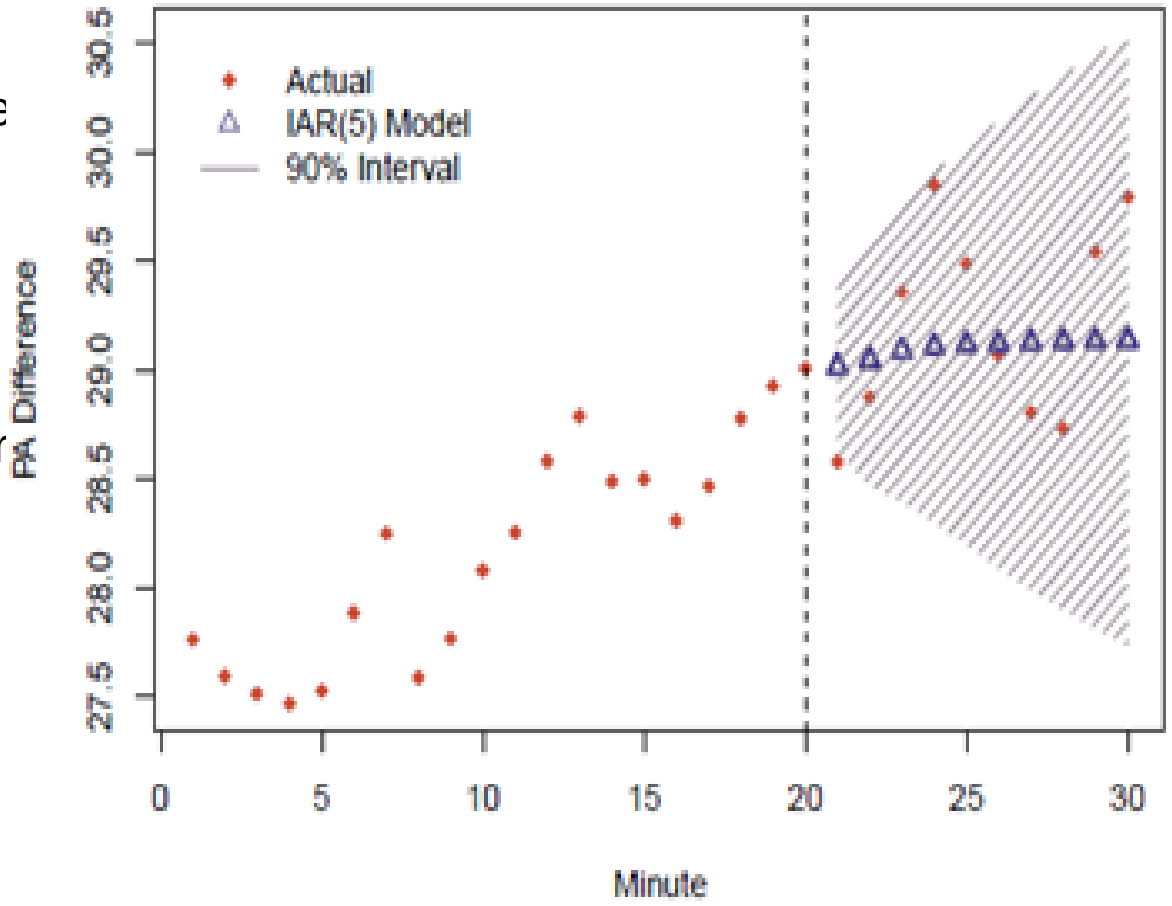
Predictive CELL

- In response to the comments made at the last Peer Review Meeting, we have equipped the tool with predictive analysis capability (CELL-S).
- Results show that the tool is capable of predicting the system dynamic behavior (represented by synchrophasor measurements) for up to 10 minutes ahead of time with very good confidence .
- This is sufficient to apply preventive redispatch or other measures to avoid system security problems.



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Technology Transfer and Collaborations

- 20+ presentations at conferences, industry meetings and DOE meetings:
  - In FY 2012: NASPI Operation Implementation Task Team
- 12 publications:
  - In FY 2012: J. Ma, Y. V. Makarov, R. Diao, P. V. Etingov, J. E. Dagle, E. De Tuglie, “The Characteristic Ellipsoid Methodology and Its Application in Power Systems,” IEEE Transactions on Power Systems (Accepted, to appear).
- Web seminars (Participants: CAISO, ISO New England, Southern Company, Midwest ISO, and BPA):
  - In FY 2012: NASPI Research Initiatives Task Team
- Submitted a preliminary proposal to Southern Company from PNNL on the CELL application
- Submitted a white paper to for a new potential project to analyze actual WECC events
- Planned FY12 collaborations include:
  - BPA (collect real-time data)
  - NERC (Dr. Bob Cummings)
  - WECC JSIS
  - Continue communications with ISO NE, Southern Company, others
  - Politecnico di Bari (Italy)

Risk Factors

- Now we can claim that the CELL approach design and demonstrated performance were successful
- The project approach is free of major flaws that would limit the project's effectiveness or efficiency
- Due to limited funding in FY12, some of the originally planned tasks can be moved to FY 2013
- Remaining technical risks
  - Accuracy of off-line decision trees for on-line application
  - Accuracy of identifying "unknown" events
  - Performance of the predictive CELL-based method

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Potential Future Work (FY13)

- Develop predictive capability to detect system insecurities ahead of time
  - Develop CELL-S approach (statistical ellipsoid)
  - Separate slow/fast motions
  - Predict slow/fast motions
  - Determine the probability and time to possible violations
- Integrate WAMN and CELL applications to demonstrate the approach
- Demonstrate actionable decision support for operators.
- Develop a prototype for remedial action scheme (RAS) applications
  - Connect CELL decision trees to remedial actions
- Develop a real-time application tool for close-loop control
  - Develop fully functional, user-friendly tool with interactive visualization
  - Provide database support for the tool
  - Close the control loop for the real-time monitoring tool, and more…
- Migrate from research project into a product used by utilities and vendors
  - Deploy a fully-functionalized tool in control centers
  - Continue aggressive activities leading toward project's commercialization

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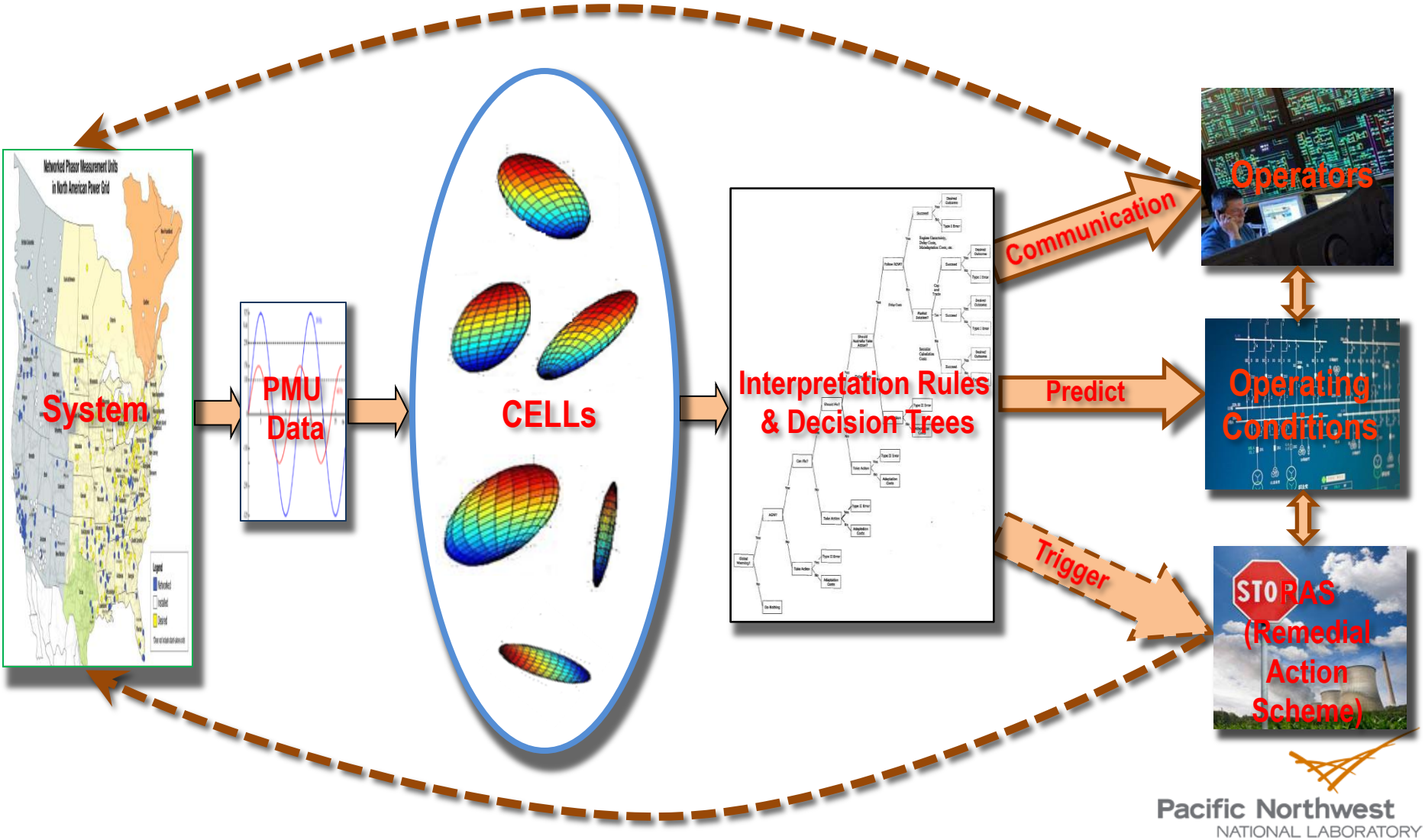
Potential Future Work (FY13)



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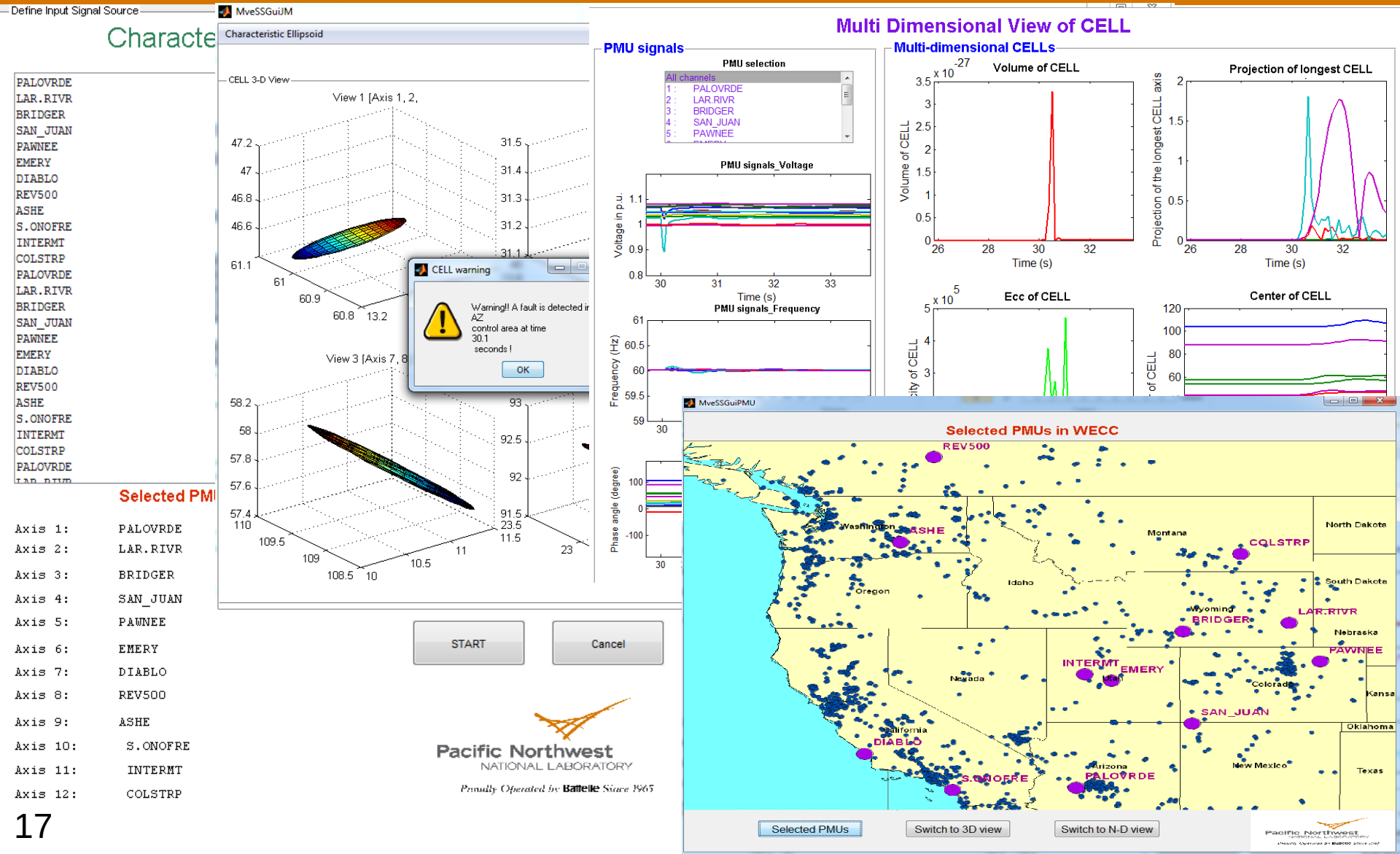
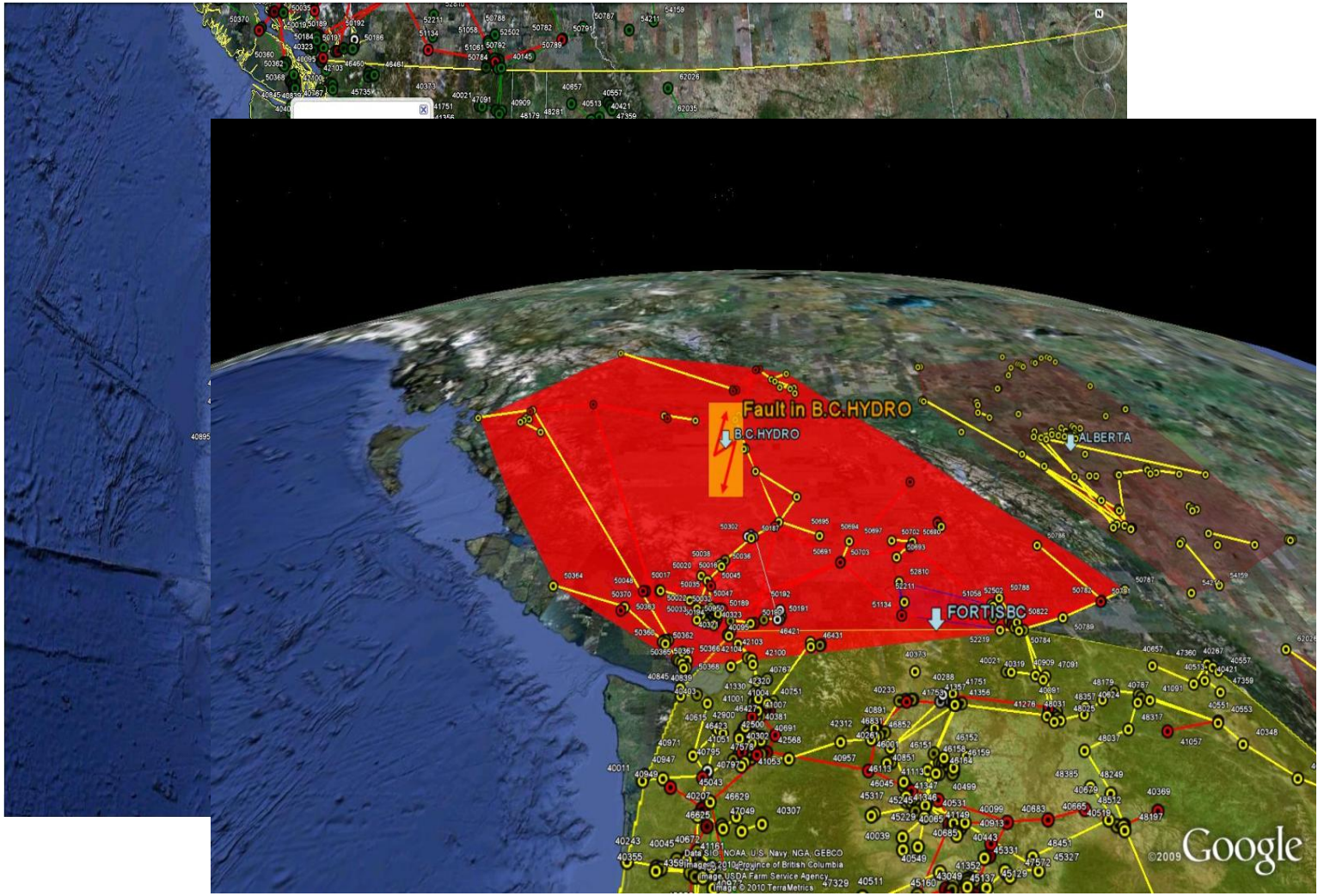
Additional Slides

Graphic User Interface



Google Earth Application



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Project Team

Mr. Jeff Dagle (P.E., Program Manager, Chief Engineer)	Program Management
Dr. Yuri V. Makarov (Principal Investigator, Chief Scientist)	Technical Strategy, Advice, Industry Contact
Dr. Bharat Vyakaranam (Project Lead, Research Engineer)	CELL Methodology, Demonstration Tool, Predictive CELL
Dr. Ruisheng Diao (Research Engineer) Dr. Pavel V. Etingov (Senior Research Engineer) Dr. Spencer Hays (Scientist)	Decision Trees, Google Earth, Demonstration Tool, Predictive CELL
Dr. Enrico De Tuglie (A/Prof., Politecnico di Bari, Italy)	CELL Methodology, Interpretation Rules

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Thanks
&
Questions?