FarmBeats: AI & IoT for Agriculture

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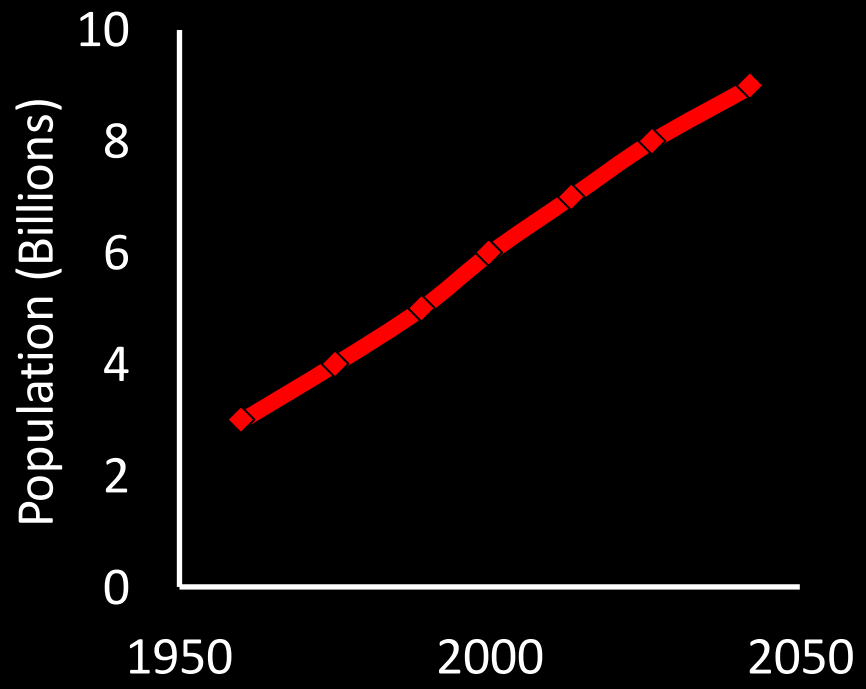
The Ag Challenge

Agricultural output needs to increase by 70% by 2050 to meet the demands

– United Nations[1]



[1]: United Nations Second Committee (Economic & Financial), 2009

The Ag Challenge

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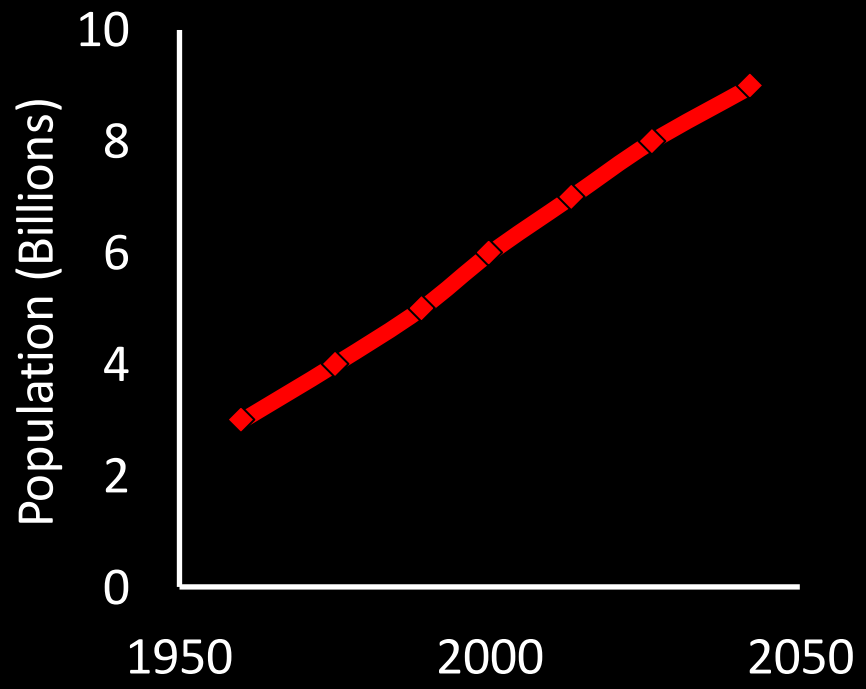
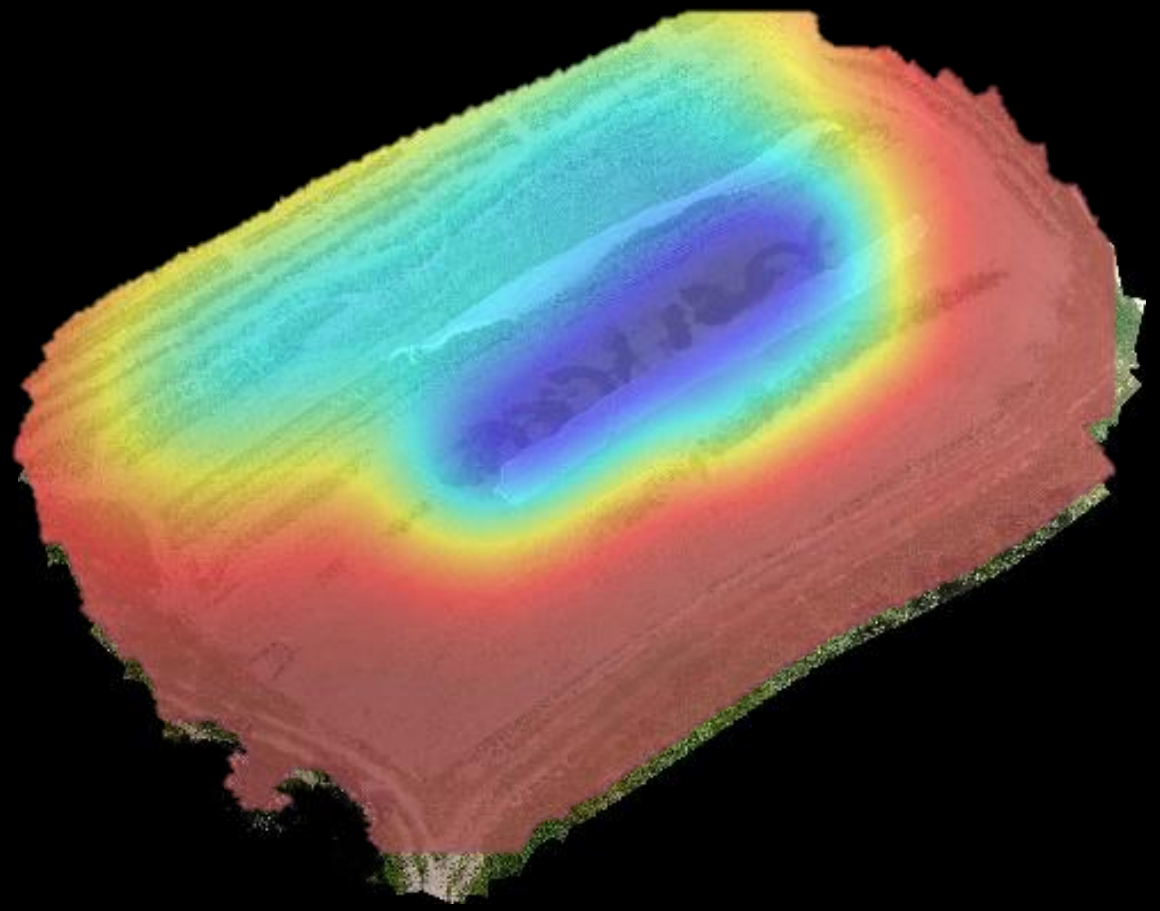


But…

- Water levels are receding
- Arable land is shrinking
- Environment is being degraded

[1]: United Nations Second Committee (Economic & Financial), 2009

Data-Driven Agriculture



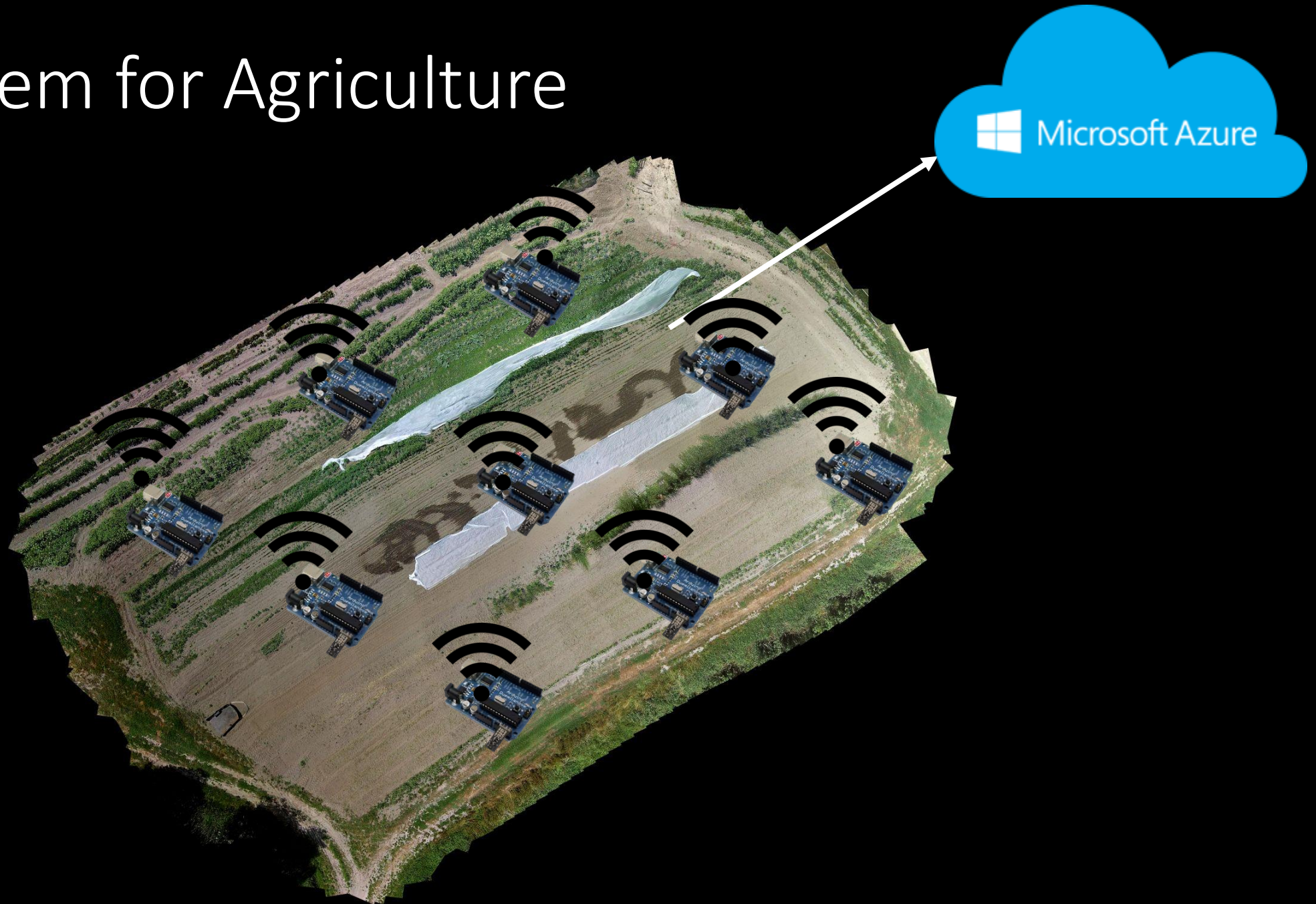
Ag researchers have shown that it:

- Improves yield
- Reduces cost
- Ensures sustainability

But…

According to USDA, high cost of manual data collection prevents farmers from using data-driven agriculture

IoT System for Agriculture



Challenge: No Internet Connectivity

- Most farms don’t have any internet coverage

- Even if connectivity exists, weather related outages can disable networks for weeks

Challenge: No Power on the Farm

- Farms do not have direct power sources

- Solar power is highly prone to weather related outages

Challenge: Limited Resources

- Need to work with sparse sensor deployments
  - Physical constraints due to farming practices
  - Too expensive to deploy and maintain

Beyond Agriculture

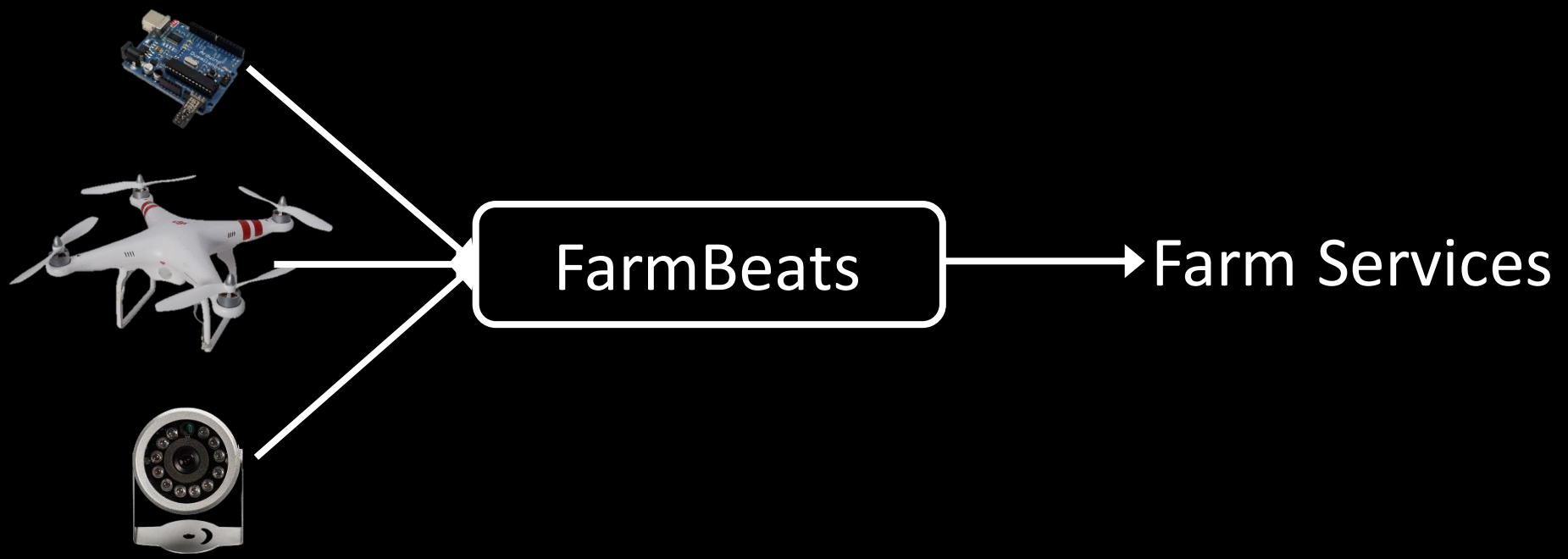
Smart Cities

Oil Fields, Mining, etc

How can one design an IoT system in challenging resource-constrained environments?

Our Solution: FarmBeats

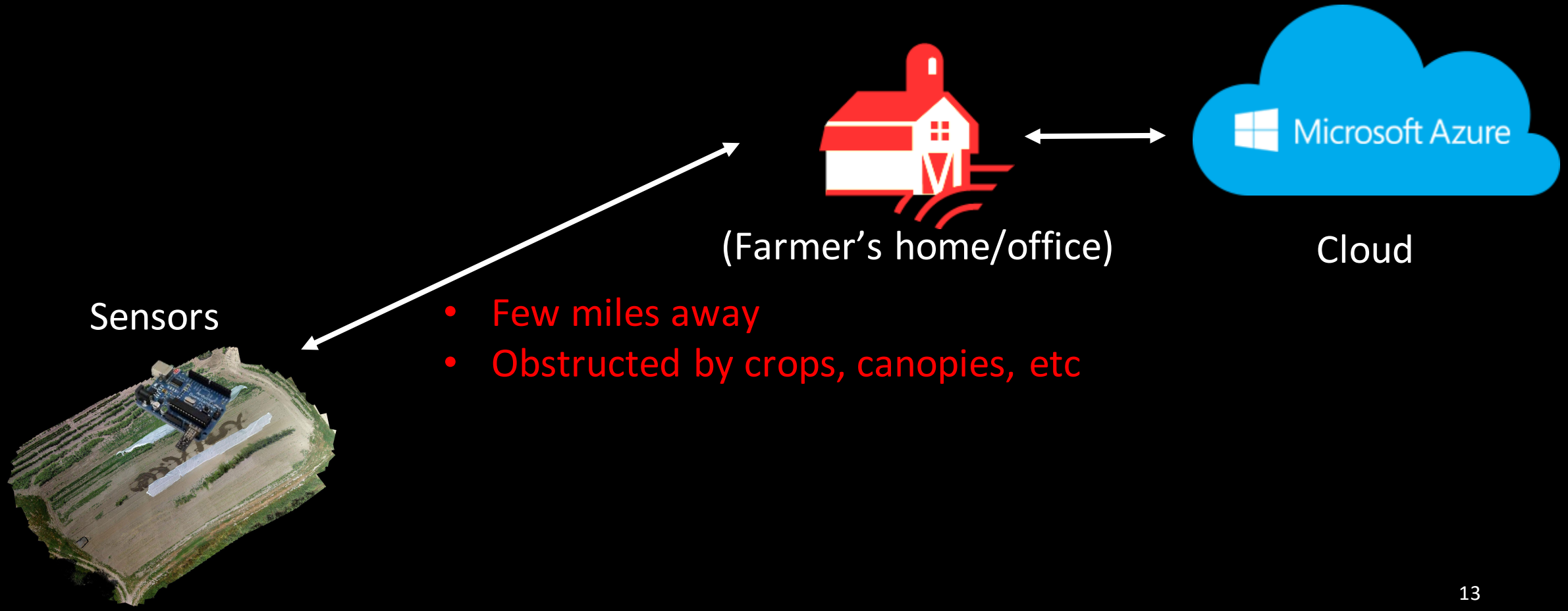
- FarmBeats: An end-to-end system that enables agricultural sensing at 2 orders of magnitude lower cost



Challenge 1: Internet Connectivity

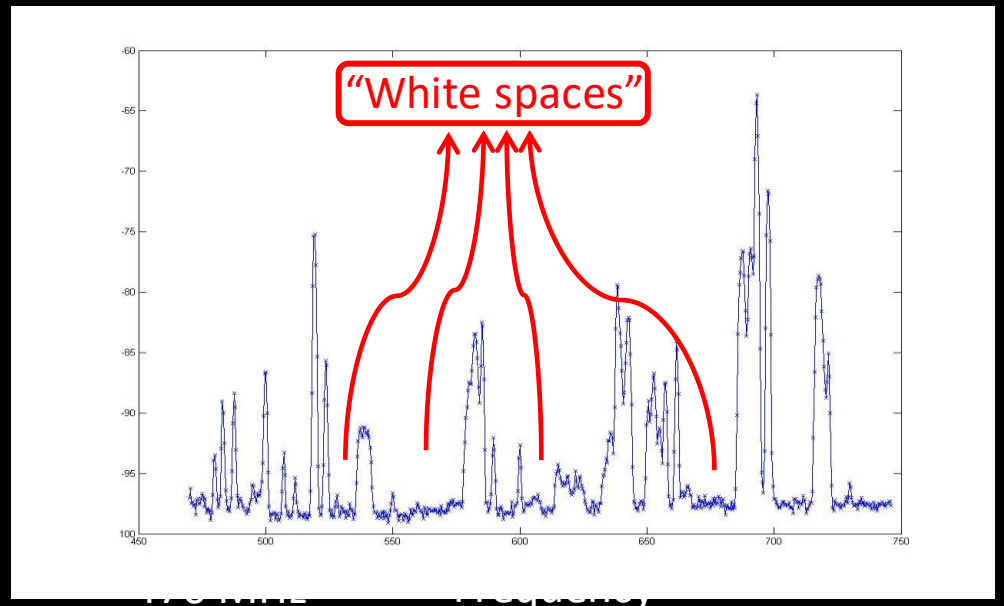
Sensors

Challenge 1: Internet Connectivity



TV White Spaces in the Farm

- What are the TV White Spaces?
  - Unused TV channels
- Benefits over Wi-Fi, Zigbee, etc
  - High throughput at long range
- Key insight for farms:
  - “lots” of TV spectrum is available, more than 100 MHz
  - Just like Wi-Fi router covers the home, TVWS base station can cover the farm



Idea: Use TV White Spaces

Sensors

TV White Spaces

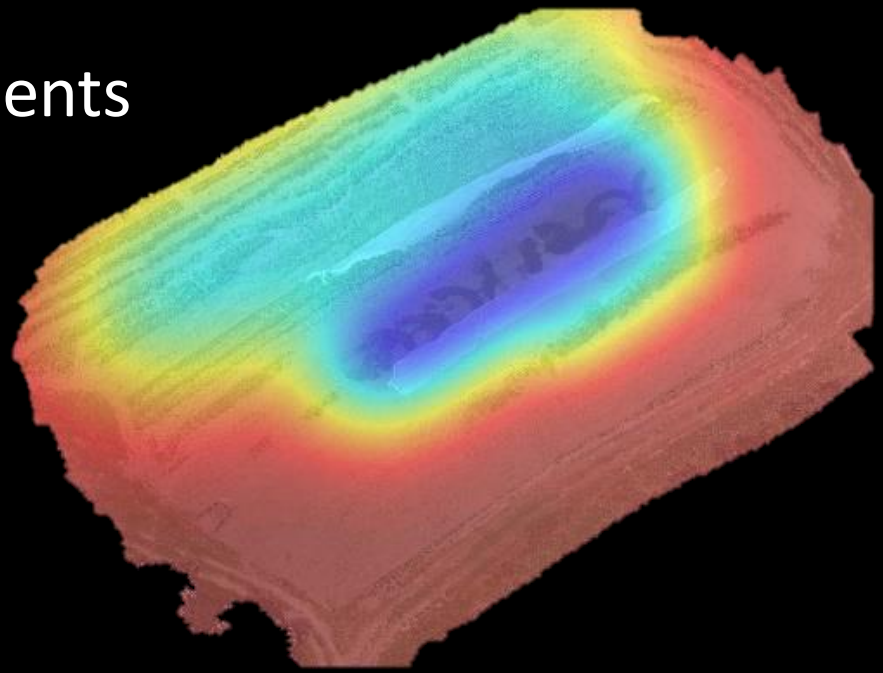
Few miles

(Farmer's home/office)

Cloud

Challenge 2: Limited Resources

- Need to work with sparse sensor deployments
  - Physical constraints due to farming practices
  - Too expensive to deploy and maintain



- How do we get coverage with a sparse sensor deployment?

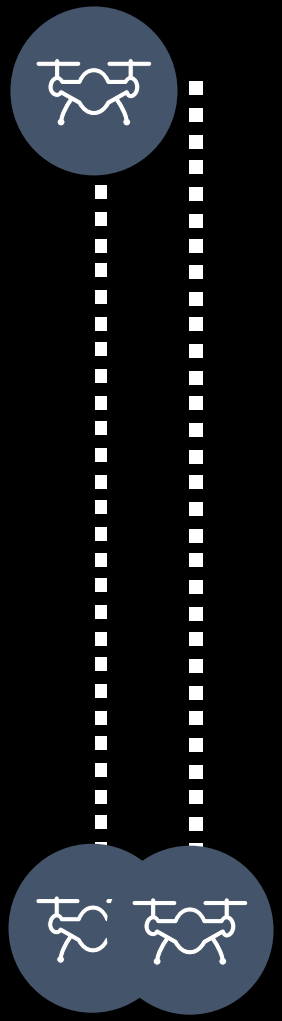
Idea: Use UAVs to Enhance Spatial Coverage

- Drones are ~1000 dollars and automatic
- Can cover large areas quickly
- Can collect visual data

Combine visual data from the UAVs with the sensor data from the farm

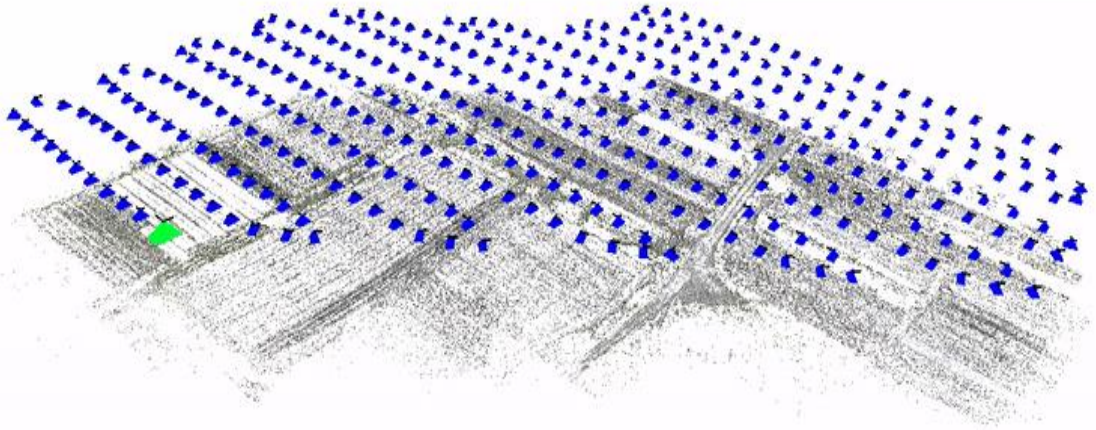
Aerial imagery in precision agriculture

Drone Video



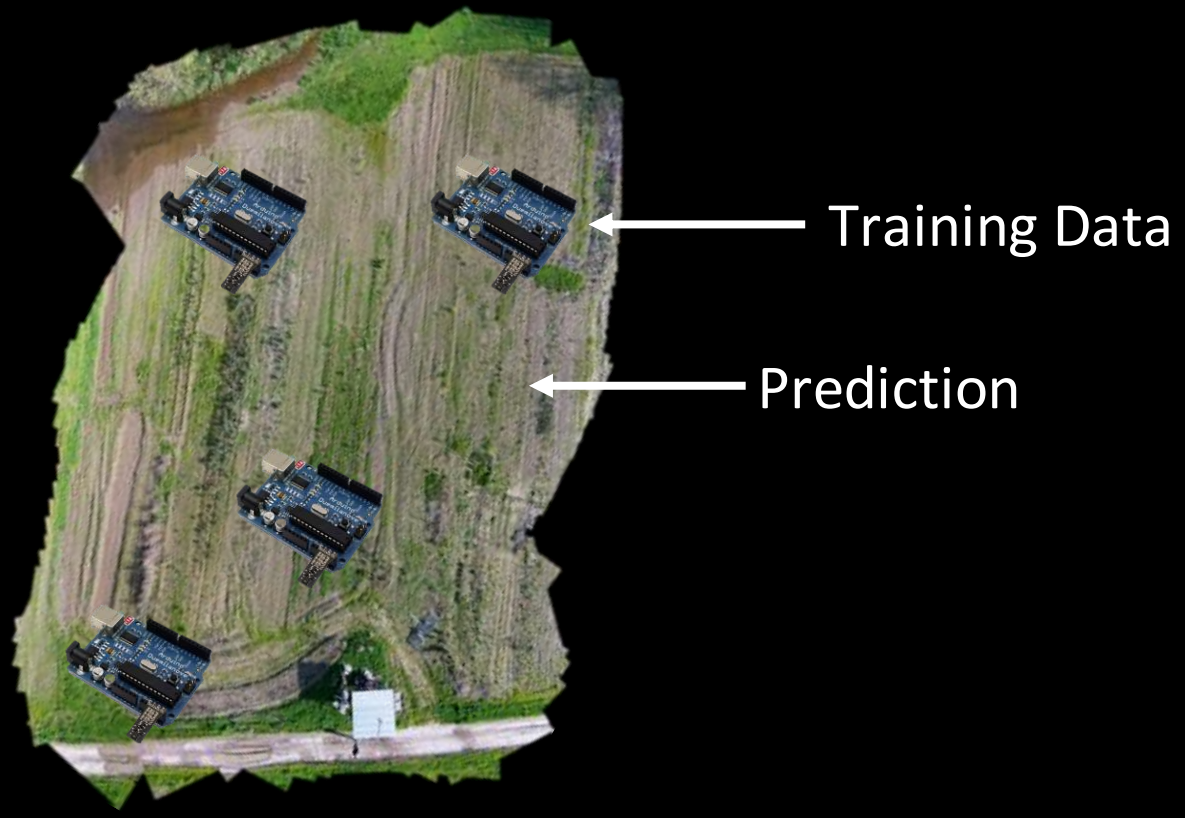
Processing RGB & multi-spectral imagery

Ariel footage



3D point cloud reconstruction

Formulate as a Learning Problem



Panoramic Overview

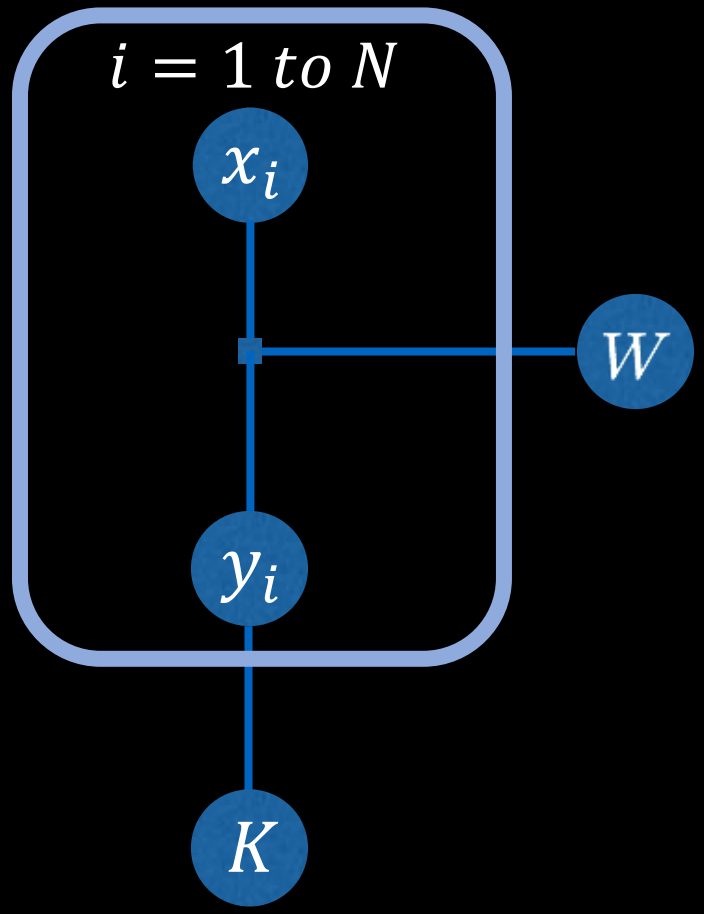
Gaussian Process Model

Features (visual)

Kernel (Model visual similarity)

Output (say, moisture)

Spatial Smoothness

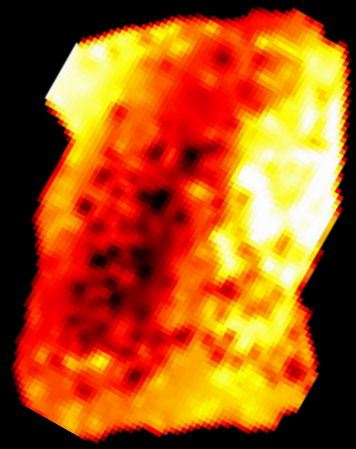


- **Training Phase:** Learn K and W
- **Test Phase:** Generate outputs for unknown areas

Idea: Use Drones to Enhance Spatial Coverage

Drone Video

Panoramic Overview

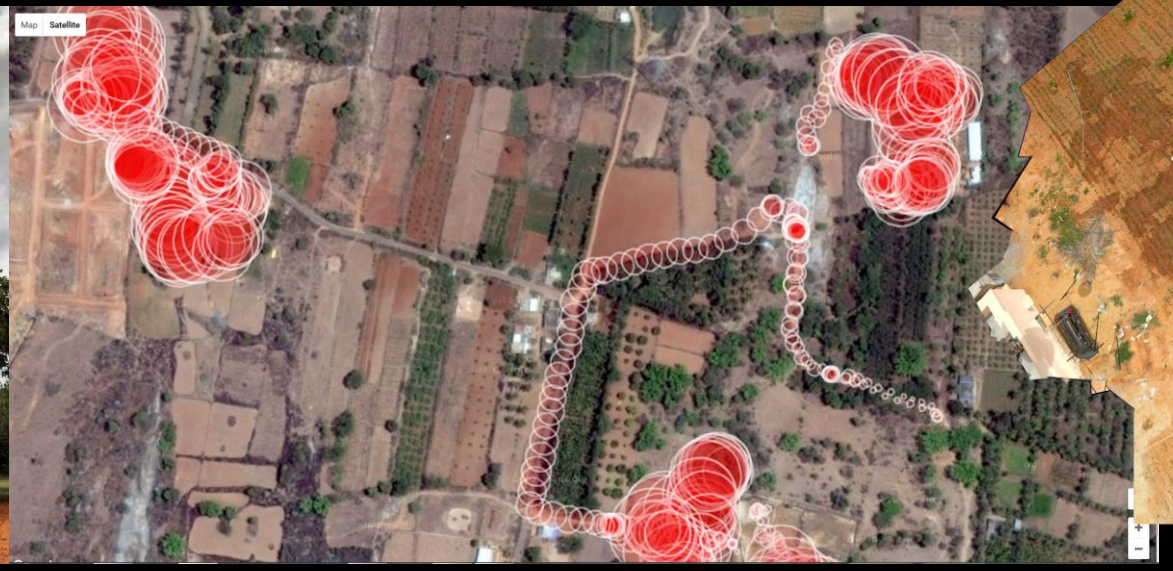


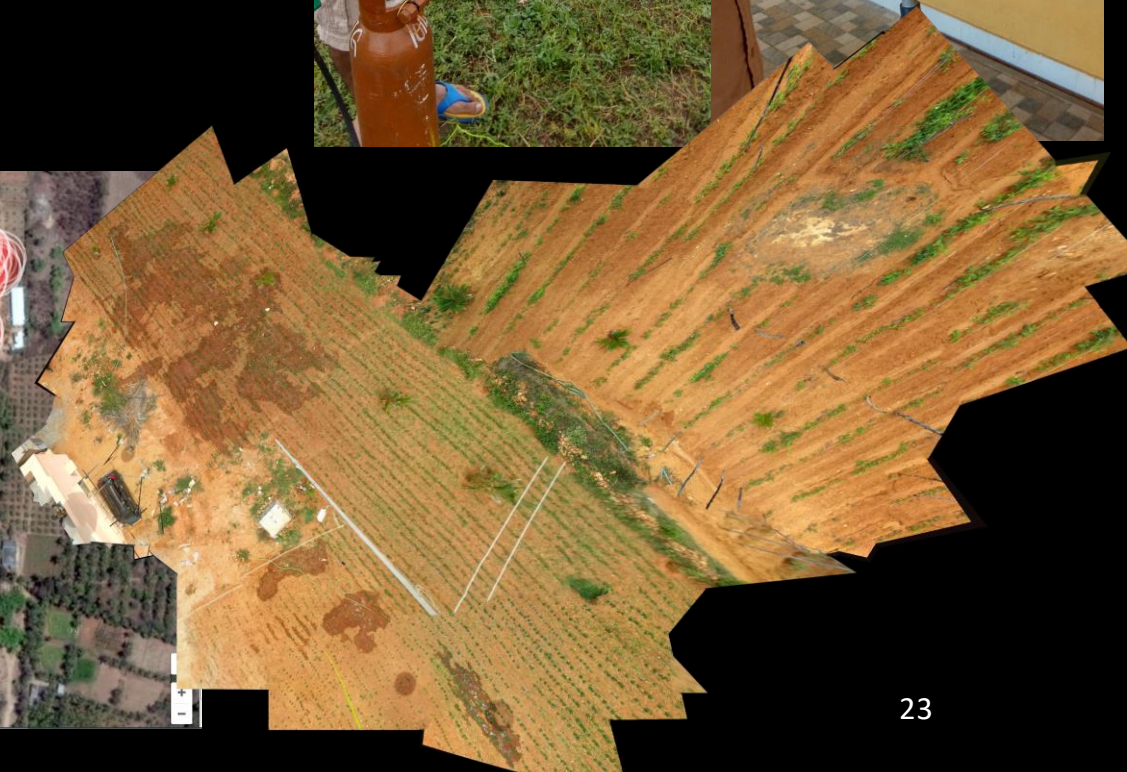
Precision Map

FarmBeats can use drones to expand the sparse sensor data and create summaries for the farm

Low-cost Aerial Imagery: Tethered Eye (TYE)

- UAVs have a few limitations in developing world:
  - limited battery life
  - Regulatory concerns
  - Cost > 1000 dollars





Challenge 3: Cloud Connectivity

- Weak Connectivity
- Prone to outages

Service characteristics

Large inputs

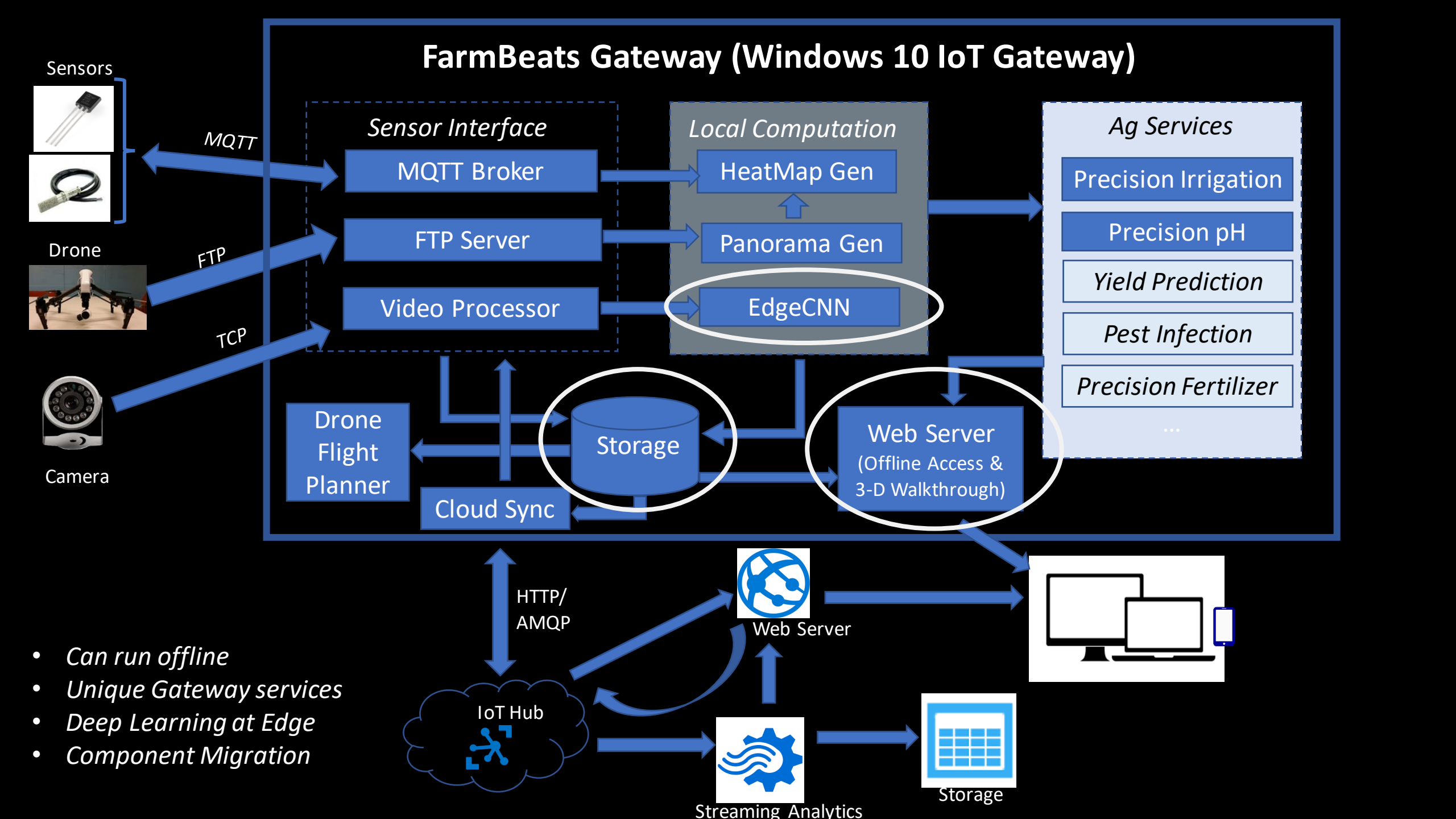
Data source	Daily size
Sensor	70K
Drone video	10G
Drone image	4G
Camera	28M

Latency constraints

Service	Latency
Query sensor data	seconds
Livestock monitoring	seconds
Irrigation schedules	hours
Pest inspection	hours
Variability analysis	Days

Idea: Compute Locally and Send Summaries

- PC on the farm delivers time-sensitive services locally
- Combines all the sensor data into summaries
- 2-3 orders of magnitude smaller than raw data
- Cloud delivers long-term analytics and cross-farm analytics


FarmBeats Gateway (Windows 10 IoT Gateway)
Sensors
Drone
Camera
MQTT
FTP
TCP
Sensor Interface
MQTT Broker
FTP Server
Video Processor
Local Computation
HeatMap Gen
Panorama Gen
EdgeCNN
Ag Services
Precision Irrigation
Precision pH
Yield Prediction
Pest Infection
Precision Fertilizer
...
Drone Flight Planner
Storage
Cloud Sync
Web Server
(Offline Access & 3-D Walkthrough)
HTTP/ AMQP
Web Server
IoT Hub
Streaming Analytics
Storage
Can run offline
Unique Gateway services
Deep Learning at Edge
Component Migration

Challenge 4: Power Availability is Variable

- Solar powered battery saw up to 30% downtime in cloudy months
- Miss important data like flood monitoring

Idea: Weather is Predictable

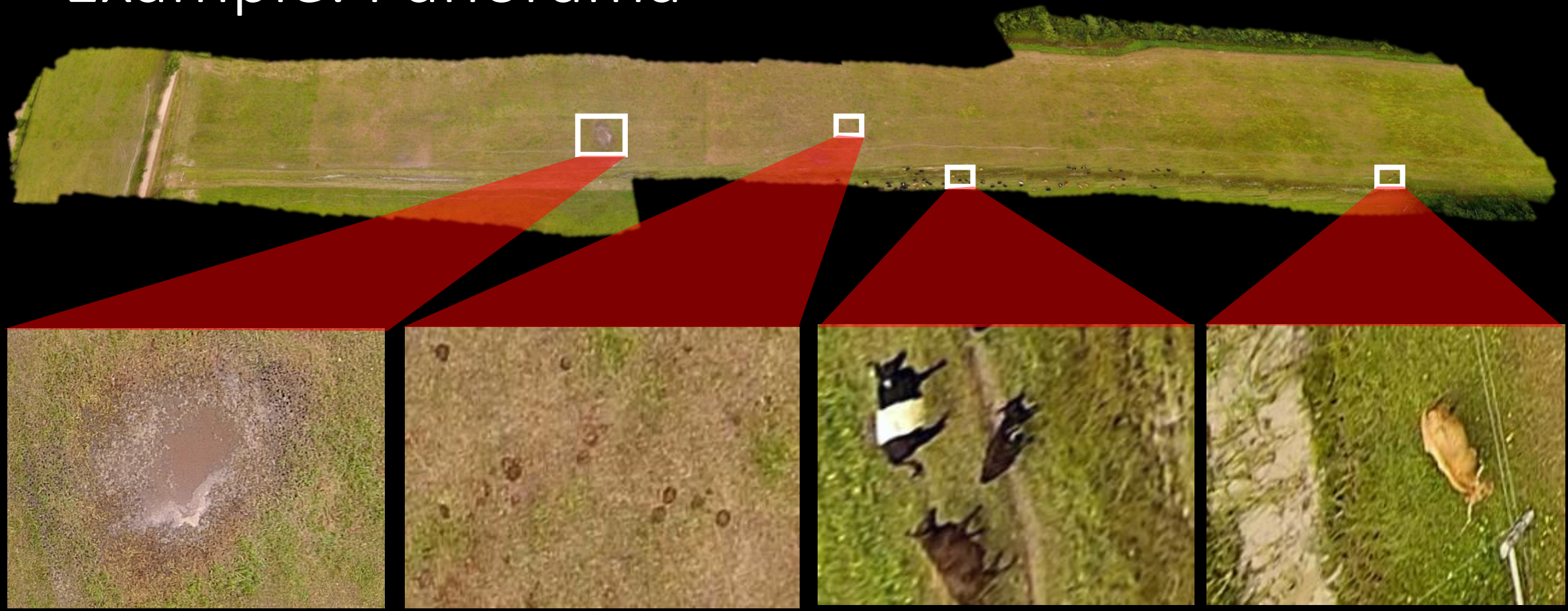
- Use weather forecasts to predict solar energy output
- Ration the load to fit within power budget

FarmBeats: Overview

Deployment Example

- Deployments in many farms: Upstate NY (Essex), WA (Carnation)
- The farm sizes are 2000 acres and 5 acres respectively
- Sensors:
  - DJI Drones
  - Particle Photons with Moisture, Temperature, pH Sensors
  - IP Cameras to capture IR imagery as well as monitoring
- Cloud Components: Azure Storage and IoT Suite

Example: Panorama



Water puddle

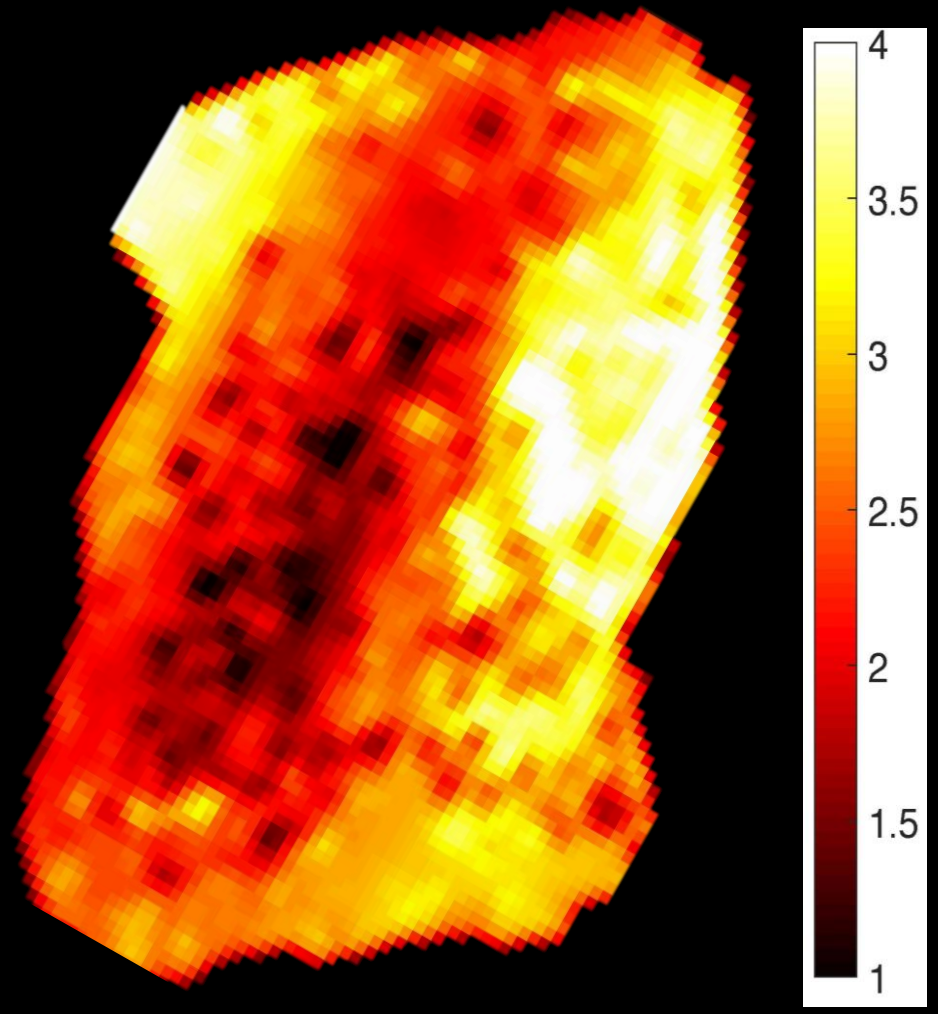
Cow excreta

Cow Herd

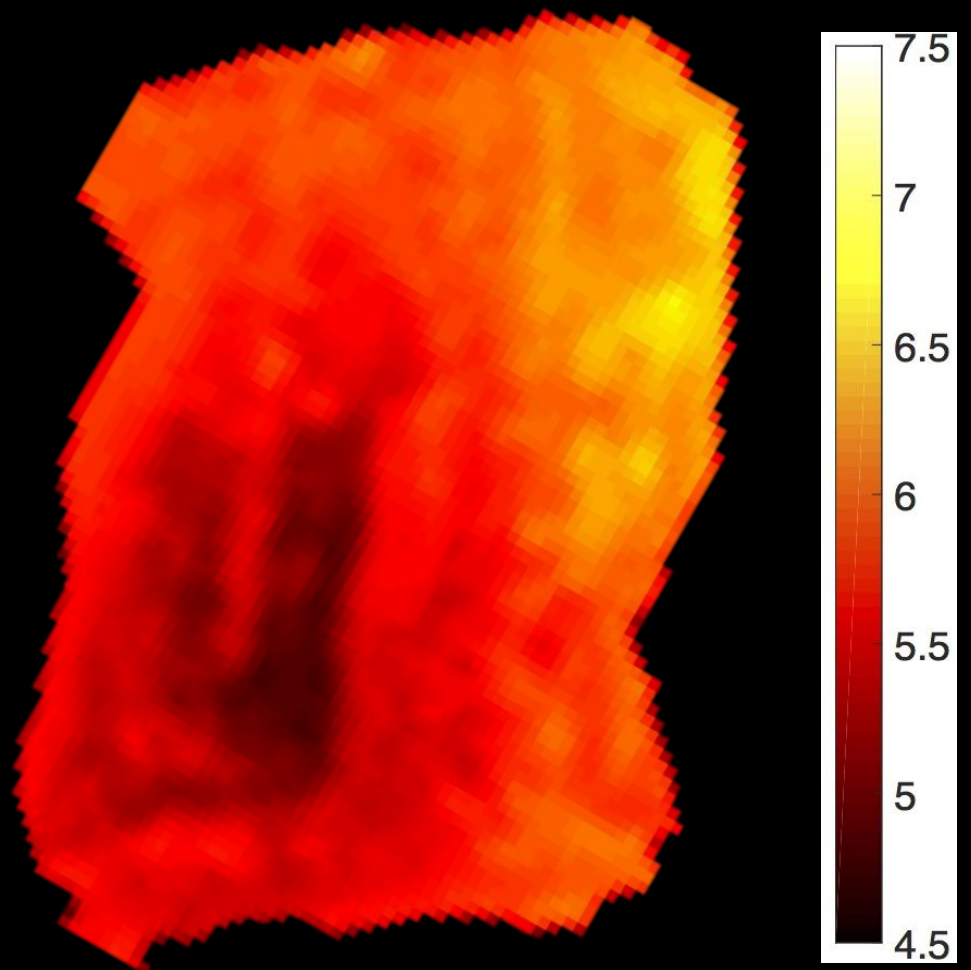
Stray cow

Precision Map: Panorama Generation

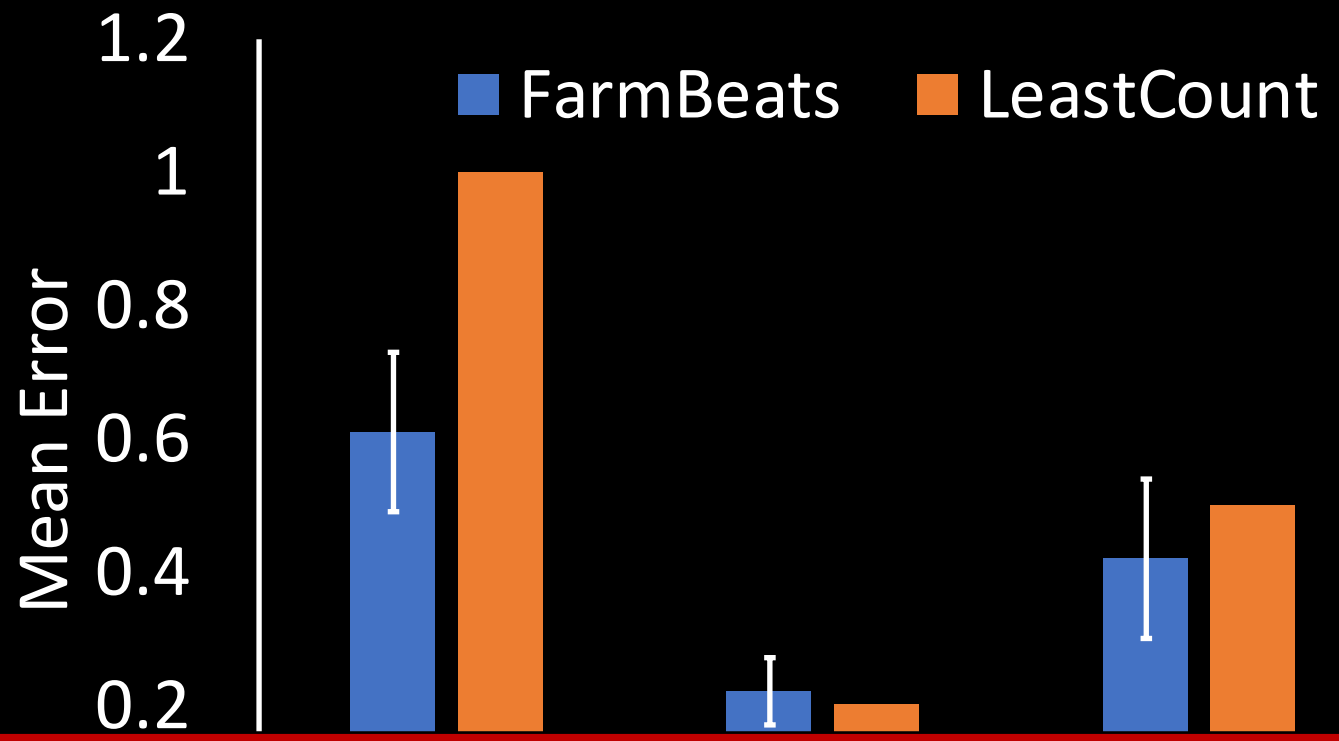
Precision Map : Moisture



Precision Map : pH



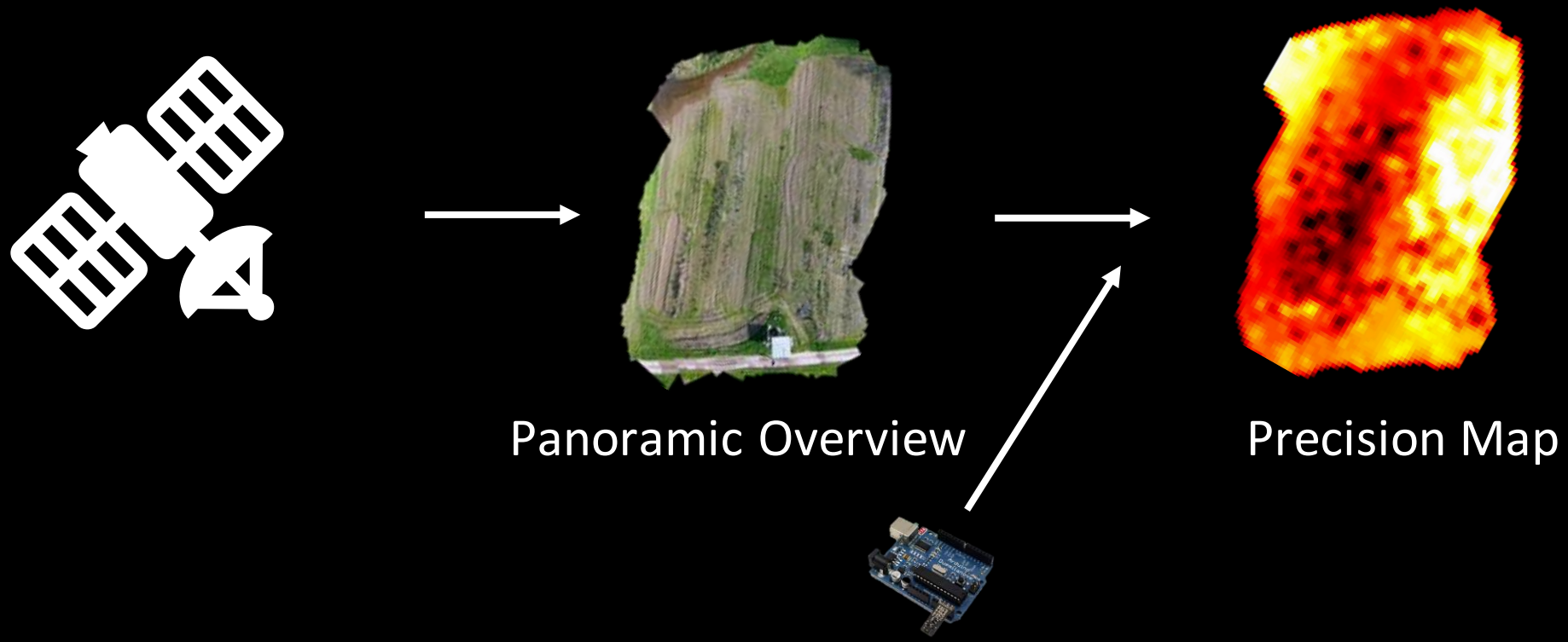
Precision Map: Accuracy



FarmBeats can accurately expand coverage by orders of magnitude using a sparse sensor deployment

Application: Cow-Shed Monitor

New Direction: Satellite Imagery



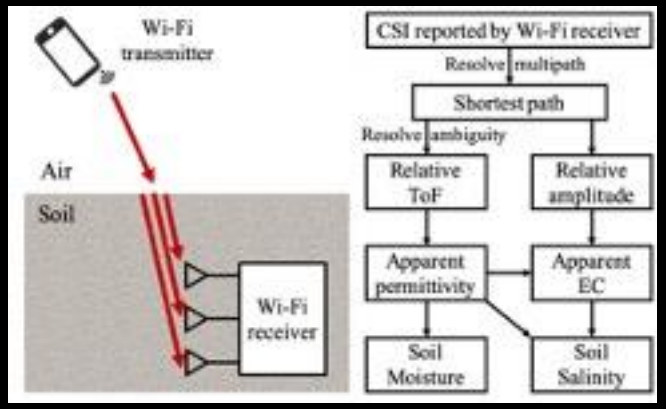
New Direction: Soil Sensing

Motivation: existing sensors are expensive

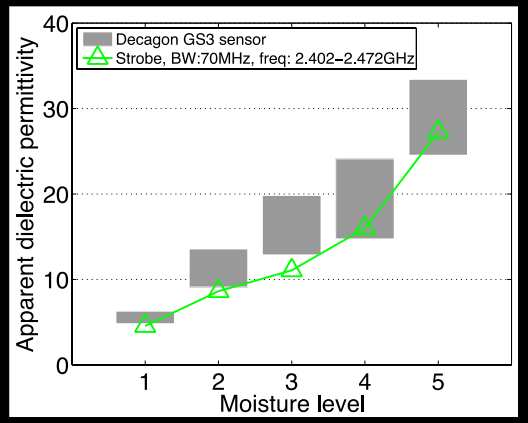
- ~100s of dollars

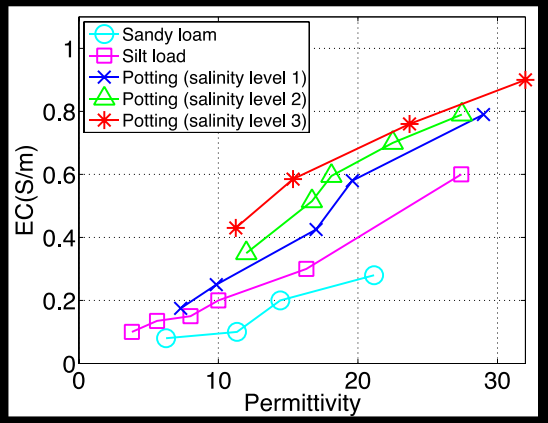
Strobe design: Wi-Fi cards with 2+ antennas

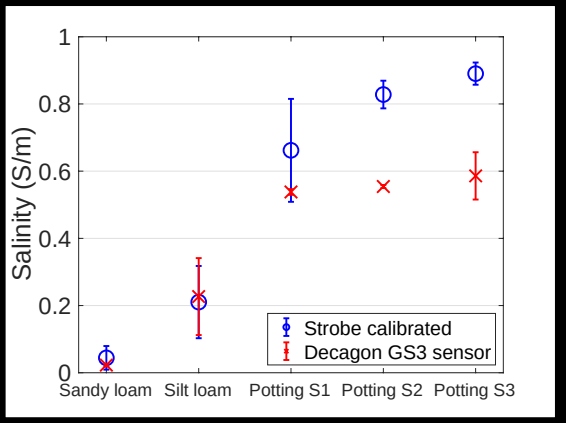
- Relative phase & amplitude

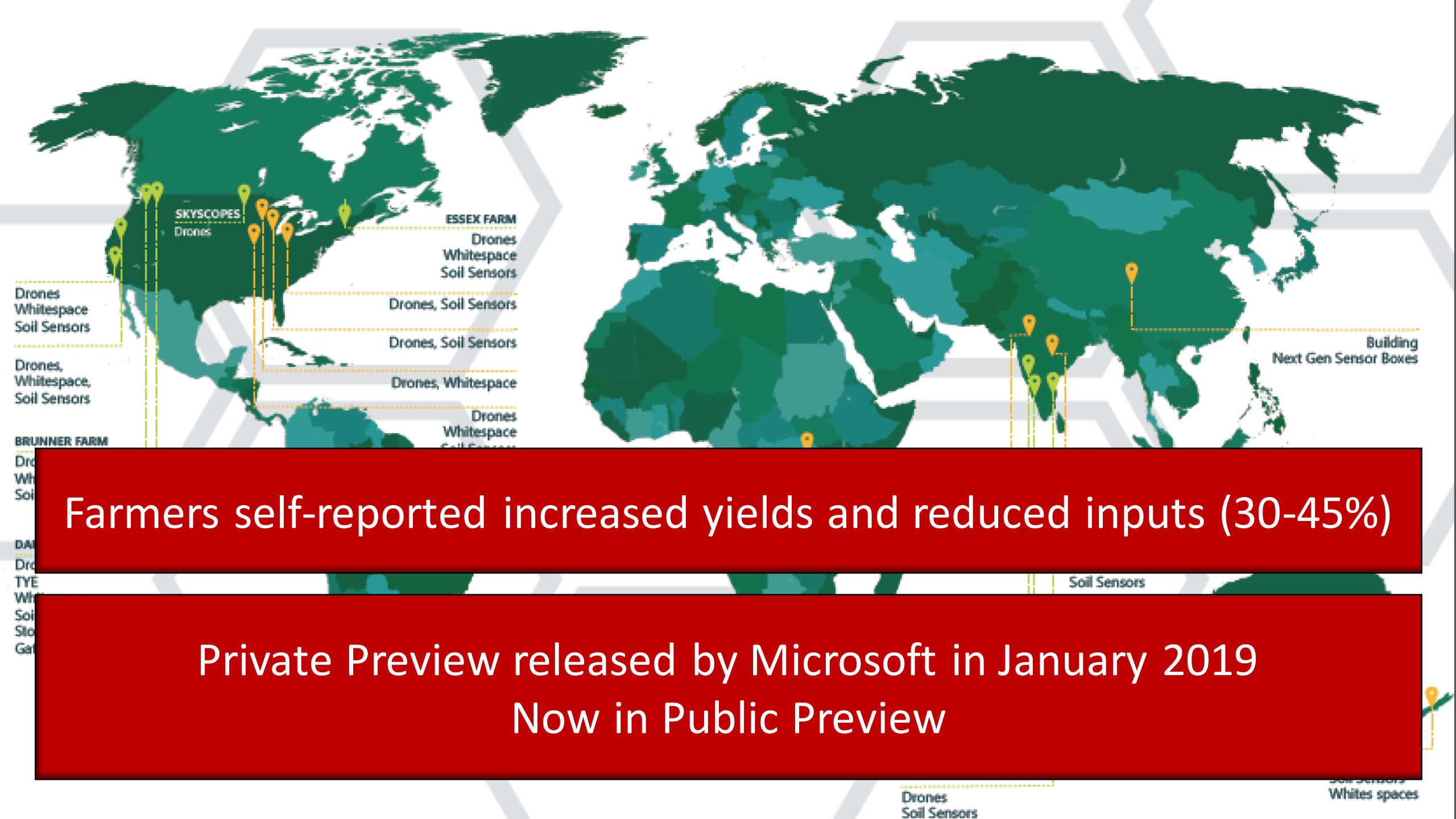


Results: Strobe can accurately detect moisture and EC change in soil









Farmers self-reported increased yields and reduced inputs (30-45%)

Private Preview released by Microsoft in January 2019
Now in Public Preview

The people and projects that inspired me in 2017

Published on December 21, 2017

Satya Nadella in fluencer + Follow
CEO at Microsoft
24 articles

16,655 318 1,233

gatesnotes The blog of **Bill Gates**

Democratizing AI for farmers around the world

FarmBeats: Experiences

Conclusion

- FarmBeats: End to end IoT system for environments constrained by:
  - Limited internet connectivity
  - Weather related variability
  - Sparse sensor deployment
- Acts as a tool to enhance farm and farmer productivity
- Used by farmers for applications beyond precision farming

Questions

Zerina Kapetanovic (UW), Jong-Ho Won (Purdue), Xinxin Jin (UCSD), Vasuki Narasimha Swamy (Berkeley), Michael Grant (WSU), Rahul Sharma (IIIT Hyderabad), Akshit Kumar (IIT Madras), Rohit Shetty (PESET), Aditya Jain (IIIT Delhi), Ranveer Chandra, Manohar Swaminathan, Sudipta Sinha, Ashish Kapoor, Akshay Nambi, Anirudh Badam, Peeyush Kumar, Peder Olsen, Raghuram Lanka, Madhu Sudarshan, Cameron Phillips, Heping Shi, Akash Devgun, Raji Kommineni (Microsoft)