Surface and Airborne Monitoring Technology for Detecting Geologic Leakage in a CO_2-Enhanced Oil Recovery Pilot, Anadarko Basin, Texas

Project Number DE-FE0012173

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Oklahoma State University

U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Transforming Technology through Integration and Collaboration
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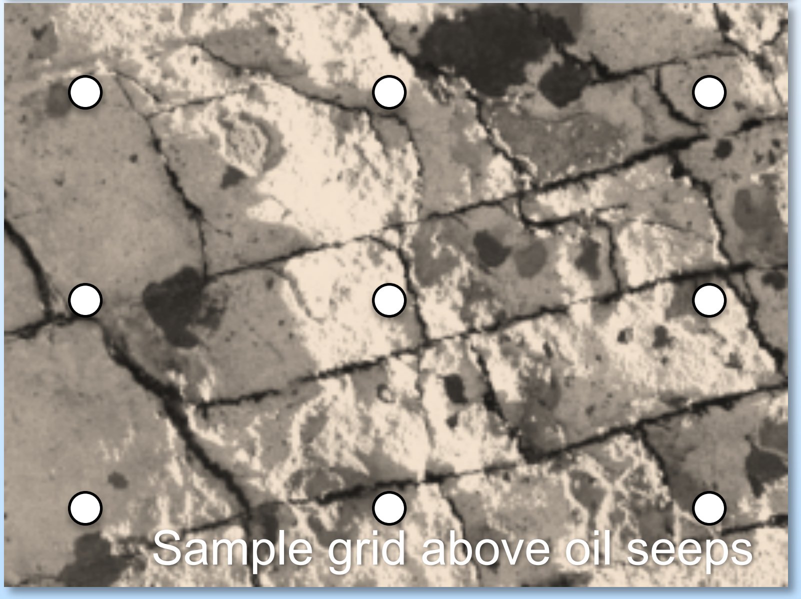
Presentation Outline

- Benefit to Program
- Goals and Objectives
- Project Team
- Technical Status
- Accomplishments to Date
- Synergy Opportunities
- Summary

Benefit to the Program

- Develop and validate technologies to ensure 99 percent storage permanence.
- Develop technologies to ensure containment effectiveness.
- Develop Best Practice Manual for monitoring, verification, accounting.
- This project is developing next-generation surface and airborne (UAV) technologies that perform well and can be deployed rapidly and at reasonable cost. Technology to be deployed at the Southwest Regional Carbon Sequestration Partnership's Farnsworth Pilot Site.

Project Motivation



- Surface monitoring integral to pilot programs; facilitates public acceptance.
- Major spatial sampling issues with current technology.
- Questions whether current technology is capable of detecting leaks.
- Deployment labor-intensive, expensive.
- New surface-based and UAV-based technology has potential to solve spatial sampling issue, reduce project costs.

Project Overview: Goals and Objectives

- Evaluate low-cost sensors for carbon dioxide and methane.
- Develop ground-based and airborne (UAV-) based sensor platforms that minimize the labor cost associated with long term monitoring.
- Collect data from an active injection site for a period of at least one year.
- Develop monitoring strategies that minimize the need for ground-based monitoring while preserving the quality of the monitoring effort.

Project Team, Roles, Responsibilities, Project Organization

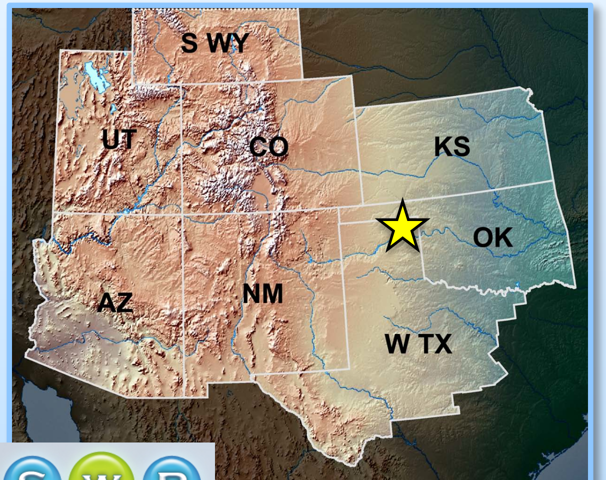
- Project Team: Oklahoma State University
  - Chemical Engineering
    - Peter E. Clark, PI
  - Geology
    - Jack Pashin, Co-PI, Geological Evaluation
  - Chemistry
    - Nicholas Materer, Co-PI, Sensor Development
  - Civil Engineering
    - Tyler Ley, Co-PI Sensor Development
  - Mechanical Engineering
    - Jamey Jacobs, Co-PI, UAV
    - Girish Chowdhray, Co-PI, Data Analysis

Technical Status

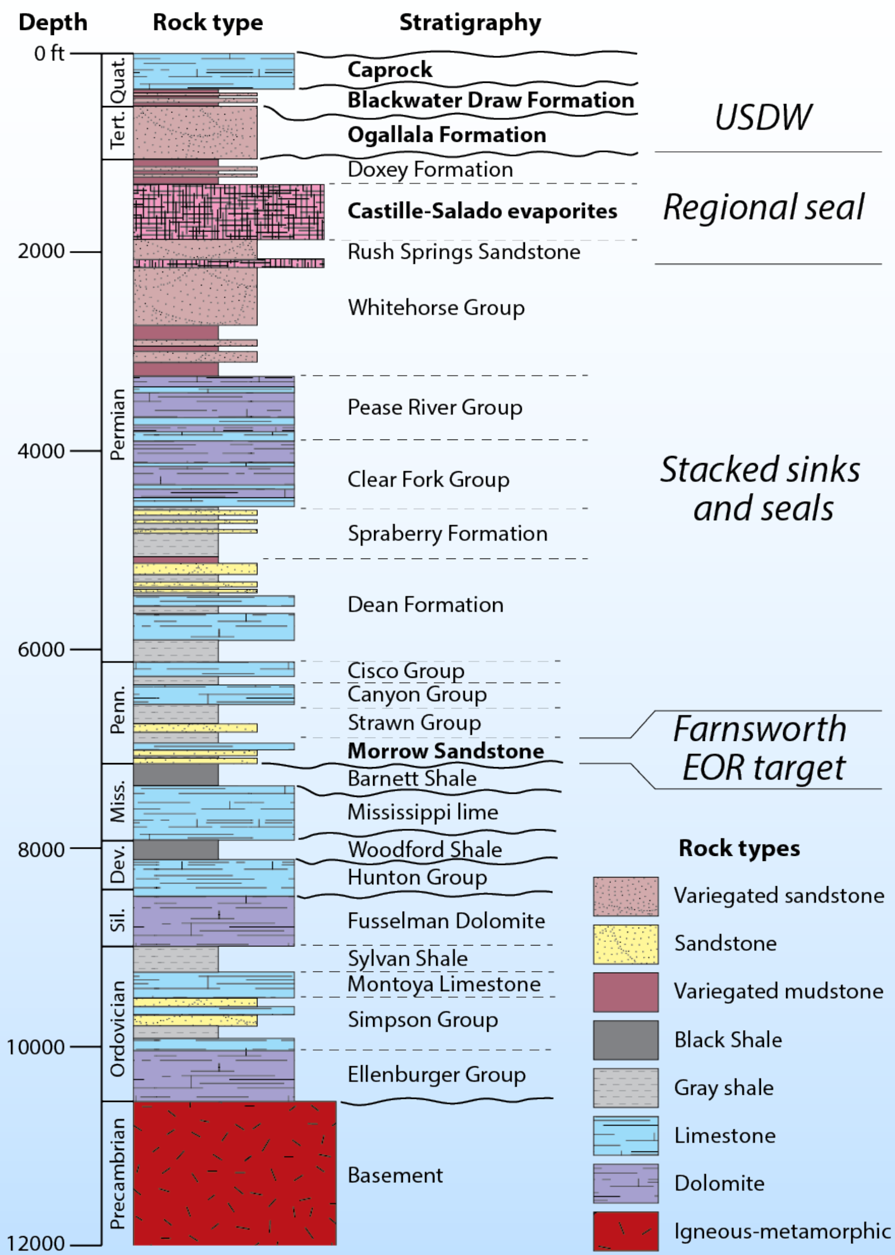
- Geological characterization and assessment of leakage risks.
- Sensor evaluation and deployment using surface and airborne platforms.
- UAV evaluation and testing; and deployment at Farnsworth Oil Unit.
- Application of advanced data analysis techniques.
- Technology Transfer, Best Practices Manual.

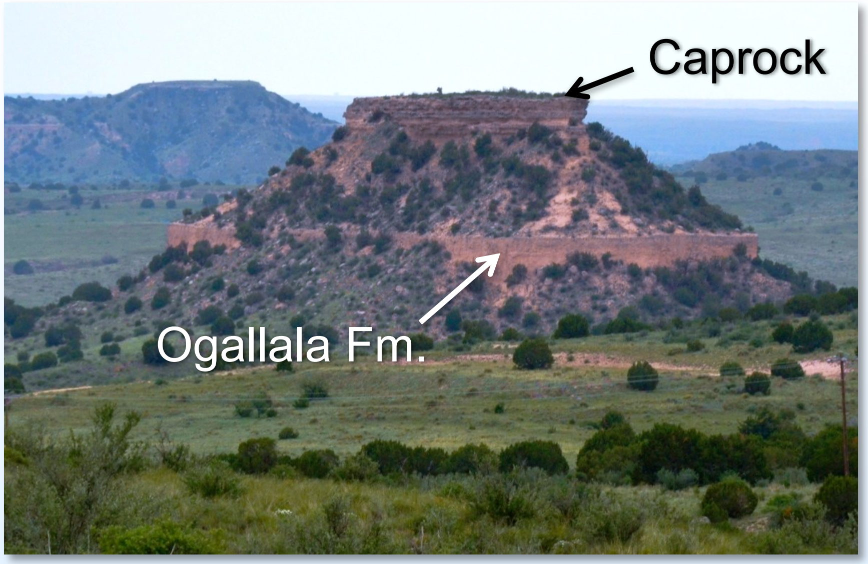
Farnsworth Oil Unit

Operator: Chaparral Energy
Reservoir: Morrow Sandstone (Penn.)
Oil Production: > 36 MMbbl
CO_2-EOR operations since 2010
SWP Phase III CCUS project underway

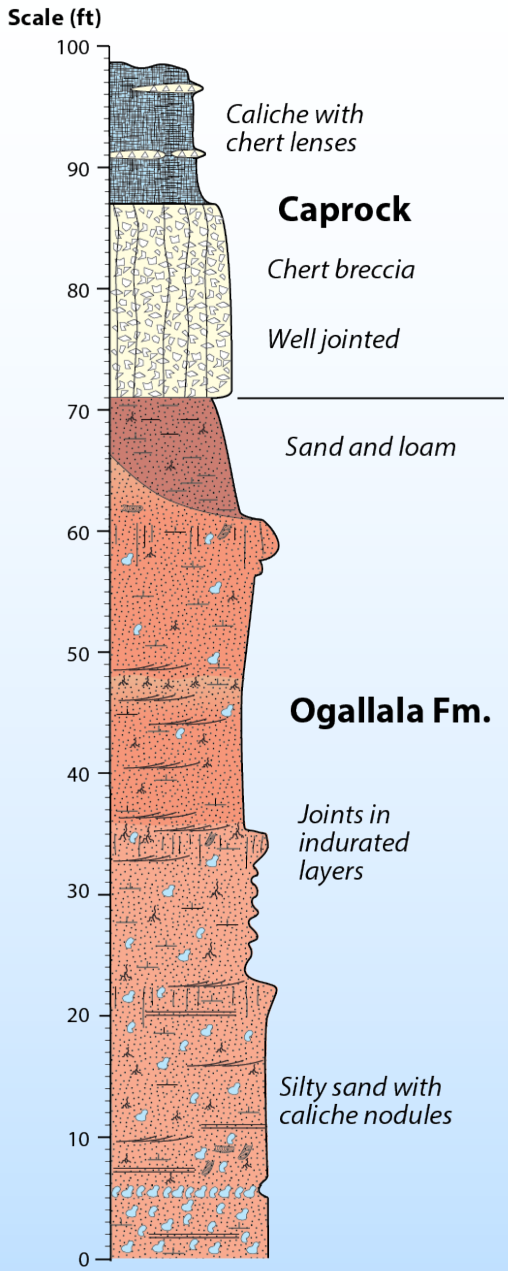


Stratigraphic Column





Surface Formations

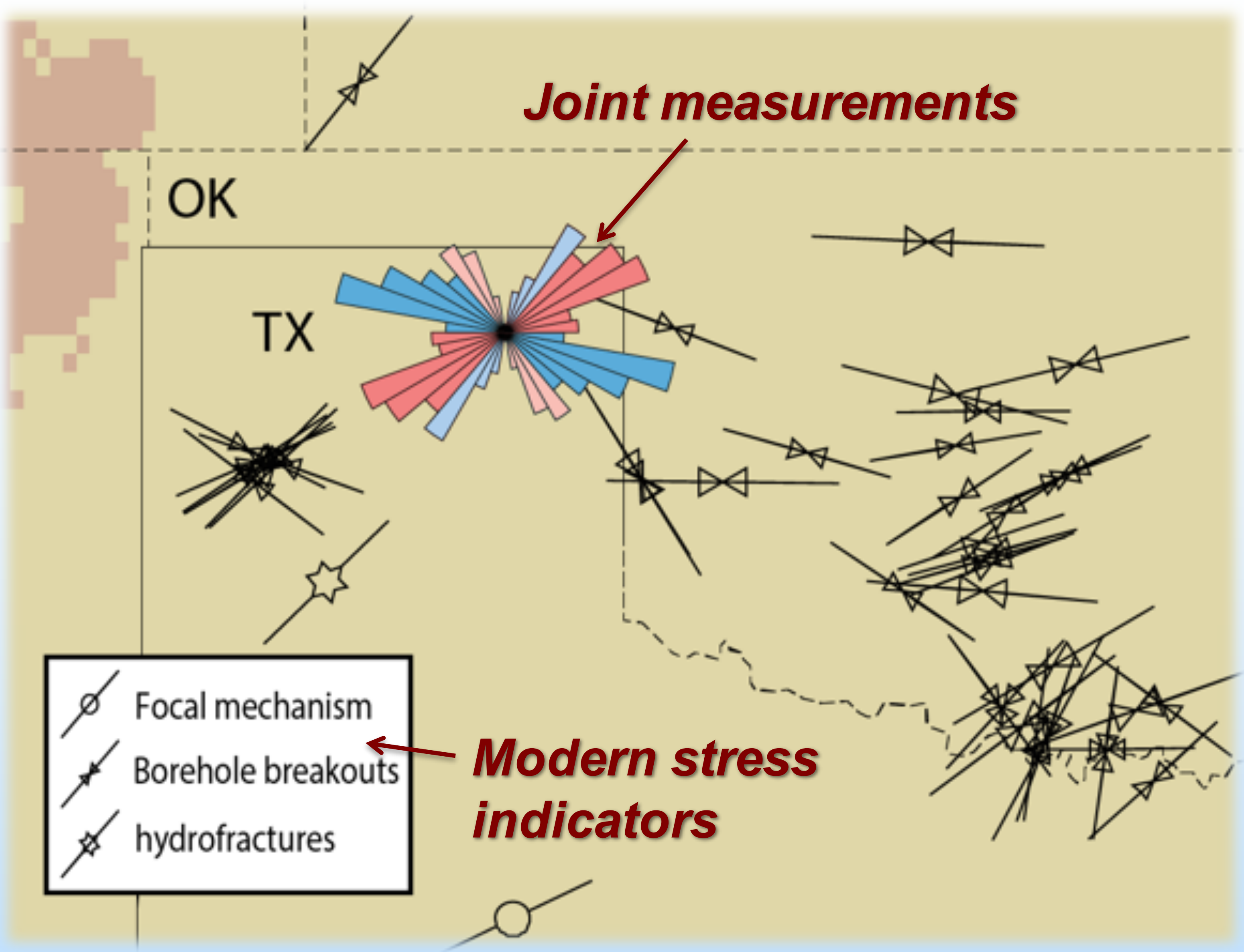


Joint Networks

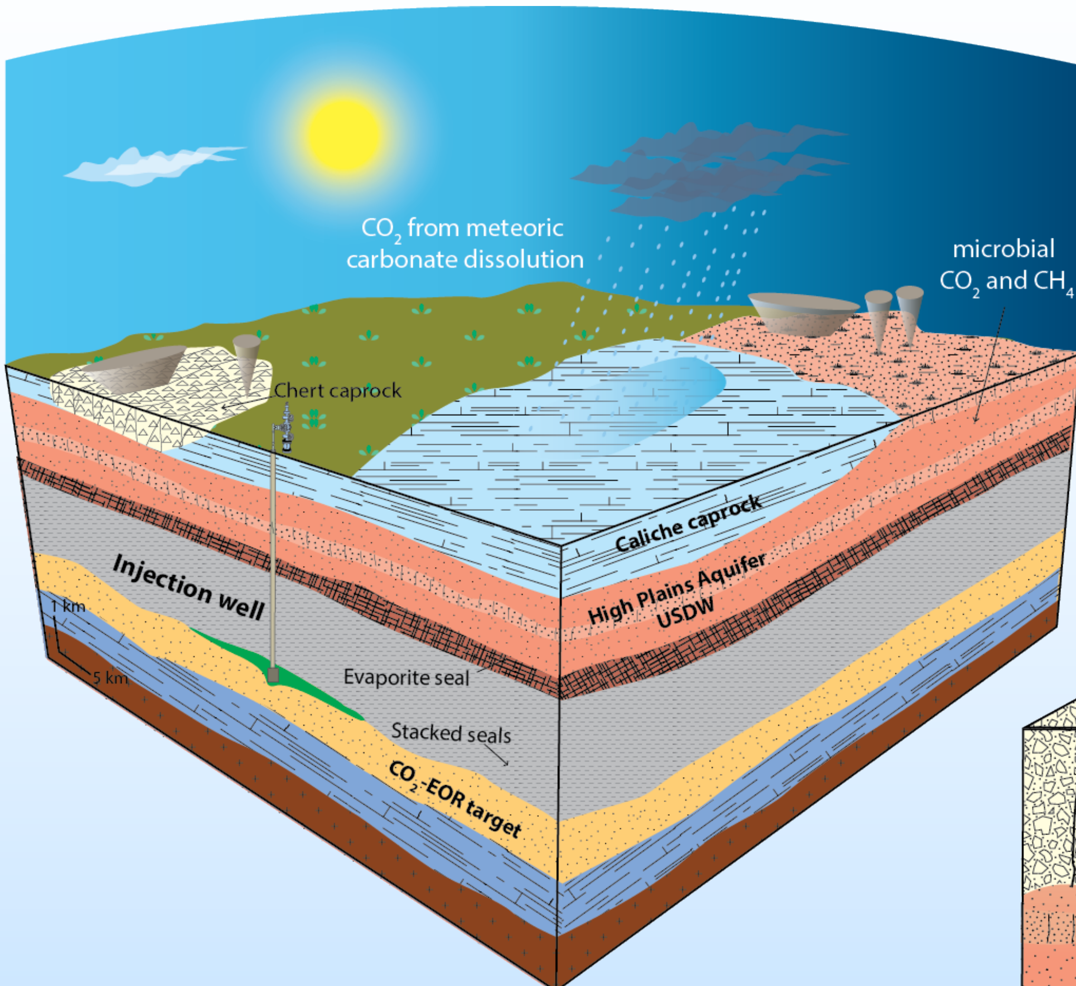
Satellite image
Chert caprock

Outcrop photo
Ogallala sandstone

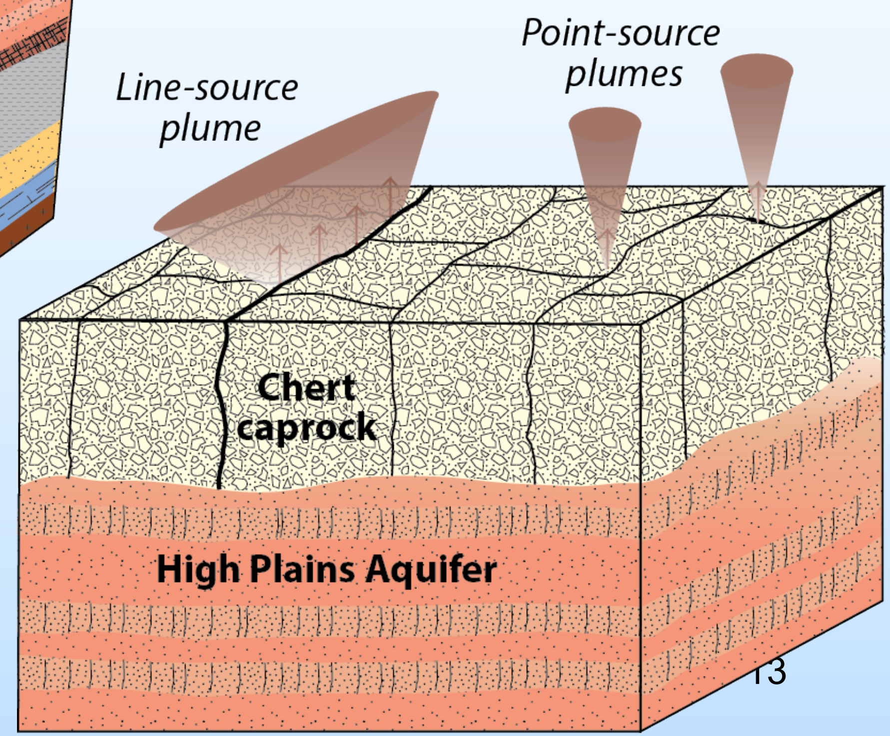
Joint Orientation



Geological Findings



- Multiple seals between reservoir and USDW.
- Natural fractures influence flow in USDW and chert caprock.
- Abundant natural sources of CO_2 and microbial CH_4 near surface.



Sensor Development

Goal: Develop a reliable and cost-effective distributed sensor network to monitor CO_2 and CH_4 emissions (solar powered, minimal maintenance).

Eight CO_2 and six CH_4 sensor elements investigated.

Three sensors were chosen based on their price and accuracy

Lessons learned:

- Almost none arrived correctly calibrated
- Automatic background/baseline corrections lead to inaccuracies
- Datasheets were incomplete; significant effort to get them to work properly

Progress

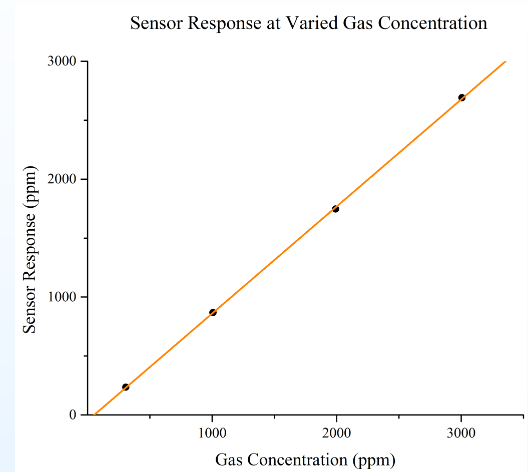
- 120 sensing nodes have been constructed
- 10 sensing nodes have been deployed on the OSU campus and are performing well
- Wireless networking is still being perfected
- These nodes will be installed at the field site in September.

Sensor Elements

CO_2 Sensor:

Senseair K-Series selected for Sensor Nodes and UAV

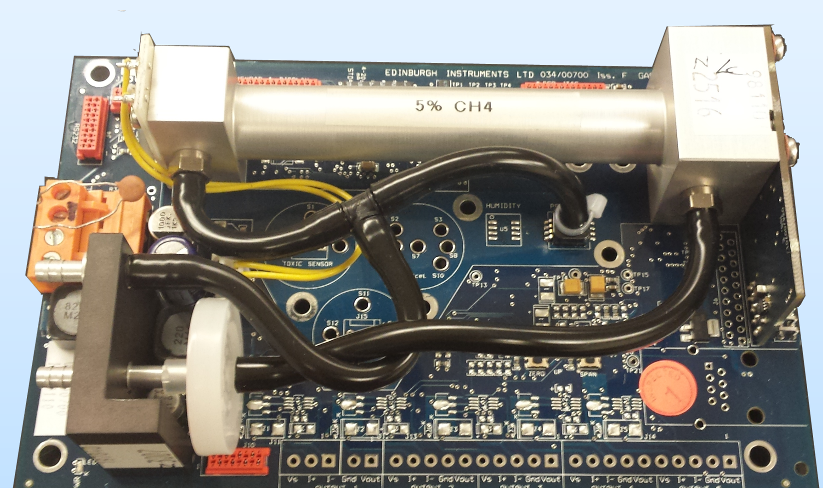
Best performance for cost



CH_4 Sensor:

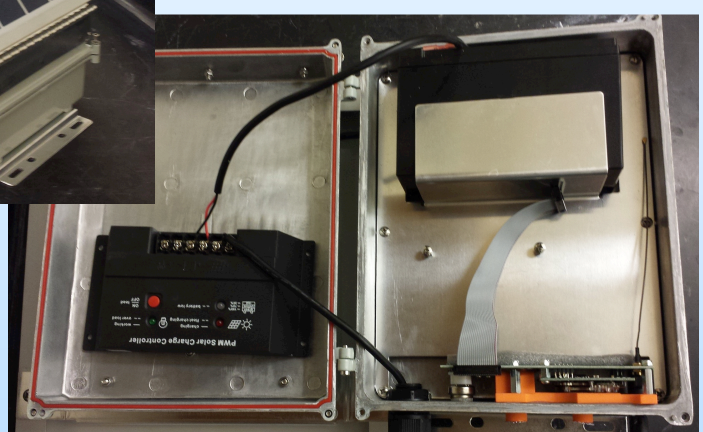
Edinburgh GasCard performed very well for CO_2 & CH_4.

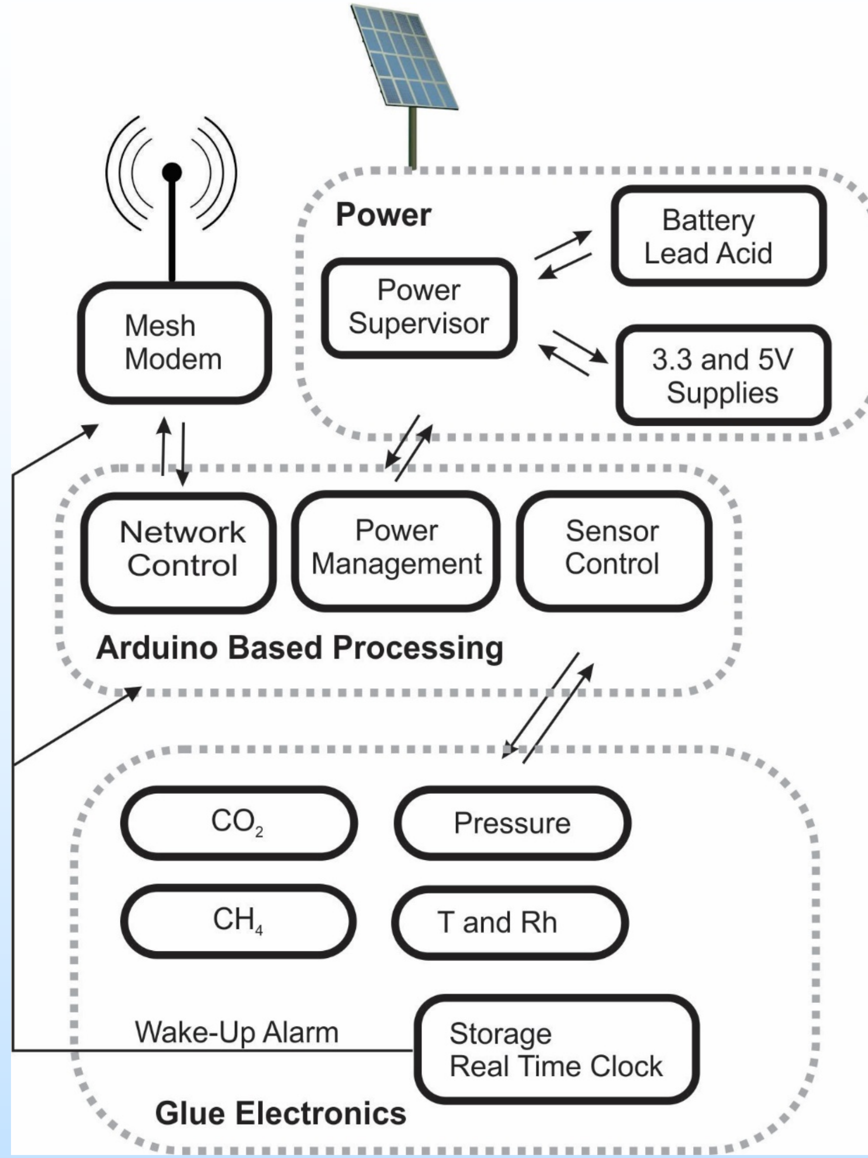
Most expensive.



Basic Sensor Node

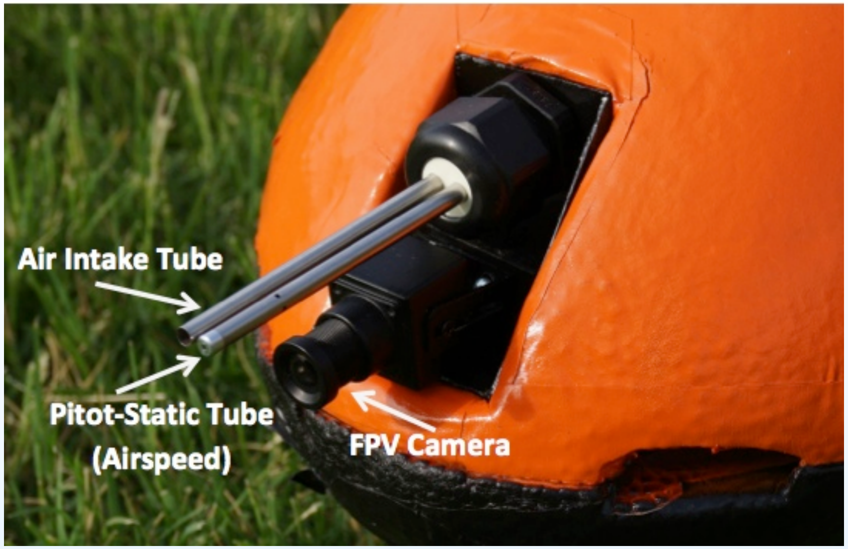
- CO_2 Sensing
  - 0 to 5000 ppm
  - background ~400 ppm
- CH_4 Sensing.
  - 0-500 ppm, background < 1 ppm
- Wireless Networking
  - ZigBee-based technology



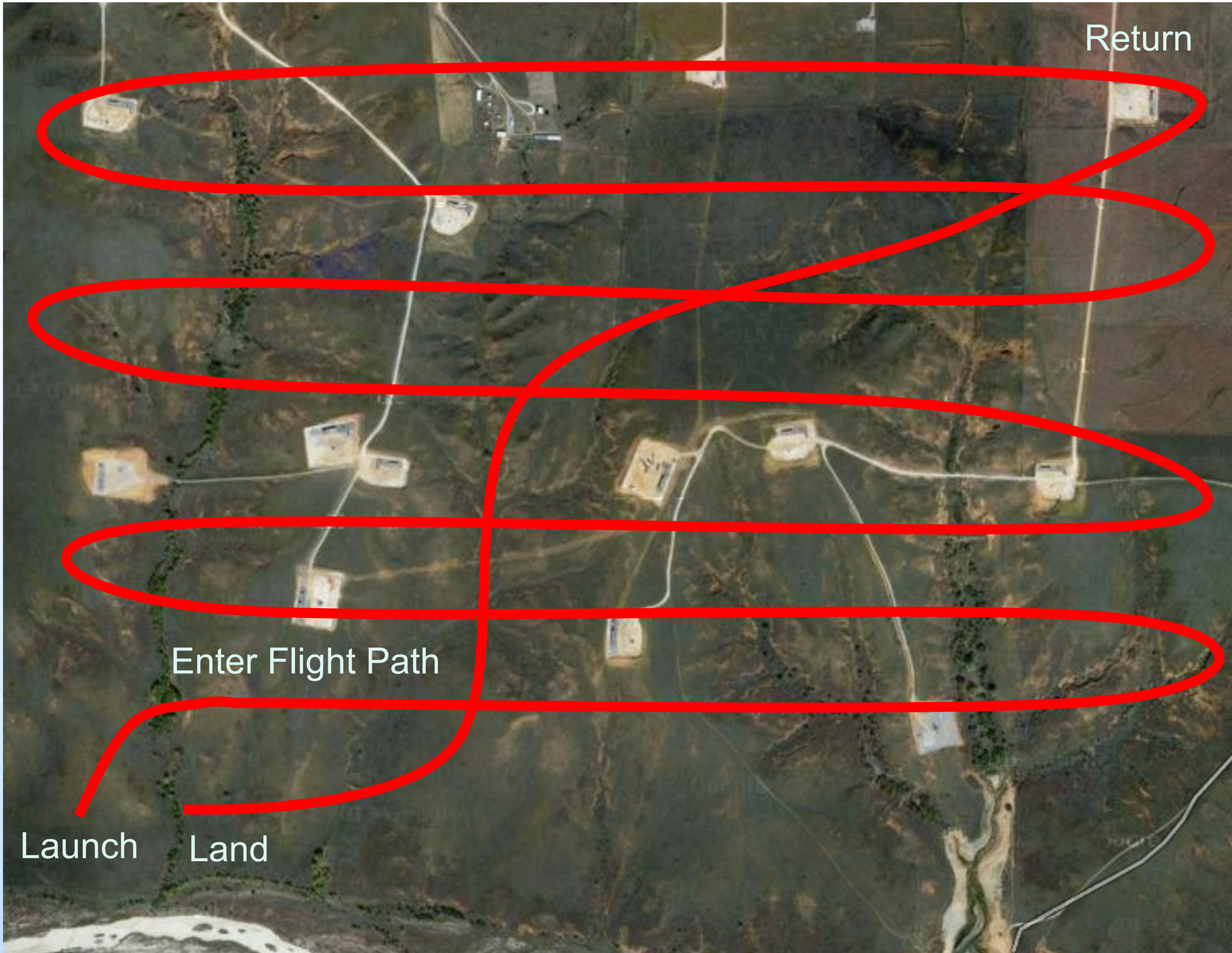


UAV Setup

- Skywalker X-8
  - EPO Foam
  - Capacity, durability, stability
  - 7’ Span, 10 lb GTOW
  - 30 min w/ 10000 mah LiPo
- Landing gear
- FPV Camera

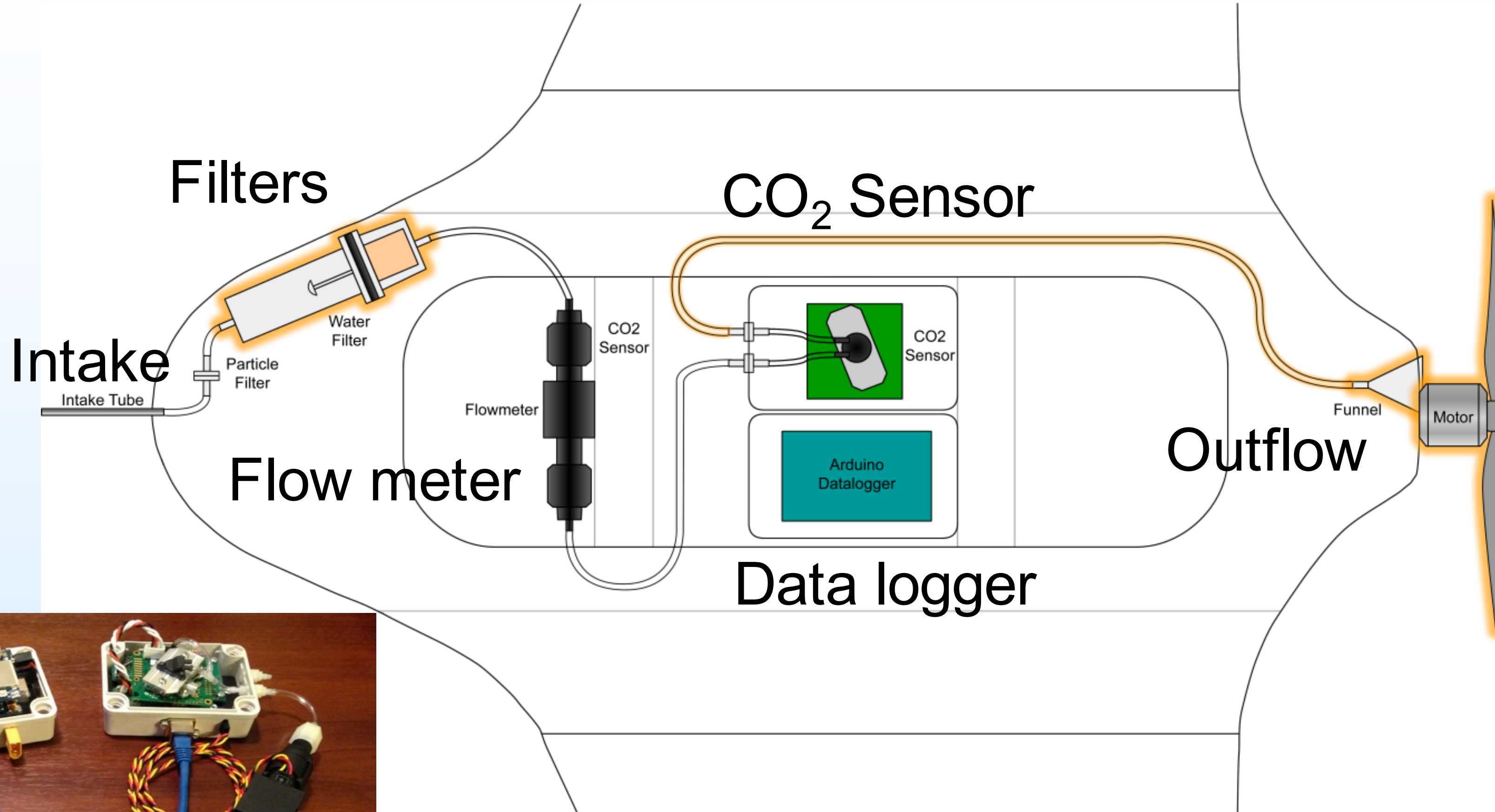


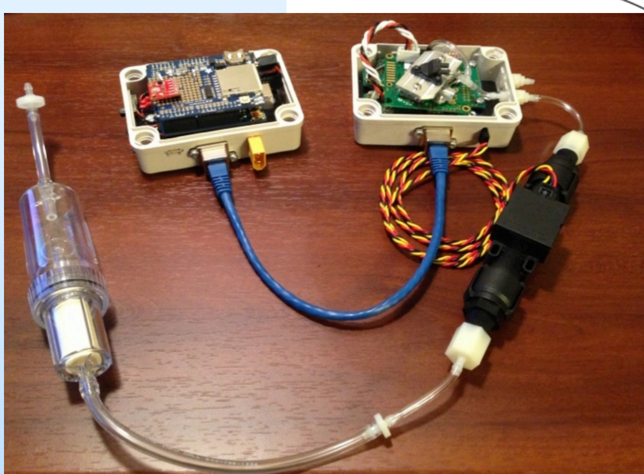
Example Flight Path



UAV Setup

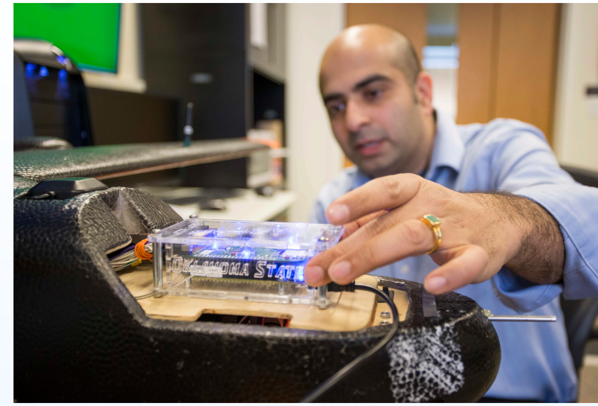
Aircraft layout

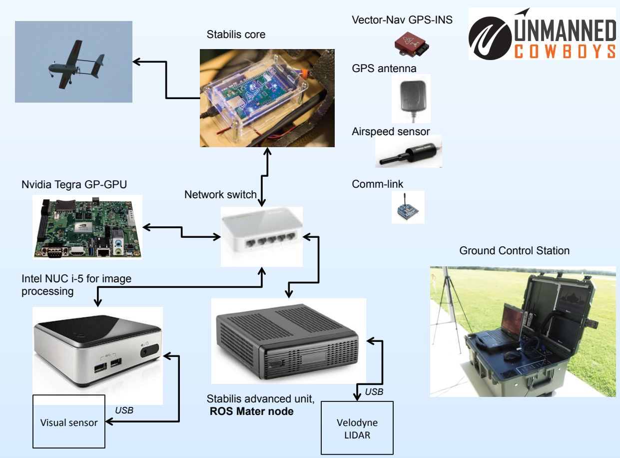


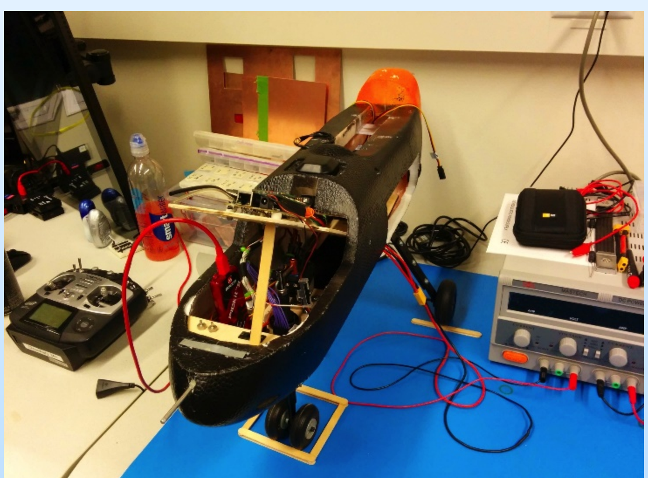


Stabilis Autopilot

- OSU Stabilis: Mission flexibility and accuracy
  - Waypoint-driven flight planning
  - Interfaces with a variety of planners
- Modular sensor and power integration
  - Parallel embedded Linux modules
- “Plug and play” autopilot
  - Adapts to mission needs and minimizes tuning of control gains





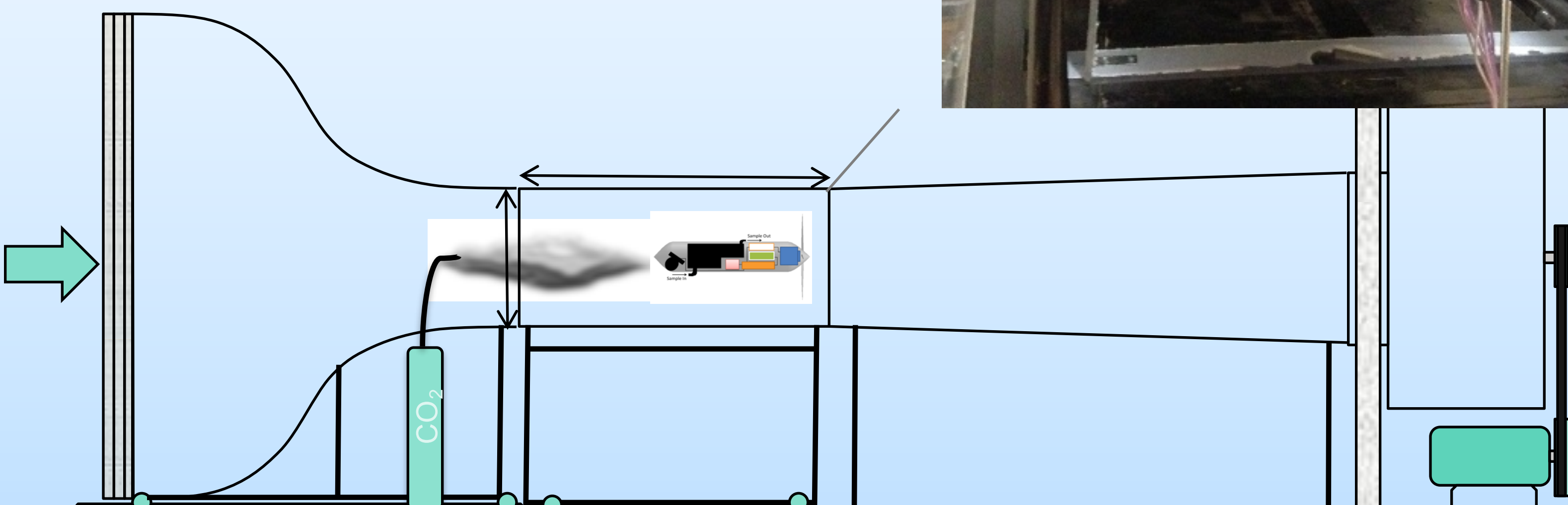


Stabilis interfaces with a Beaglebone Black

http://beagleboard.org/Products/BeagleBone%20Black

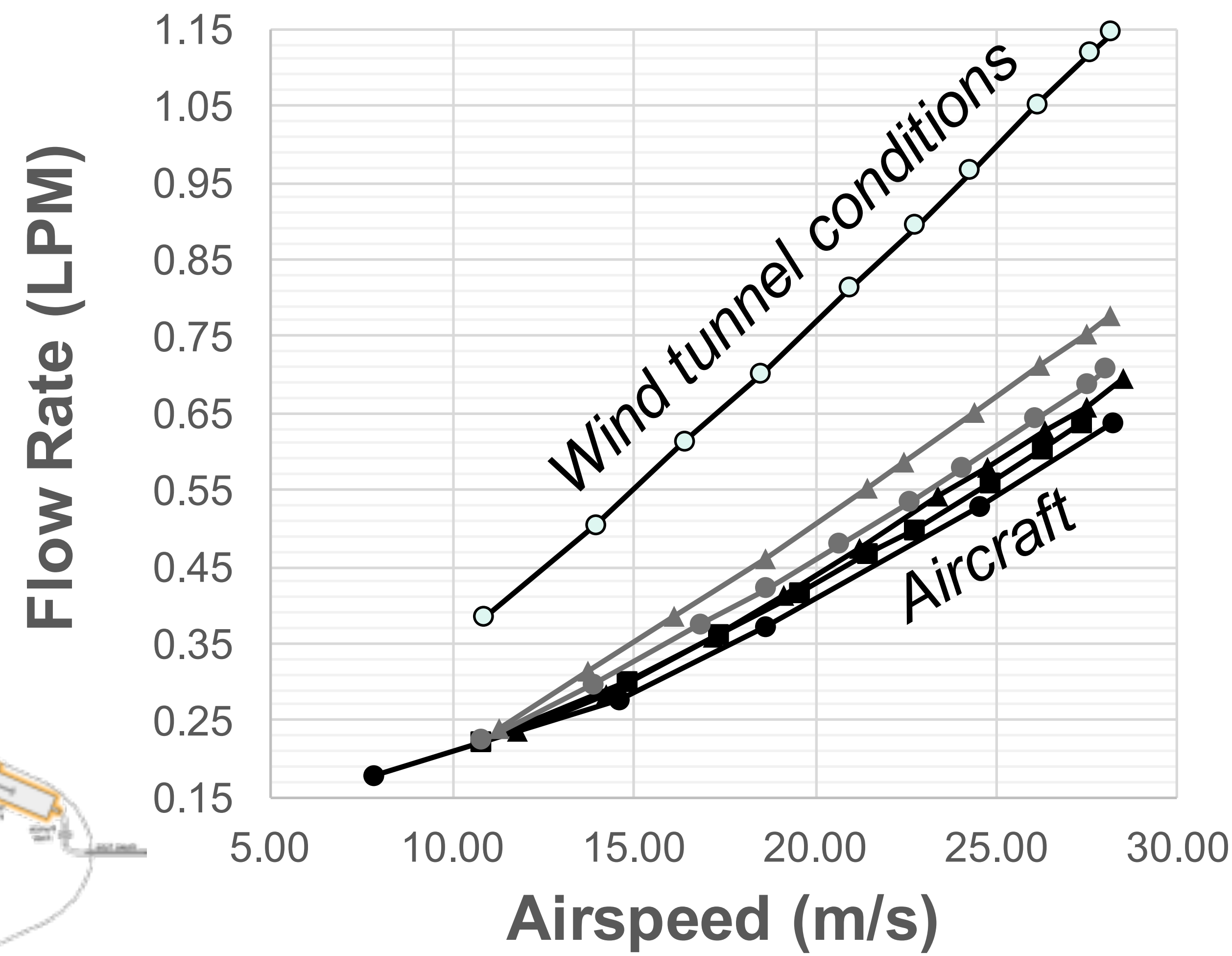
Test Results

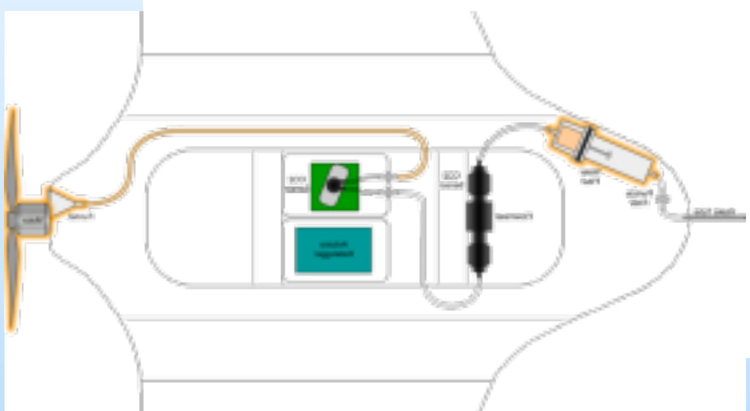
- Wind tunnel tests for flow rate and response time
- OSU low speed wind tunnel
  - 3’ x 3’ test section
  - 55 knot max speed



Test Results

CO_2 Sensor – Flow Rate

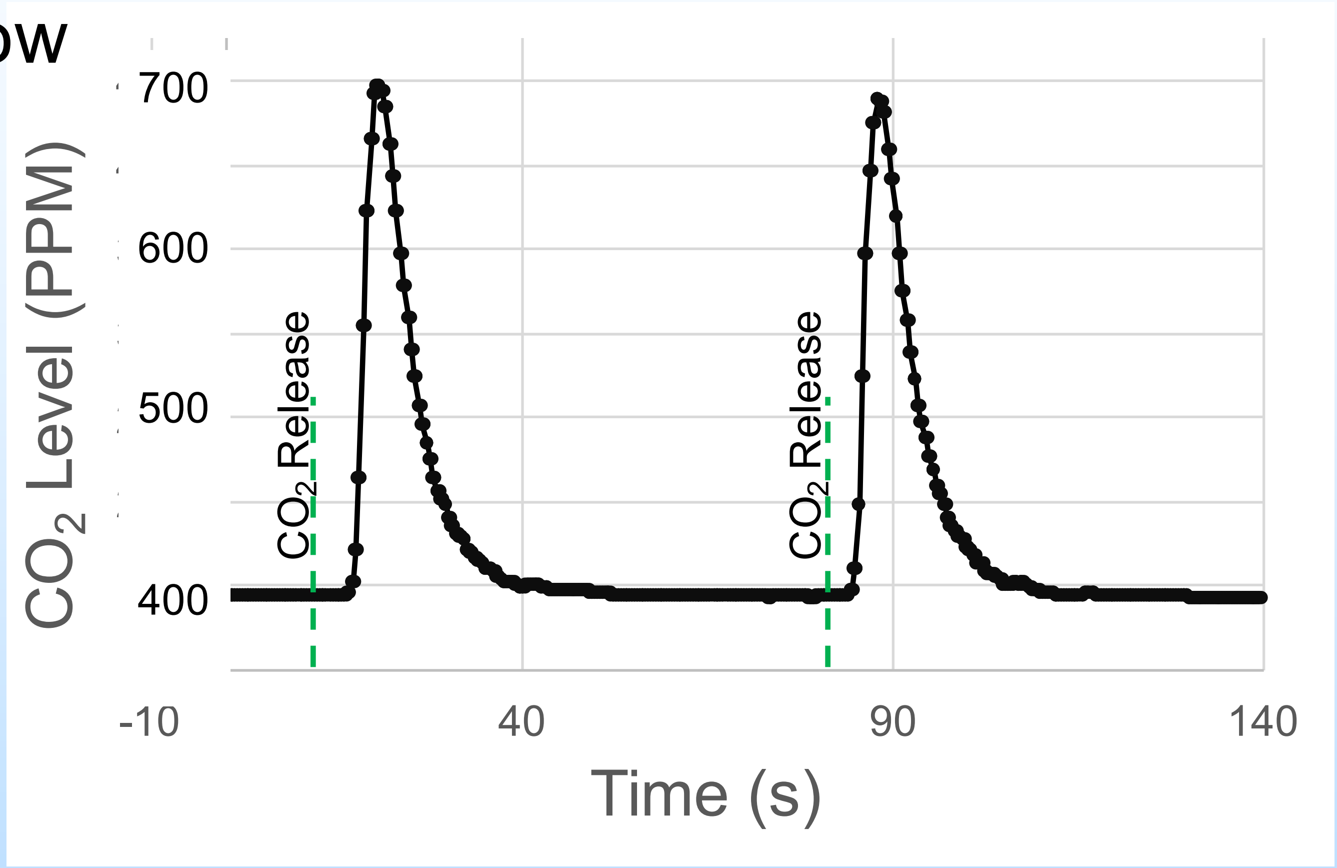




Test Results

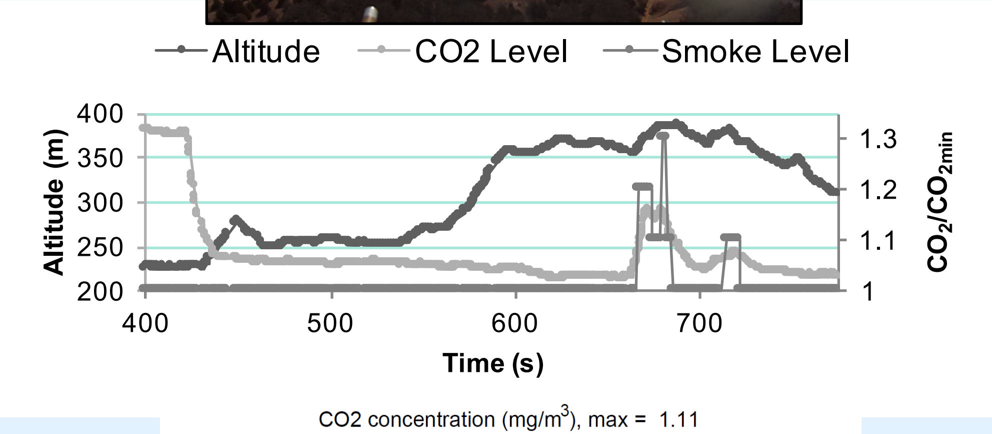
CO_2 Sensor – Response Time

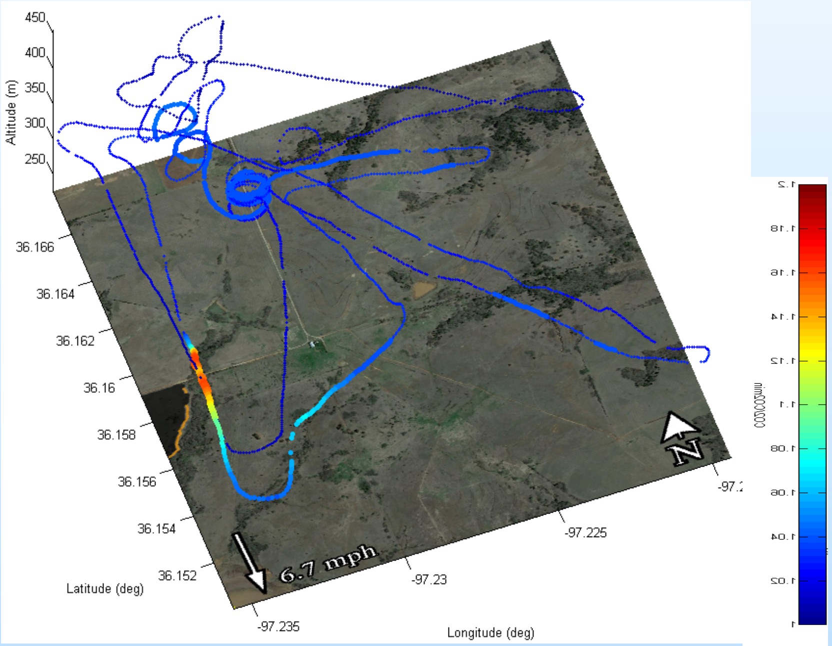
- Funnel, no filter configuration
- CO_2 released 17” from intake for 1 sec @ 30 SCFH
- 28 knot airspeed
- 0.435 LPM flow

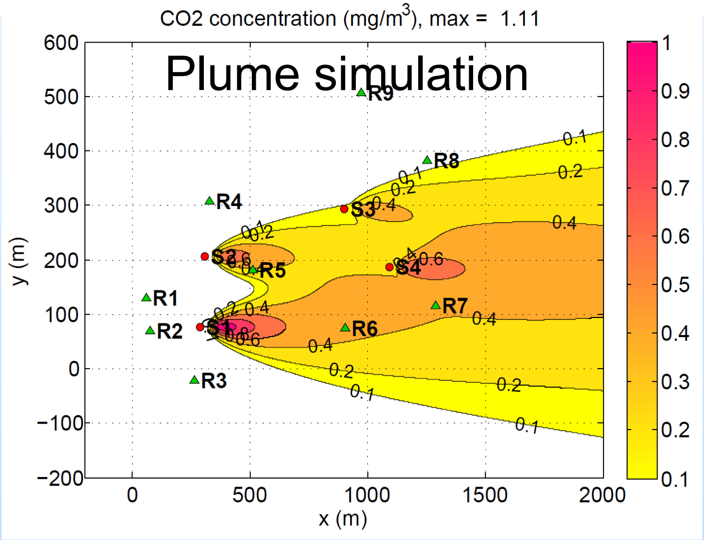


Test Results

- Fire in distance
- Fire observation flight
- Wind 7.4 mph SSE
- Pass 2 12 min later
- 0.45 LPM, 7.5 s delay

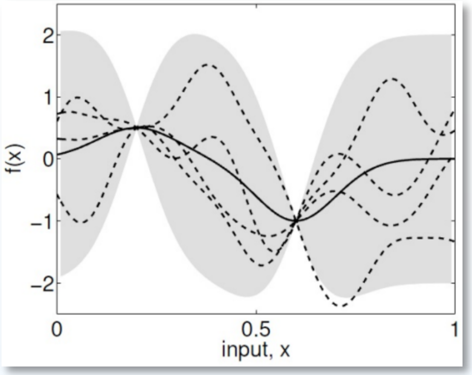




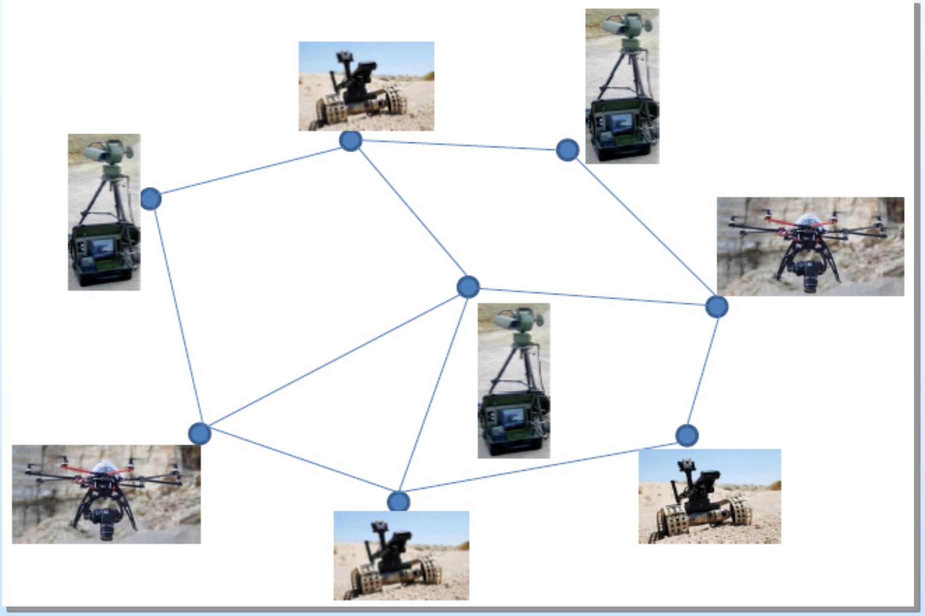


Information Fusion using GP

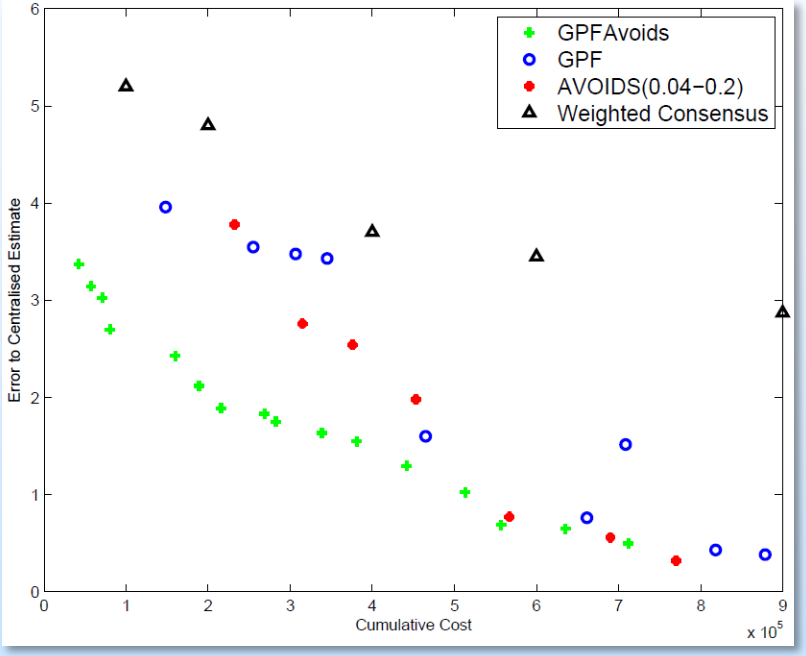
- Gaussian Process: Bayesian Nonparametric model for spatially correlated distributions
- Distributed static and dynamic heterogeneous agents learning parts of the CO_2 and CH_4 models
- Naïve data sharing can overwhelm the network, how to minimize communication for distributed inference?
- Transmit compressed generative GP models instead of transmitting data
- **Value-of-Information** metrics utilized to minimize network clutter



Gaussian processes model correlated data as distributions over functions



Distributed network topology with static and dynamic agents



GP-Fusion with adaptive Value of Information (VoI) thresholds minimizes error with less communication

Accomplishments to Date

- Field site at Farnsworth Oil Unit.
- Geologic framework characterized; hypotheses formulated to help guide field operations.
- Robust and cost-effective near-surface and airborne sensors identified.
- UAV platform selected, instrumented, field-tested.
- Data management and processing techniques evaluated and tested.
- Ready for deployment at Farnsworth.

Synergy Opportunities

- Limitless opportunities for collaboration.
- Sensor technologies deployable for a broad range of geological and operational monitoring applications.
- Sensor development and application fertile ground for collaborative research.
- UAV monitoring technology has utility at virtually all storage sites and can perform multiple tasks simultaneously (i.e., flux monitoring plus checking on status of operations).
- Wider deployment of technology helps define applicability, limitations, and best practices.

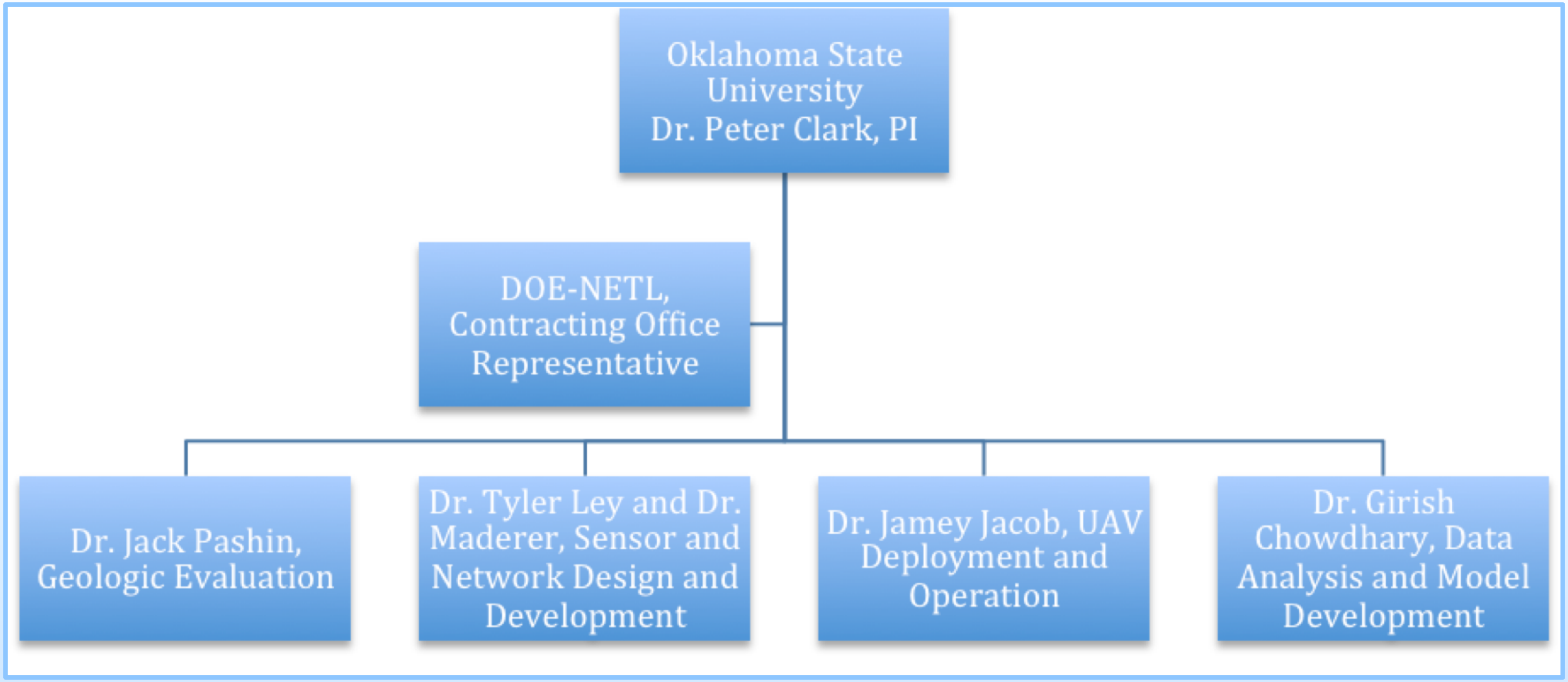
Summary

- Numerous shale and evaporite seals make Farnsworth a favorable storage site.
- Abundant natural fractures and natural CO_2 and CH_4 sources near surface; facilitate heterogeneous gas flux.
- Identifying robust and cost-effective options for near-surface and airborne CO_2 and CH_4 sensors required compromises.
- UAVs instrumented, tested.
- Gaussian Process viable approach to data manipulation and modeling.
- Ready for field deployment at Farnsworth.

Appendix

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

Organization Chart



Gantt Chart

	Year 1 (2013-14)				Year 2 (2014-15)				Year 3 (2015-16)				Check
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
Task 1.0 Project Management and Planning													**$ -**
	Task 1.0 Project Management and Planning												$ 239,993
													$ -
Task 2.0 Geologic Evaluation													**$ -**
	Subtask 2.1 Site Selection												$ 58,144
			Subtask 2.2 Geologic Framework										$ 66,024
					Subtask 2.3 Leakage Evaluation								$ 137,449
													$ -
Task 3.0 Land-Based Sensor System													$ -
	Subtask 3.1 Sensor Development and Evaluation												$ 314,129
		Subtask 3.2 Sensor Network Design & Assembly											$ 235,597
					Subtask 3.3 Sensor Network Deployment, Monitoring							Removal	$ 508,369
													$ -
Task 4.0 UAV Design, Evaluation, and Deployment													$ -
	SubTask 4.1 UAV Design												$ 87,928
				Subtask 4.2 UAV Evaluation									$ 59,753
					Subtask 4.3 UAV Deployment & Monitoring							Removal	$ 141,310
													$ -
Task 5.0 Data Analysis													$ -
	Subtask 5.1 Data Preparation												$ 71,196
				Subtask 5.2 Predictive Representation									$ 75,114
							Subtask 5.3 System Optimization						$ 117,189
													$ -
Task 6.0 Technology Transfer													$ -
	Task 1.0 Project Management and Planning												$ 145,770
													$ -
	$168,214	$246,746	$261,282	$301,063	$155,491	$155,491	$169,820	$144,912	$163,737	$163,737	$163,737	$163,737	**$ 2,257,965**
	Total BP1		$	977,304	Total BP2		$	625,713	Total BP3		$	654,948	per sub task

Current Status

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