EERC

Critical Challenges. **Practical Solutions.**

DEVELOPMENT OF INTELLIGENT MONITORING SYSTEM (IMS) MODULES FOR THE AQUISTORE CO_2 STORAGE PROJECT

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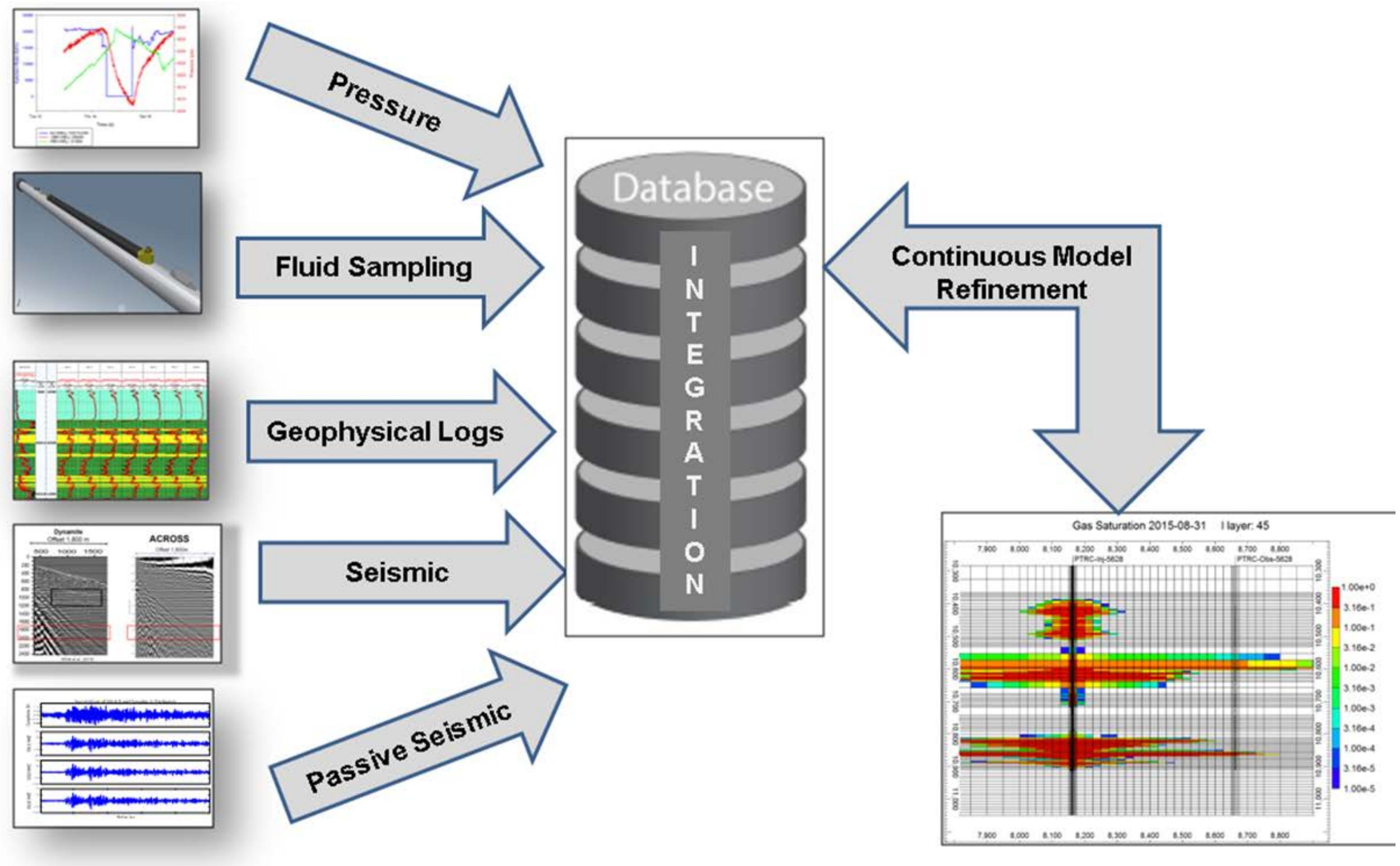
Critical Challenges. **Practical Solutions.**

PRESENTATION OUTLINE

- Technical status
  - Workflow design
  - Database
  - IMS modules
  - Graphical user interface (GUI)
- Accomplishments to date
- Synergy opportunities
- Lessons learned
- Summary



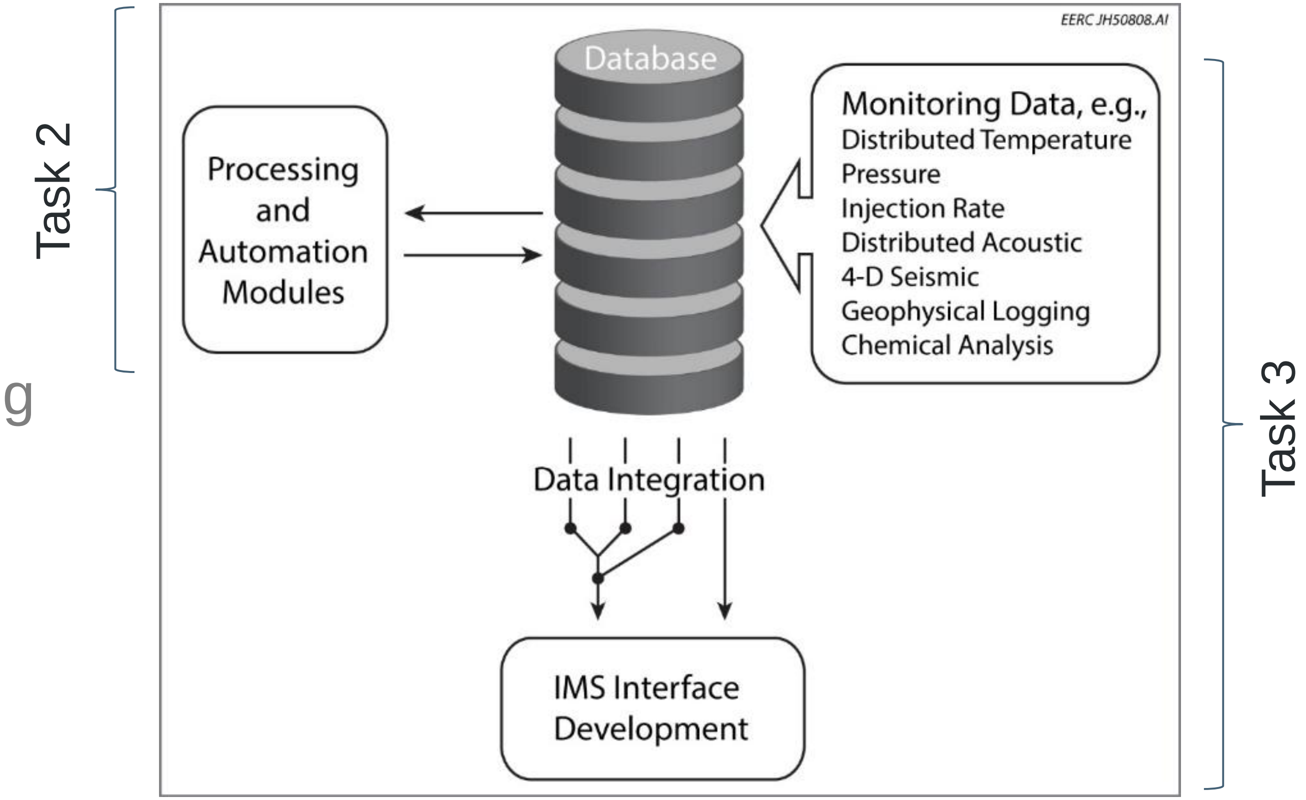
TECHNICAL STATUS

2) IMS Module Development

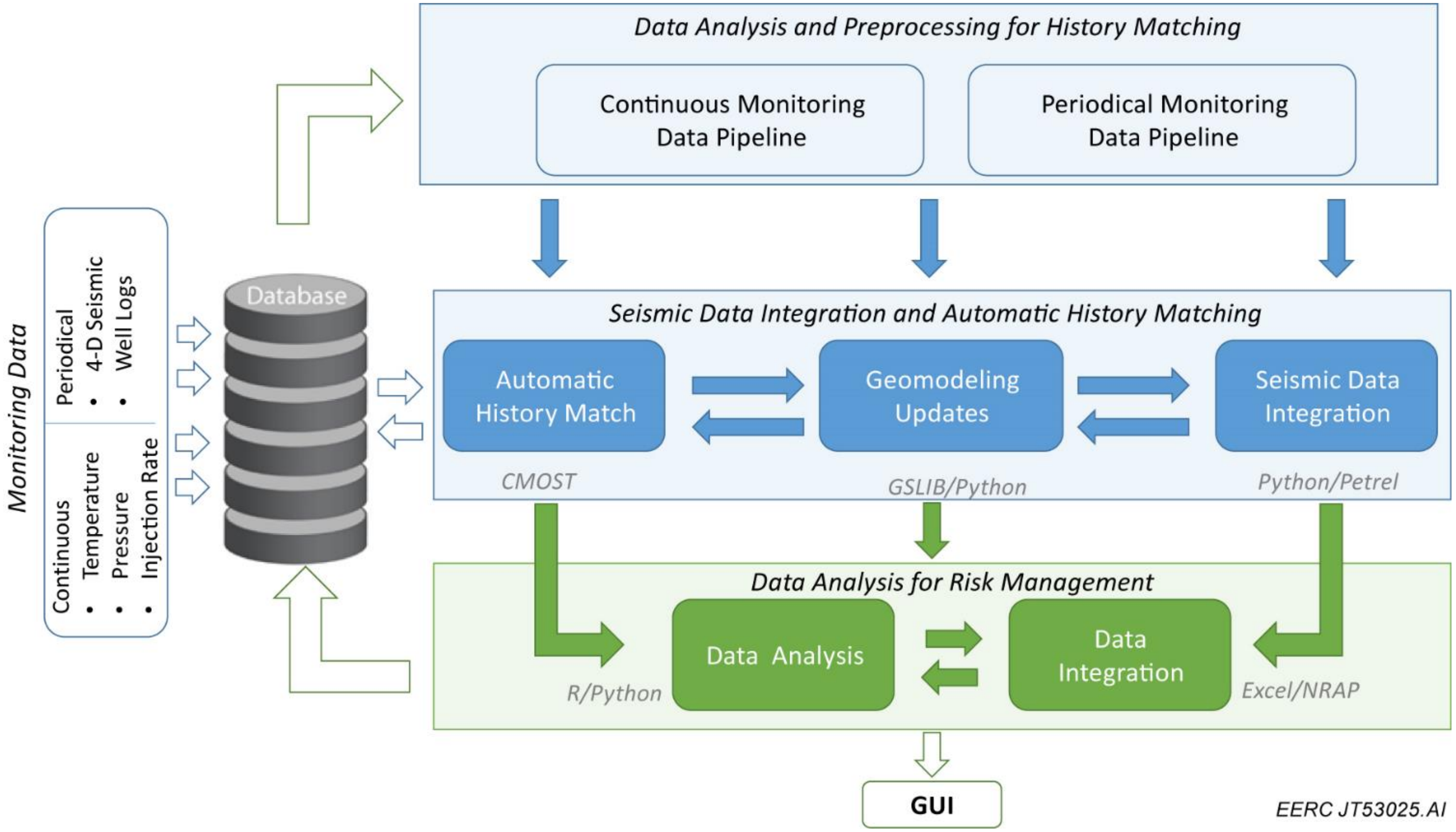
- 2.1) Workflow Design
- 2.2) Data-Preprocessing Design
- 2.3) Seismic Data Integration
- 2.4) History Match Automation
- 2.5) Integration and Automation Testing

3) IMS Architecture Development

- 3.1) Database Development
- 3.2) Data Integration
- 3.3) IMS Interface Development
- 3.4) Process and System Testing



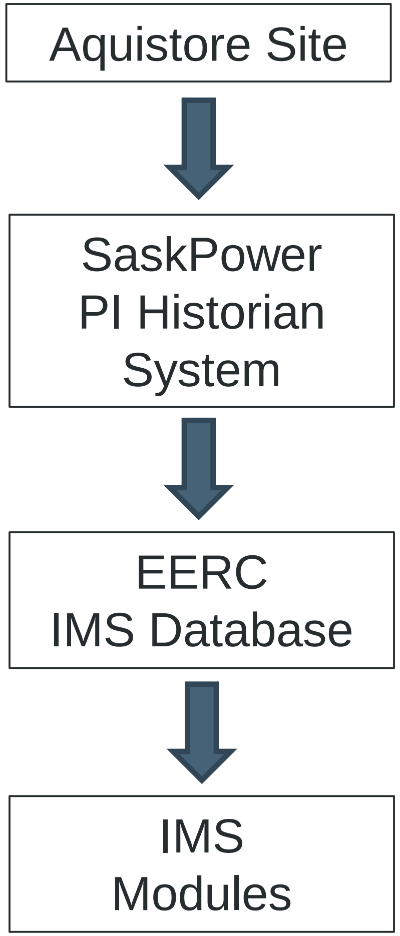
WORKFLOW DESIGN (2.1)



DATABASE DEVELOPMENT (3.1)

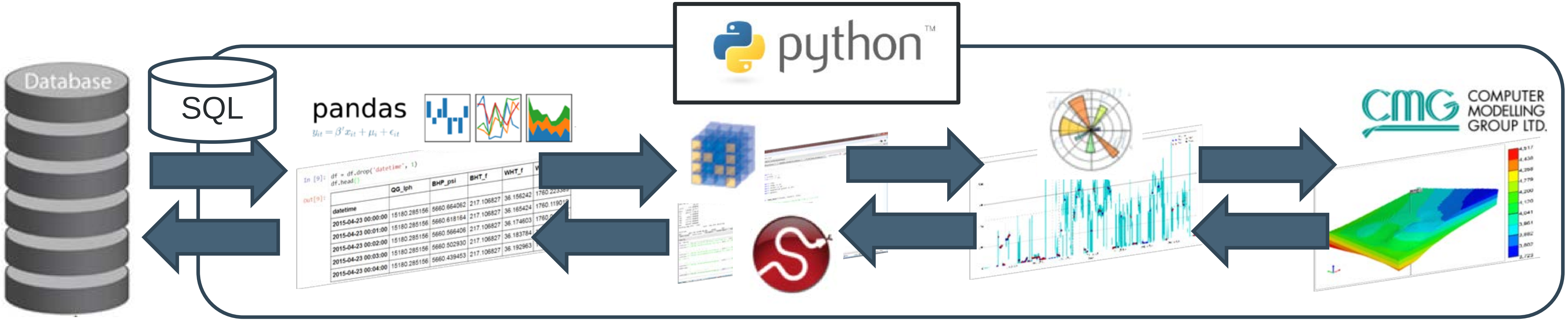
- Creation and population of a database that serves as a core data-handling system for the project.
  - First component developed (Q1 2016)
  - Multiple security features
  - Ongoing updates and improvements

- Currently includes data from the Aquistore CO_2 storage site from April 2015 through April 2017.



DATA PREPROCESSING DESIGN (2.2)

- Link the simulation module to the database (DB).
  - Allow for both import and export of key data.
  - Quality control/quality control (QC/QA) before being delivered to simulation models.
  - Two possible interaction options: automatic and manual.
- Filtering to remove noise.
- Data reduction to sizes and rates compatible with simulations and algorithm performance.



HISTORY MATCH AUTOMATION (2.4)

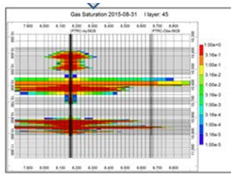
Real Data

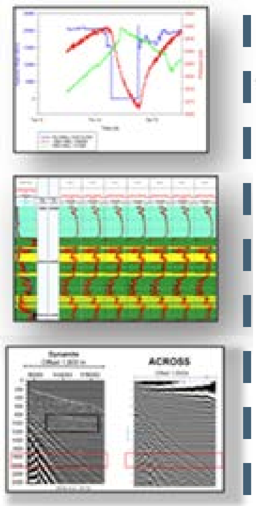
Preprocessed Data

Geologic Model

Reservoir Simulation

Simulation Results





Real-time monitoring data:
- Pressure,
- CO_2 injection rate

Well logs:
- PNL,
- Spinner survey

Seismic data:
- CO_2 plumes from 4-D difference computations

Adjust Model Parameters

Evaluate Global and Local Objective Functions

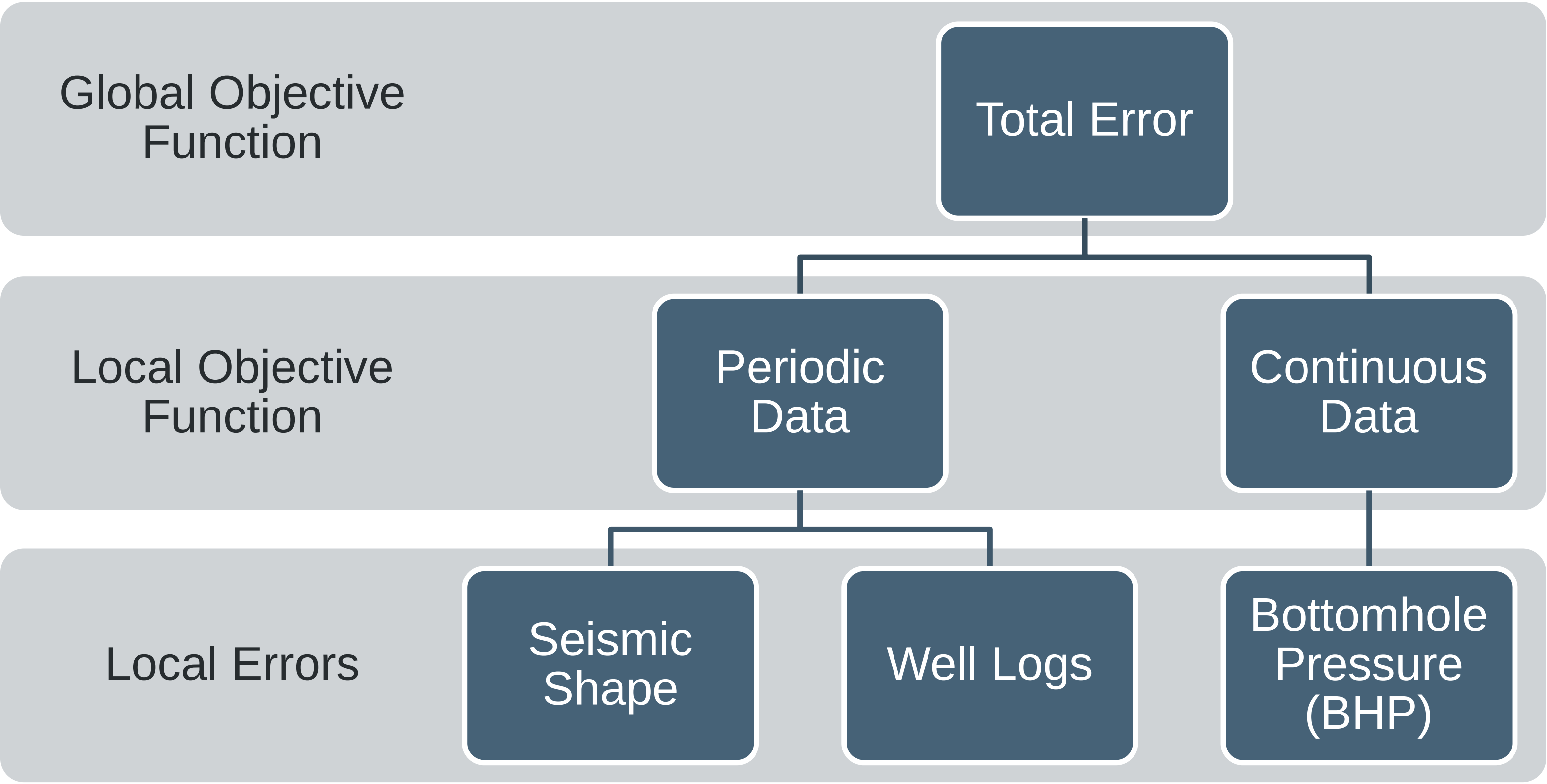
No

Goodness of Fit Criteria Satisfied?

Yes

END CURRENT UPDATE

OBJECTIVE FUNCTION HIERARCHY

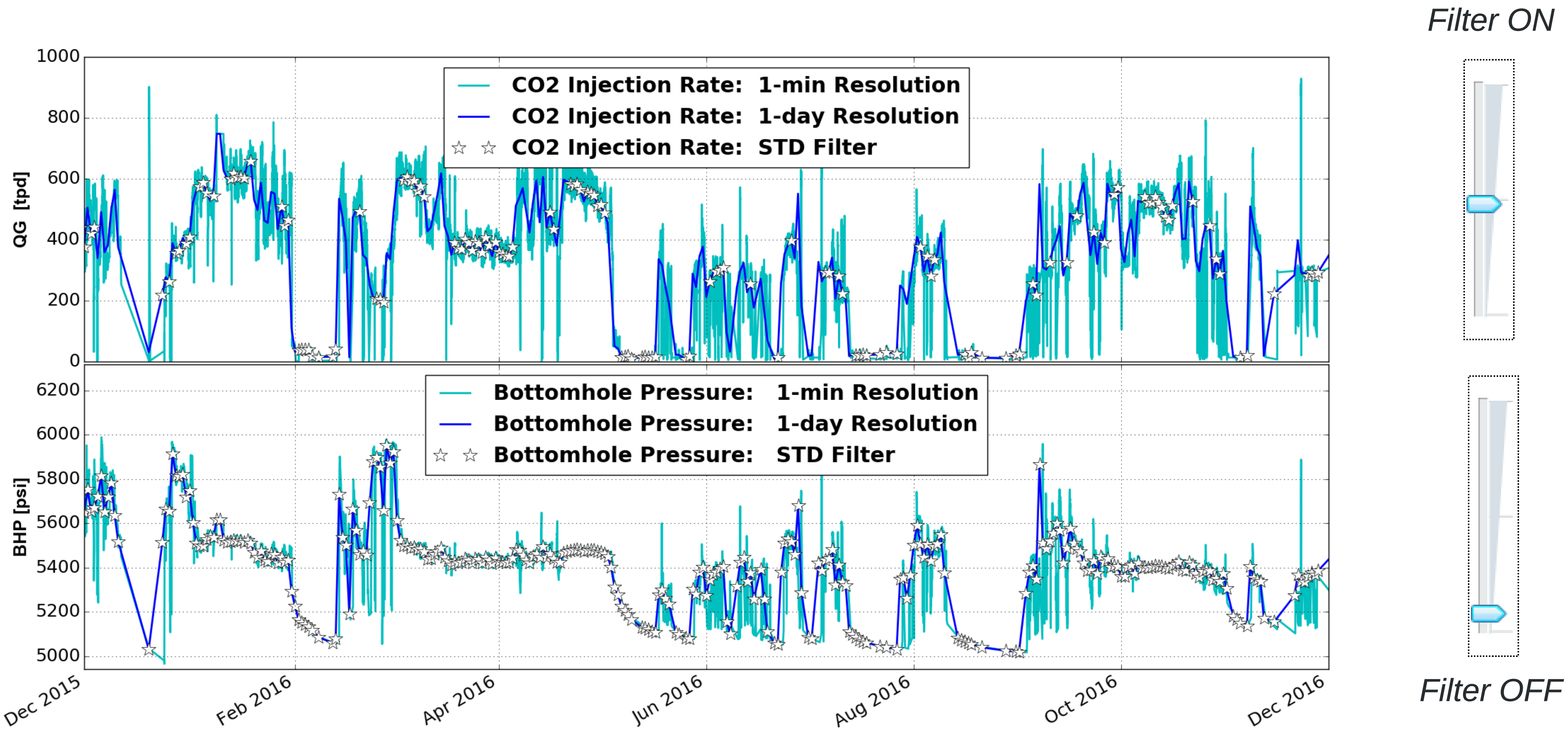


$$Total = \frac{\sum(Local * weighting\_factor)}{Number\ of\ Terms}$$

$$Local = \frac{\sum(Error * weighting\_factor)}{Number\ of\ Terms}$$

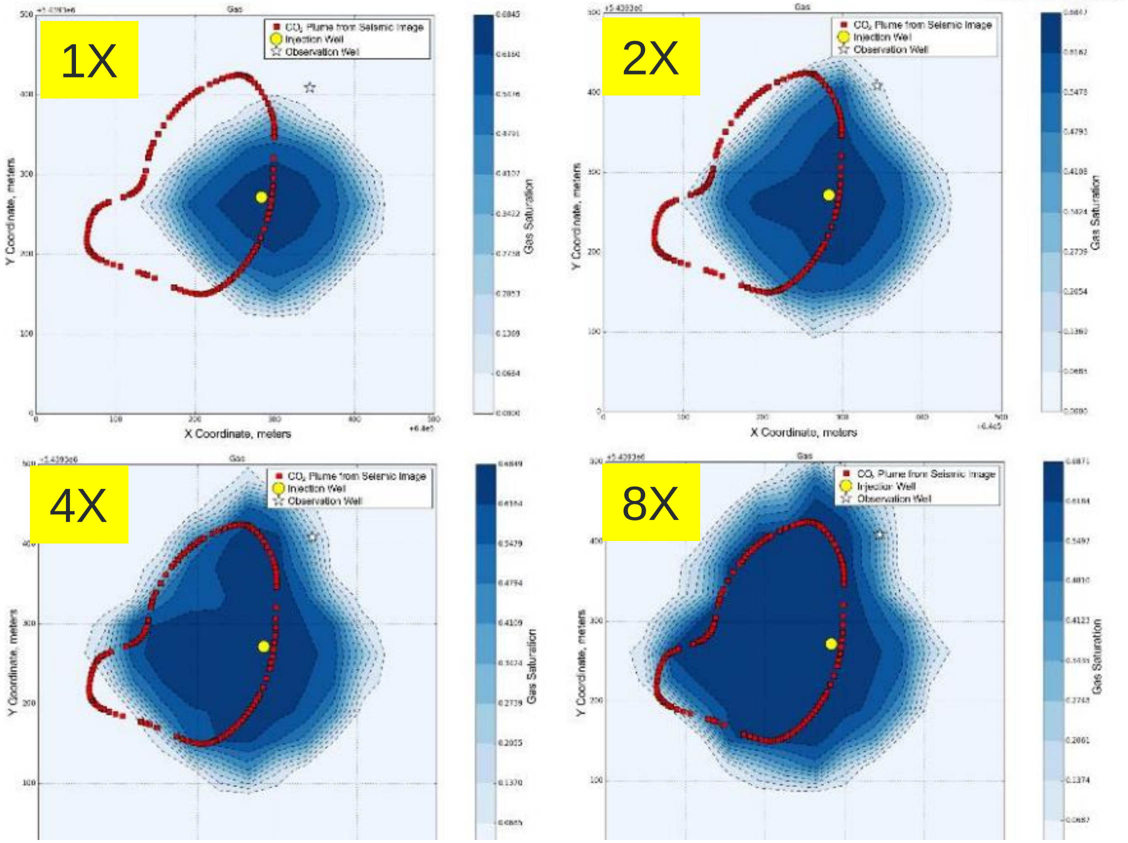
$$Error = \sqrt{\frac{\sum(Simulated - Measured)^2}{Number\ of\ Measurements}}$$

EXAMPLE: REAL-TIME DATA PREPROCESSING

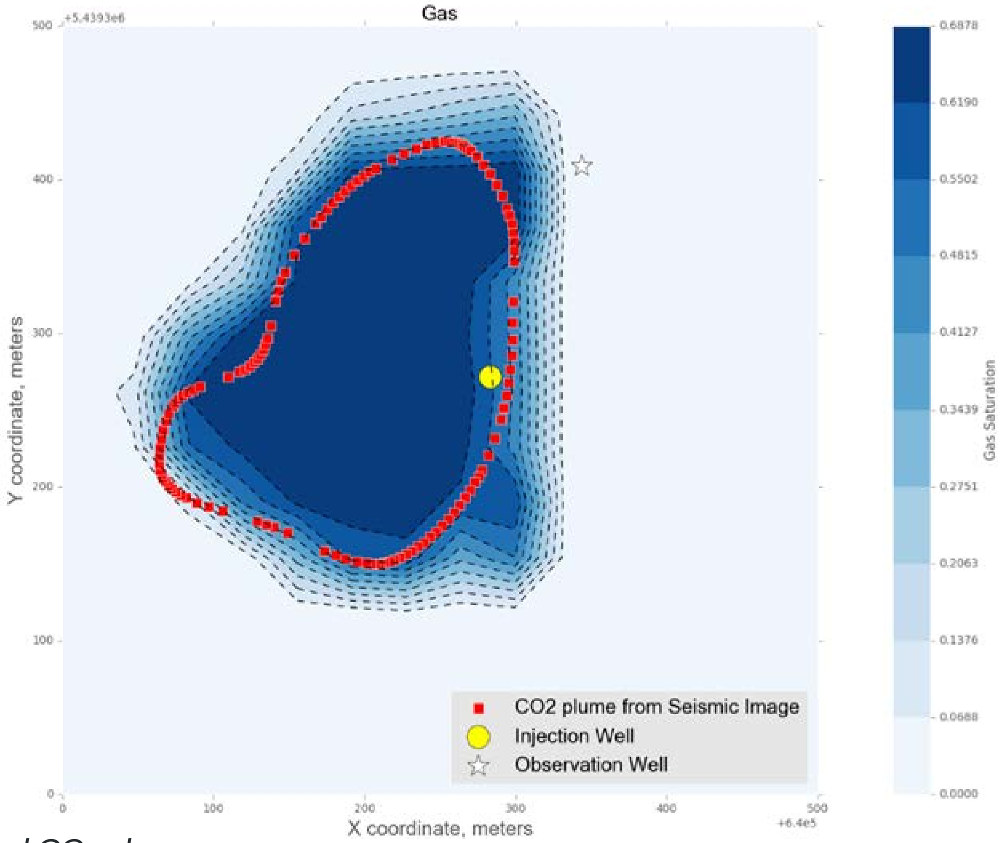


HISTORY MATCH EXAMPLE: CO_2 PLUME SHAPE*

Sensitivity of the Simulated CO_2 Plume to Local Permeability Multipliers



Goodness of Fit Criteria Satisfied After a History Match Test



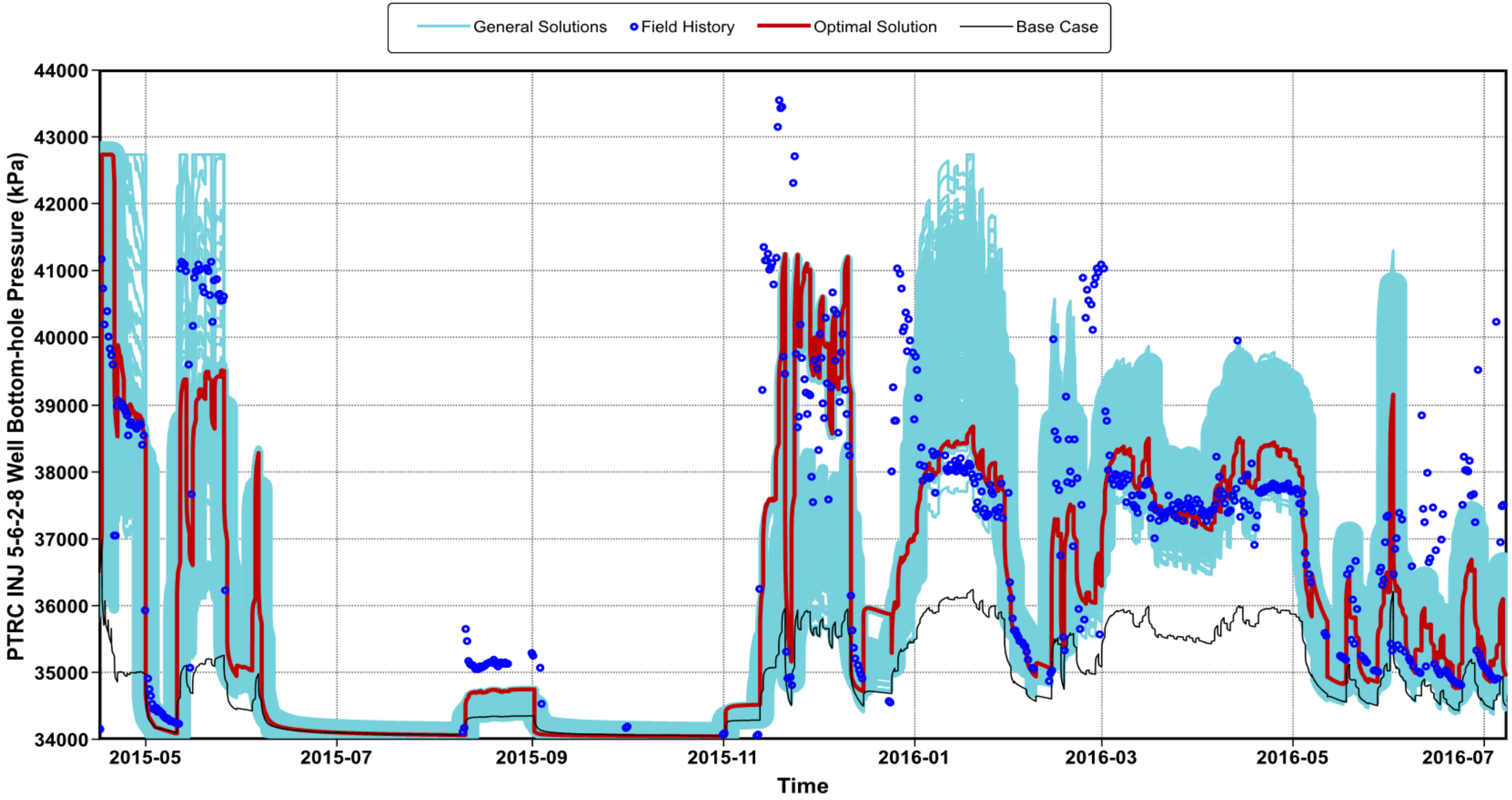
*Test case for demonstration purposes only. It does not represent the location of the actual CO_2 plume.

HISTORY MATCH EXAMPLE: WELL LOGS

PNL at the Observation Well

Spinner Survey at the Injector Well

HISTORY MATCH EXAMPLE: BHP

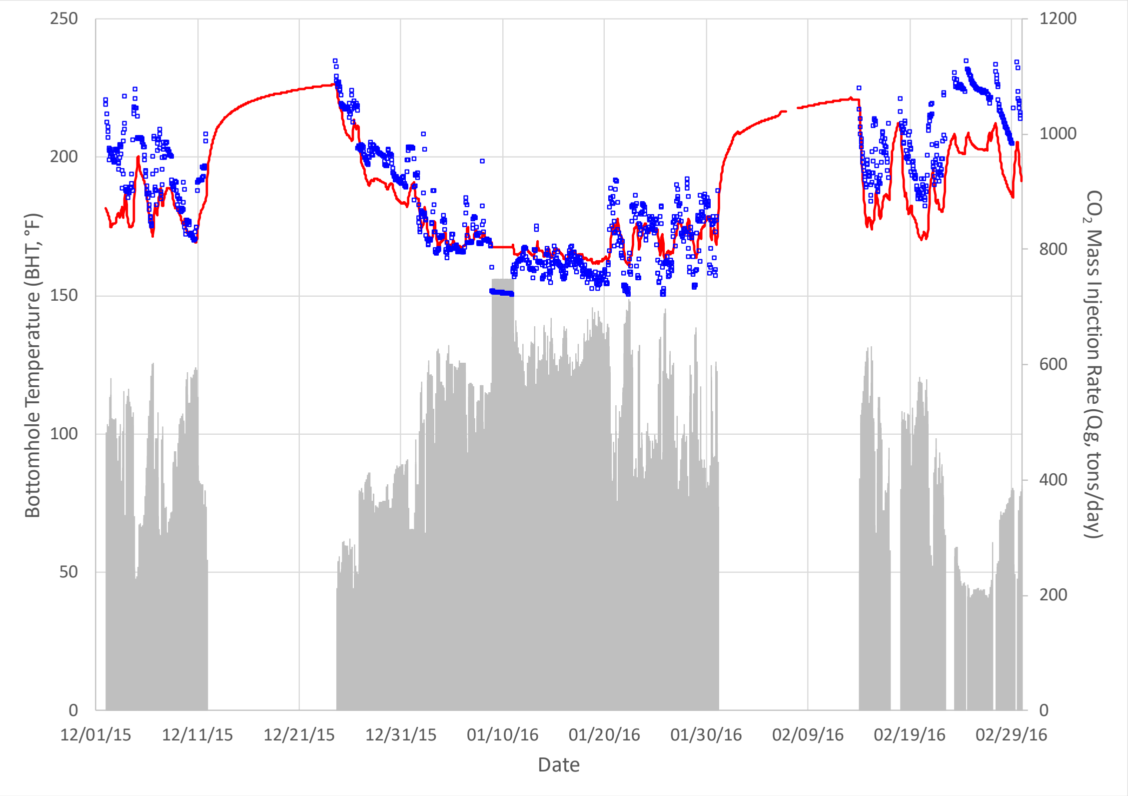


DATA INTEGRATION (3.2)

Integration and Analysis of Simulation Outputs with the Direct-Monitoring Data

- Provide immediate feedback via the generation of an “action level.”
  - Examine changes in various inputs.
  - Compare those changes to established site performance and operating limits.
  - Develop threshold decision criteria.

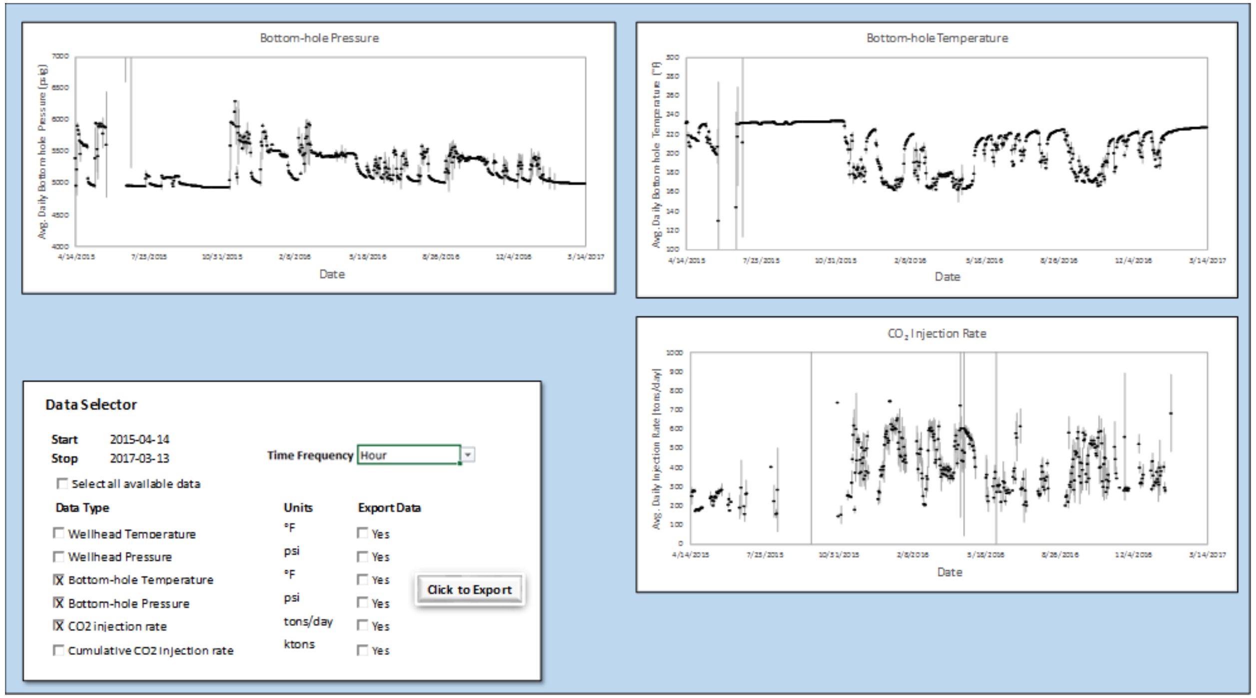
- New algorithms to perform geospatial analysis and advanced statistical analysis are forthcoming.



Example time-series plot showing CO_2 mass injection rate (gray bars), measured bottomhole temperature (BHT) (red line) and predicted BHT (blue squares).

IMS INTERFACE DEVELOPMENT (3.3)

- Design, programming, and implementation of the GUI for the IMS.
- Initial GUI design (Milestone 6) was completed on February 22, 2017.
- Real-time linkage to the database for continuous measurements.
- Query field where the user can select a date range, time frequency, and specific measurements to view or export.
- Expanding to include Task 2 simulation output and Task 3 statistical models.



Example GUI dashboard layout showing BHP, BHT, and CO_2 mass injection rate (Qg), and a user query field.

ACCOMPLISHMENTS TO DATE

Completed

- Workflow design
- Initial database schema (M2)
- Data-preprocessing design (M3)
- 3-D seismic algorithm (M4)
- Data integration algorithm (M5)
- GUI design (M6)
- Baseline models (seismic, geology, and reservoir simulation)

Under Way

- Shot record plume tracking tested (M7)
- Design of the automatic history match module (M8)
- Updated database schema (M9)
- Data submission to Energy Data eXchange (EDX) (D2)

LESSONS LEARNED

- **Research difficulty:**
  - Time requirements for repeat logging or seismic methods

    ➔ Automated history matching may still experience the associated time delay from the periodic data acquisition and interpretation.
- **Research challenge:**
  - Data set incongruence

    ➔ Scientific and engineering judgment needed to transform qualitative interpretations into quantitative changes to simulation input in order to improve the simulation output.
- **Research gap:**
  - Discontinuous injection cycle the normal operating procedure

    ➔ Need to adapt existing analytical and semianalytical models for utilizing continuous measurements to account for transient effects.

SYNERGY OPPORTUNITIES

- **Potential leverage on advanced techniques for**
  - Data integration and assimilation.
  - Data analytics and automated learning.
  - Closed-loop management.

- **Collaboration with other R&D projects**
  - Field testing of emerging technologies

- **IMSs have broad applicability for commercial or demonstration projects.**
  - Tools and workflows could be applied in any CO_2 storage project to effectively monitor an active injection site in real time.

PROJECT SUMMARY

- **Successfully developed new workflows designed to:**
  - Handle real-time monitoring data from the SaskPower database for the Aquistore site.
  - Store and handle information in a secure database.
  - Perform data-preprocessing linked to an automated history match.
  - Integrate periodic and continuous data into automated history match.

- **Significant progress towards:**
  - Utilizing the continuous monitoring data to model (in real-time) and predict bottomhole conditions.
  - Developing algorithms to establish threshold decision criteria for real-time decision support.
  - Developing associated risk management action levels.

- **Future plans:**
  - Integrate new seismic data into the modeling and simulation.
  - Complete the programming and implementation of the GUI.
  - Complete the process and system testing.

THANK YOU!

Critical Challenges. **Practical Solutions.**

APPENDIX

- Benefits to the program
- Project overview:
  - Goals
  - Objectives
  - Tasks
  - Milestones and deliverables
  - Success criteria
- Organization chart
- Gantt chart
- Bibliography
- Acknowledgments
- Contact information

BENEFITS TO THE PROGRAM

The Energy & Environmental Research Center (EERC) is developing an intelligent monitoring system (IMS) to automate monitoring of carbon dioxide (CO_2) injection and storage data for the Aquistore site in southeastern Saskatchewan, Canada.

An IMS will allow a CO_2 storage site operator to more efficiently manage operations in the context of the site's evolving risk profile, to optimize storage efficiency and storage capacity, and to better guide cost-effective monitoring, verification, and accounting (MVA) efforts. In particular, it will allow integrating diverse data from near-surface and subsurface monitoring networks and converting these data into meaningful and actionable information, accommodating output formats of different applications and sensor systems, and providing an interface to automate field operations in order to improve storage performance and efficiency and/or reduce project risk.

This technology contributes to the following Carbon Storage Programefforts: ensure 99% CO_2 storage permanence, develop technologies that improve reservoir storage efficiency and ensure containment effectiveness, and develop best practices manuals for MVA.

PROJECT OVERVIEW – GOALS

Developed and demonstrate software and workflows capable of

1) Improving short- and long-term prediction of the distribution of CO_2 saturations and reservoir pressure by using seismic and pressure data to reduce uncertainty of simulation predictions through iterative automated history matching.
2) Providing processing and integration of monitoring data and simulation results to allow the CO_2 storage site operator to more effectively monitor and manage operations and a site's evolving risk profile.
3) Providing decision support for improving storage performance and efficiency and/or reducing project risk through expedited response times and minimization of human error.

PROJECT OVERVIEW – OBJECTIVES

- Develop and demonstrate new real-time-data-capable workflows, algorithms, and a user interface which automate the integration of CO_2 storage site-monitoring and simulation data.
- The algorithms and workflows developed will integrate continuous monitoring data, periodic monitoring data, and reservoir simulations with algorithms for visualization and real-time decision-making support.
- Develop and test an automated history-matching workflow to improve short- and long-term prediction of the distribution of CO_2 saturations and reservoir pressure.
- Develop and test a technical user interface that will present the results for visualization and real-time decision support.
- IMS will be completed using monitoring data acquired at Petroleum Technology Research Centre's (PTRC's) Aquistore CO_2 storage site near Estevan, Saskatchewan.

PROJECT OVERVIEW – TASKS

1) Project Management and Reporting
2) IMS Module Development
    2.1) Workflow Design
    2.2) Data-Preprocessing Design
    2.3) Seismic Data Integration
    2.4) History Match Automation
    2.5) Integration and Automation Testing
3) IMS Architecture Development
    3.1) Database Development
    3.2) Data Integration
    3.3) IMS Interface Development
    3.4) Process and System Testing

Automated history matching and seismic data integration

Database integration and user interface

PROJECT MILESTONES/DELIVERABLES

Task/ Subtask	Milestone/Deliverable Title	Planned Completion Date	Verification Method
1.1 – Project Management	M1 – Project Kickoff Meeting Held	12/31/15	Presentation file submitted to DOE.
3.1 – Database Development	M2 – Initial Database Schema Completed	3/31/16	Reported in subsequent quarterly report.
2.2 – Data-Preprocessing Design	M3 – Data-Preprocessing Design Completed	6/30/16	Reported in subsequent quarterly report.
2.3 – Seismic Data Integration	M4 – 3-D Seismic Algorithm Completed	9/30/16	Reported in subsequent quarterly report.
3.2 – Data Integration	M5 – Draft Data Integration Algorithm Completed	12/31/16	Reported in subsequent quarterly report.
3.3 – IMS Interface Development	M6 – Initial GUI Design Completed	2/28/17	Reported in subsequent quarterly report.
2.3 – Seismic Data Integration	M7 – Shot Record Plume Tracking Tested	9/30/17	Reported in subsequent quarterly report.
2.4 – History Match Automation	M8 – Design of History Match Automation Completed	9/30/17	Reported in subsequent quarterly report.
3.1 – Database Development	M9 – Updated Database Schema Completed	9/30/17	Reported in subsequent quarterly report.
3.3 – IMS Interface Development	M10 – GUI Coding Completed	10/31/17	Reported in subsequent quarterly report.
2.5 – Integration and Automation Testing	M11 – Initial Automation Testing Completed	12/31/17	Reported in subsequent quarterly report.
3.4 – Process and System Testing	M12 – Full System Testing Initiated	12/31/17	Reported in subsequent quarterly report.
3.4 – Process and System Testing	M13 – Process and System Testing Completed	6/30/18	Reported in subsequent quarterly report.

PROJECT OVERVIEW – SUCCESS CRITERIA

Task 2

2.2) Data-Preprocessing Design (100% SC*)
- ♦ Milestone (M3) completed.

2.3) Seismic Data Integration (50% SC*)
- ♦ 3-D seismic algorithm completed (M4)
- ♦ Shot record plume tracking in progress (M7)

2.4) History Match Automation (70% SC*)
- ♦ Milestone (M8) in progress

2.5) Integration and Automation Testing (30% SC*)
- ♦ Subtask initiated

Task 3

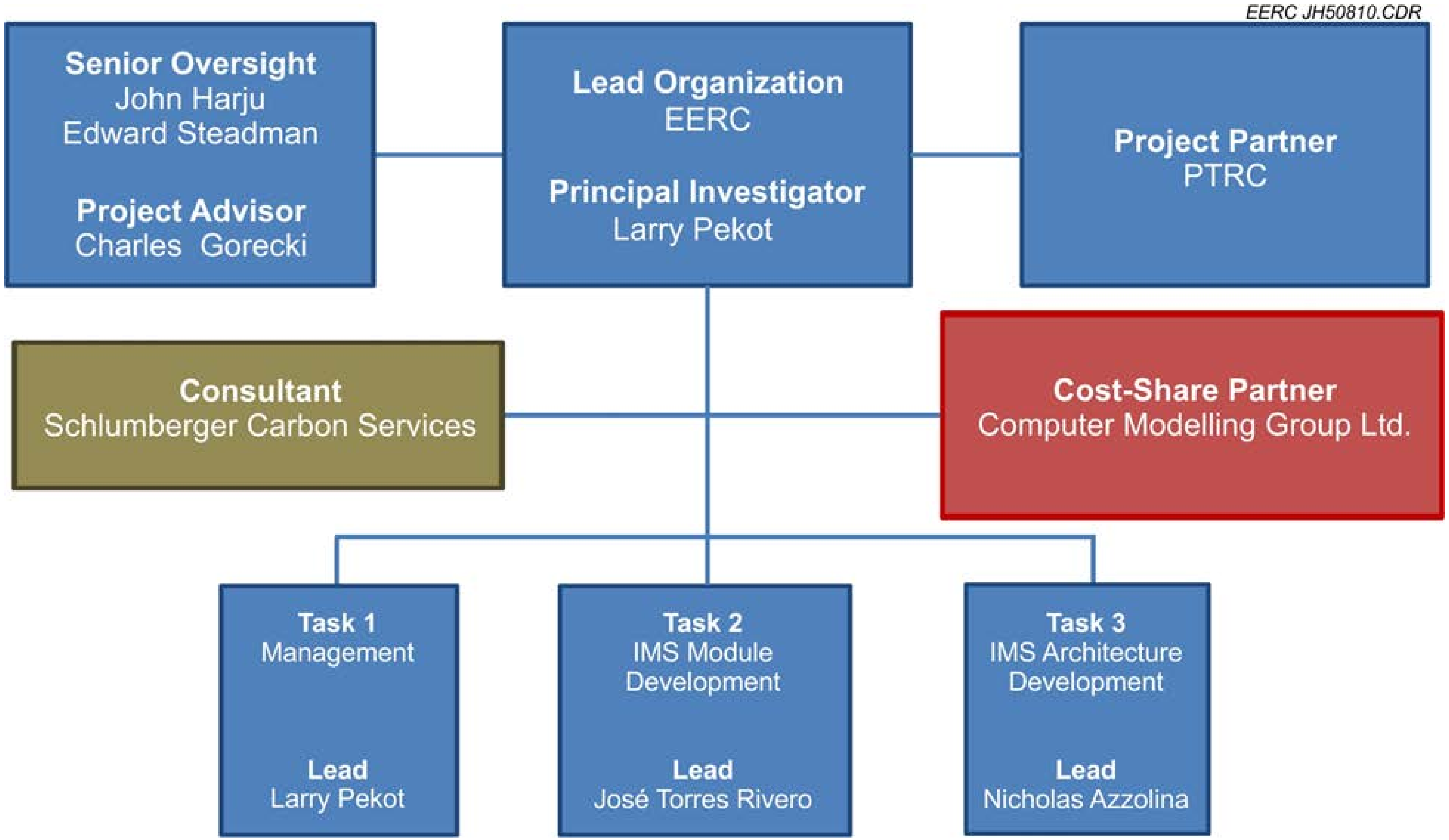
3.1) Database Development (60% SC*)
- ♦ Initial database schema completed (M2)
- ♦ Updated database schema in progress (M9)

3.2) Data Integration (70% SC*)
- ♦ Milestone (M5) completed

3.3) IMS Interface Development (40% SC*)
- ♦ Milestone (M6) completed

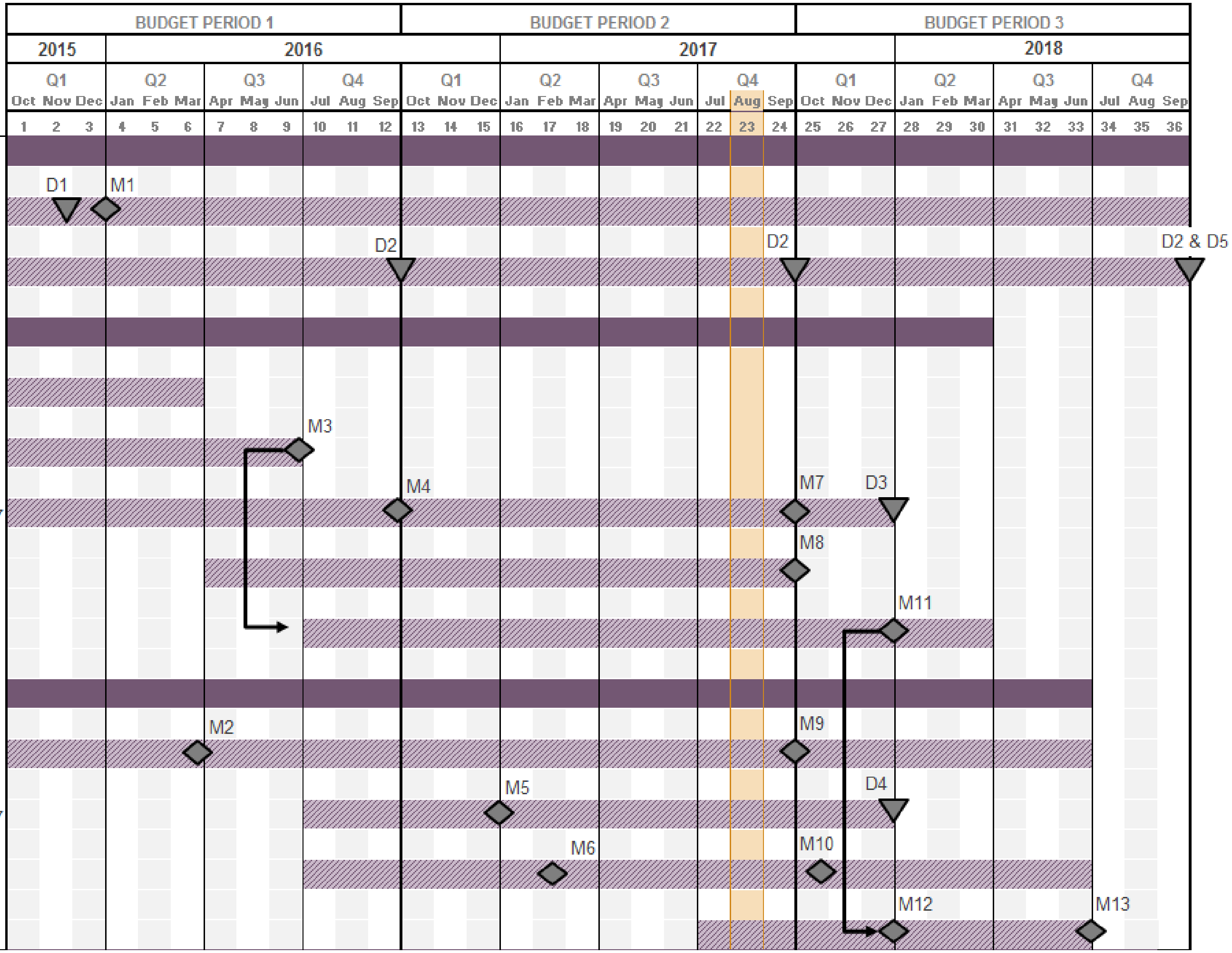
**Approximate percentage of subtask completion (apc) by August 1, 2017*

ORGANIZATION CHART



GANTT CHART

TASK	ACTIVITY	START DATE	END DATE
1.0	**Project Management, Planning, and Reporting**	**10/1/2015**	**9/30/2018**
1.1	Project Management	10/1/2015	9/30/2018
1.2	Project Reporting	10/1/2015	9/30/2018
2.0	**IMS Module Development**	**10/1/2015**	**3/31/2018**
2.1	Workflow Design	10/1/2015	3/31/2016
2.2	Data-Preprocessing Design	10/1/2015	6/30/2016
2.3	Seismic Data Integration	10/1/2015	12/31/2017
2.4	History-Match Automation	4/1/2016	9/30/2017
2.5	Integration and Automation Testing	7/1/2016	3/31/2018
3.0	**IMS Architecture Development**	**10/1/2015**	**6/30/2018**
3.1	Database Development	10/1/2015	6/30/2018
3.2	Data Integration	7/1/2016	12/31/2017
3.3	IMS Interface Design	7/1/2016	6/30/2018
3.4	Process and System Testing	7/1/2017	6/30/2018



Deliverables (D)

D1	Updated PMP
D2	Data Submission to EDX
D3	Interim Report- Shot Record Plume Tracking
D4	Topical Report- Data Integration for Risk Profiling
D5	Final Technical Report

Milestones (M)

M1	Project Kickoff Meeting Held
M2	Initial Database Schema Completed
M3	Data-Processing Design Completed
M4	3-D Seismic Algorithm Completed
M5	Draft Data Integration Completed
M6	Initial GUI (graphical user interface) Design Completed
M7	**Shot Record Plume Tracking Tested**
M8	**Design of History Match Automation Completed**
M9	**Updated Database Schema Completed**
M10	**GUI Coding Completed**
M11	**Initial Automation Testing Completed**
M12	**Full System Testing Initiated**
M13	**Process and System Testing Completed**

Activity Bar

Summary Task

Critical Path

BIBLIOGRAPHY

No peer-reviewed publications generated from this project to date.

ACKNOWLEDGMENT

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Disclaimer

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