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
Developing the Technologies and
Infrastructure for CCS

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Presentation Outline

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

- Dr. Peter Clark – Principal Investigator
- Dr. Jack Pashin – Geological Characterization
- Drs. Tyler Ley, Nick Materer – Sensor and Network Design and Development
- Dr. Jamey Jacob – UAV Deployment and Operation
- Dr. Girish Chowdhary – Data Analysis, UAV Autonomy, and Model Development

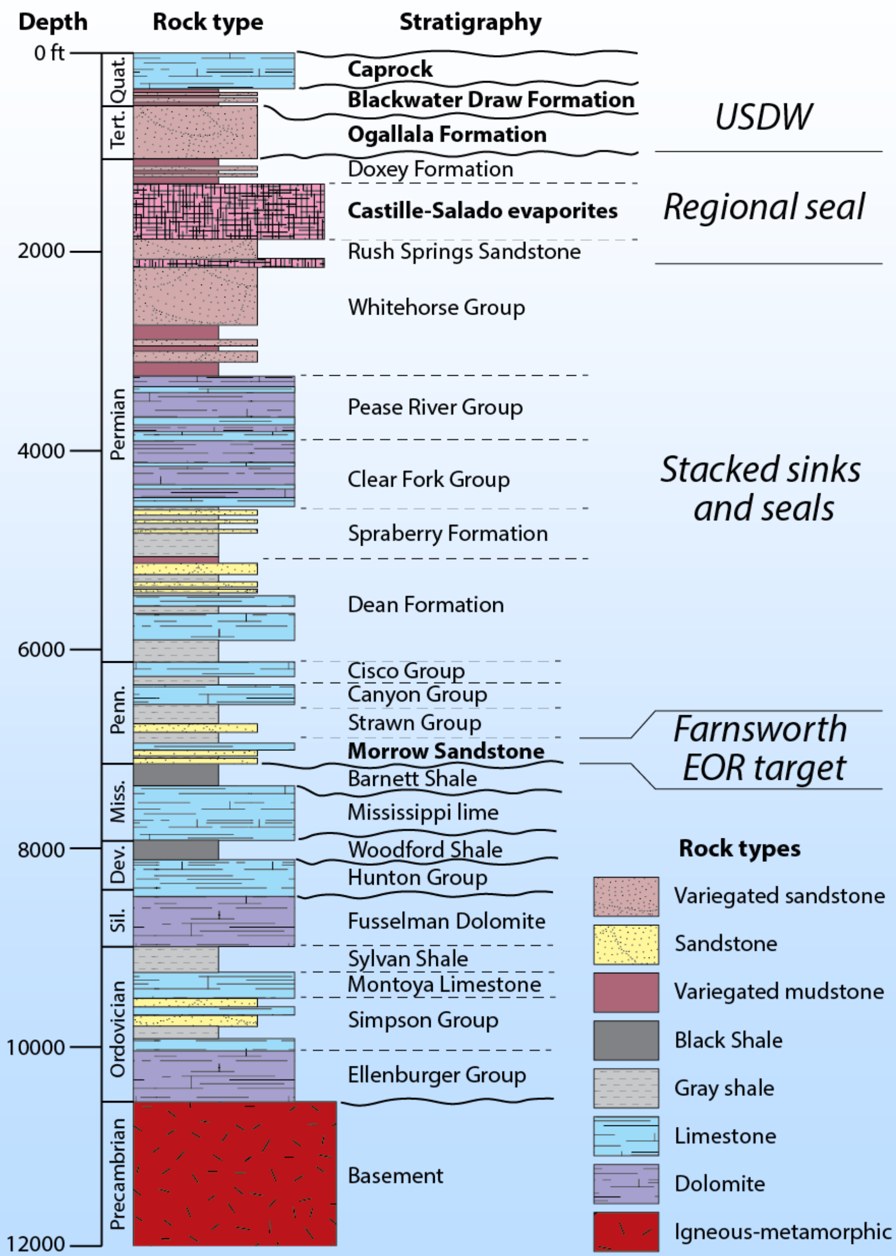
Technical Status

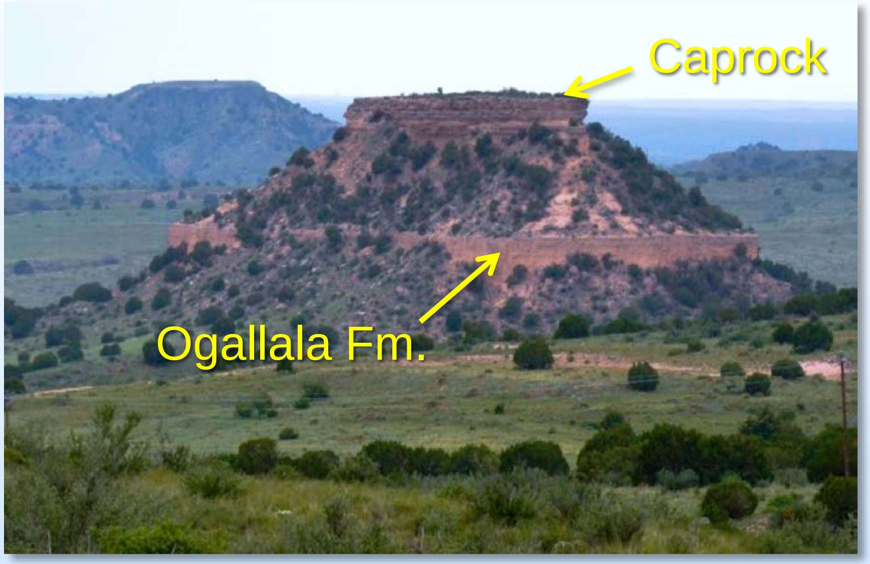
- Geological characterization and assessment of leakage risks.
- Sensor evaluation and deployment using surface and airborne platforms.
- UAV evaluation and testing; and deployment at Farnsworth Oil Unit.
- Application of advanced data analysis techniques.
- Technology Transfer, Best Practices Manual.

Farnsworth Oil Unit

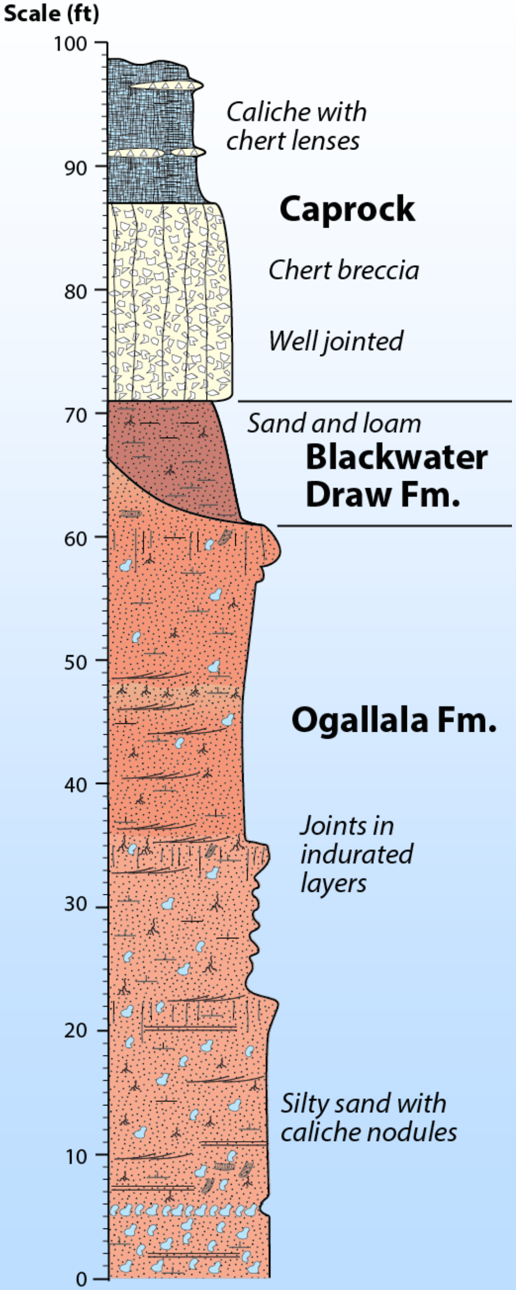
Operator: Chaparral Energy
Reservoir: Morrow Sandstone (Penn.)
Oil Production: >100 MMbbl
CO_2-EOR operations since 2010
SWP Phase III CCUS project underway

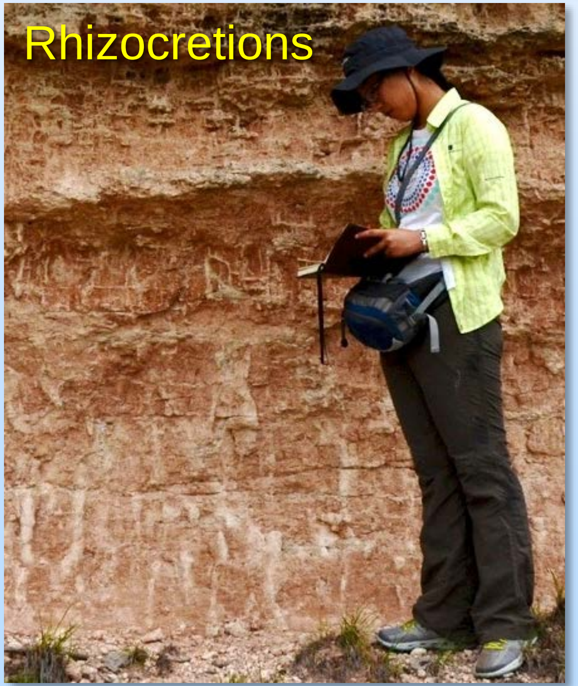
Stratigraphic Column



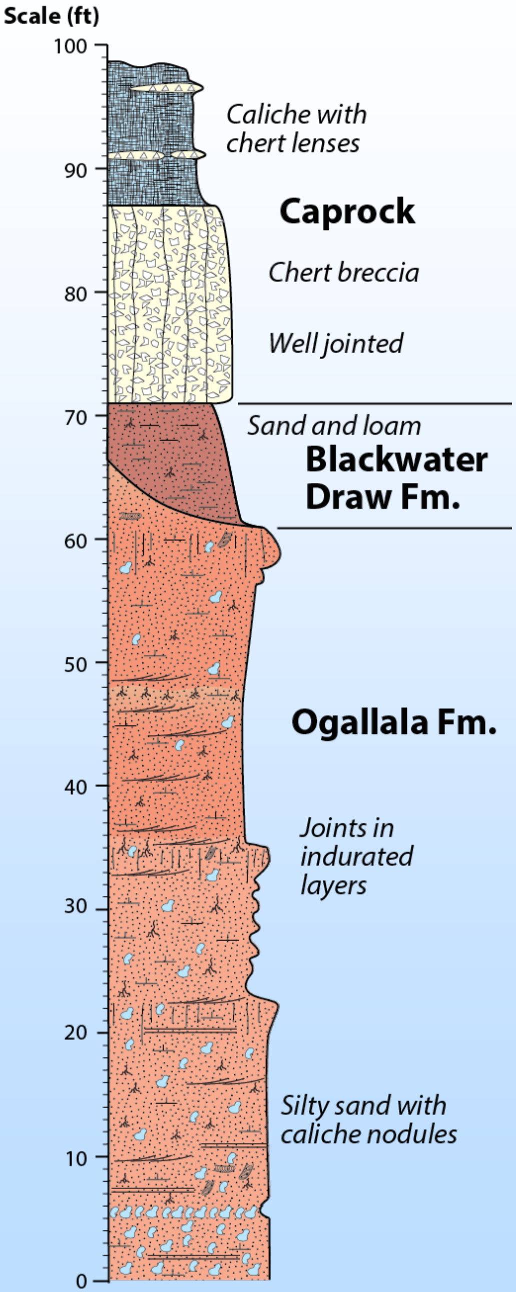


Surface Formations





Joint Networks

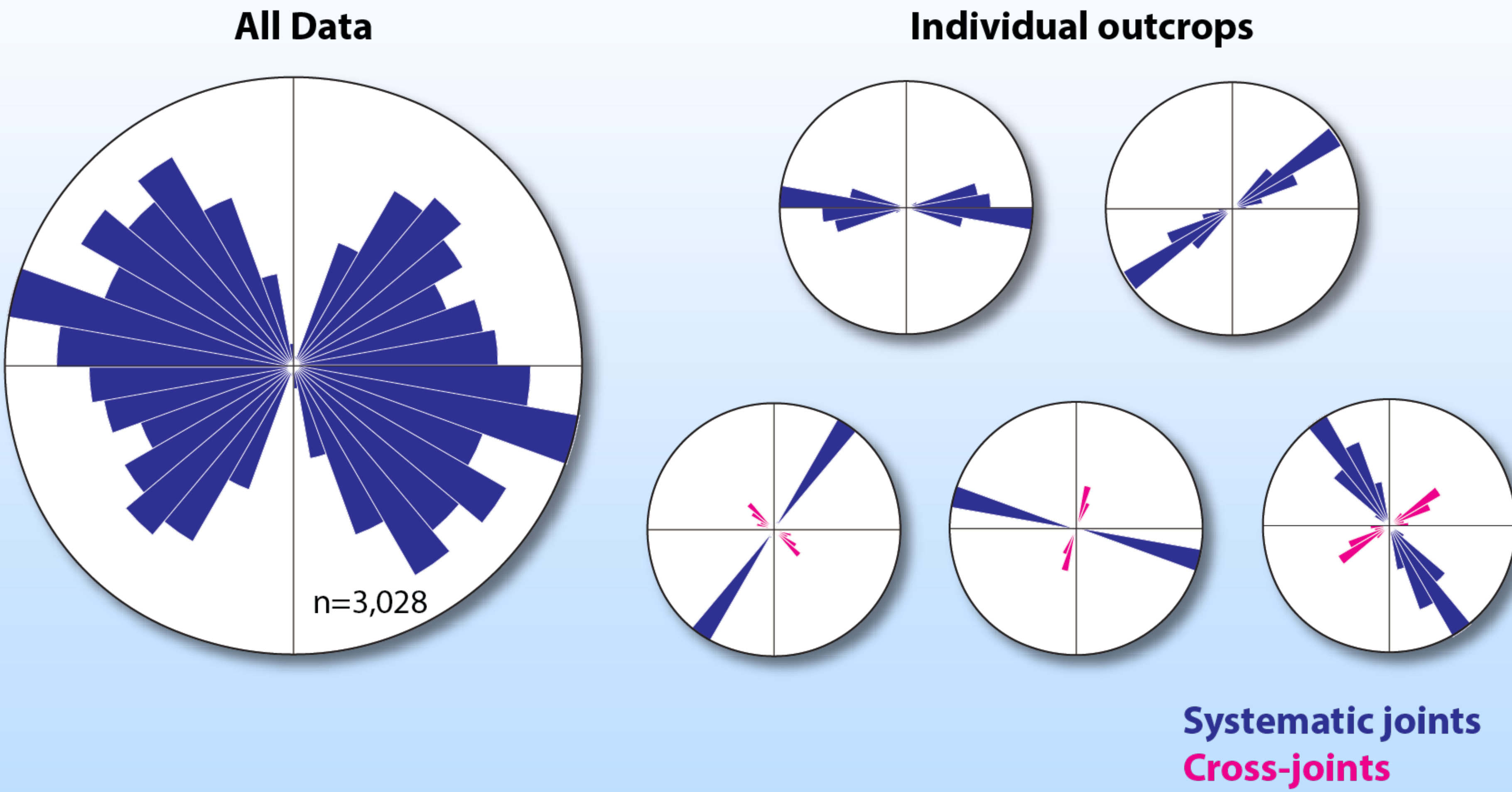


Joint Networks

Satellite image
Siliceous caprock

Outcrop photo
Ogallala sandstone

Joint Orientation



Sensor Development Goals

Provide a cost effective distributed sensor network to monitor CO_2 and CH_4 emissions at the field site.

① Find economical sensing elements with good precision and accuracy.

② Find technology for surface and airborne deployment.

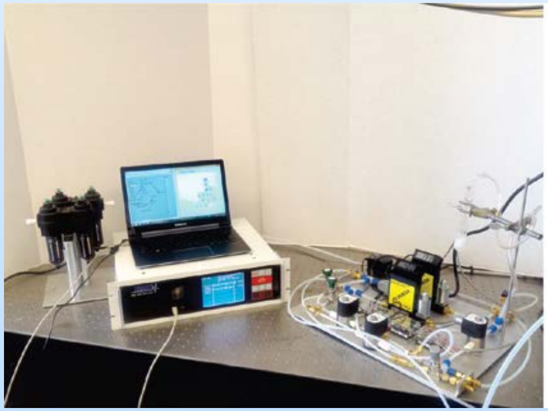
③ Establish wireless network (Zigbee tech).

④ Provide an adequate power supply (solar or battery).

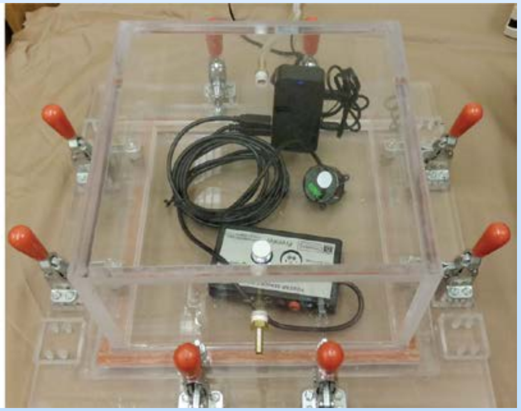
Sensing Element Selection

High accuracy testing apparatus source.

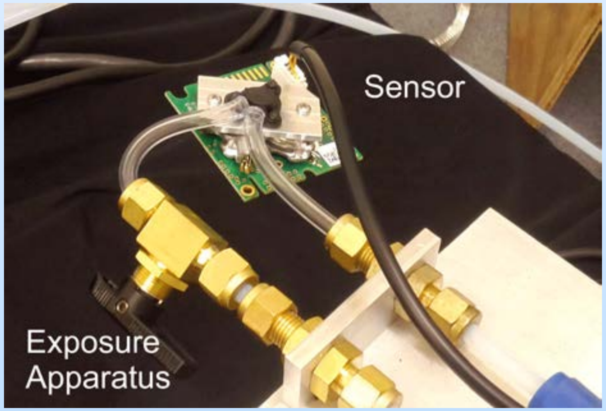
- Flow meters for mixing gases.
- Wind tunnel testing.
- Commercial NIST Traceable Dual Gas Sensor Unit.



Standard



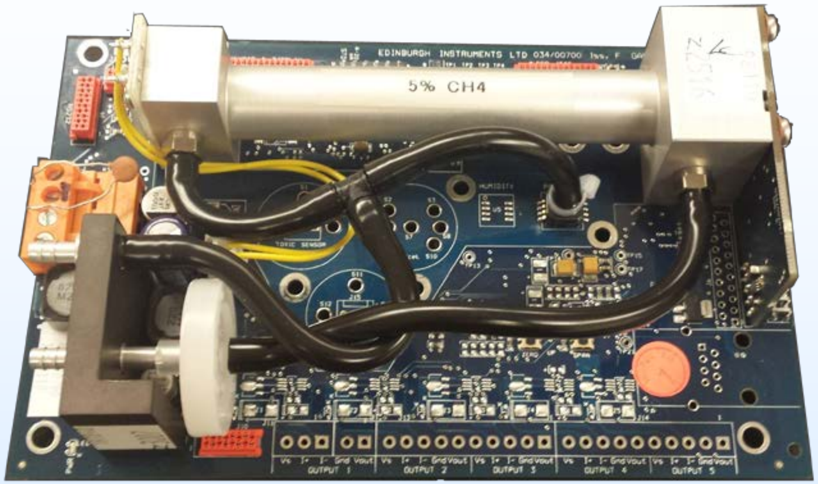
Environmental Testing

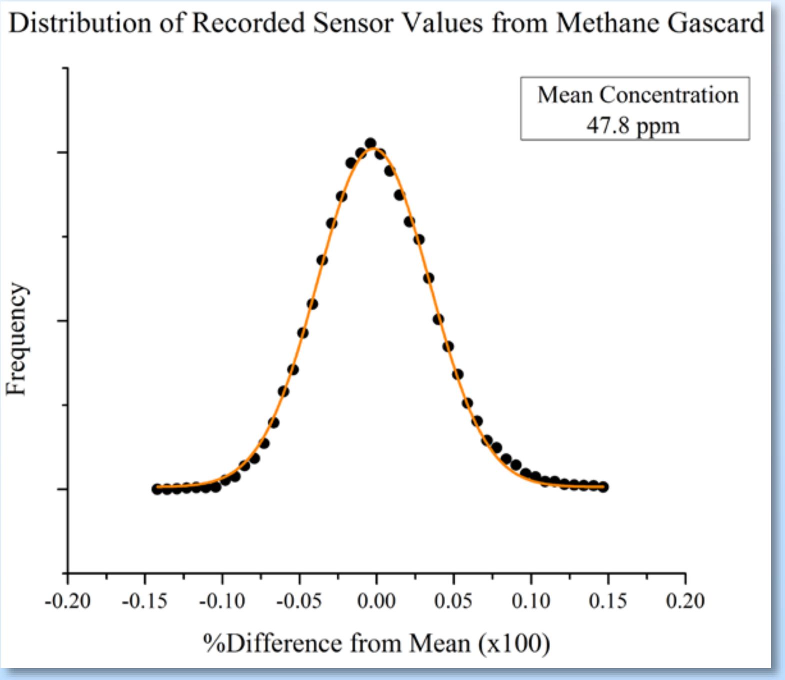


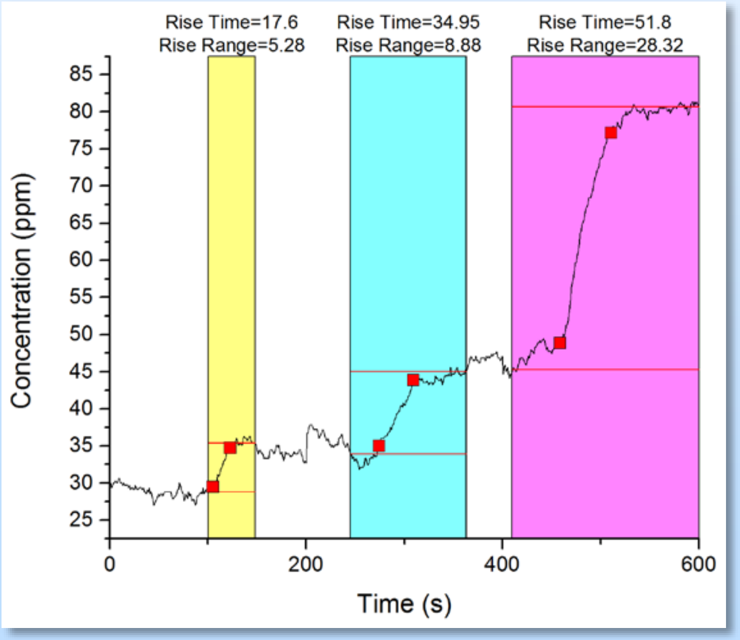
Flow Testing

Edinburgh GasCard Sensor

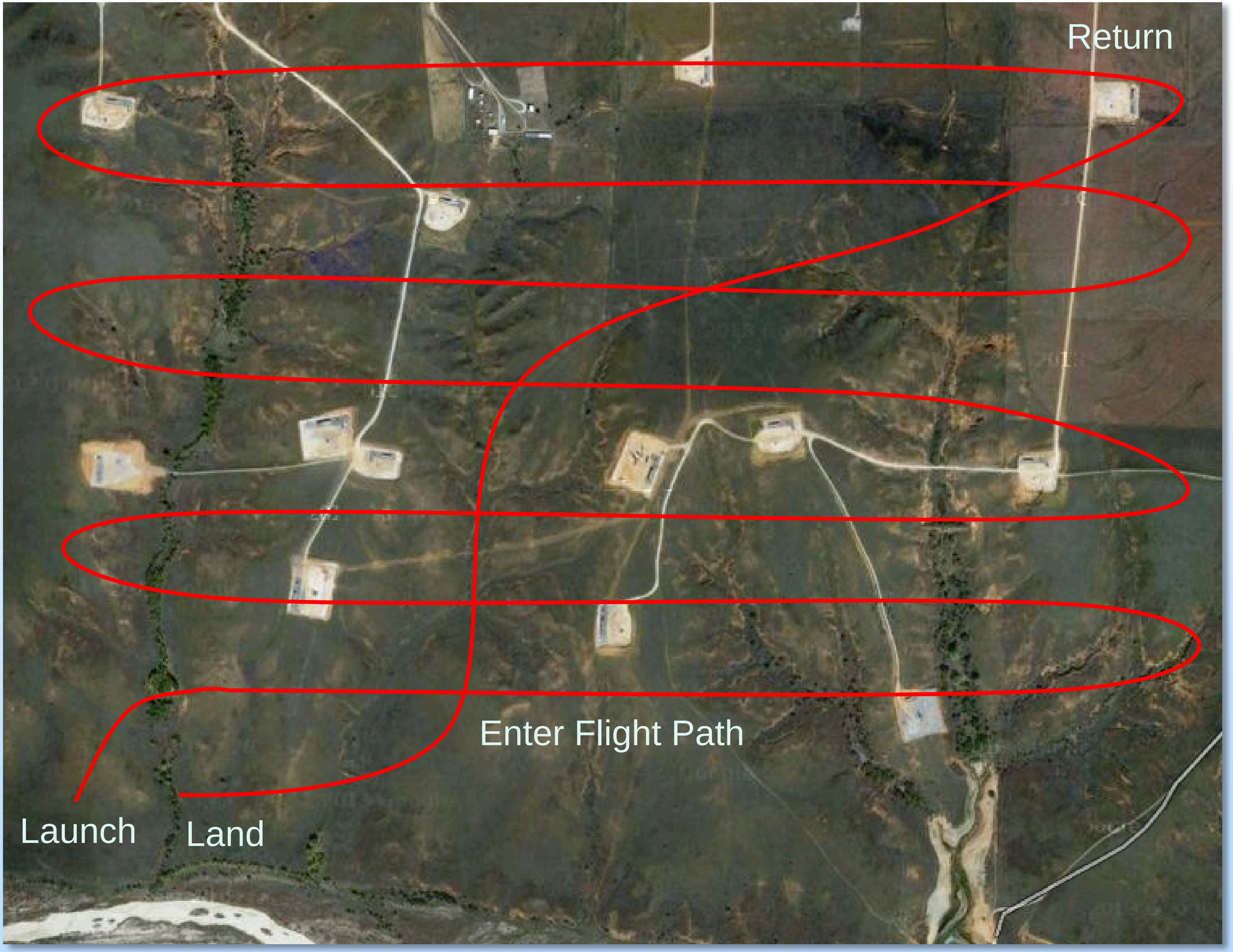
Preformed very well for both Carbon Dioxide and Methane







Field testing



Flight Testing and FAA COAs

- Primary flight testing will take place at OSU UAFS; additional flight testing capability at Ft. Sill in restricted airspace if needed.
- FAA COAs (Certificate of Authorization) are pending at OSU Unmanned Aircraft Flight Station.
- Once vehicle configuration is finalized, COA will be applied for at Texas site – approximate 2-3 month timeline from application to approval.
- Data from Mesonet sites will be used to provide meteorological conditions.

Platform Options

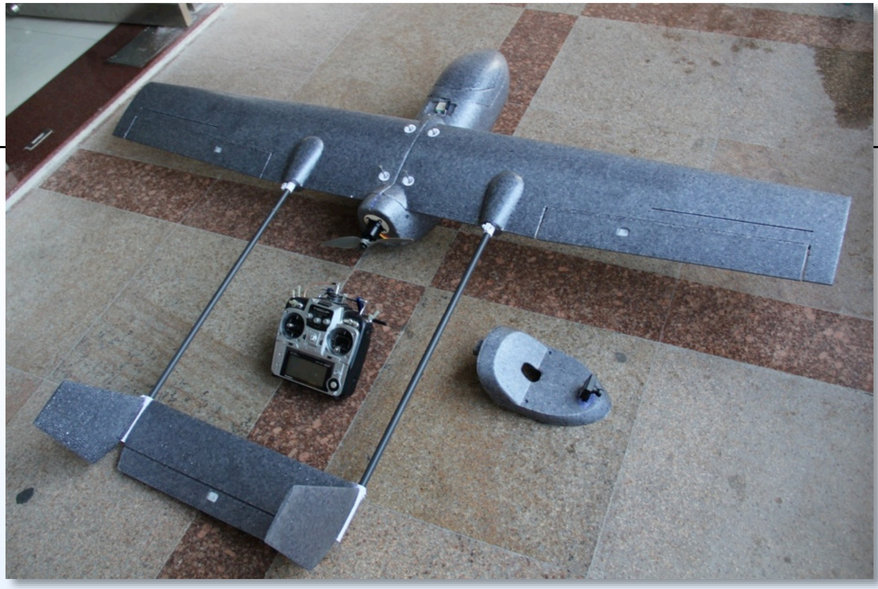
•2000+ flight hours using both COTS and over 50 custom vehicle designs ranging from NAV to small SUAS; gas, electric and fuel cell

Firebird

Considerations

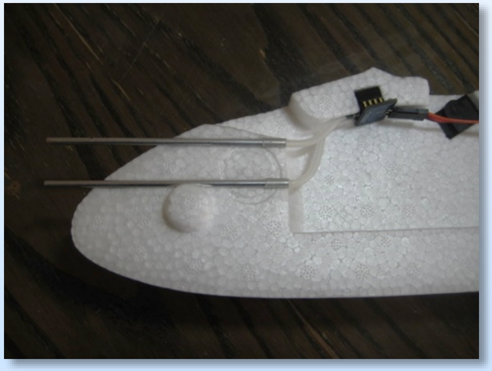
- •Payload capability
- •Endurance and range
- •Launch & recovery logistics
- •Stall/cruise speed
- •Orbit radius
- •Probe placement

Initial Test Bed



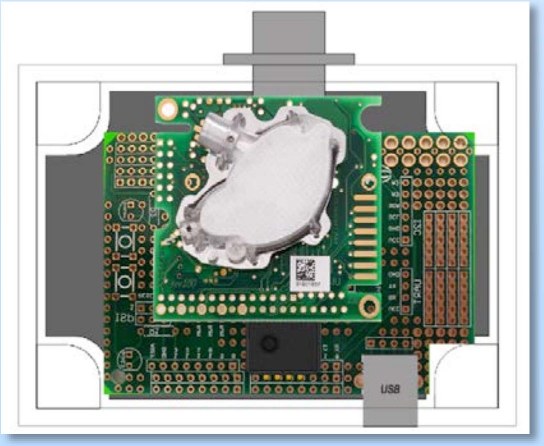
UAV

- Lightweight (2 lb empty, 6 lb full)
- Hand launched, belly land
- Reliable – no crashes over a 30+ flights
  - Frangible: won't cause damage even in event of a mishap
- Outfitted with CO_2 sensor system in addition to optional atmospheric sensors and cameras.



CO_2 Sensor Systems

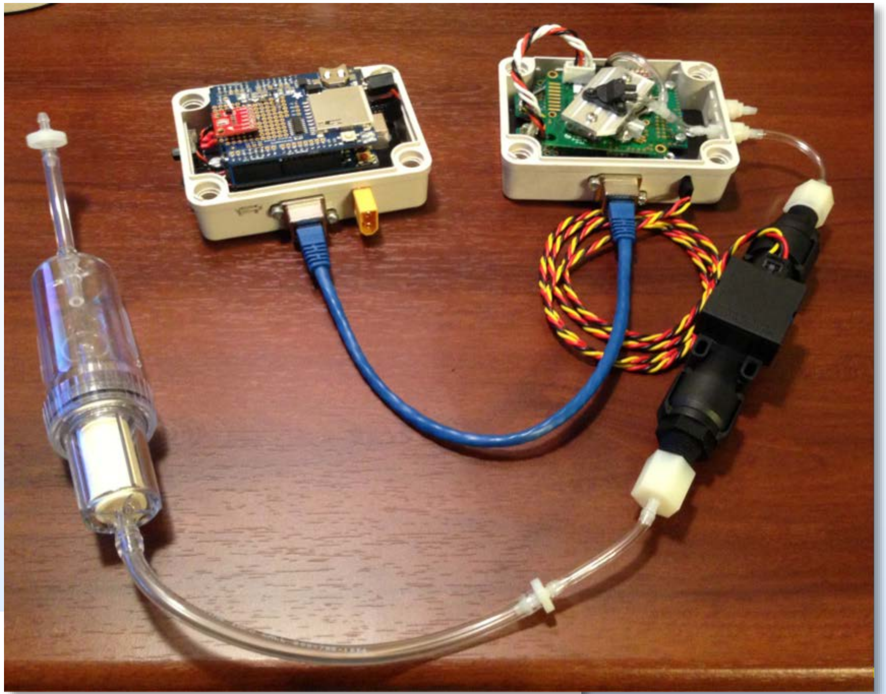
- Based on Sensair K-30FR (fast response)
  - 0-5000 ppm range, accuracy ±30 ppm ±3% of reading
  - 1-2 sec response time, 2Hz sampling rate
- Intake tube in nose brings air into filter and then sensor
- Datalogger records CO_2 data, corresponding altitude and GPS location
- Low cost (~$400 for entire data collection system)

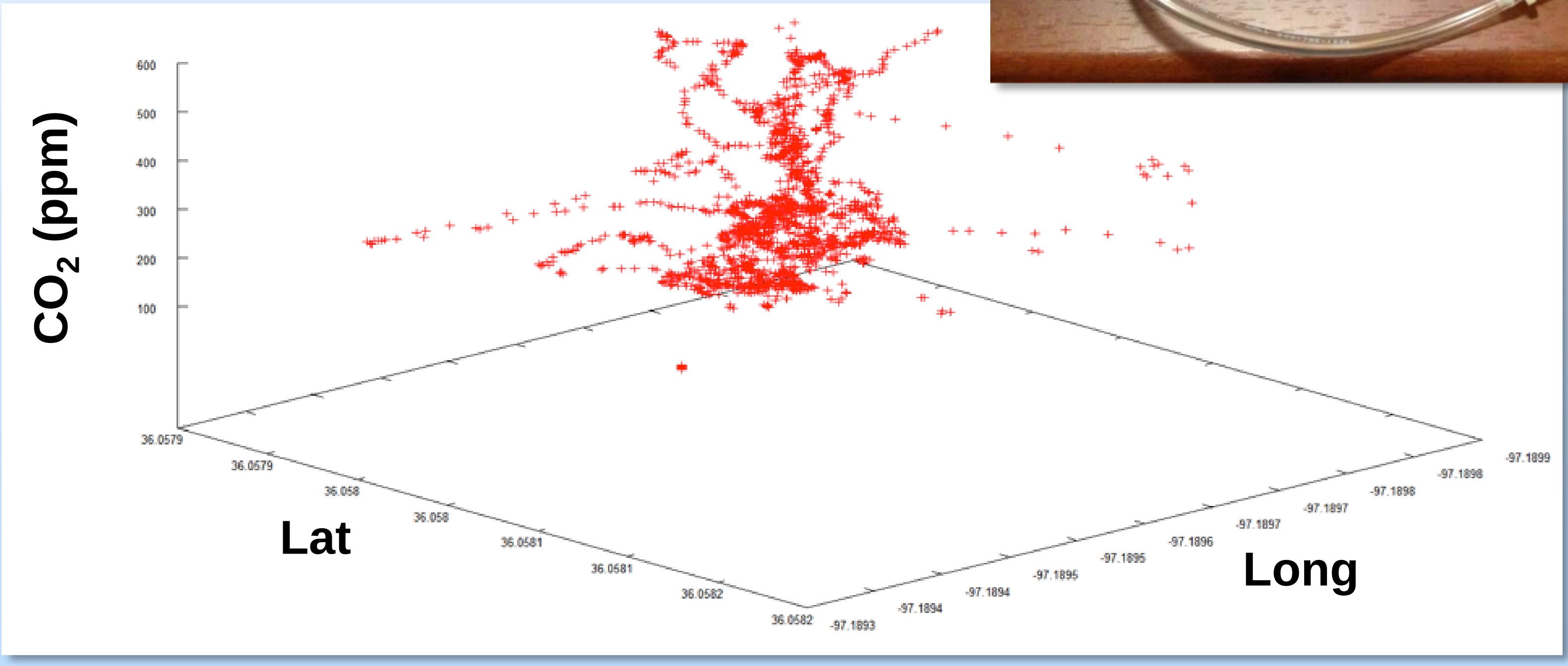


Ground Tests

CO_2 Sensor System Tests

- Sensair K-30FR tested in various ground conditions
- Ground tested during controlled fire burn via car to demonstrate operability in field
- Currently undergoing calibration

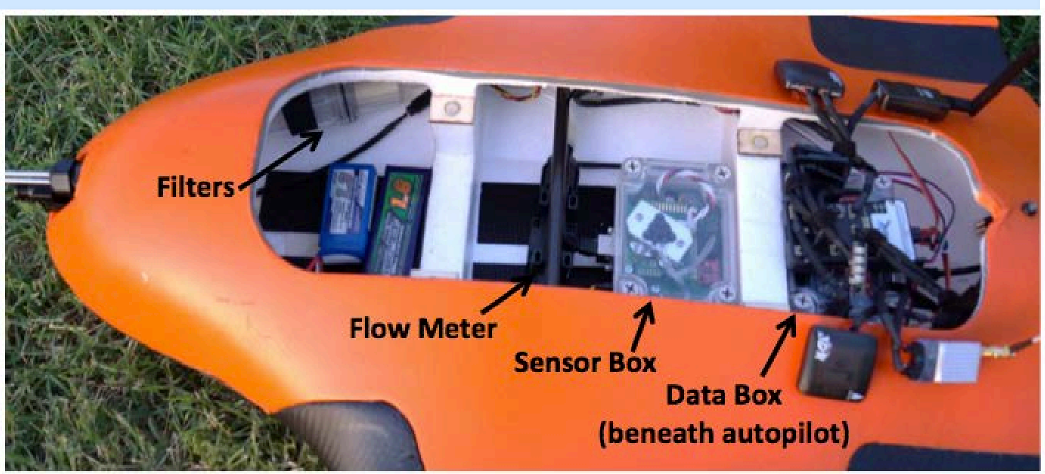


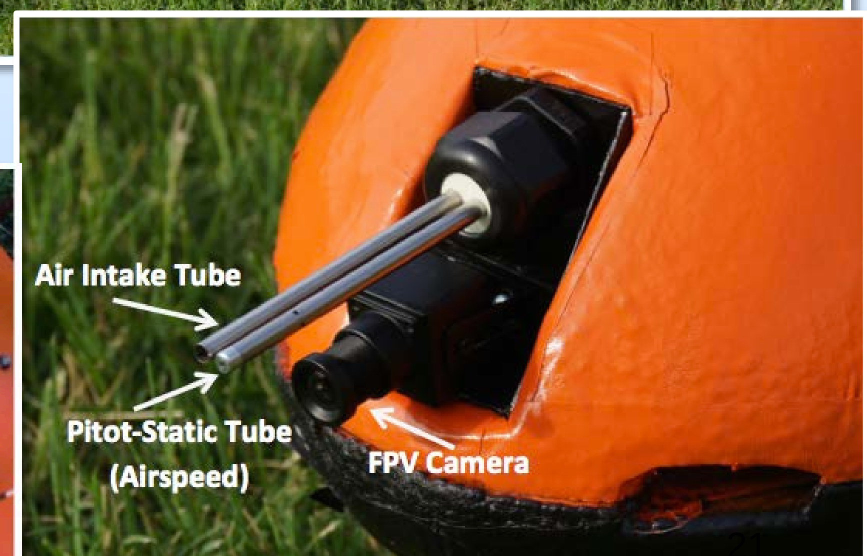


Final platform

Skywalker X8

- 7 ft span, 8 lb. GTOW, 45 kt cruise speed
- Sensair K-30FR CO_2 Sensor integrated into platform
- Currently undergoing calibration
- FAA Certificate of Authorization for vehicle pending

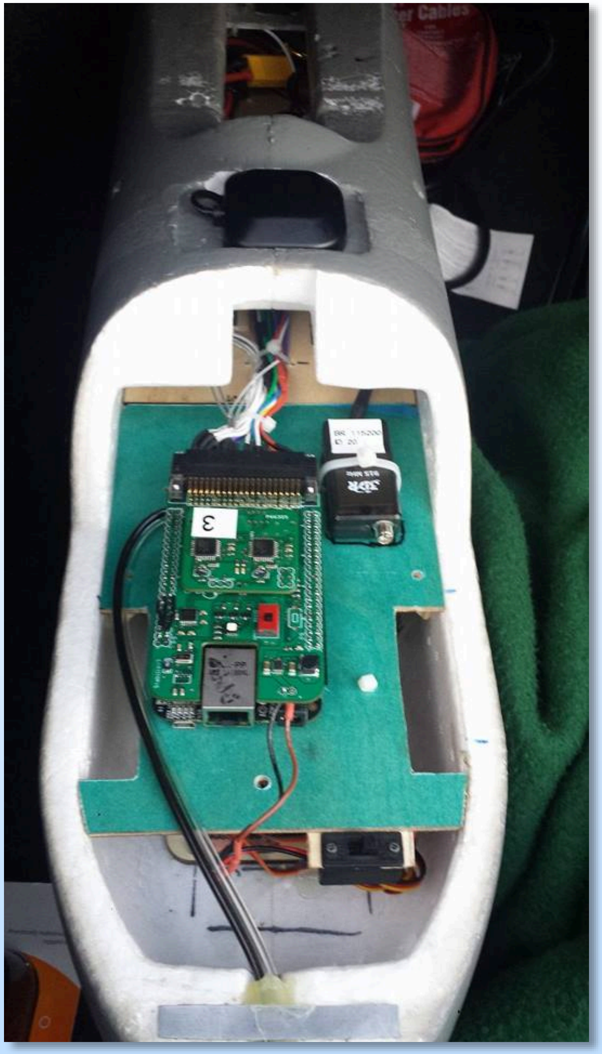




Stabilis Autopilot

- Mission flexibility and accuracy
  - Waypoint-driven flight planning
  - VN200 inertial navigation solution
    - http://www.vectornav.com/products/vn200-rug
- Modular sensor and power integration
  - Parallel embedded Linux modules
- “Plug and play” autopilot
  - Minimizes tuning and maximizes stability
  - Stability augmentation of manual flight

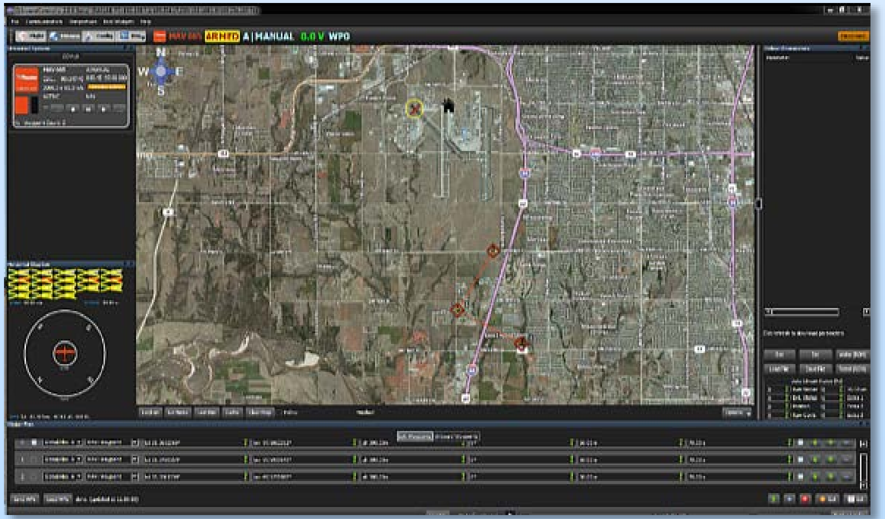
Stabilis interfaces with a Beaglebone Black



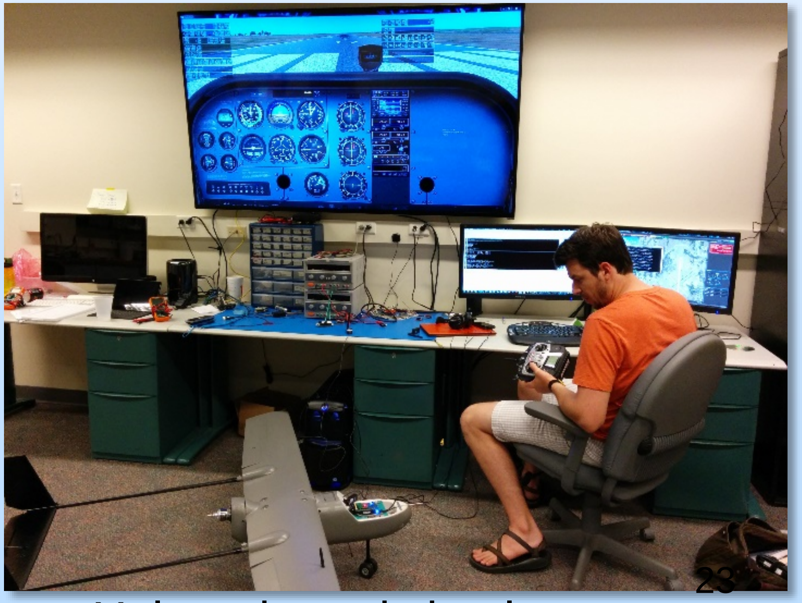
http://beagleboard.org/Products/BeagleBone%20Black

Hardware in the Loop Simulations

- X-Plane based simulation
  - Realistic flight dynamic models and sensor emulation
  - Database of locations and weather effects
  - Servo and control signal visualization
- QGground Control
  - GPS-based waypoints
  - Can interface with a variety of mission planners



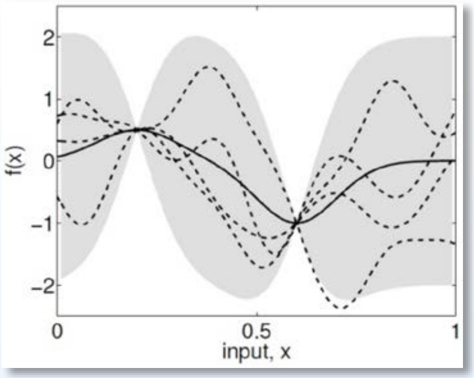
Q Ground Control



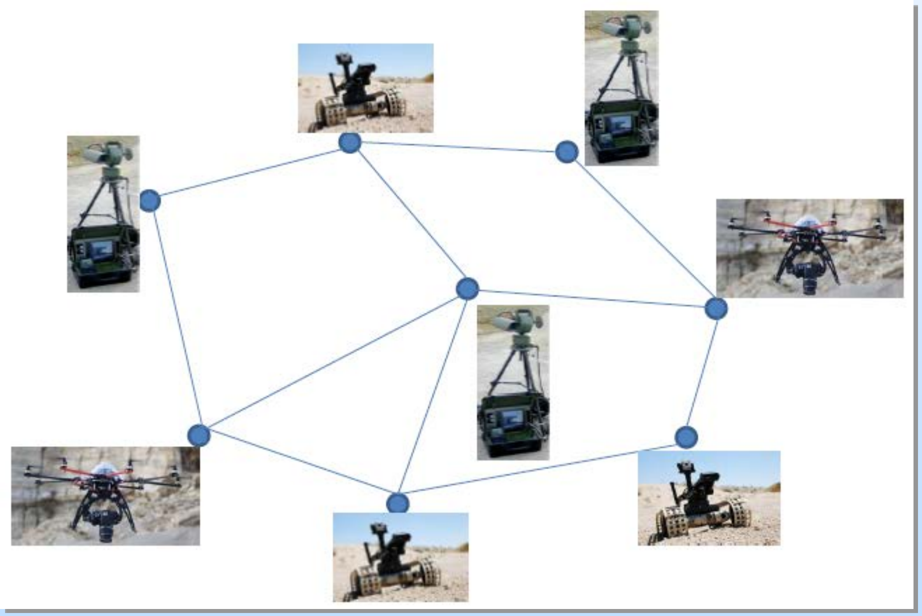
Xplane-based simulator

Information Fusion using GP

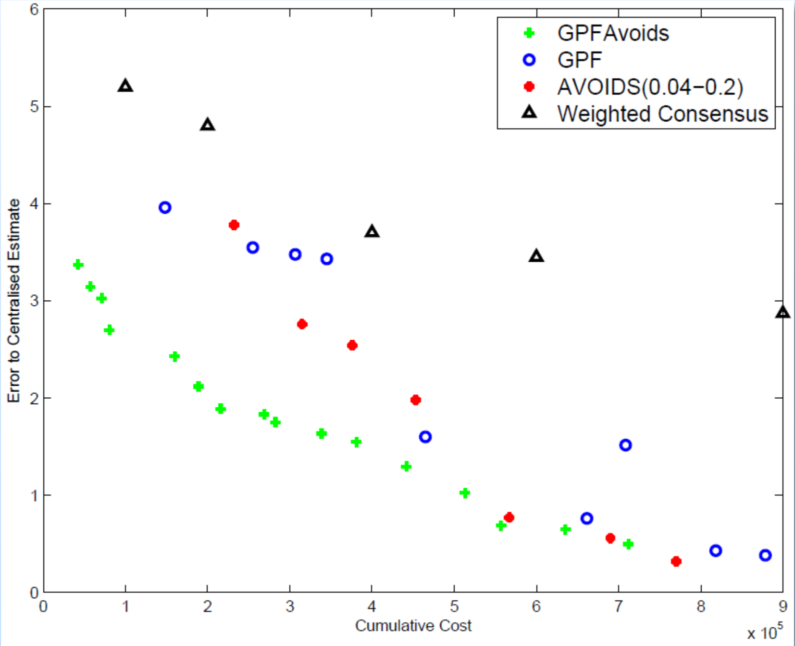
- Gaussian Process: Bayesian Nonparametric model for spatially correlated distributions
- Distributed static and dynamic heterogeneous agents learning parts of the CO_2 and CH_4 models
- Naïve data sharing can overwhelm the network, how to minimize communication for distributed inference?
- Transmit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



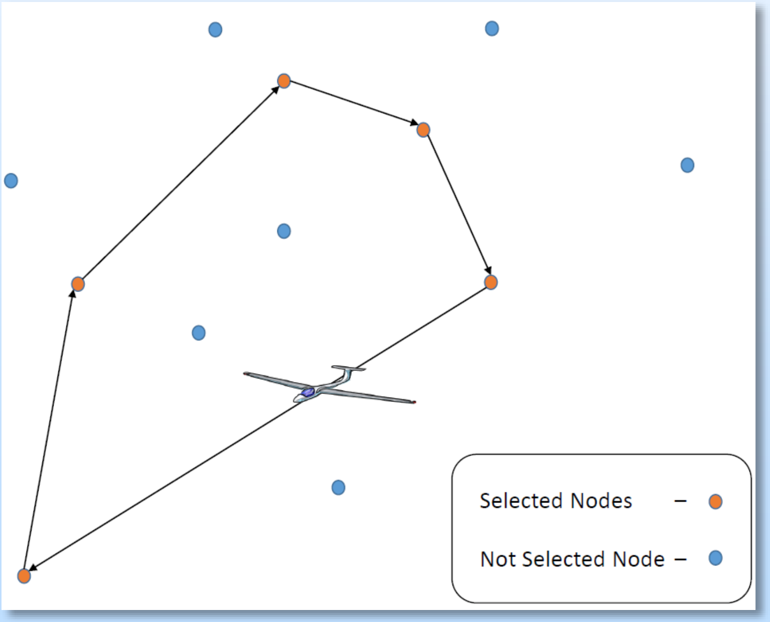
Distributed network topology with static and dynamic agents



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

Data Harvesting through UAV based Data-Ferrying

- Data-ferrying UAV has limited endurance
- Every node collects data at different rate and with different *value of information*
- How to select the most *informative* subset of nodes to visit?
- Learns to anticipate and exploit nonstationary entropy model using Sigmoidal Gaussian Cox Processes as in [4]



Our algorithm improves optimality of UAV allocation

Poisson arrival rate parameters are accurately estimated

Accomplishments to Date

- Field site at Farnsworth Oil Unit selected; access agreement in late-stage review.
- Basic geologic framework characterized; Surface and near-surface fracture networks being analyzed.
- Robust and cost-effective near-surface and airborne sensors identified.
- UAV platform selected, being field-tested.
- Data management and processing techniques evaluated; successful testing on NATCARB and synthetic datasets.

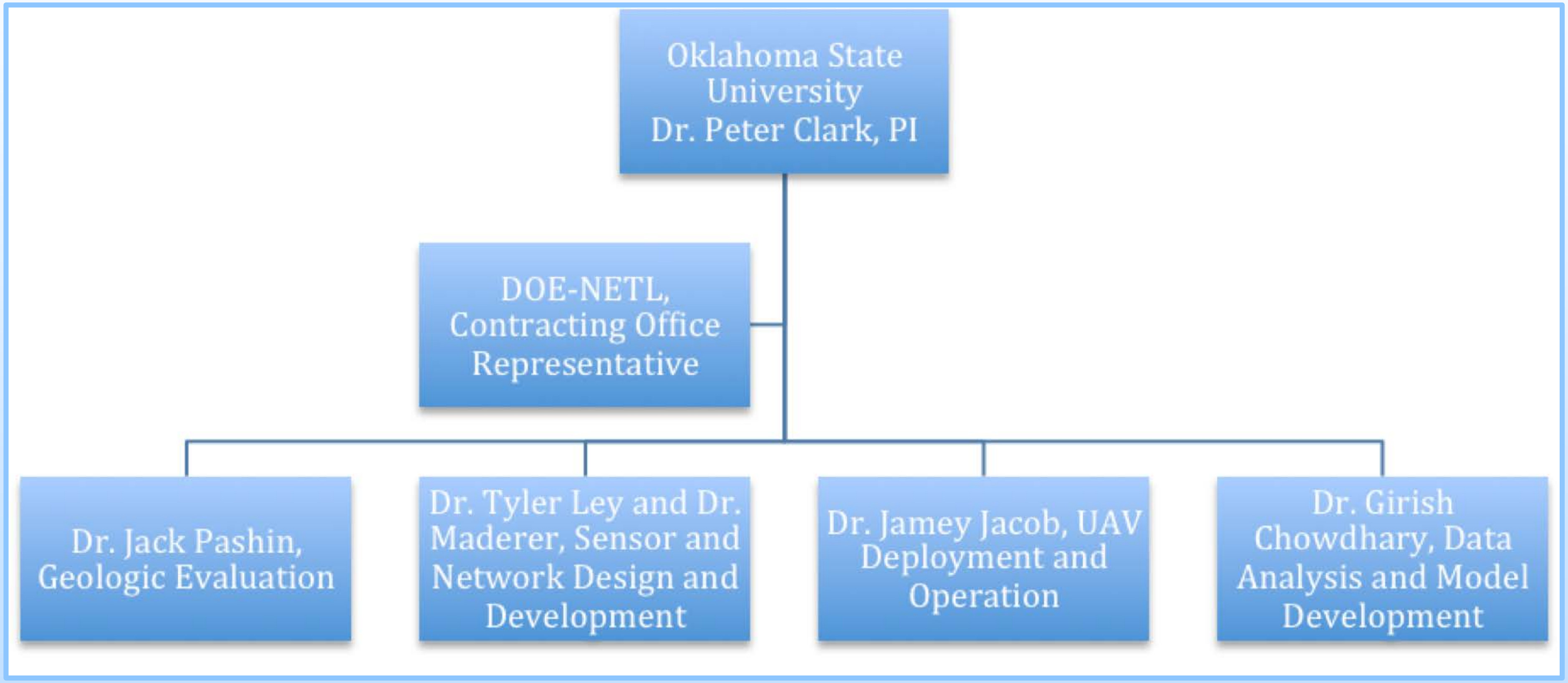
Summary

- Numerous shale and evaporite seals make Farnsworth a favorable storage site.
- Abundant natural fractures at and 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.
- Several UAVs fit to task; include lightweight options.
- Gaussian Process viable approach to data manipulation and modeling.
- Project moving toward field deployment according to plan.

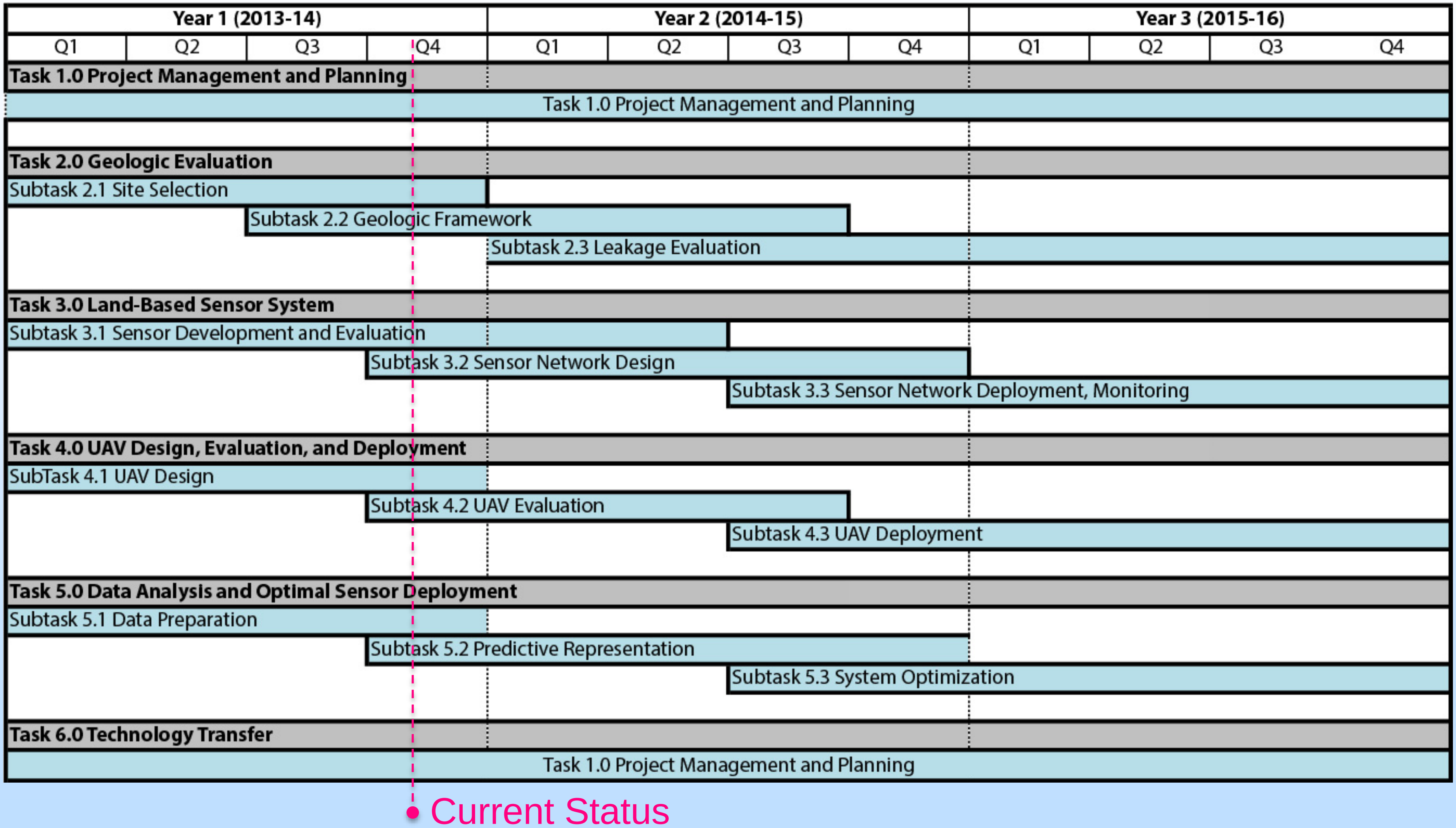
Appendix

– 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)
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
Task 2.0 Geologic Evaluation
Subtask 2.1 Site Selection
Subtask 2.2 Geologic Framework
Subtask 2.3 Leakage Evaluation
Task 3.0 Land-Based Sensor System
Subtask 3.1 Sensor Development and Evaluation
Subtask 3.2 Sensor Network Design
Subtask 3.3 Sensor Network Deployment, Monitoring
Task 4.0 UAV Design, Evaluation, and Deployment
SubTask 4.1 UAV Design
Subtask 4.2 UAV Evaluation
Subtask 4.3 UAV Deployment
Task 5.0 Data Analysis and Optimal Sensor Deployment
Subtask 5.1 Data Preparation
Subtask 5.2 Predictive Representation
Subtask 5.3 System Optimization
Task 6.0 Technology Transfer
Task 1.0 Project Management and Planning
Current Status

Bibliography

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