Development of a Framework for Data Integration, Assimilation, and Learning for Geological Carbon Sequestration

(DIAL-GCS)

Project #: DE-FE0026515

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National Energy Technology Laboratory
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Carbon Storage and Oil and Natural Gas Technologies Review Meeting
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    - Hoonyoung Jeong (petroleum engineer)
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    - Sergey Fomel, Tieyuan Zhu (geophysics)
    - Clay Templeton (web development)
  - Information School: David Arctur (data scientist)
  - Texas Advanced Computing Center: Weijia Xu (HPC)

Outline

- Benefits to the program
- Technical status
- Accomplishments to date
- Synergy opportunities
- Summary

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Benefit to the Program

Carbon storage program goals being addressed

Develop and validate technologies to ensure 99 percent storage permanence

IMS: integrative carbon storage reservoir management technology that combines real-time measurement of reservoir properties with project-specific data management and data processing workflows

Expected benefits of this IMS Project

Transform scientific knowledge to decision knowledge and public knowledge:

- Promote data sharing and visual analytics
  - Better collaboration among team members
  - Public outreach
- Streamline GCS management and decisionmaking
- Facilitate the optimal allocation of monitoring resources

Challenges and Motivations

- GCS is highly interdisciplinary
- Data sharing and discovery is difficult
- Lack of project-specific risk assessment and data assimilation tools
- Lack of systematic demonstration of machine learning technologies

Project Overview:
Goals and Objectives

A. **Develop GCS data management module for storing, querying, exchanging, and visualizing GCS data from multiple sources and in heterogeneous formats**
   – Success Criterion: Whether a flexible, user-friendly Web portal is set up for enabling data exchange and visual analytics

B. **Incorporate a complex event processing (CEP) engine for detecting abnormal situations by seamlessly combining expert knowledge, rule-based reasoning, and machine learning**
   – Success Criterion: Whether a set of decision rules are developed for identifying abnormal signals in monitoring data

Project Overview:
Goals and Objectives

C. Enable uncertainty quantification and predictive analytics using a combination of coupled-process modeling, data assimilation, and reduced-order modeling

- Success Criterion: Whether a suite of computational tools are developed for UQ and predictive analytics

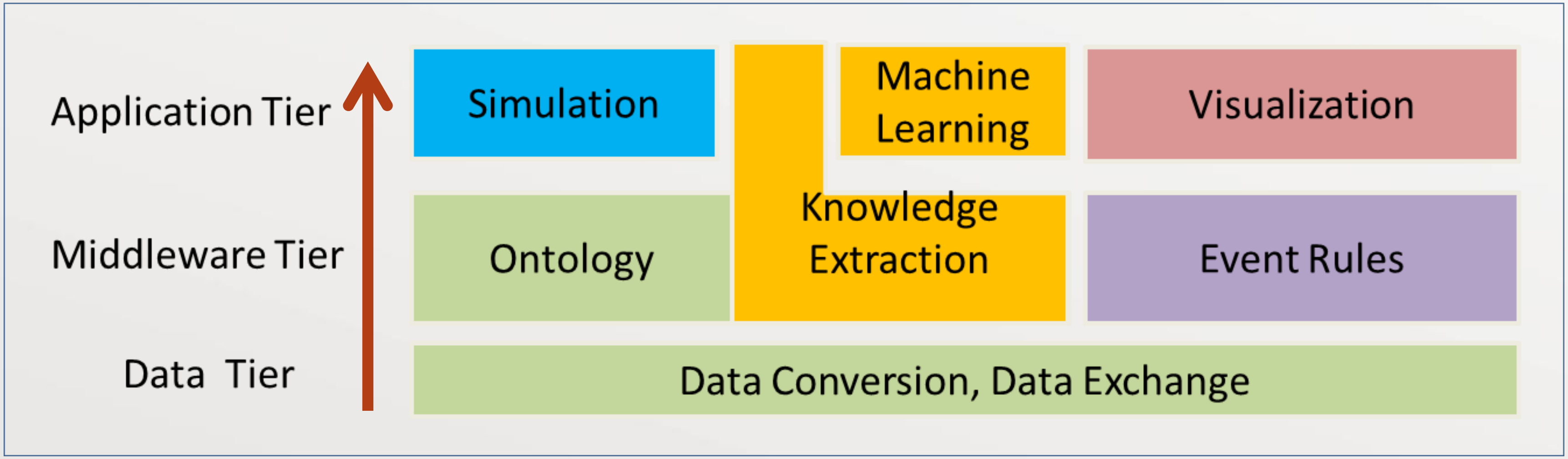
D. Integrate and demonstrate the system's capabilities with both real and simulated data

- Success Criterion: Whether the IMS tools developed under Goals A to C are integrated, streamlined, and demonstrated for a realistic GCS site

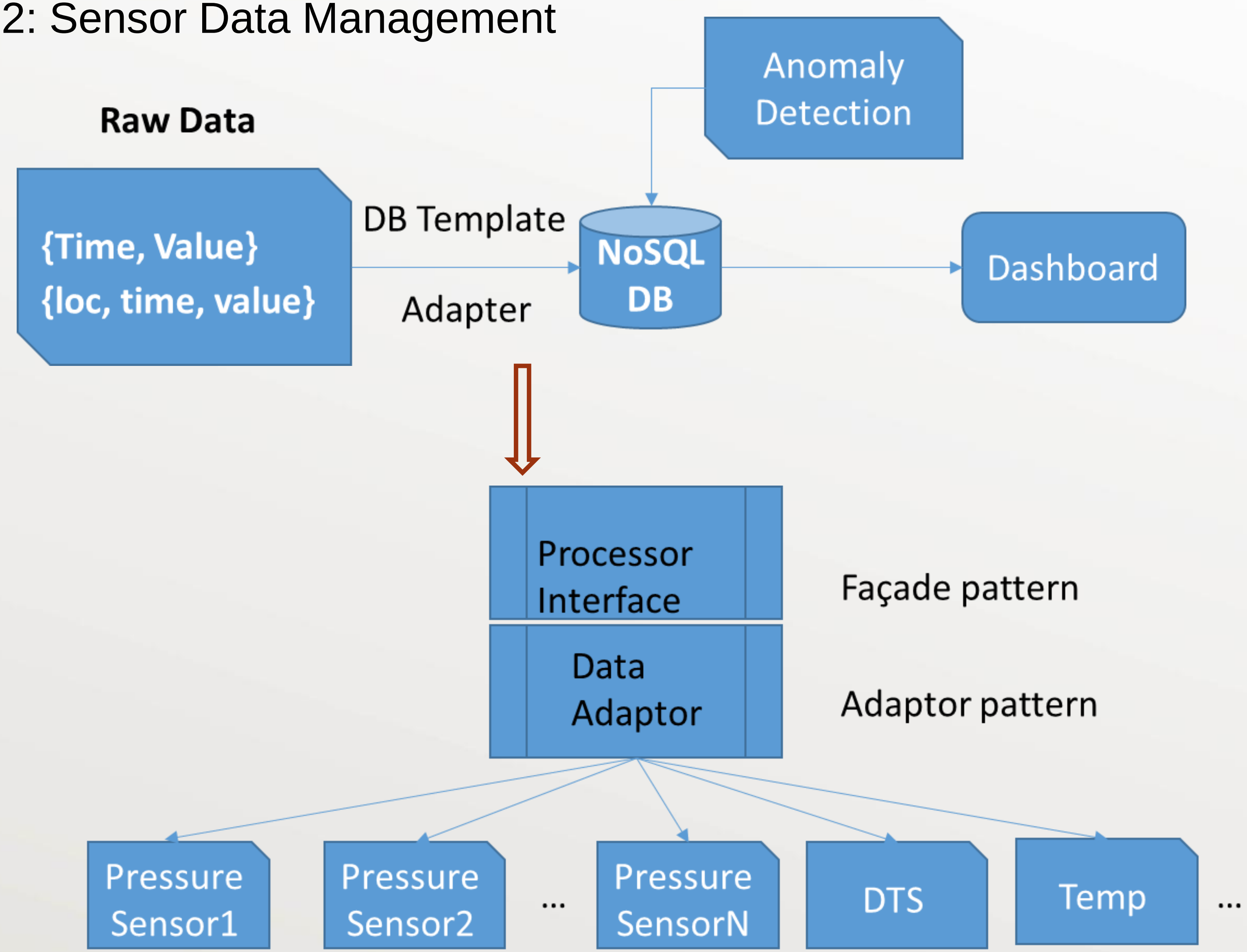
Technical Status

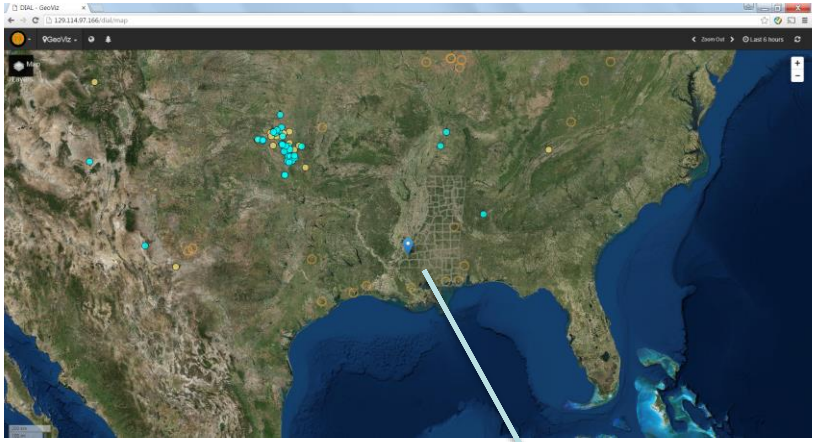
System Architecture of DIAL-GCS

Task 2: Sensor Data Schema Development and Serialization (Y1)
Task 3: Development of CEP, machine learning (Y1-2)
Task 4: Coupled Modeling and Data Assimilation (Y1-3)
Task 5: Integration and Demonstration (Y1-3)

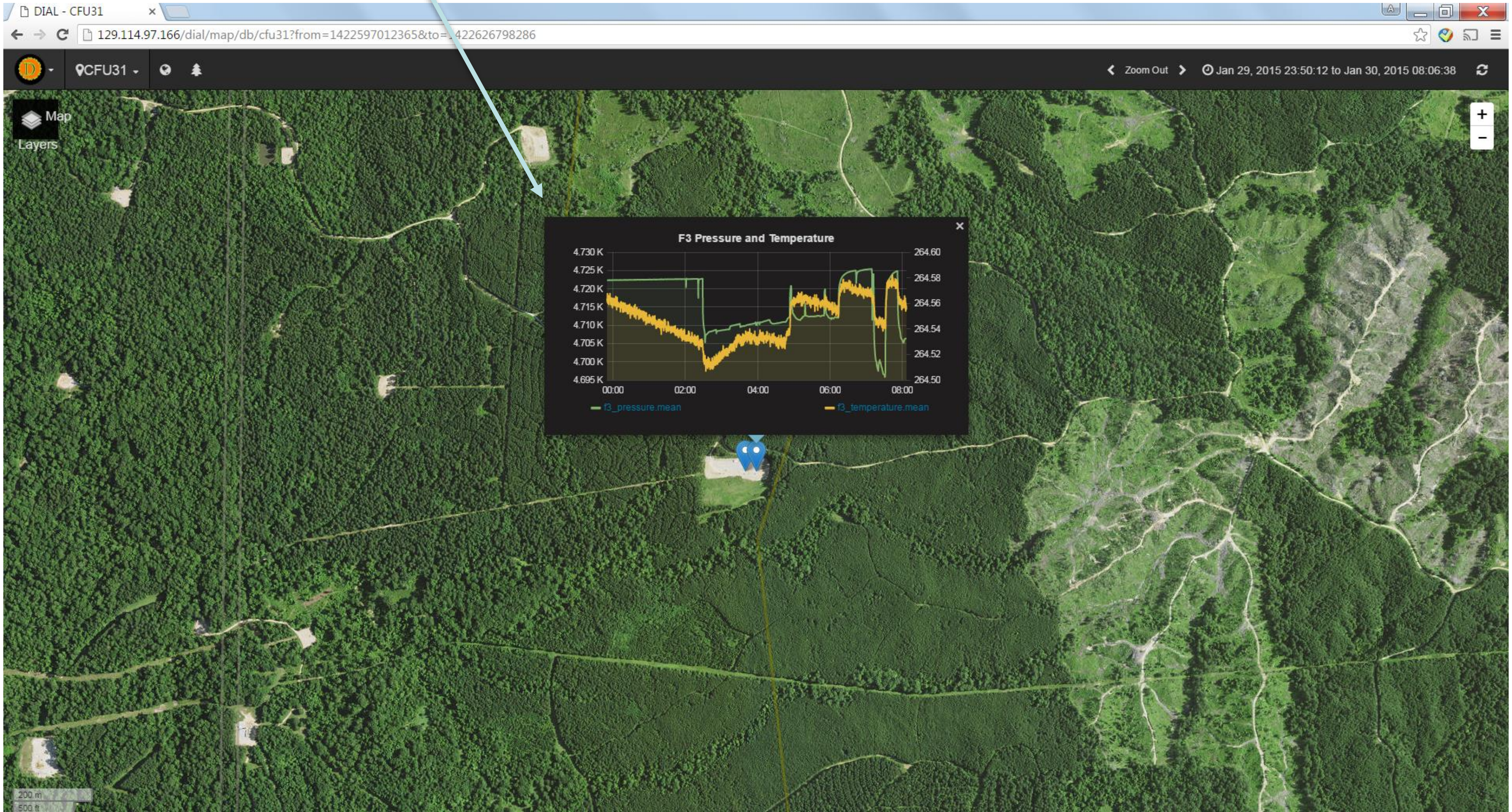


Task 2: Sensor Data Management

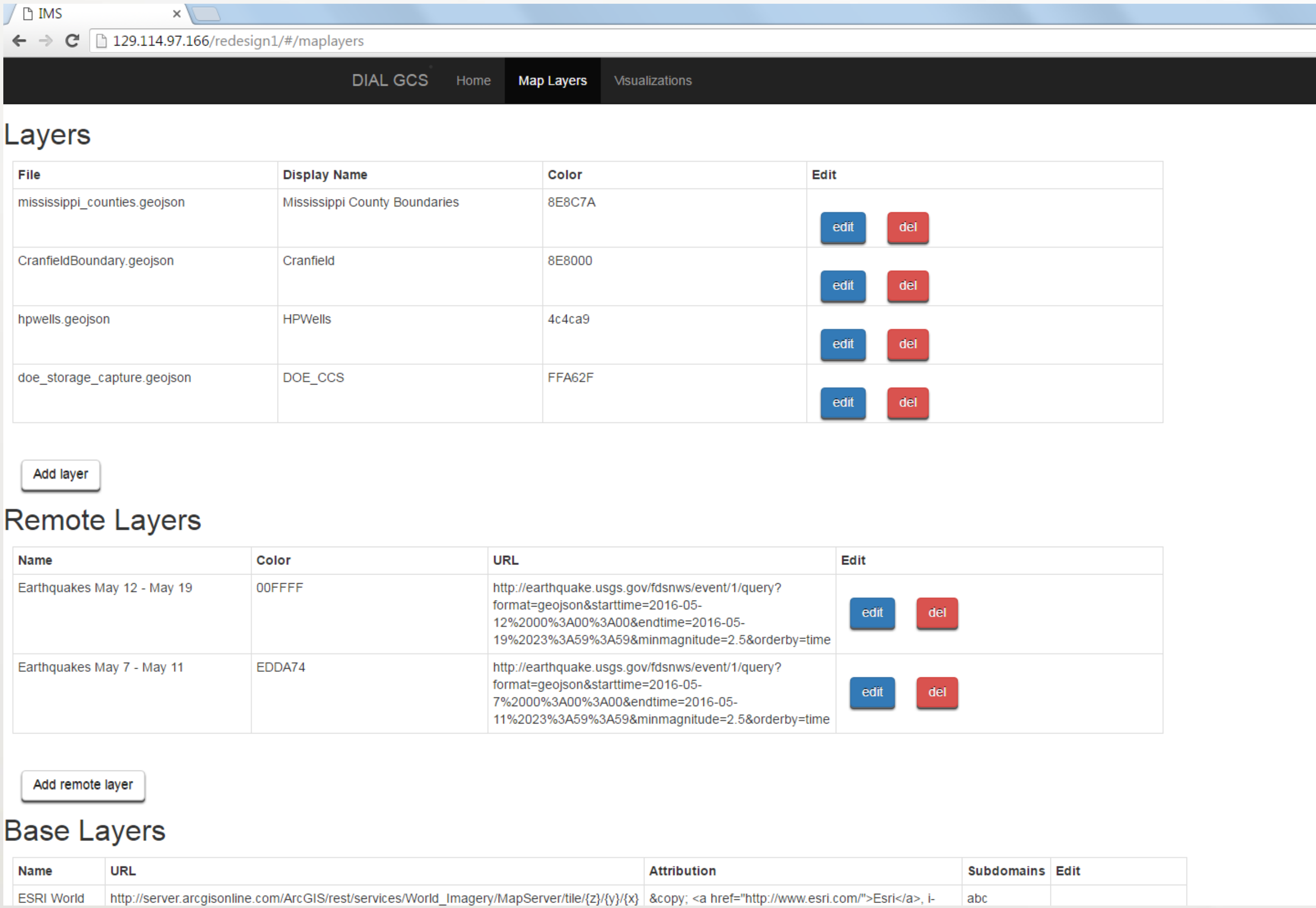




DIAL Frontend



Web-GIS Admin



IMS

129.114.97.166/redesign1/#/maplayers

DIAL GCS | Home | Map Layers | Visualizations

Layers

File	Display Name	Color	Edit
mississippi_counties.geojson	Mississippi County Boundaries	8E8C7A	edit del
CranfieldBoundary.geojson	Cranfield	8E8000	edit del
hpwells.geojson	HPWells	4c4ca9	edit del
doe_storage_capture.geojson	DOE_CCS	FFA62F	edit del

Add layer

Remote Layers

Name	Color	URL	Edit
Earthquakes May 12 - May 19	00FFFF	http://earthquake.usgs.gov/fdsnws/event/1/query?format=geojson&starttime=2016-05-12%2000%3A00%3A00&endtime=2016-05-19%2023%3A59%3A59&minmagnitude=2.5&orderby=time	edit del
Earthquakes May 7 - May 11	EDDA74	http://earthquake.usgs.gov/fdsnws/event/1/query?format=geojson&starttime=2016-05-7%2000%3A00%3A00&endtime=2016-05-11%2023%3A59%3A59&minmagnitude=2.5&orderby=time	edit del

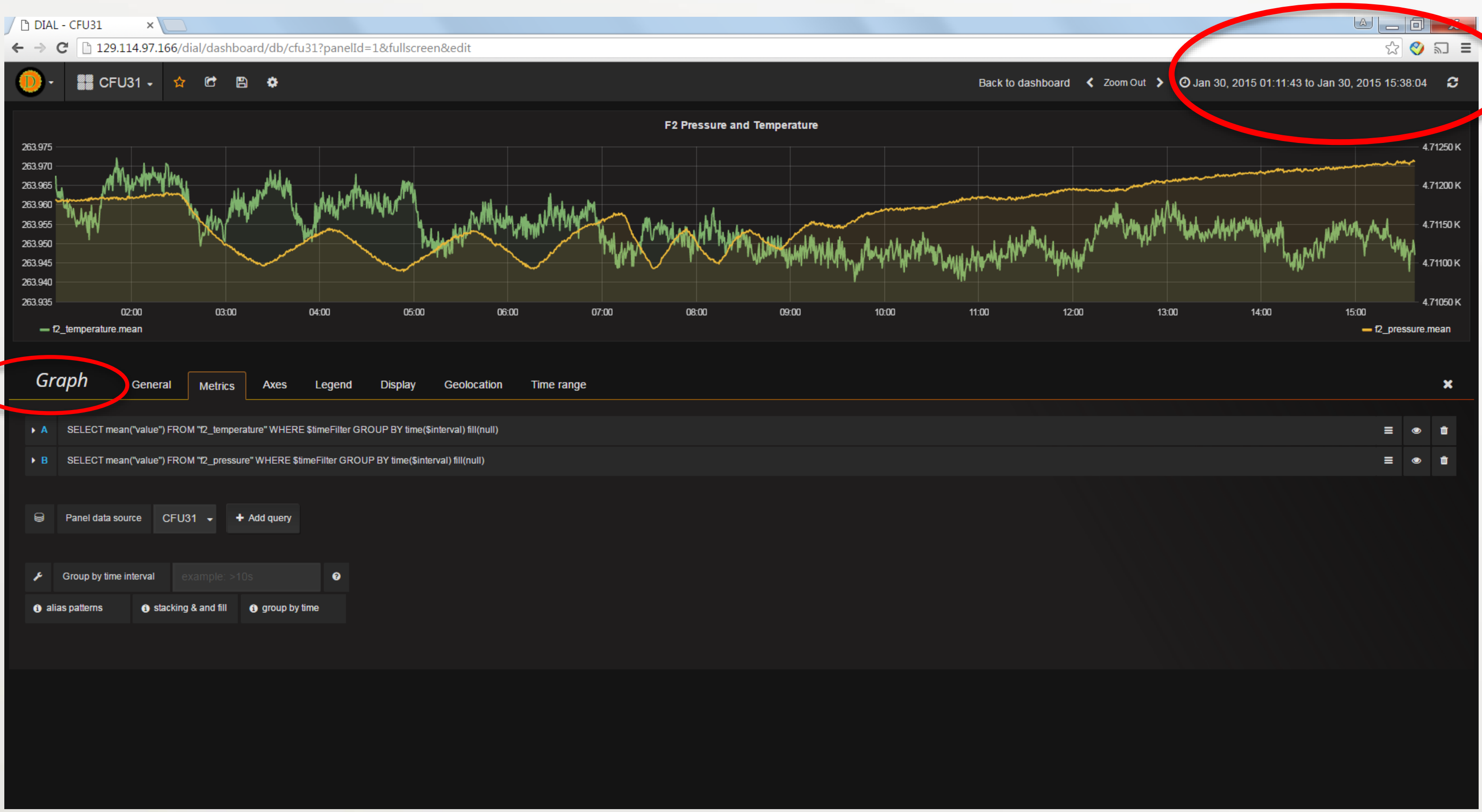
Add remote layer

Base Layers

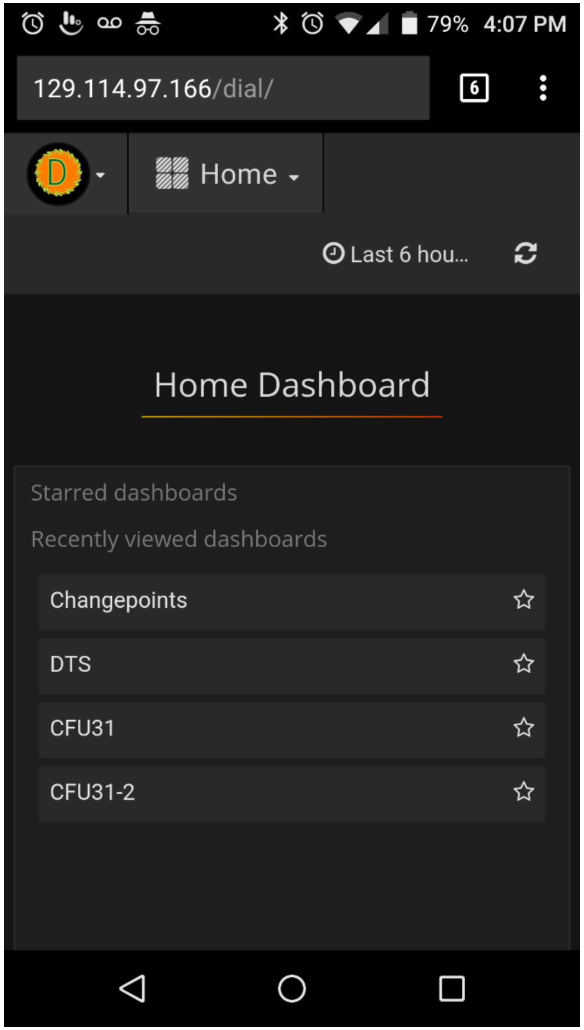
Name	URL	Attribution	Subdomains	Edit
ESRI World	http://server.arcgisonline.com/ArcGIS/rest/services/World_Imagery/MapServer/tile/{z}/{y}/{x}	© Esri, i-	abc	

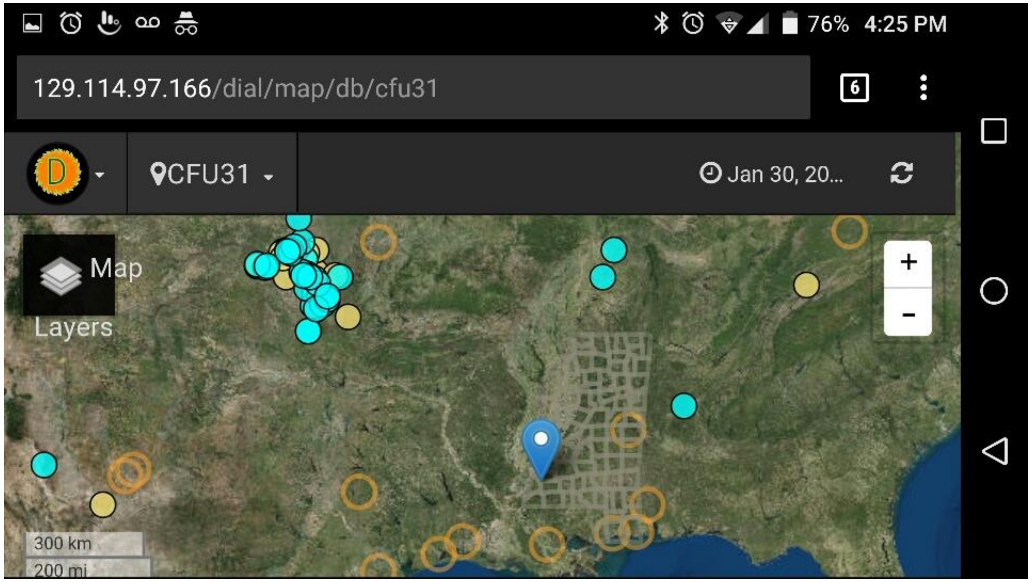
A Dashboard for Visual Analytics

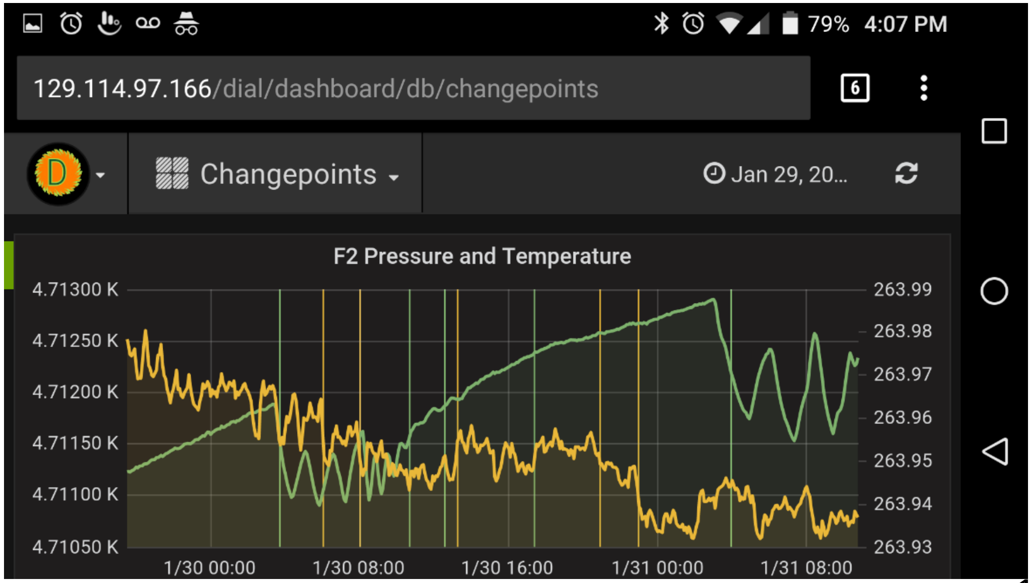
- Live monitoring datastreams
- Connect to different NoSql servers
- Web-based database query and visualization interface



Mobile Frontend







Task 3: CEP Development

Three event processing stages

- Signaling
  - Detection of abnormal event
- Triggering
  - Associate an event with a pre-defined rule or rule set
- Evaluation
  - Provide diagnostics/reasoning on an event

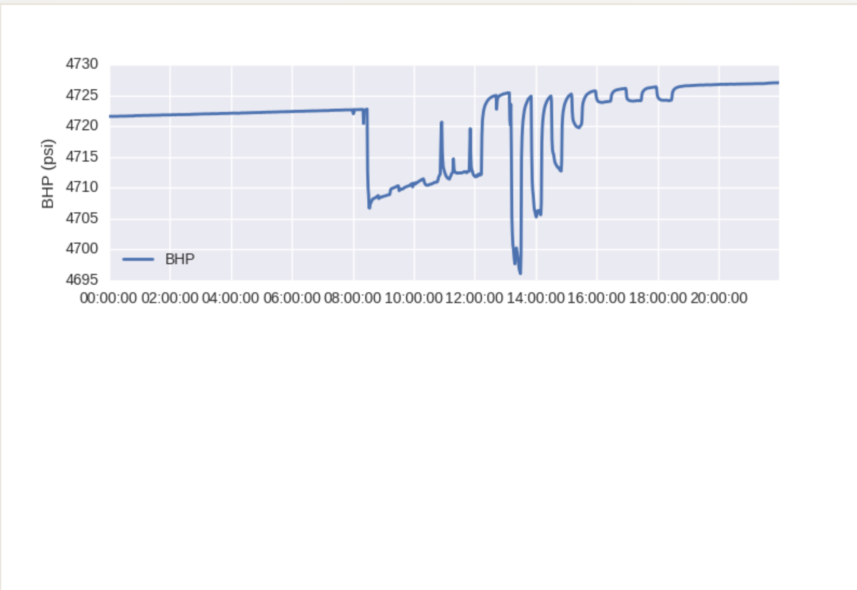
Anomaly Detection

Sensing Technology	*Category*	*Data (temporal/spatial)*	*Possible Event*
Seismic imaging	Geophysical	Discrete/vector	Time-lapse change
Downhole pressure gauge	Geophysical	Continuous/scalar	Abrupt change from a nominal trend
Soil gas sampling	Geochemical	Discrete/scalar	Change in gas ratio (CO_2 vs. O_2)
Groundwater sampling	Geochemical	Discrete/scalar	Sampled values (pH, dissolved CO_2) exceeding threshold
Distributed temperature sensing	Geophysical	Continuous/vector	Temperature change

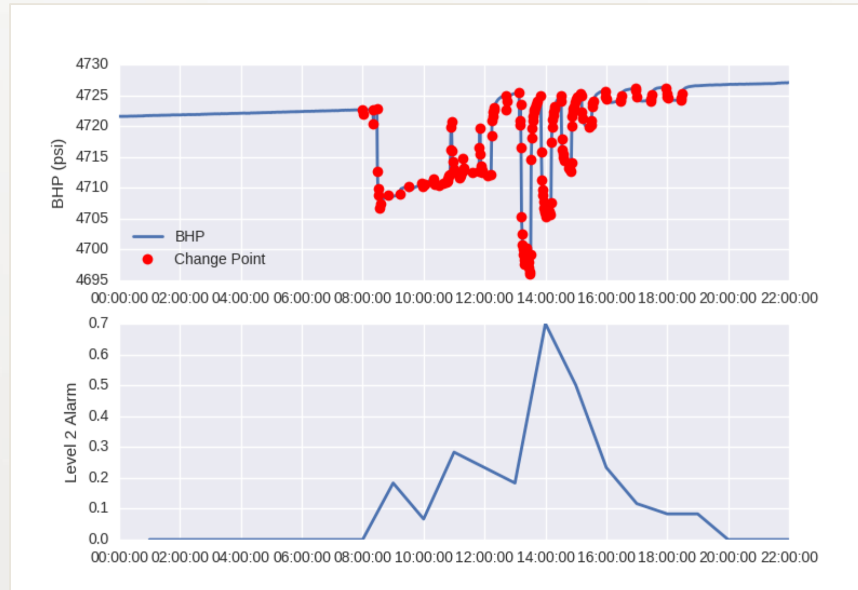
Demo Dataset

Detection of Leakage

Raw Data



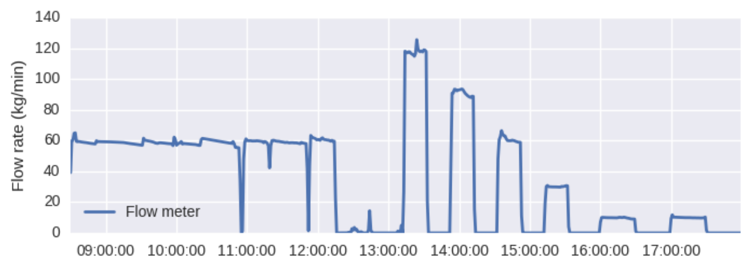
Downhole Pressure CPT



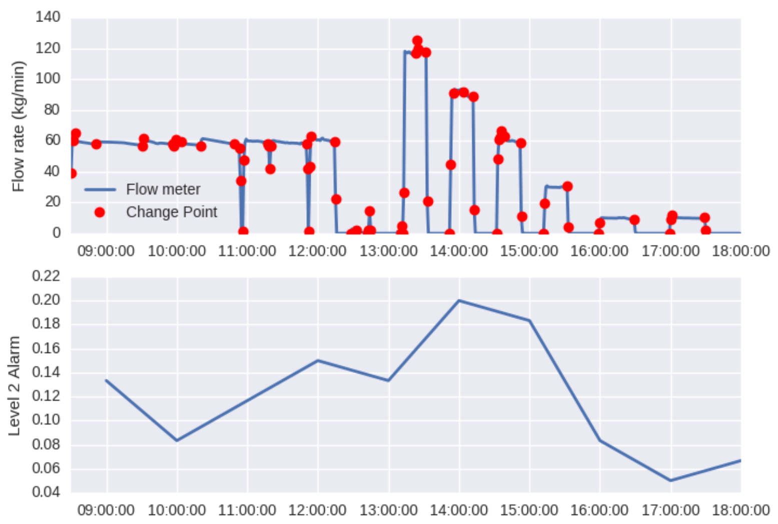
Level 0: Raw Data
Level 1: Events
Level 2: Aggregated events and alarms

Flow Meter Data

Raw Data

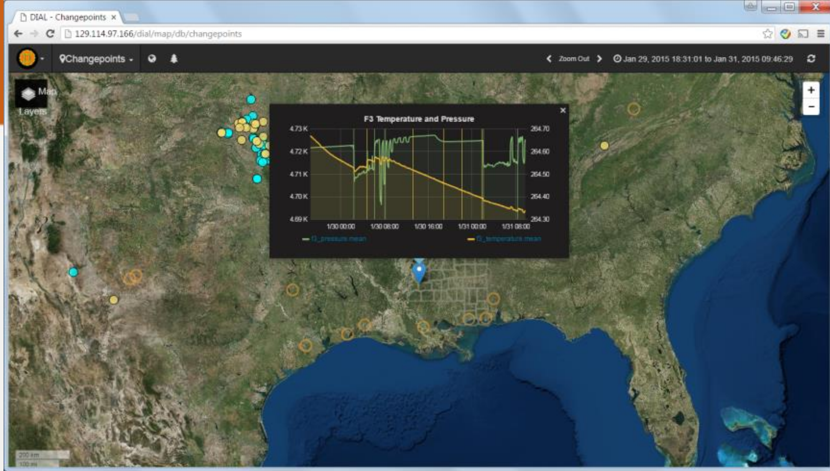


Flow Meter CPT

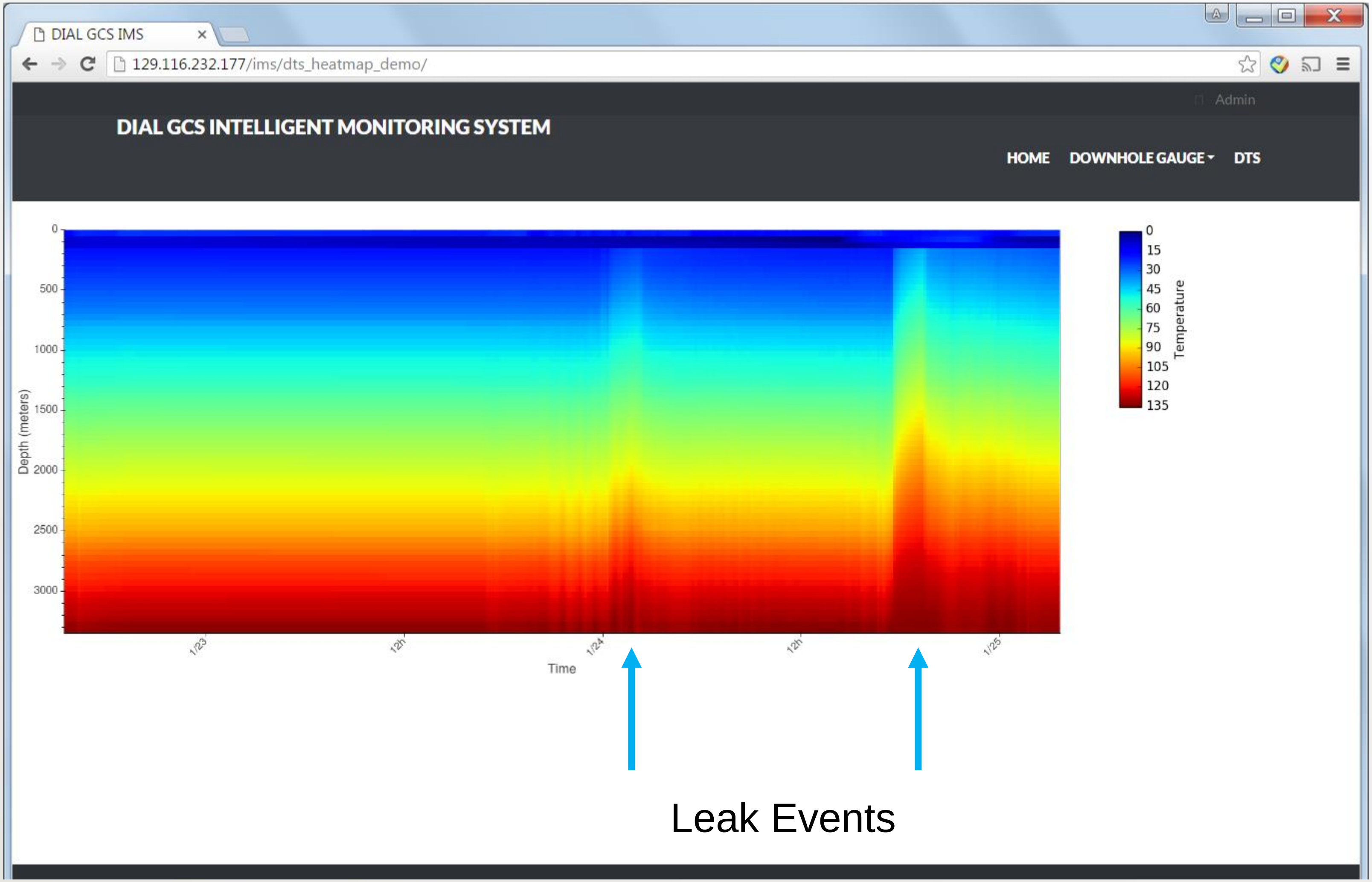


Level 0: Raw Data
Level 1: Events
Level 2: Aggregated events and alarms

Web-Based Anomaly Detection (Preliminary)



Beyond Time/Scalar Tuples

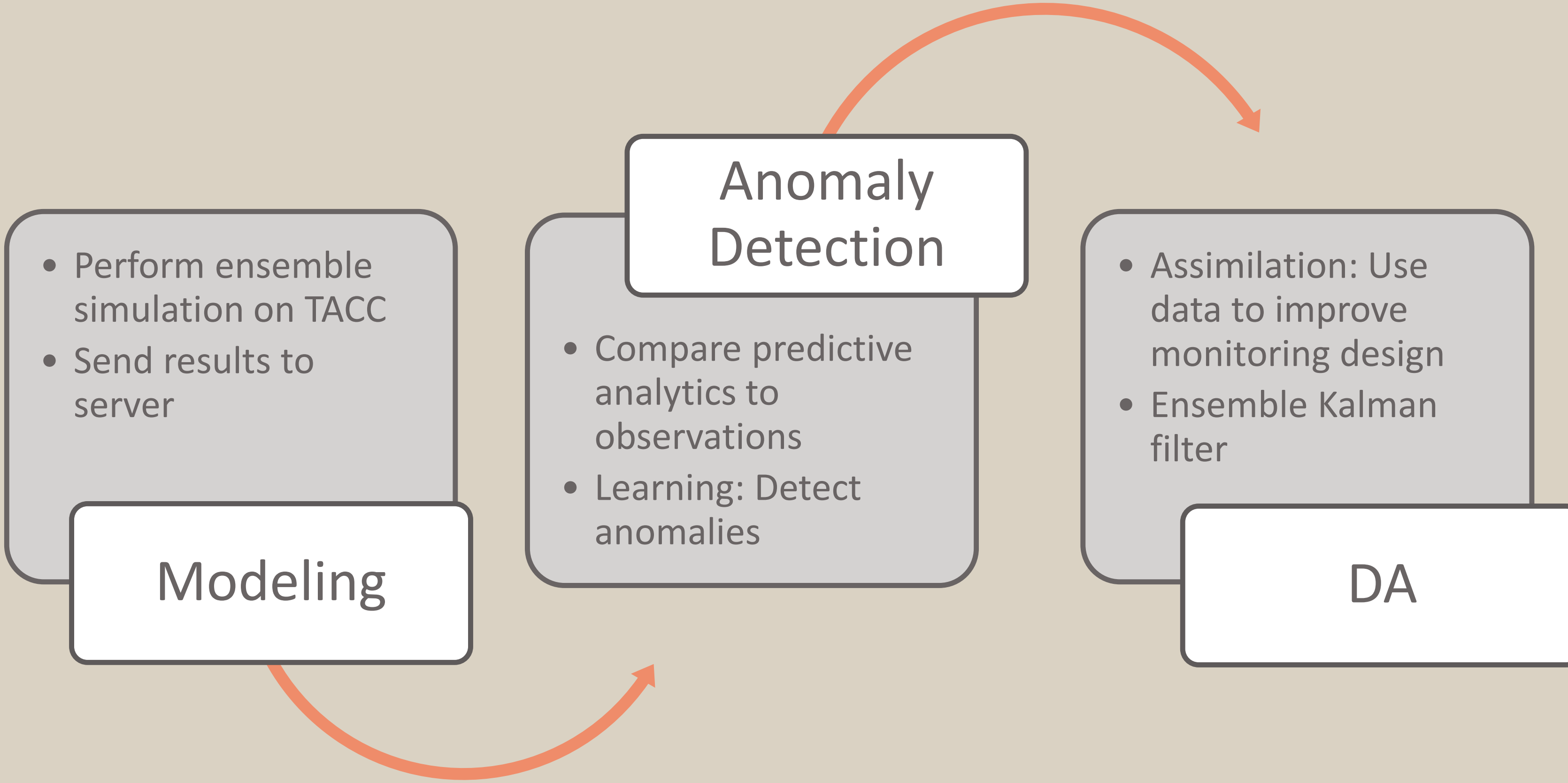


Data Courtesy: Barry Freifeld

Task 4 Modeling & Data Assimilation

- Phase 1: Develop “virtual observatories” at for testing monitoring design, risk management, uncertainty quantification
  - All models need to make use of high-performance computing
  - Main focus: Flow, Seismic, and Geochemistry
- Phase 2: Integrate process-level models with anomaly detection and data assimilation

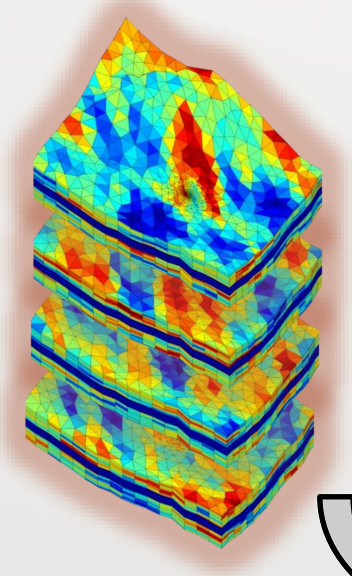
General Workflow

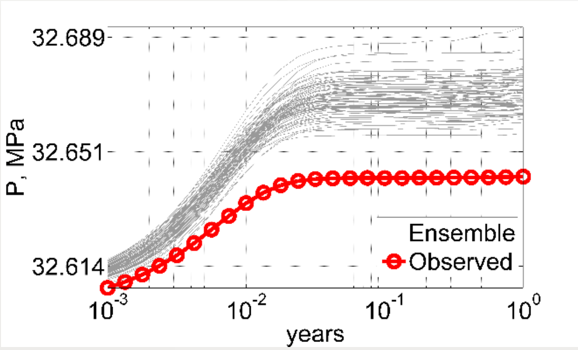


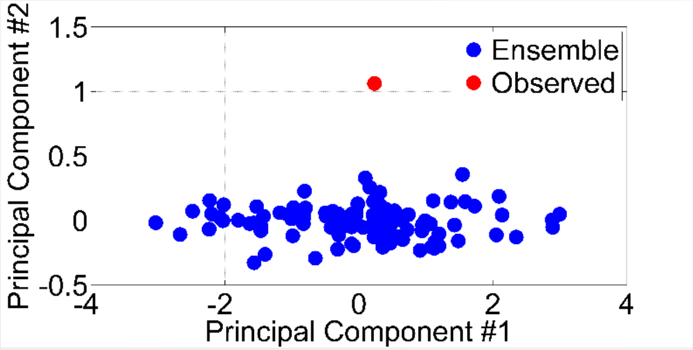
Flow Modeling

UQ, Predictive Analytics, and Machine Learning

Ensemble
Of Realizations







Perform ensemble
simulation

Anomaly detection

By Hoonyoung Jeong

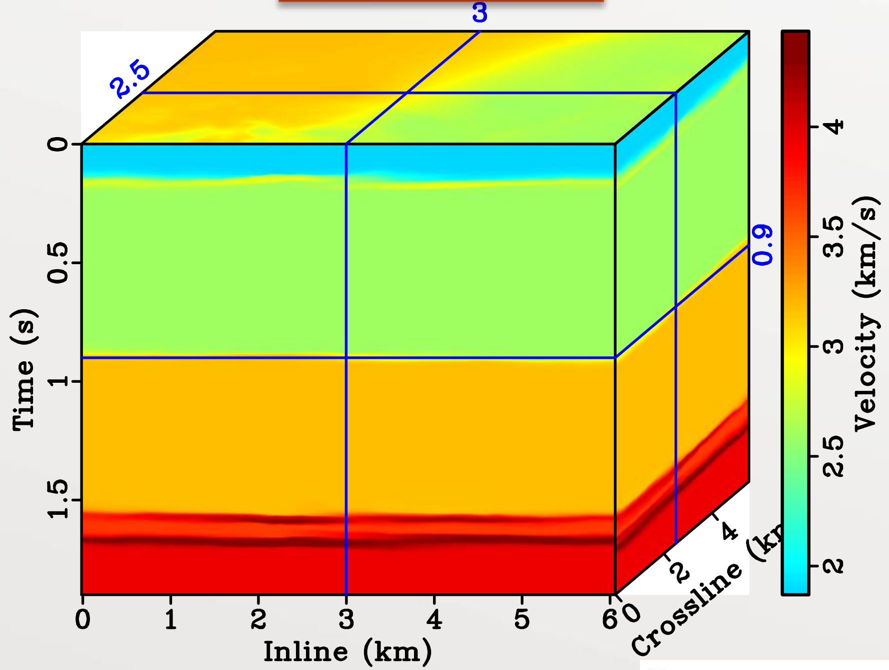
Seismic-Based Anomaly Detection

- Role:
  - Virtual observatory for assessing efficacy of seismic surveys for picking up leakage
  - Quantify time-lapse response of seismic velocity to different leak scenarios or features
- Methodology
  - Create 3d velocity and density models using well logs and reflection seismic data

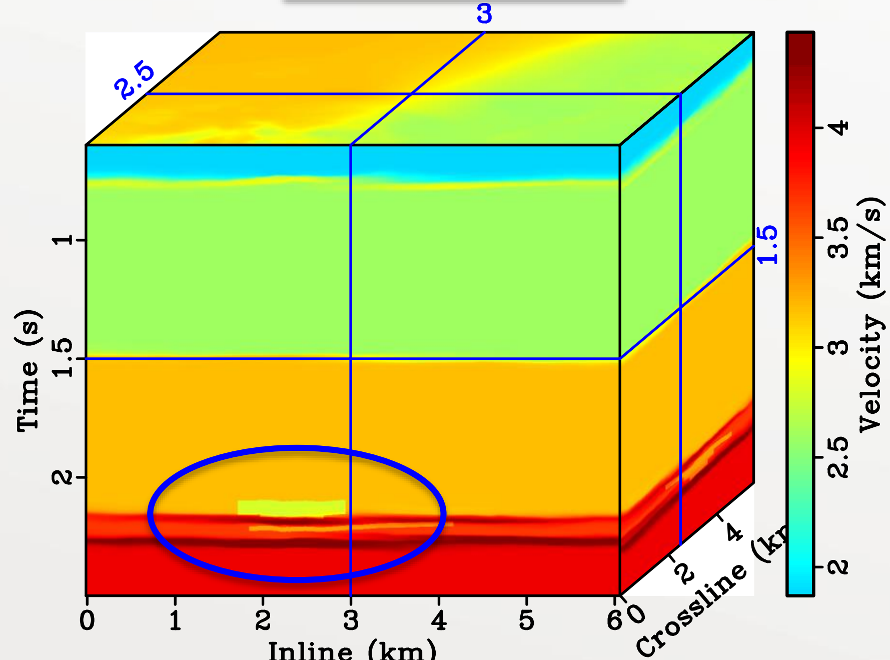
By Tieyuan Zhu & Sergey Fomel

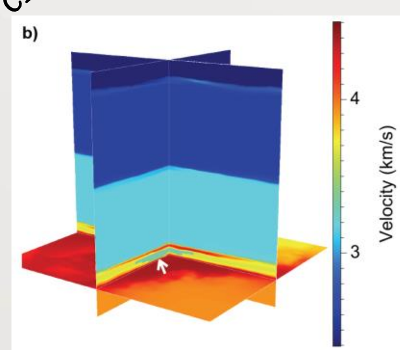
Two velocity models (in time)

Pre-injection

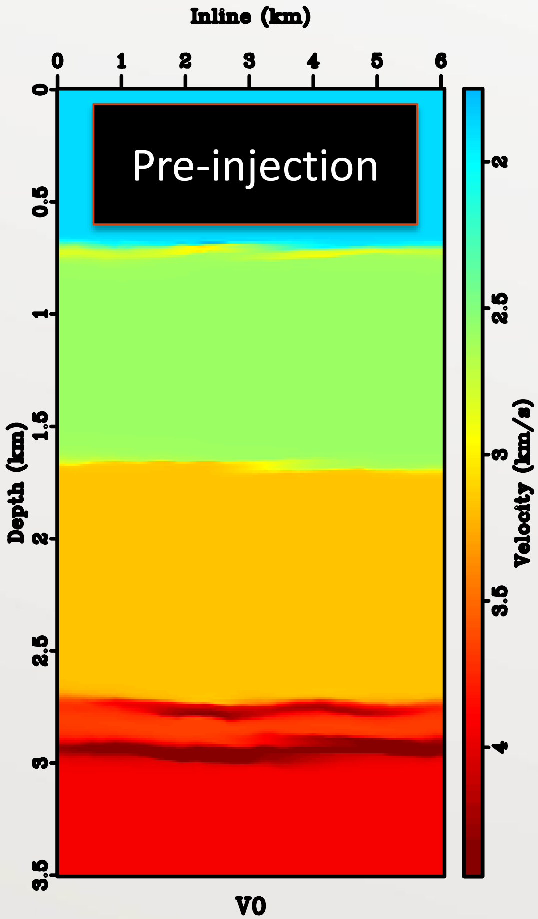


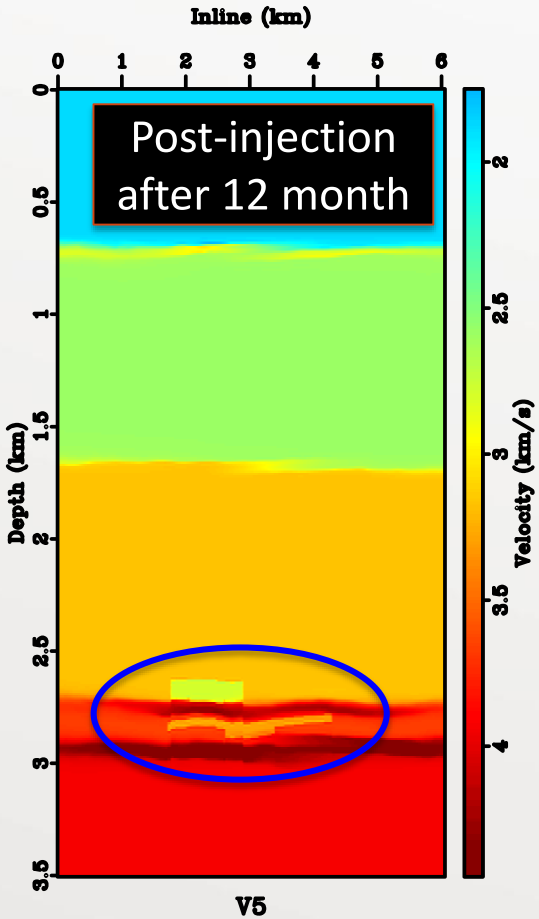
Post-injection after 1 year





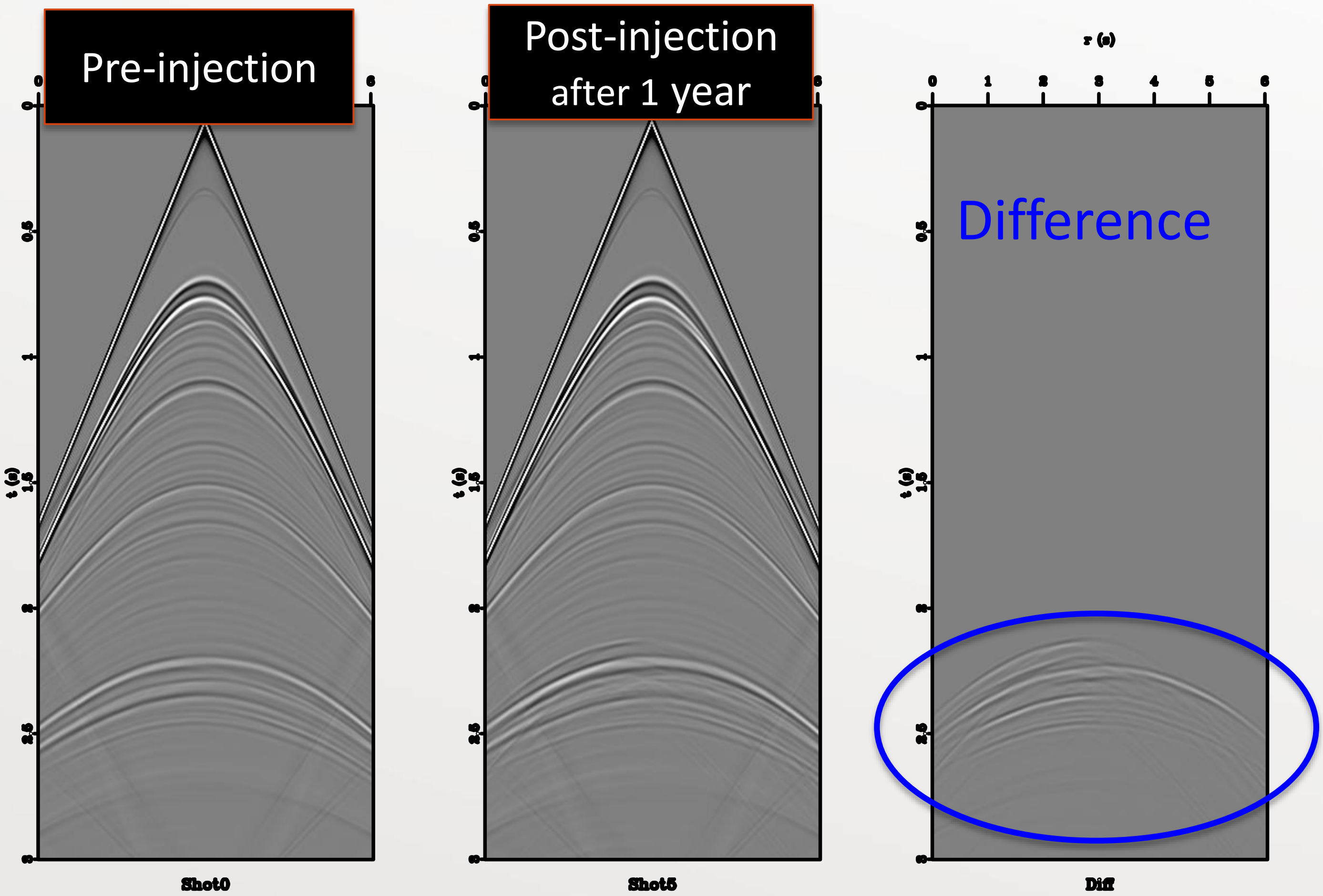
2D modeling: inline velocity slices





The two slices are windowed from the previous two velocity models.

Simulated seismic data: 2D slices



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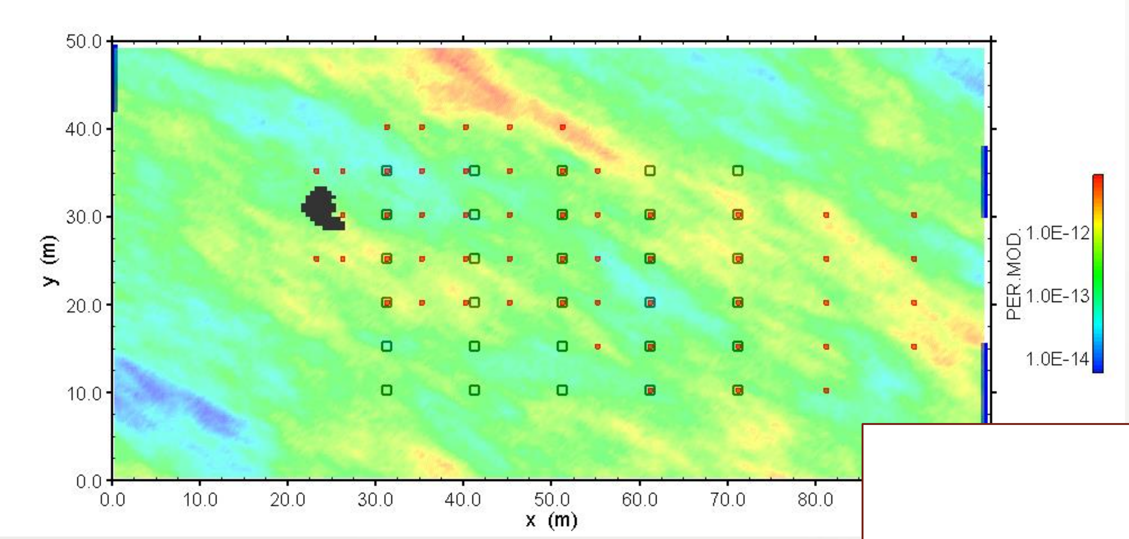
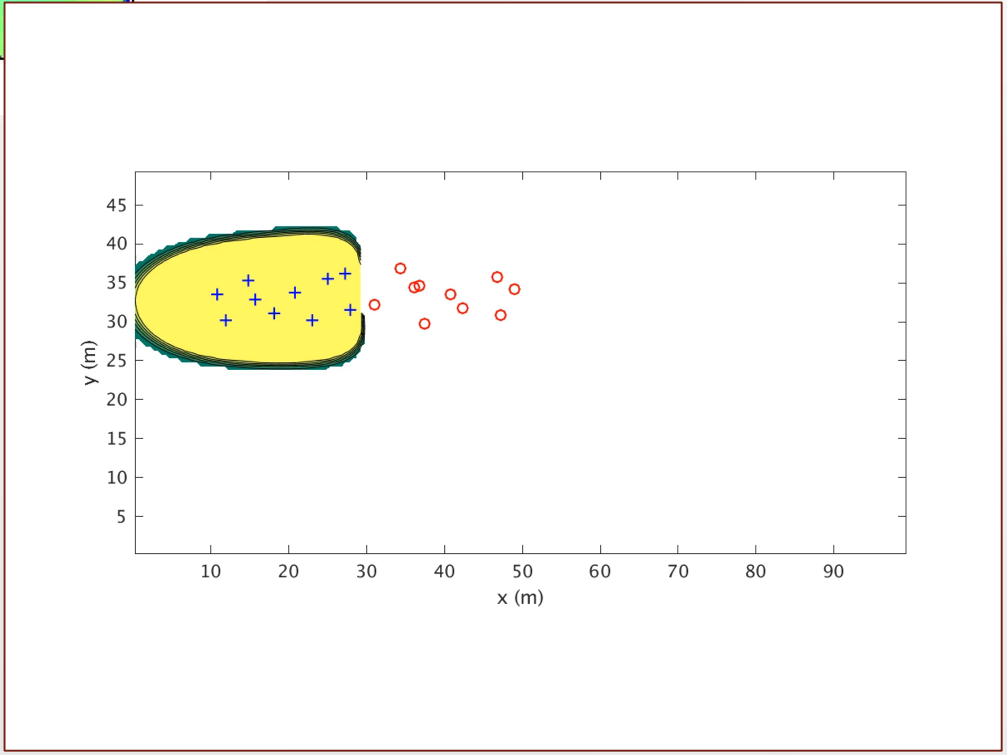
Geochemical Data Inversion

- Roles
  - Ingesting geochemical data for anomaly detection
  - Leak source attribute recovery
- Methodology
  - Adopted a flexible parameterization technique (level set) for representing source geometry

Shallow Aquifer Leak Source Recovery



Forward model: TOUGHREACT



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Accomplishments to Date

Description	Task
Developed prototypes for demonstrating datastream management, visualization, and Web-GIS, including capabilities to load data from different sensor sources;	2, 5
Developed multiphysics models, including a multiphase CO_2 simulation model, a forward seismic time-lapse response model, and geochemical data inversion capabilities	4
Implemented anomaly detection algorithms and integrated with the Web	3

Summary & Future Work

- Year 1 activities focus on IMS infrastructure building
  - Developed Web-based protocol for demonstrating all aspects of IMS
  - Our current IMS has user-friendly dashboard and AI capabilities
  - Developed modeling capabilities

- In Year 2, we will continue to
  - Enhance data visualization capability
  - Implement more complex event processing algorithms
  - Multiphysics model integration
  - Develop monitoring network design capabilities
  - Build web-based UQ and predictive analysis capabilities

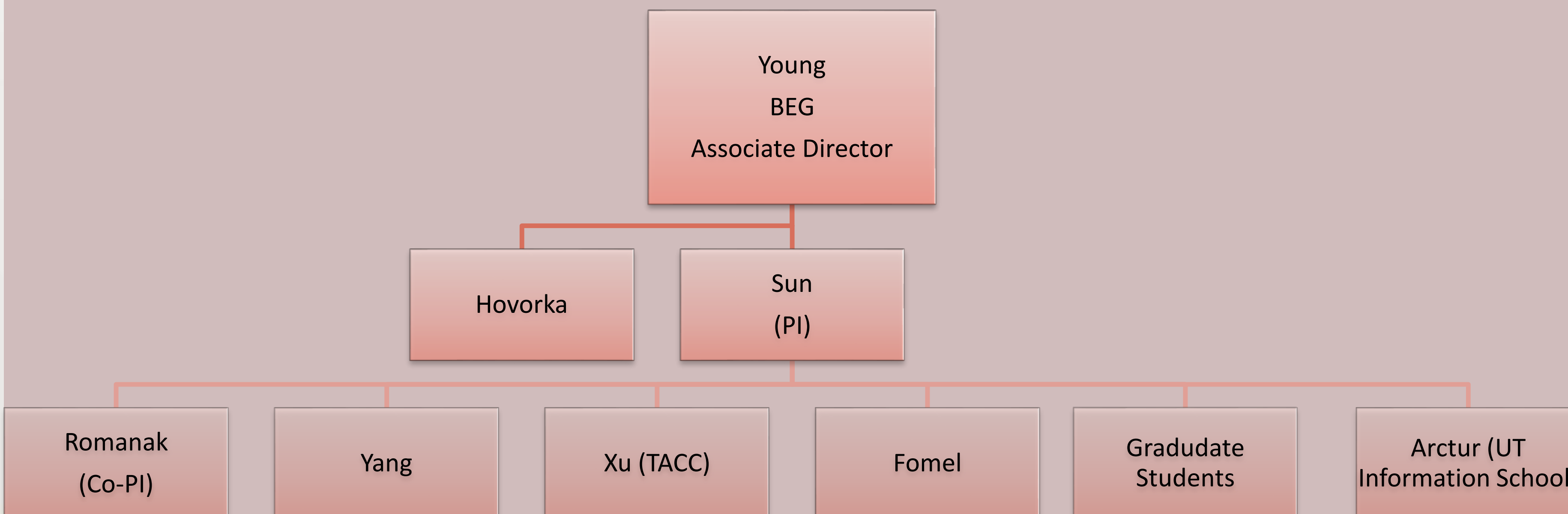
Synergy Opportunities

- EDX: Big Data computing for data discovery and anomaly detection
- NRAP: reduced models
- Collaborate with other teams to demonstrate IMS capabilities

Appendix

– These slides will not be discussed during the presentation, but are mandatory

Organization Chart



Gantt Chart

Table 2. Project Gantt chart
(Numbers in table rows indicate milestones).
(Phase I ; Phase II)

Task	Description	Year 1				Year 2				Year 3			
		1	2	3	4	1	2	3	4	1	2	3	4
1	Update project management plan	1											
2	Sensor data management												
2.1	Ontology/schema development												
2.2	Sensor data adaptor development		2										
3	CEP Development												
3.1	Rule definition												
3.2	Reasoning and machine learning												
3.3	Testing					3							
4	Coupled modeling/Assimilation												
4.1	Coupled modeling												
4.2	Data assimilation						4						
5	Integration and demonstration												
5.1	Integration											5	
5.2	Demonstration												
6	Synthesis of results												
6.1	Dissemination of results												
6.2	Technology transfer												6

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Bibliography

- Sun, A., Islam, A., Wheeler, M., Identifying Attributes of CO2 Leakage Zones in Shallow Aquifers Using a Parametric Level Set Method, submitted to Greenhouse Gases: Science and Technology
- Sun et al., Development of an Intelligent Monitoring System for Geological Carbon Sequestration (GCS). Abstract submitted to 2016 Fall Meeting of American Geophysical Union.