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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Jamey Jacob, and Girish Chowdhary

Oklahoma State University

U.S. Department of Energy

National Energy Technology Laboratory
Mastering the Subsurface Through Technology, Innovation and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 16-18, 2016

Presentation Outline

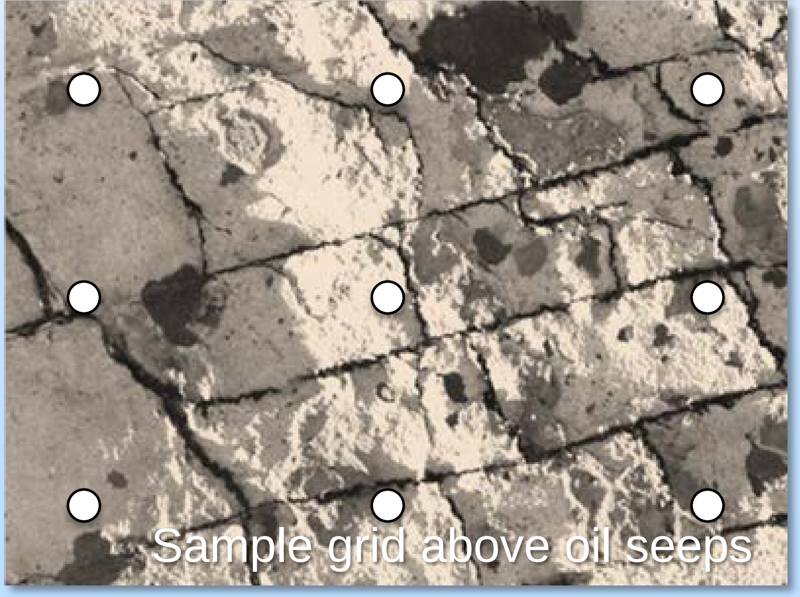
- Benefit to Program
- Goals and Objectives
- Project Team
- Technical Status
- Accomplishments to Date
- Synergy Opportunities
- Summary

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


Li-Cor soil gas unit


Sample grid above oil seeps

- 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 Chowdhary, Co-PI, Data Analysis

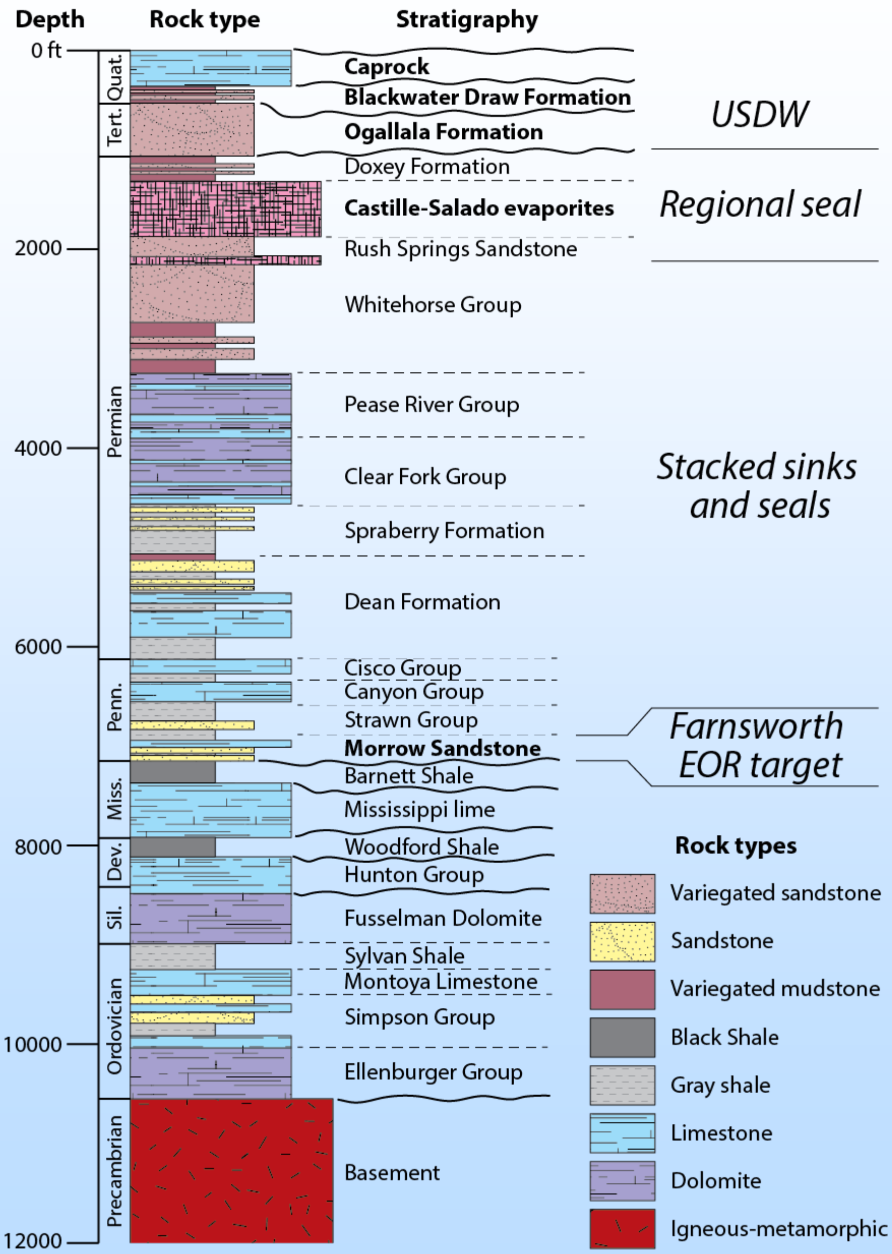
Technical Status

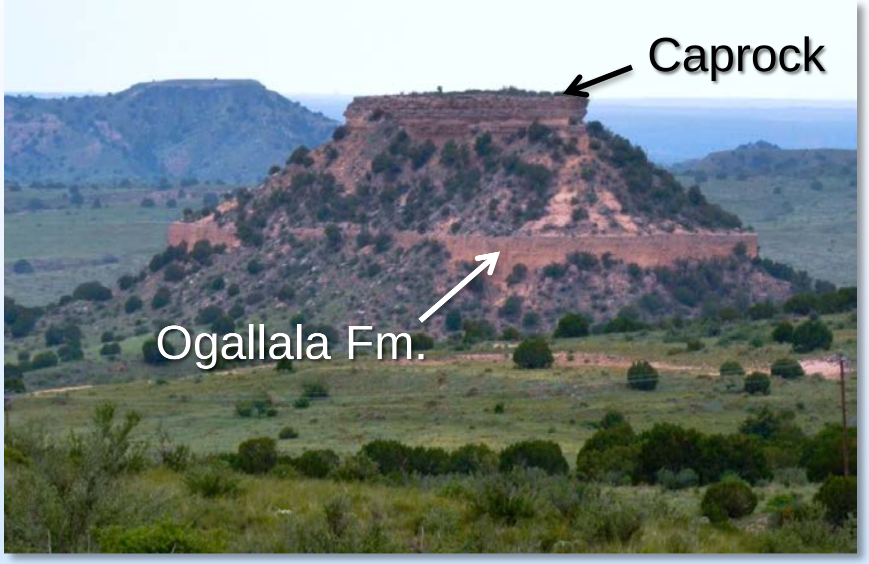
- Geological characterization and assessment of leakage risks.
- Sensor evaluation and deployment using surface and airborne platforms.
- UAV evaluation and testing; and deployment at Farnsworth Oil Unit.
- Application of advanced data analysis techniques.
- Technology Transfer, Best Practices Manual.

Farnsworth Oil Unit

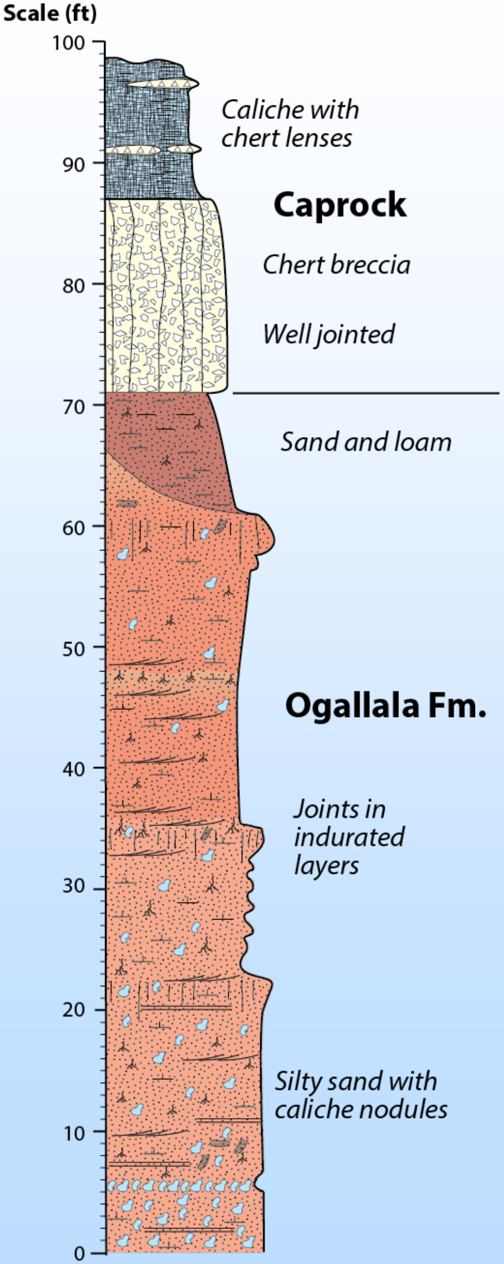
Operator: Chaparral Energy
Reservoir: Morrow Sandstone (Penn.)
Oil Production: > 36 MMbbl
CO_2-EOR operations since 2010
SWP Phase III CCUS project underway

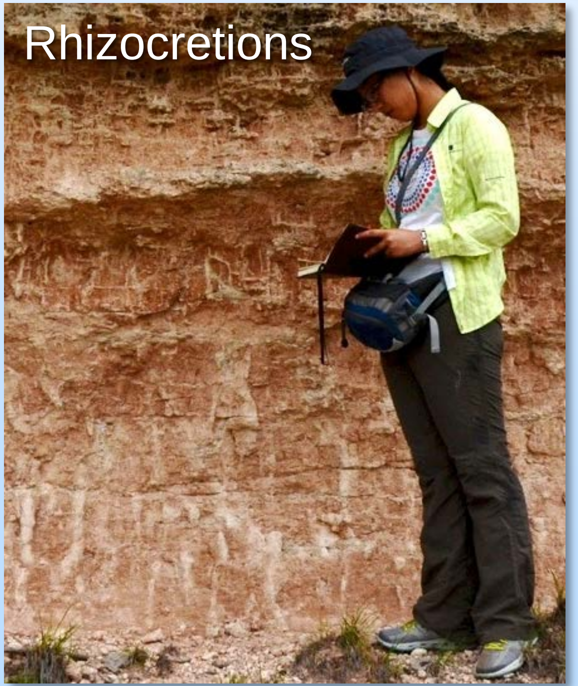
Stratigraphic Column





Surface Formations



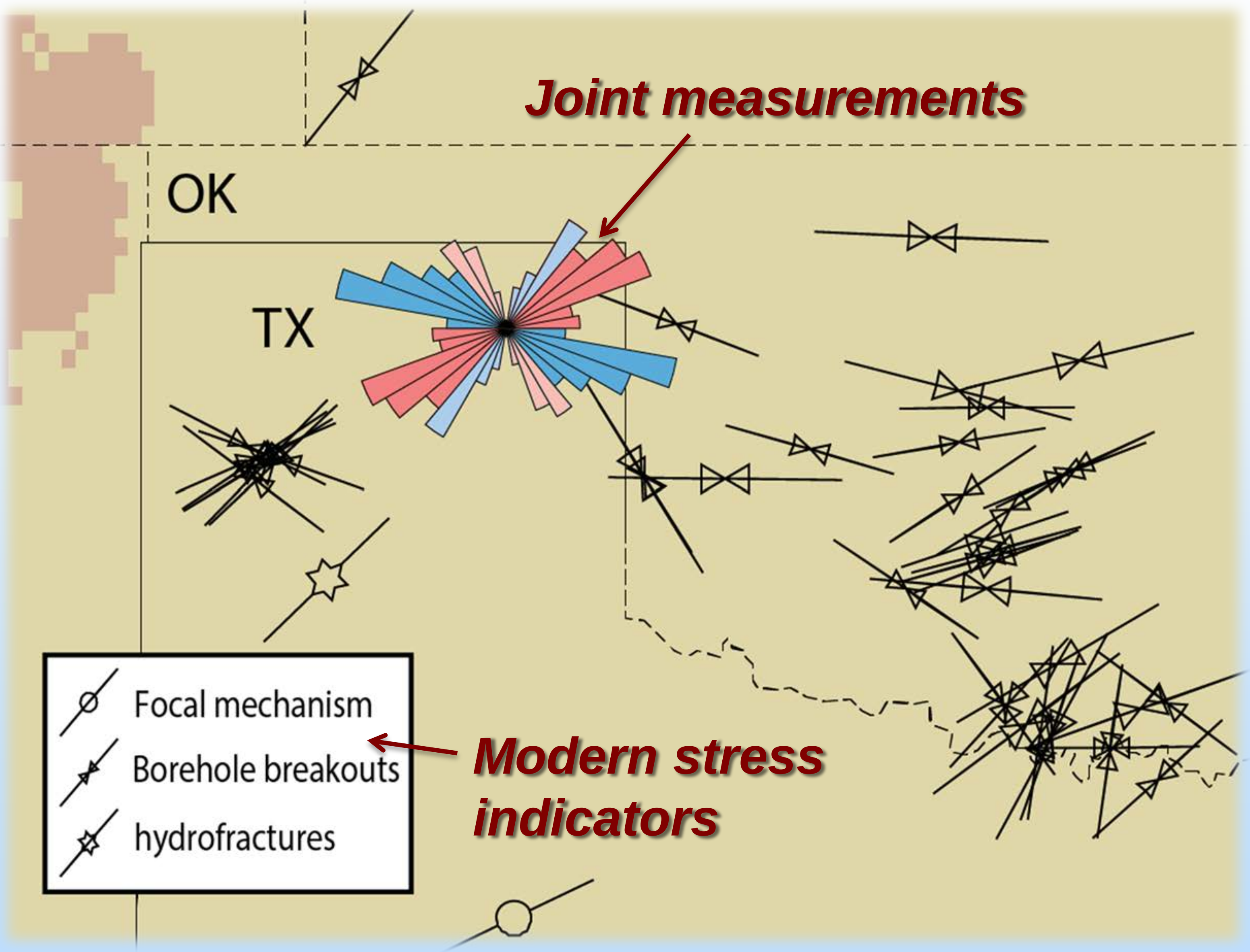


Joint Networks

Satellite image
Chert caprock

Outcrop photo
Ogallala sandstone

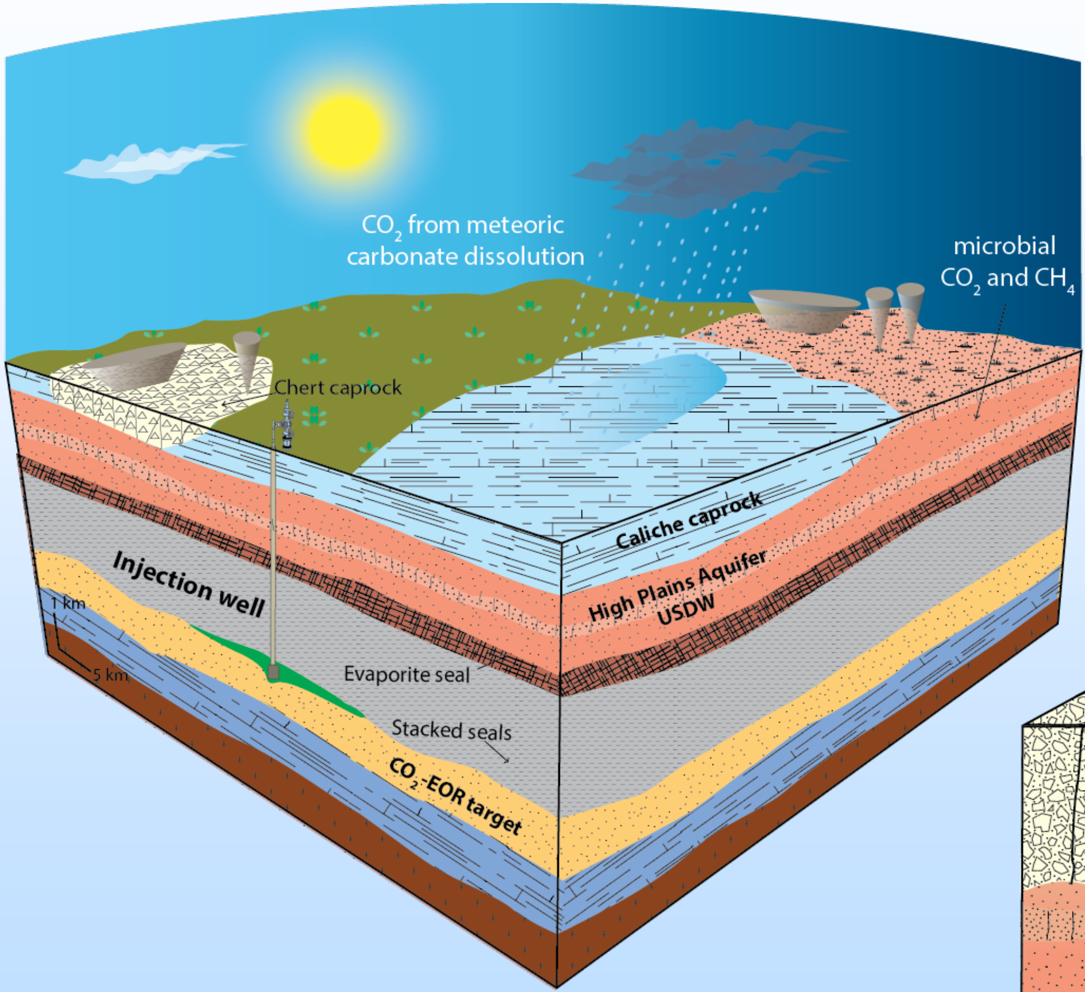
Joint Orientation



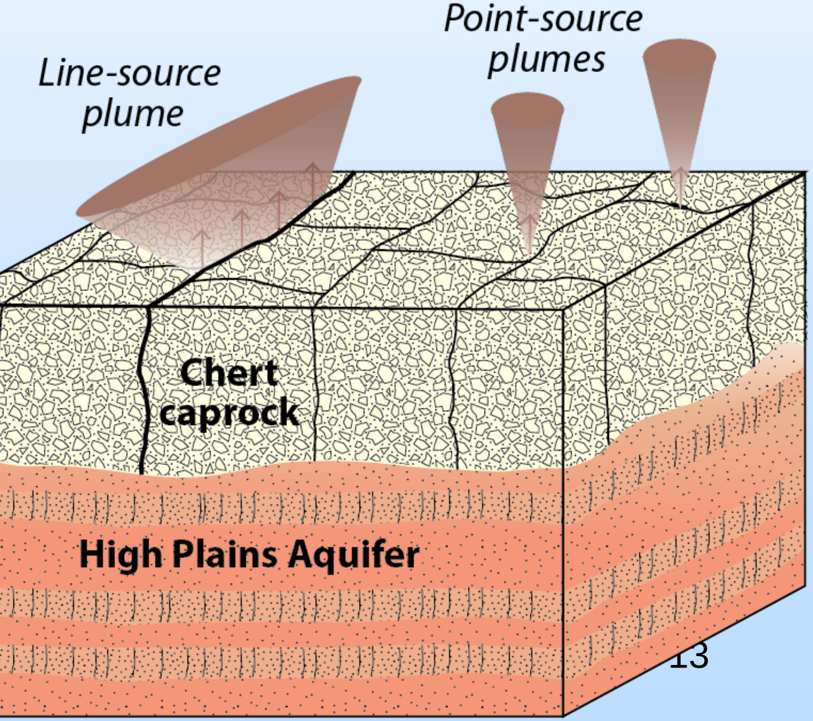
Joint measurements

Modern stress indicators

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

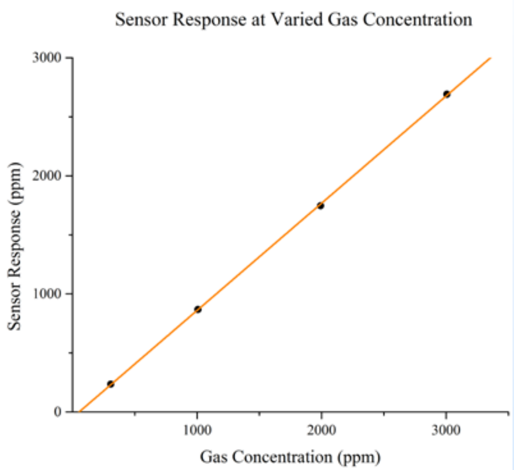
Lessons learned:

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

Sensor Elements

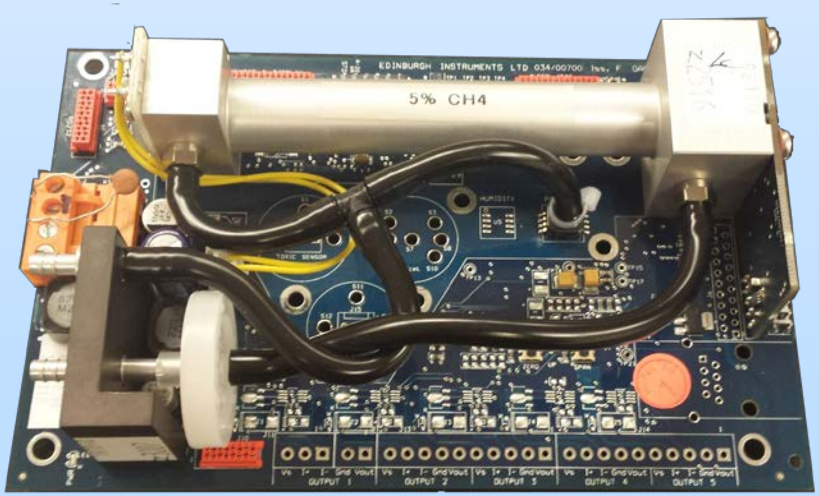
CO_2 Sensor:
Senseair K-Series selected for Sensor Nodes and UAV

Best performance for cost

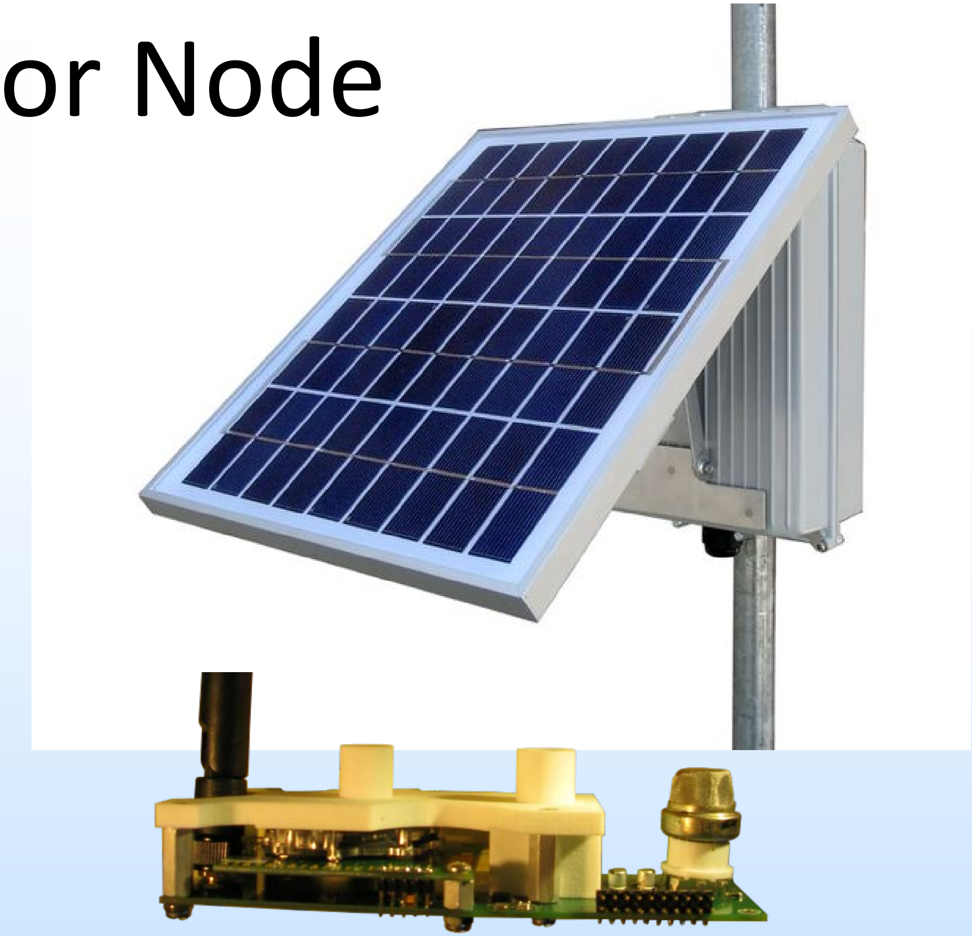


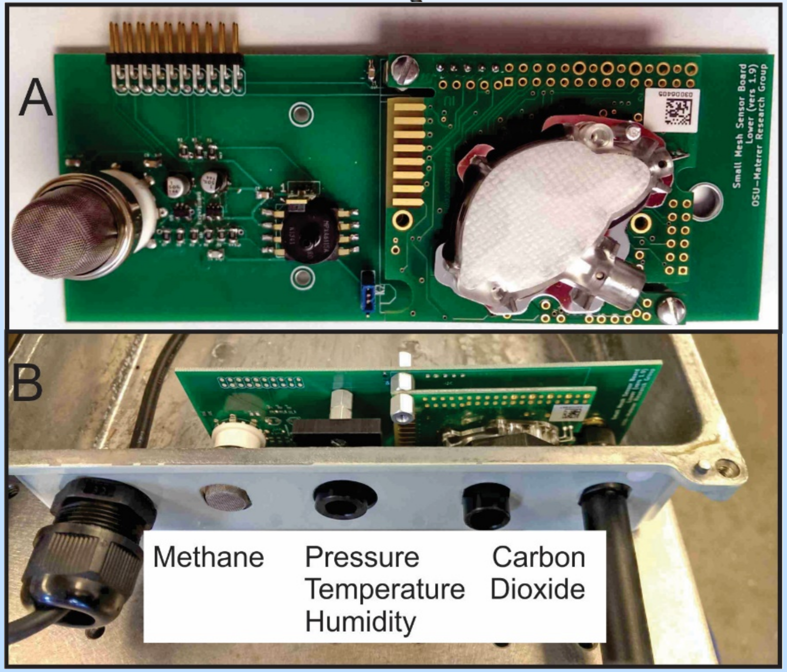
CH_4 Sensor:
Edinburgh GasCard performed very well for CO_2 & CH_4.

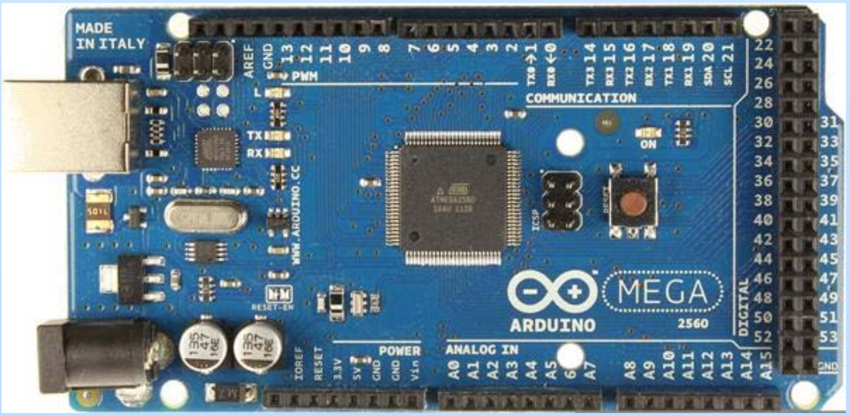
Most expensive.



Sensor Node

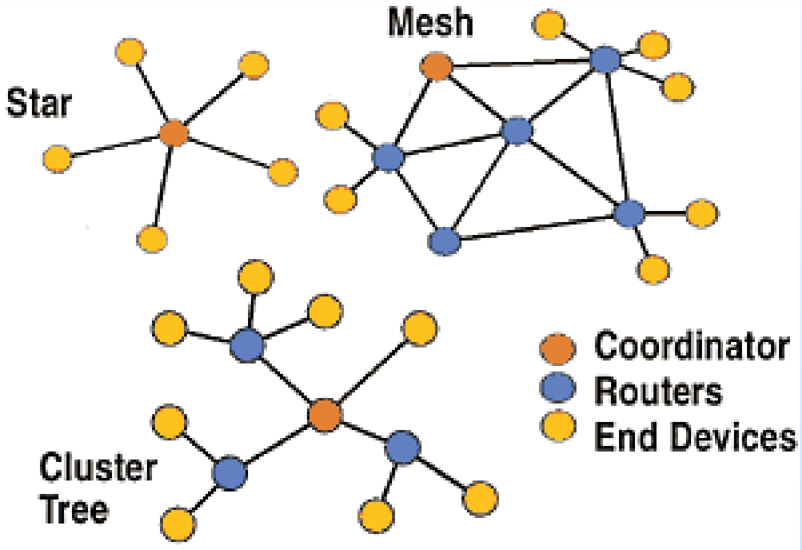



A
Small Mesh Sensor Board
Lower (vers 1.9)
OSU–Meterer Research Group
B
Methane
Pressure
Temperature
Humidity
Carbon
Dioxide


MADE
IN ITALY
COMMUNICATION
ARDUINO
MEGA
2560
POWER
ANALOG IN
DIGITAL

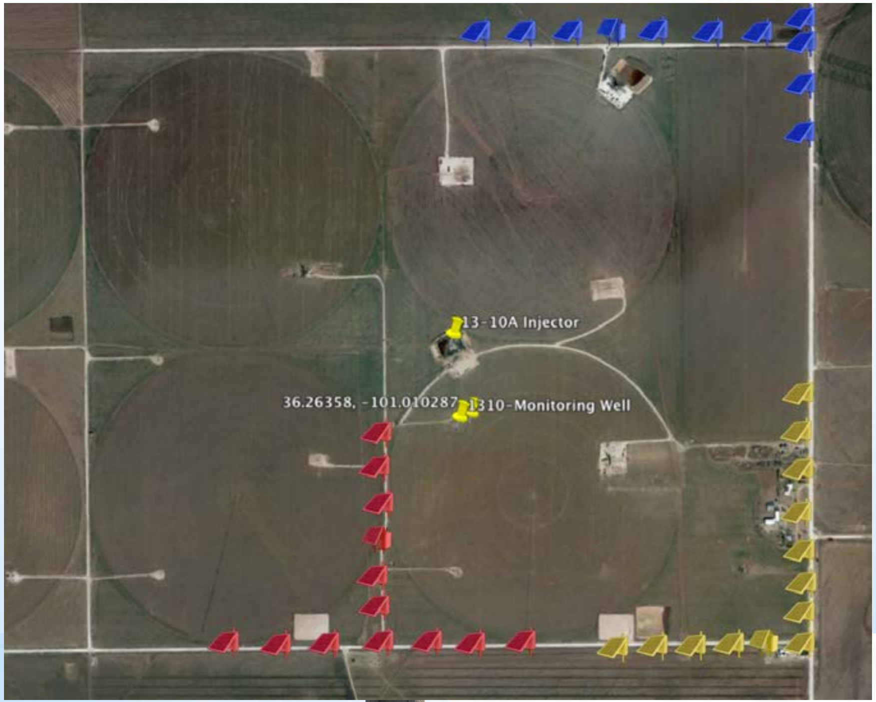
Sensor Grid

- Many different configurations possible—Used cluster tree layout



- Used ZigBee Technology
- Real time collection can be used
- Sensor Nodes (Routers + End Devices)
- Coordinator Nodes will have high accuracy sensors and cell modem

Farnsworth Injection Well Site



Deployed in Farnsworth Oil Unit

- One subnet is deployed and two more are being installed this week!
- Response is steady and reliable
- Some variation in gas concentration can be detected

Airborne Sensor System

Airborne CO_2 Sensor Requirements

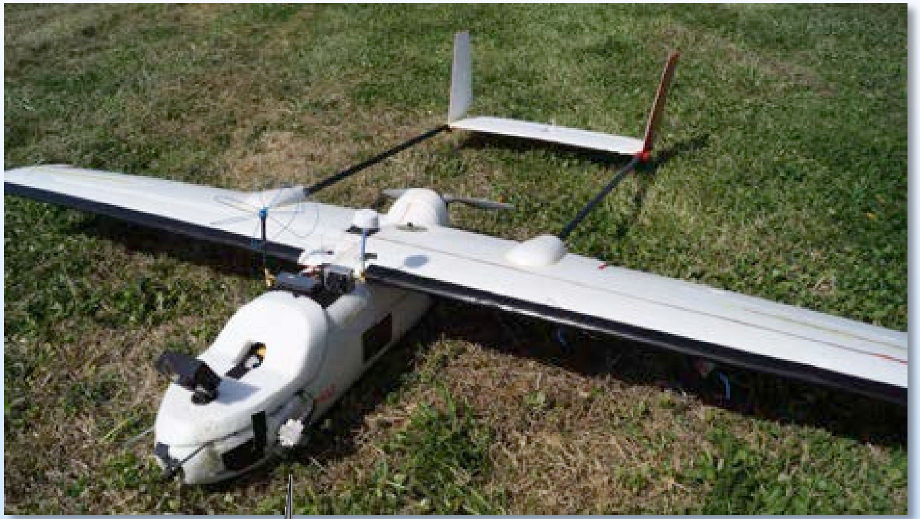
- Quick response
- Low cost
- Good accuracy
- Low SWAP (Size, Weight and Power)

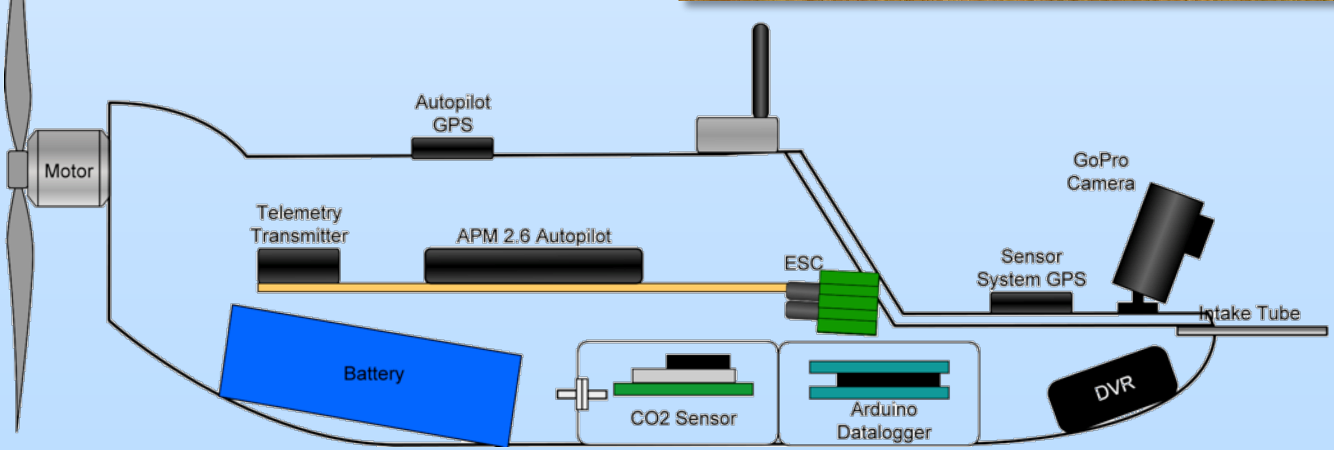
» *Non-Dispersive Infrared preferred option*

Sensor Model	Measurement Range	Accuracy	Response Time	Cost
Senseair K-30 FR	0-5,000 ppm	±30 ppm + 3% of reading	2 sec	$220
LiCor LI-820	0-20,000 ppm	±< 3% of reading	0.5 sec	$3900
Vaisala GMP343	0-20,000 ppm	±5 ppm + 2% of reading	8 sec	$3090
Vernier CO_2 Sensor	0-10,000 ppm	±100 ppm	120 sec	$250

Unmanned Aircraft System

- Skyhunter UAS; 7 foot wingspan; handlaunched
- 15 lb GTOW, 45-60 min endurance

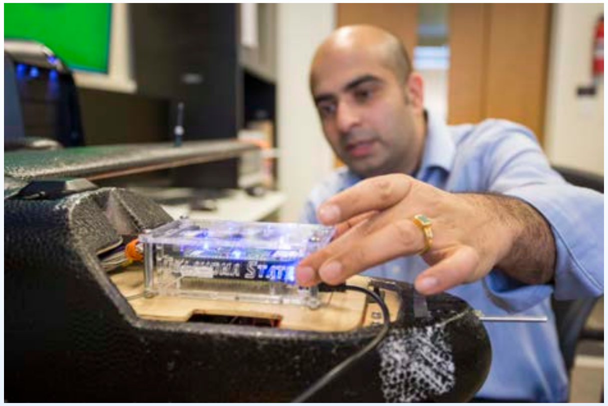


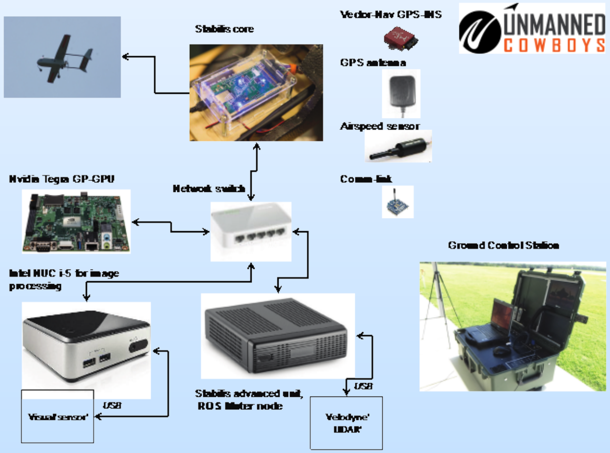


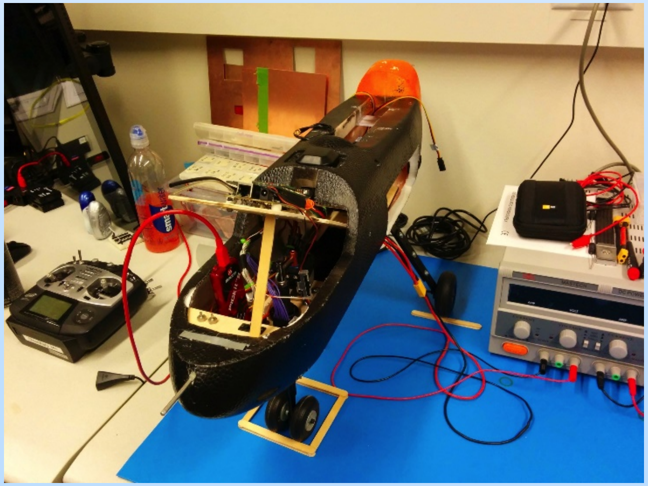
Example Flight Path

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





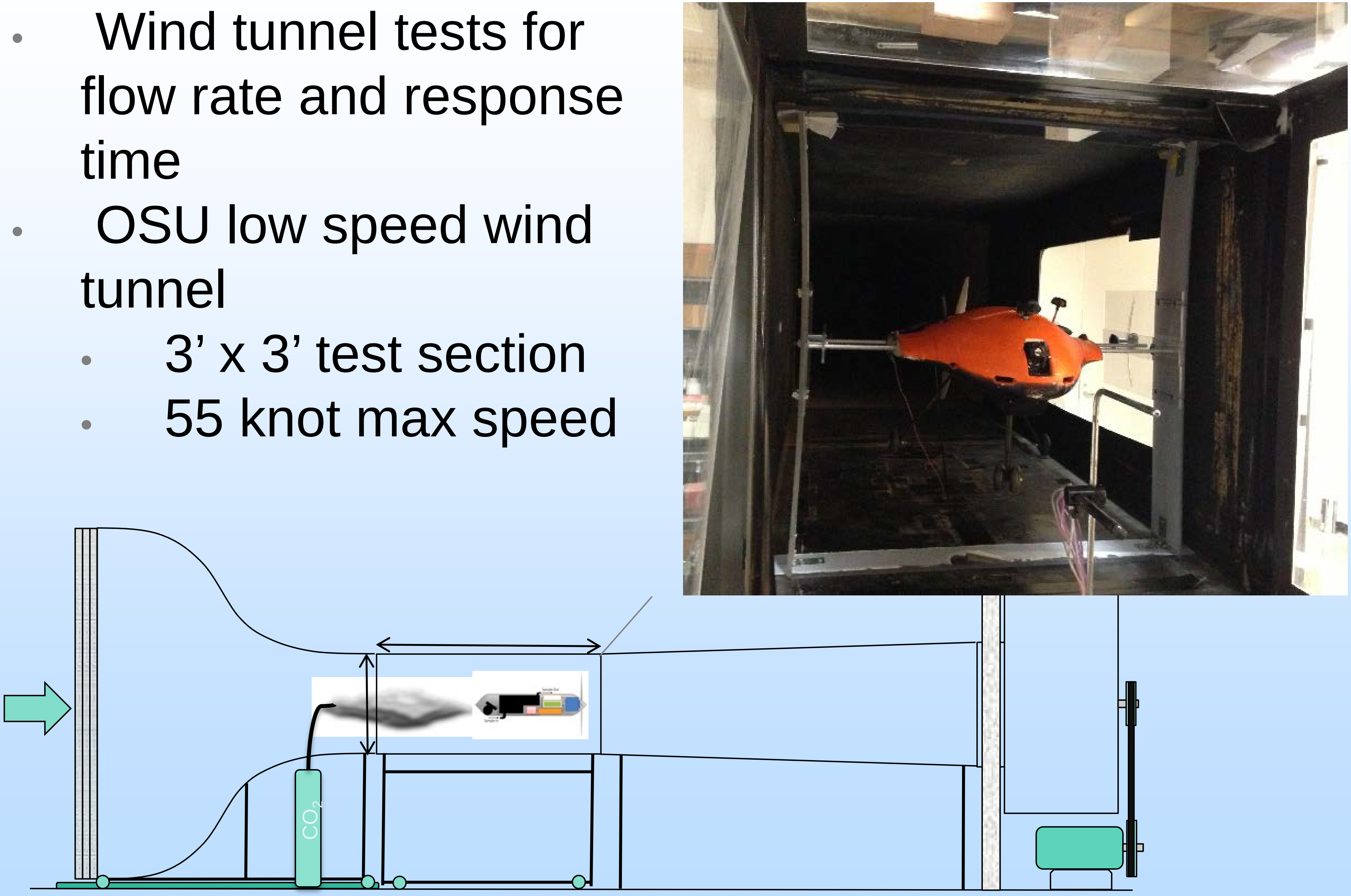


Stabilis interfaces with a Beaglebone Black

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

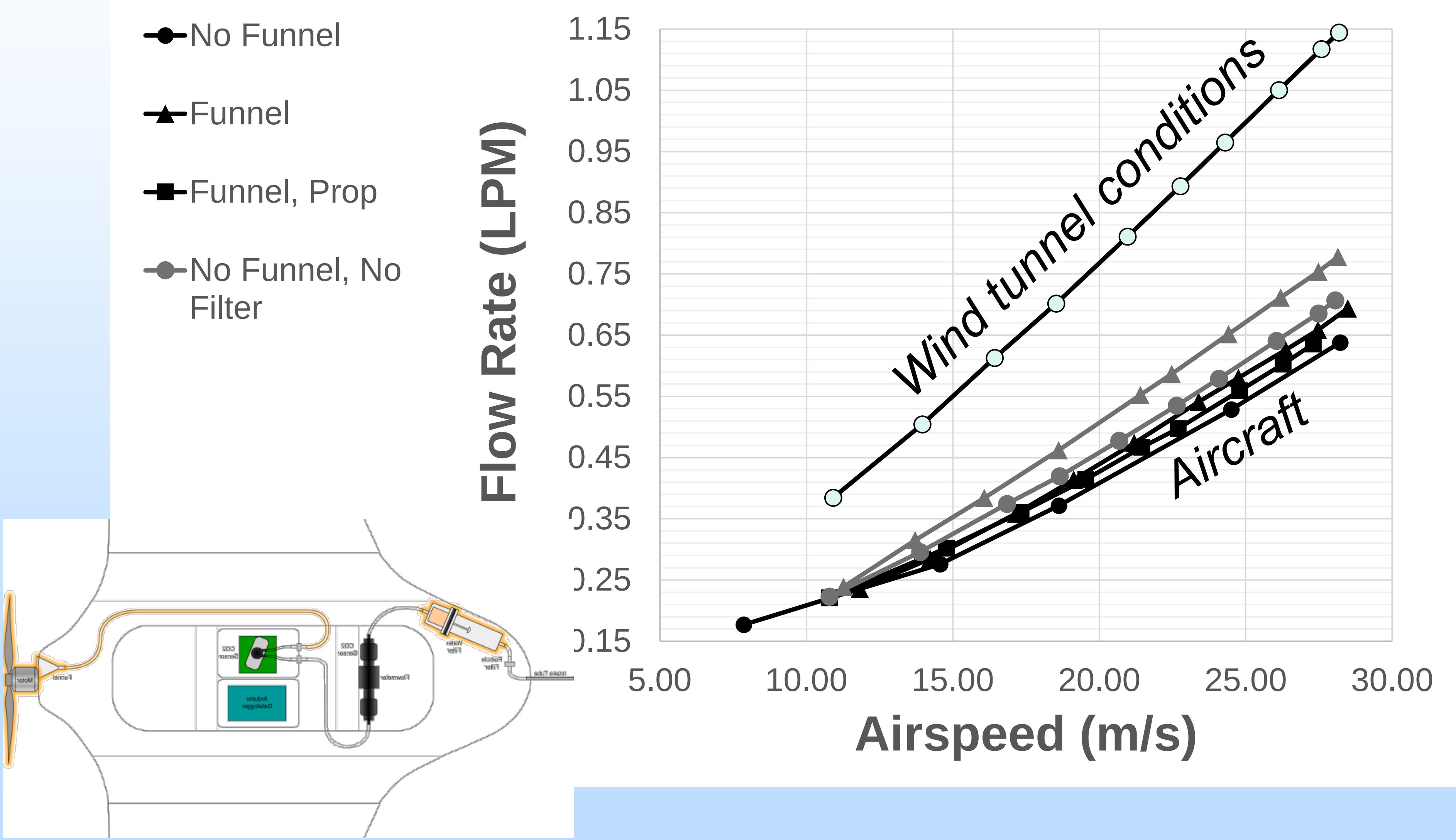
Test Results

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



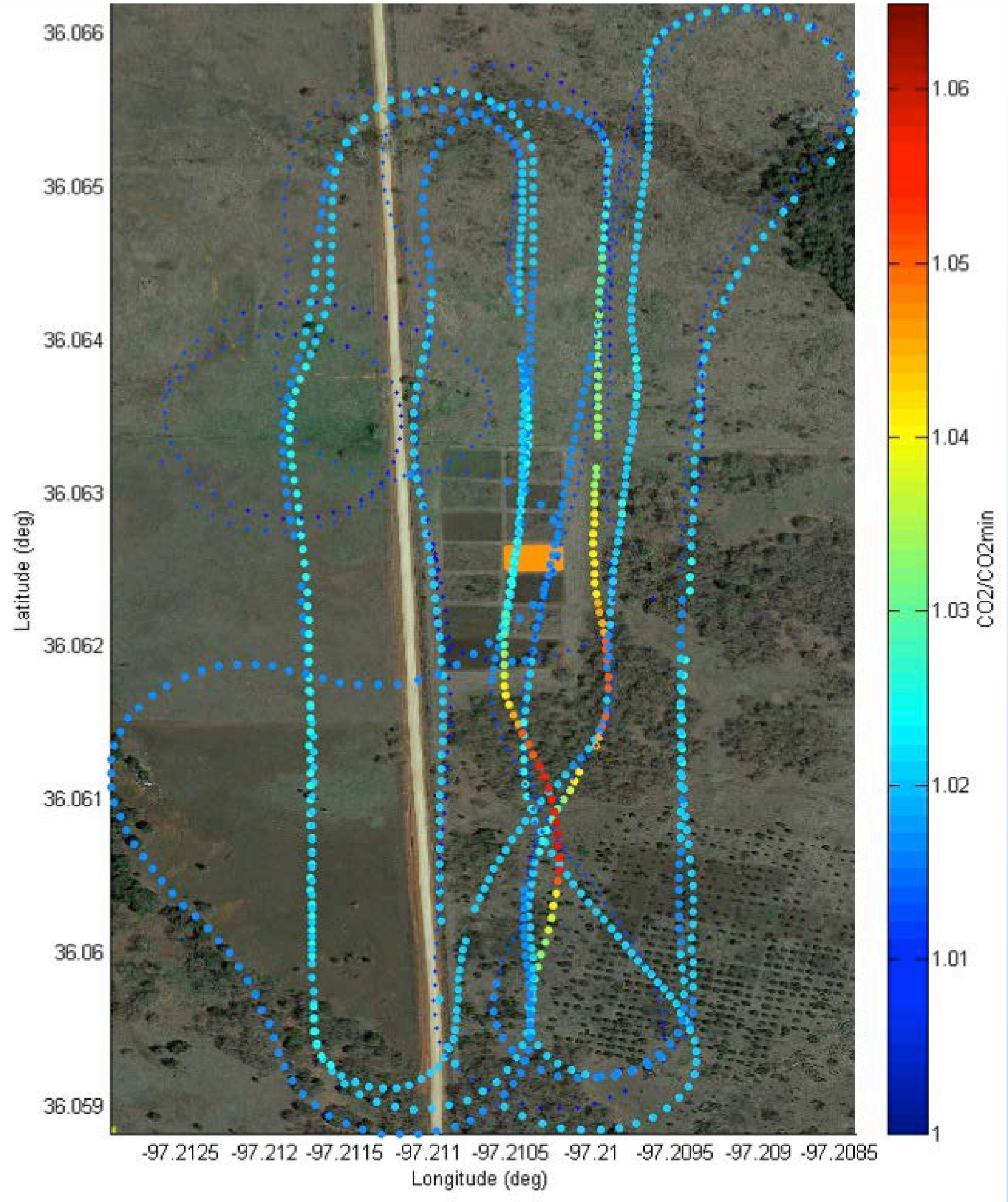
Test Results

CO_2 Sensor – Flow Rate



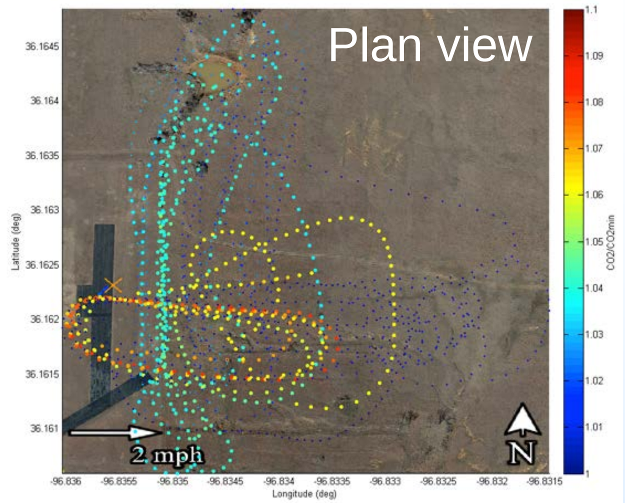
Validation Flight Tests

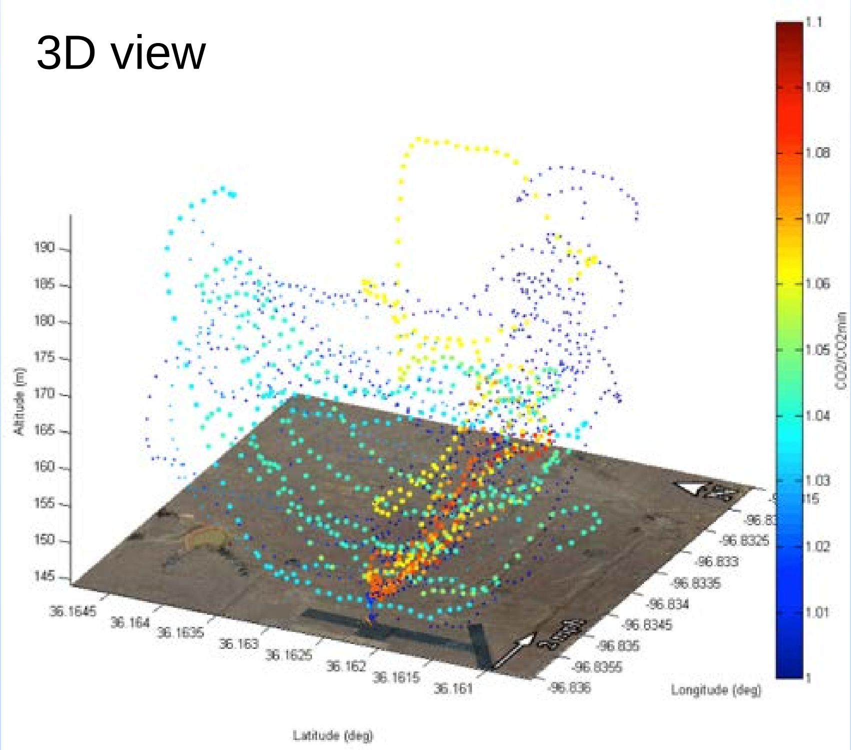
- CO$_2$ tank point sources
- 2.5 mph SSE, 5 mph gust
- Low altitude passes only
- 0.5 LPM
- 7 sec data latency

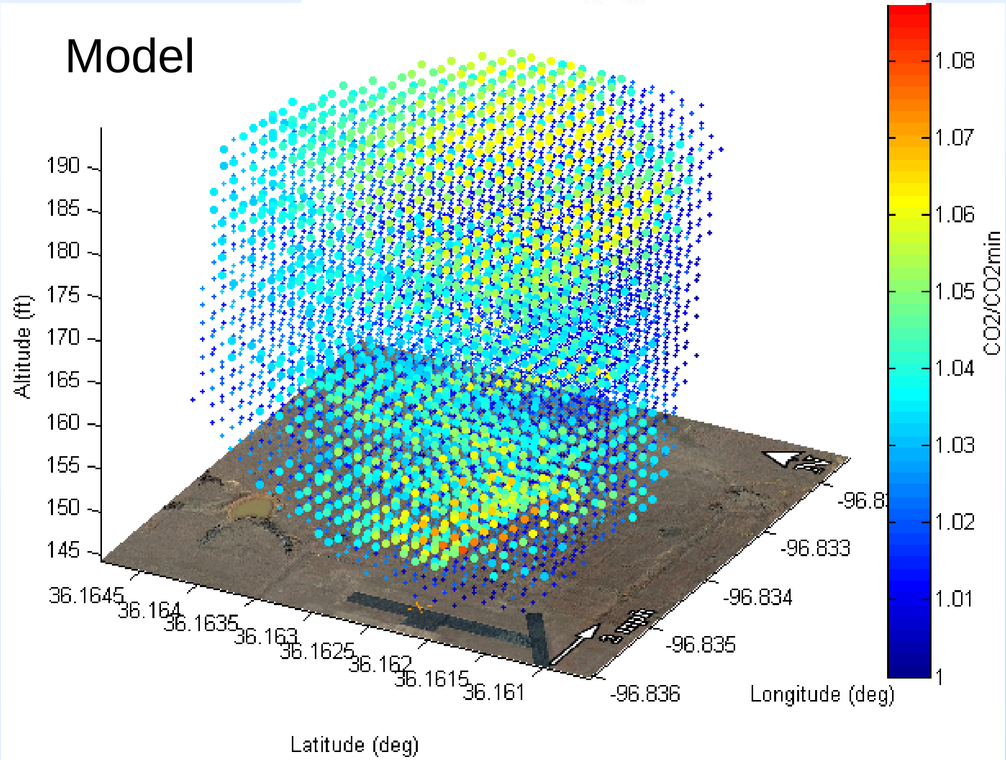


Validation Flight Tests

- ~5 lb heated CO_2 tank
- 125 g release for 30 s on upwind passes
- 3 kg for 12 min on crosswind passes
- Correlation with ground network

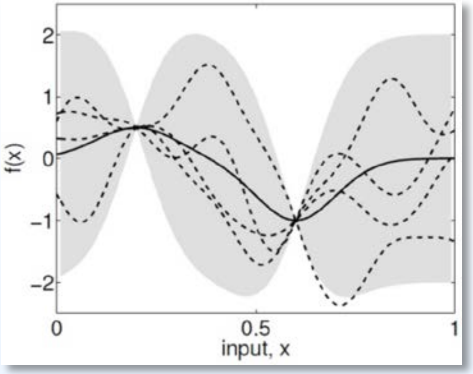




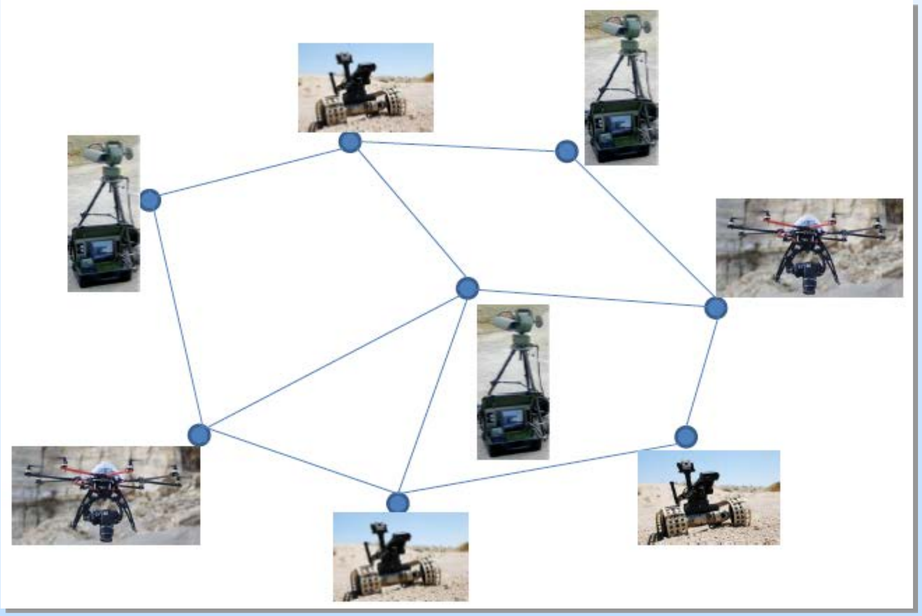


Information Fusion using GP

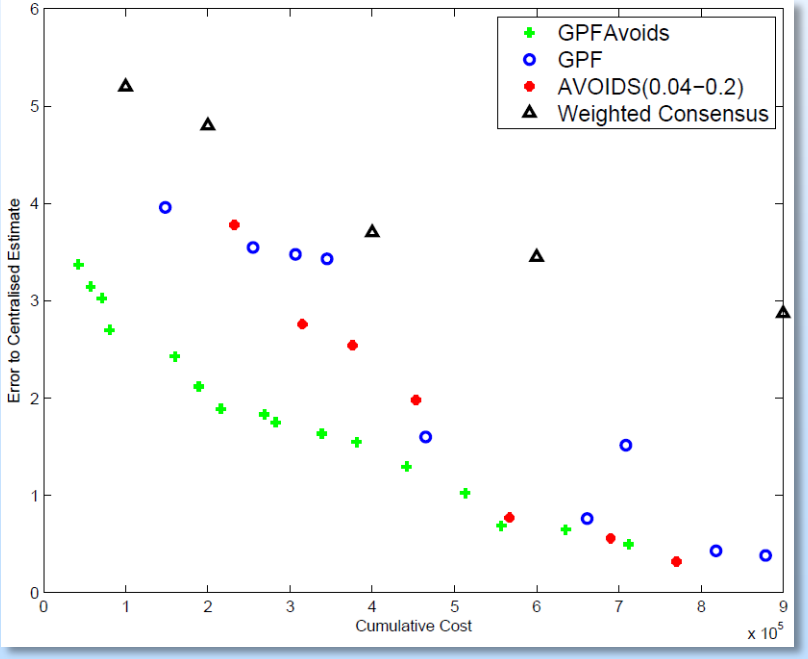
- Gaussian Process: Bayesian Nonparametric model for spatially correlated distributions
- Distributed static and dynamic heterogeneous agents learning parts of the CO_2 and CH_4 models
- Naïve data sharing can overwhelm the network, how to minimize communication for distributed inference?
- Transmit 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.
- Deployment at Farnsworth underway.

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.

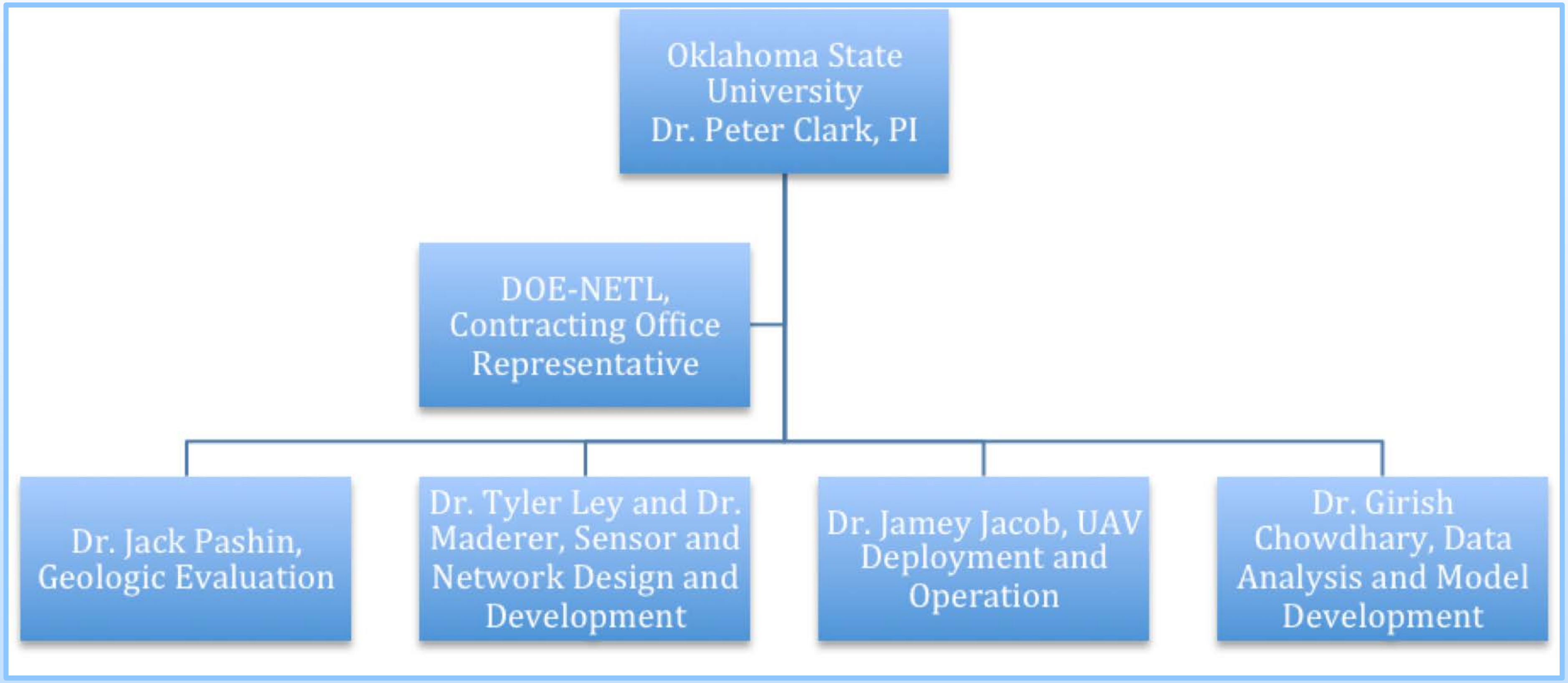
Summary

- 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, being deployed.
- Gaussian Process viable approach to data manipulation and modeling.
- Field deployment underway at Farnsworth.

Appendix

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

Organization Chart



Oklahoma State University
Dr. Peter Clark, PI

DOE-NETL, Contracting Office Representative

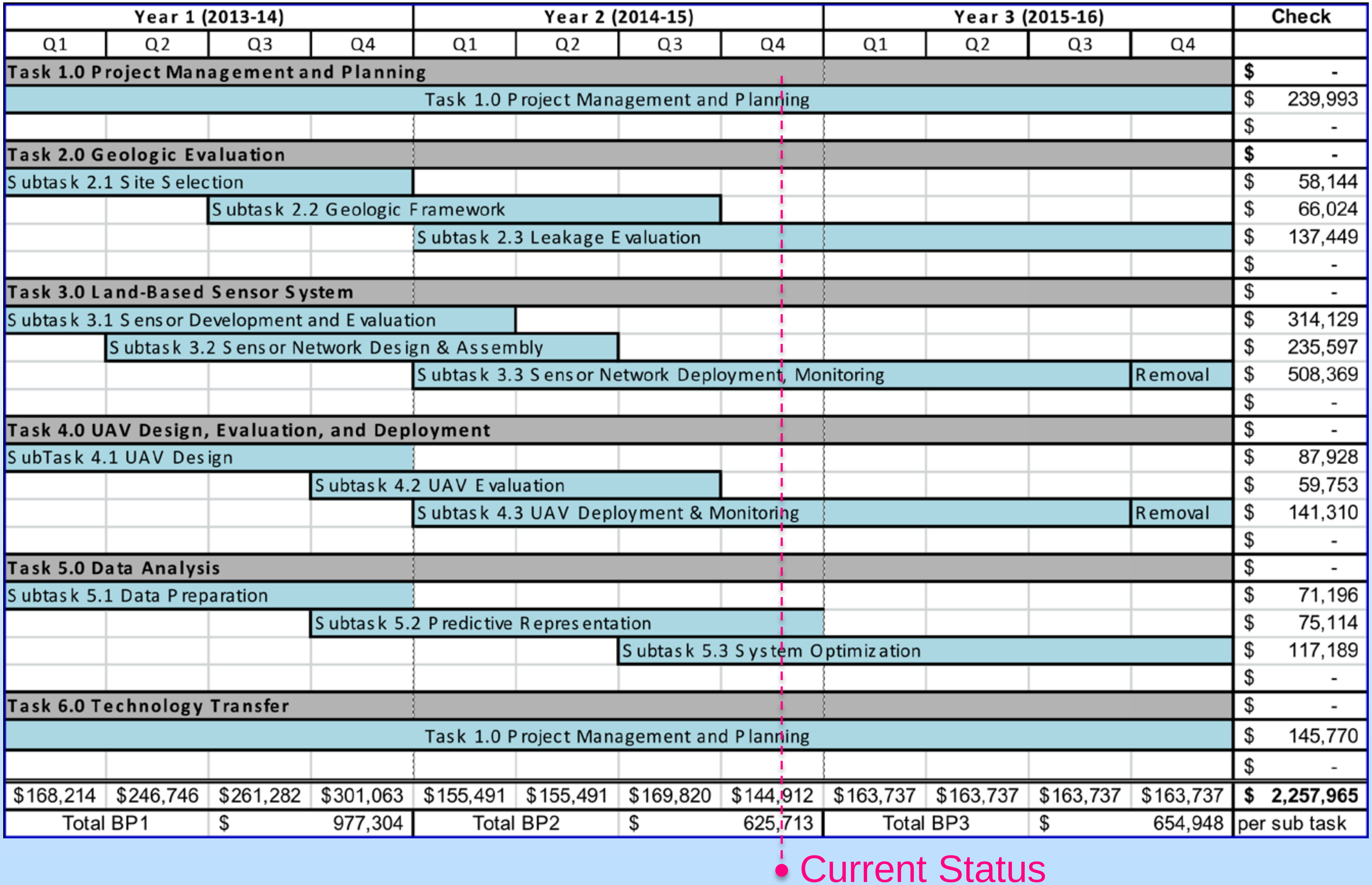
Dr. Jack Pashin, Geologic Evaluation

Dr. Tyler Ley and Dr. Maderer, Sensor and Network Design and Development

Dr. Jamey Jacob, UAV Deployment and Operation

Dr. Girish Chowdhary, Data Analysis and Model Development

Gantt Chart



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Current Status

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