FarmBeats: An IoT System for Data-Driven Agriculture

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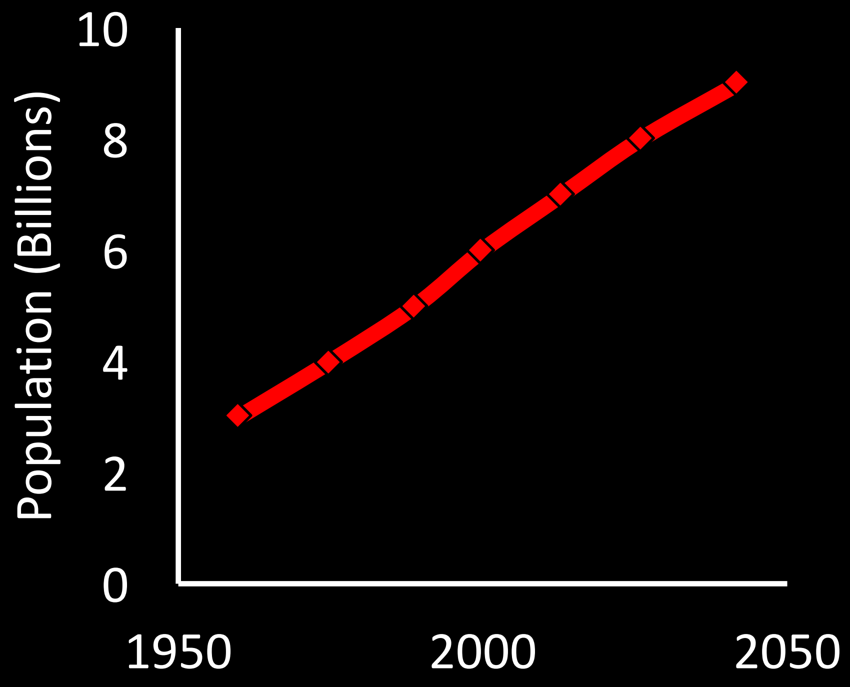
Microsoft

Why Agriculture?

Agricultural output needs to **double by 2050** to meet the demands
– United Nations[1]



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

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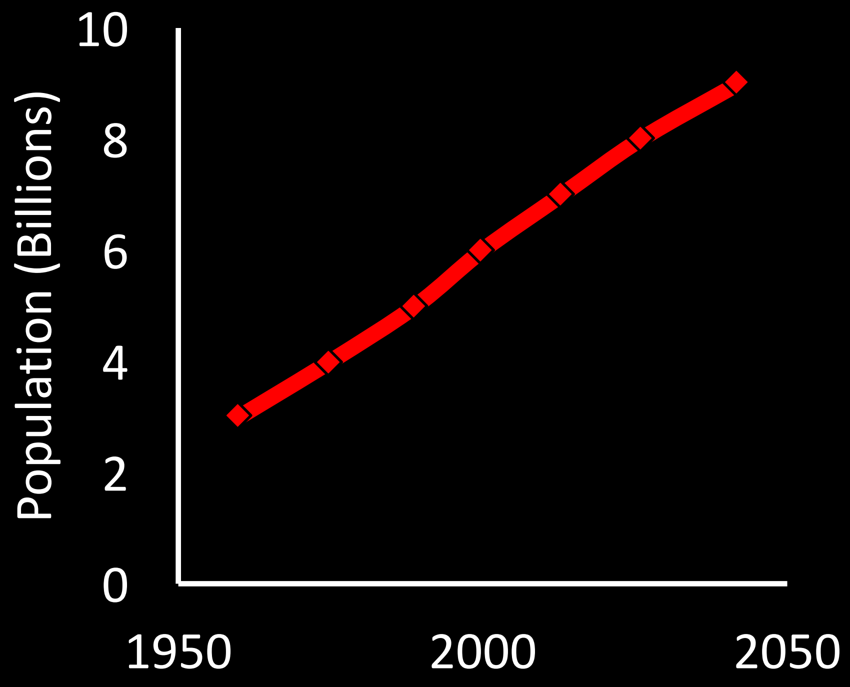

But…

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

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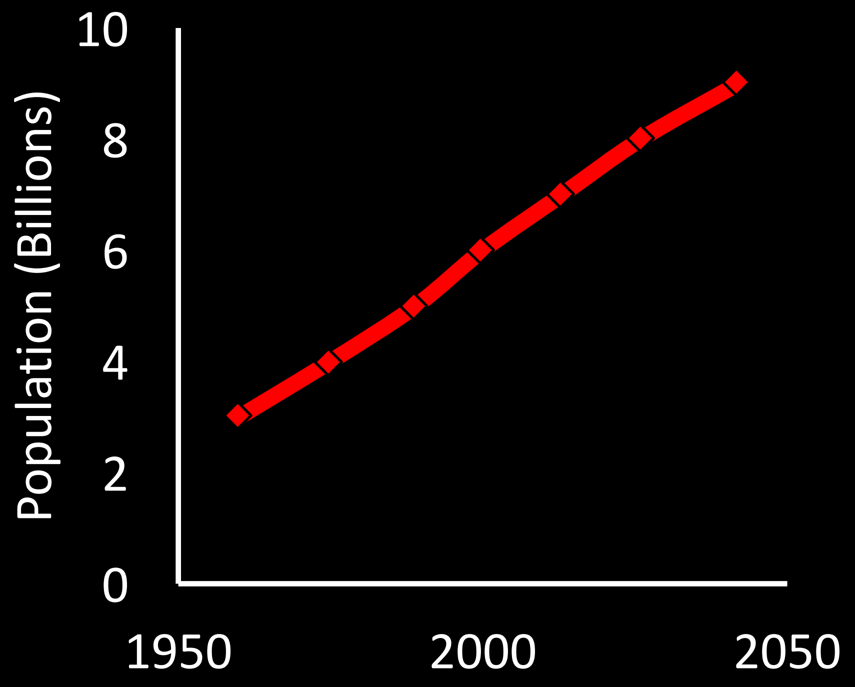
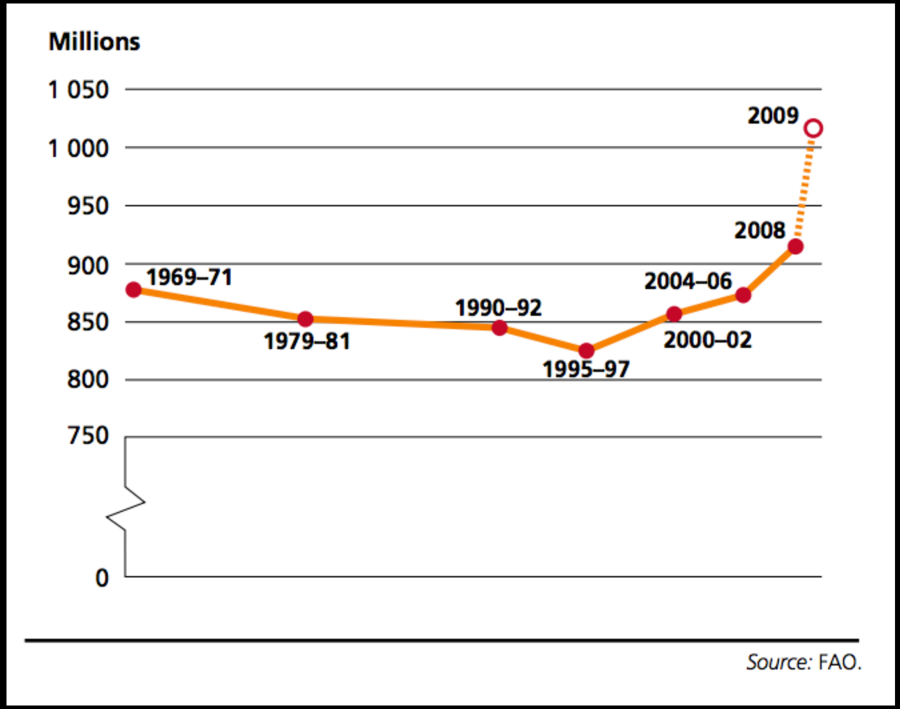
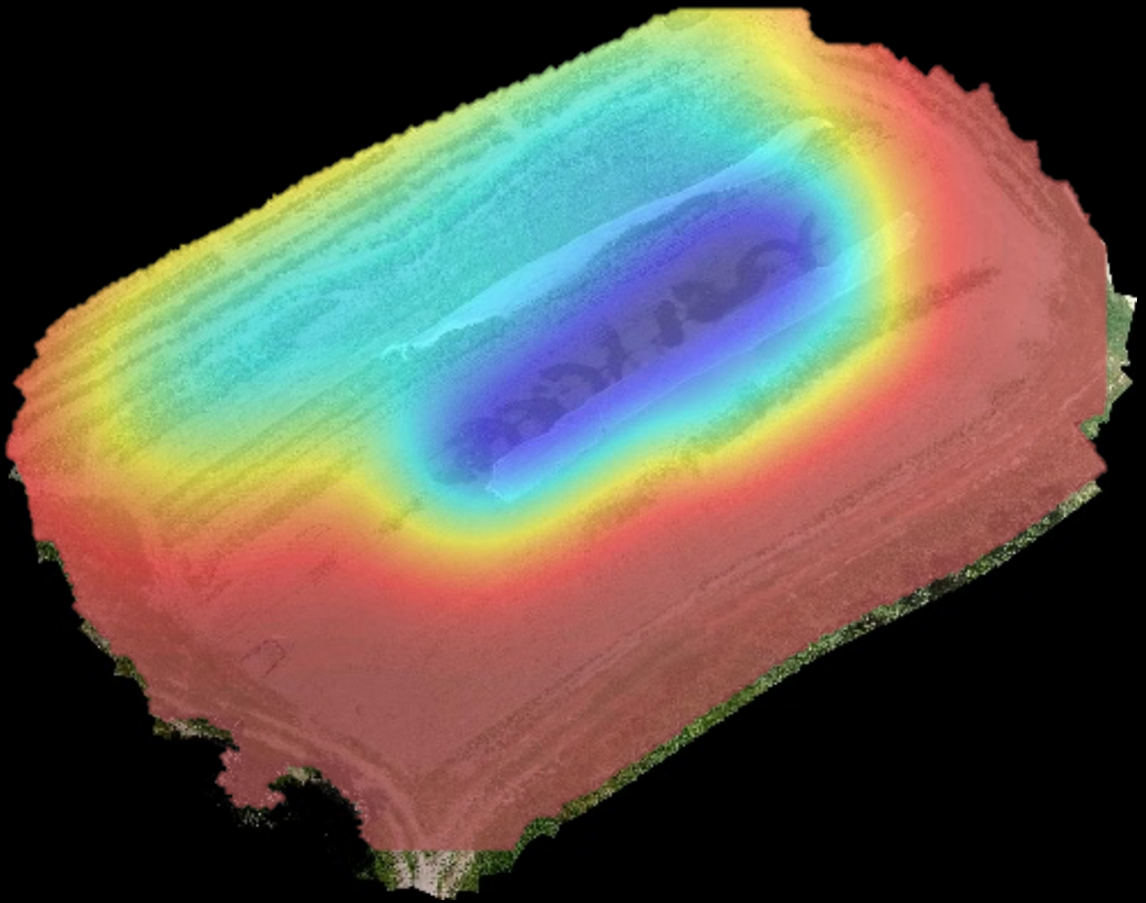


Number of World's Hungry People



Solution: Data-Driven Agriculture



Ag researchers have shown that it:

- Reduces waste
- Increases productivity
- Ensures sustainability

But…

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

IoT System for Agriculture

Problem 1: No Internet Connectivity

- Most farms don’t have any internet coverage
- Even if connectivity exists, weather related outages can disable networks for weeks

Problem 2: No Power on the Farm

- Farms do not have direct power sources

- Solar power is highly prone to weather variability

Problem 3: Limited Resources

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

Beyond Agriculture

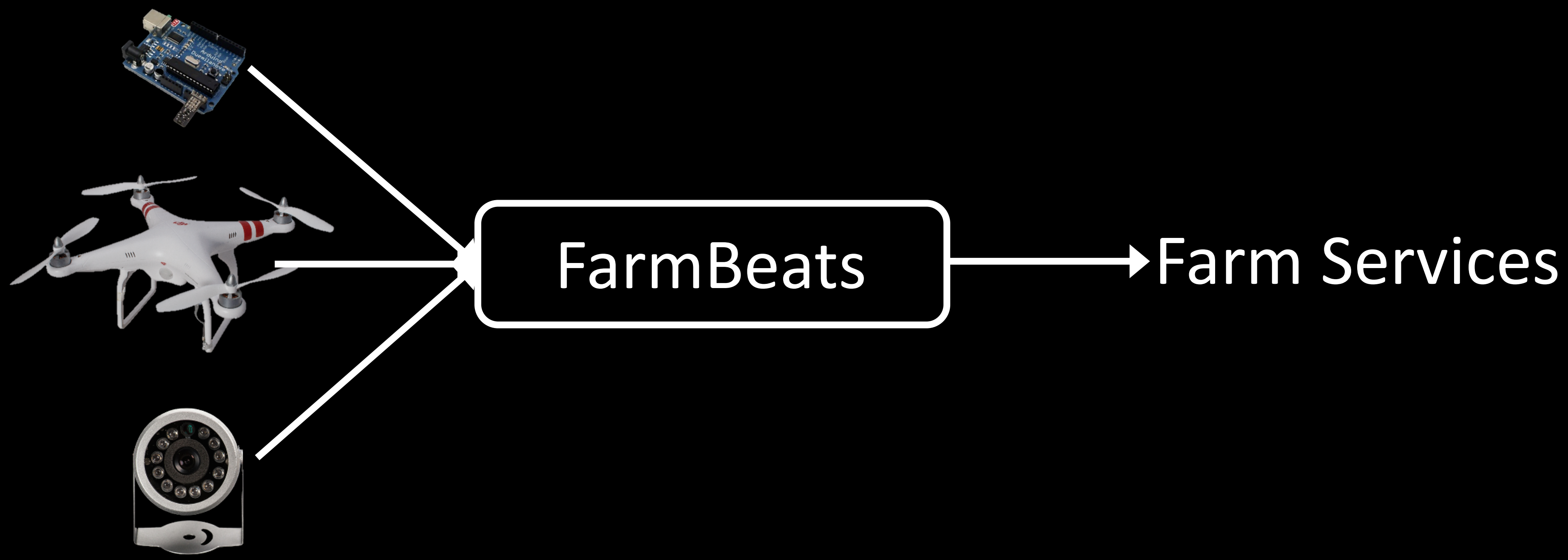
Mining

Oil Fields

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

In this talk

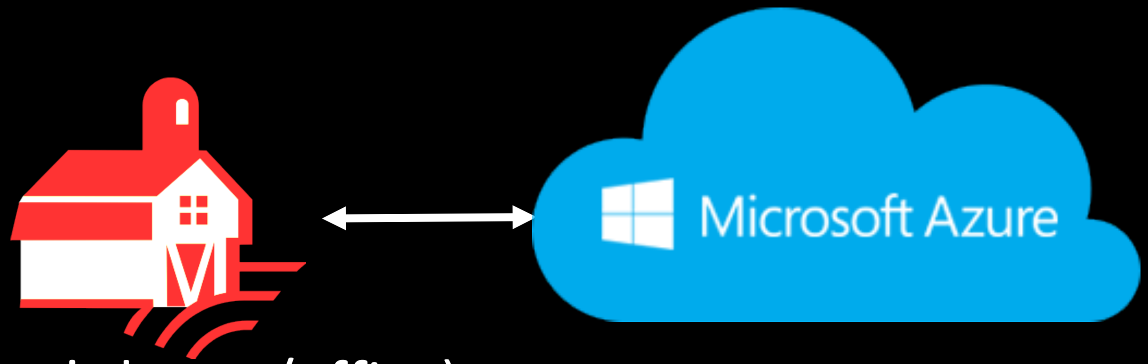
- FarmBeats: An end-to-end IoT system that enables seamless data collection for agriculture



In this talk

- FarmBeats: An end-to-end IoT system that enables seamless data collection for agriculture
- Solves three key challenges:
  - Internet Connectivity
  - Power Availability
  - Limited Sensor Placement
- Deployed in two farms in NY and WA for over six months

Challenge: Internet Connectivity



(Farmer's home/office)

Cloud

Challenge: Internet Connectivity

(Farmer's home/office)

Microsoft Azure

Cloud

Sensors

- Few miles away
- Obstructed by crops, canopies, etc

Idea: Use TV White Spaces

- Can provide long-range connectivity

- Can travel through crops and canopies, because of low frequencies

- Large chunks are available in rural areas=> can support large bandwidth

Idea: Use TV White Spaces

Base Station

- Weak Connectivity
- Prone to outages

TV White Spaces

Few miles

(Farmer's home/office)

Microsoft Azure

Cloud

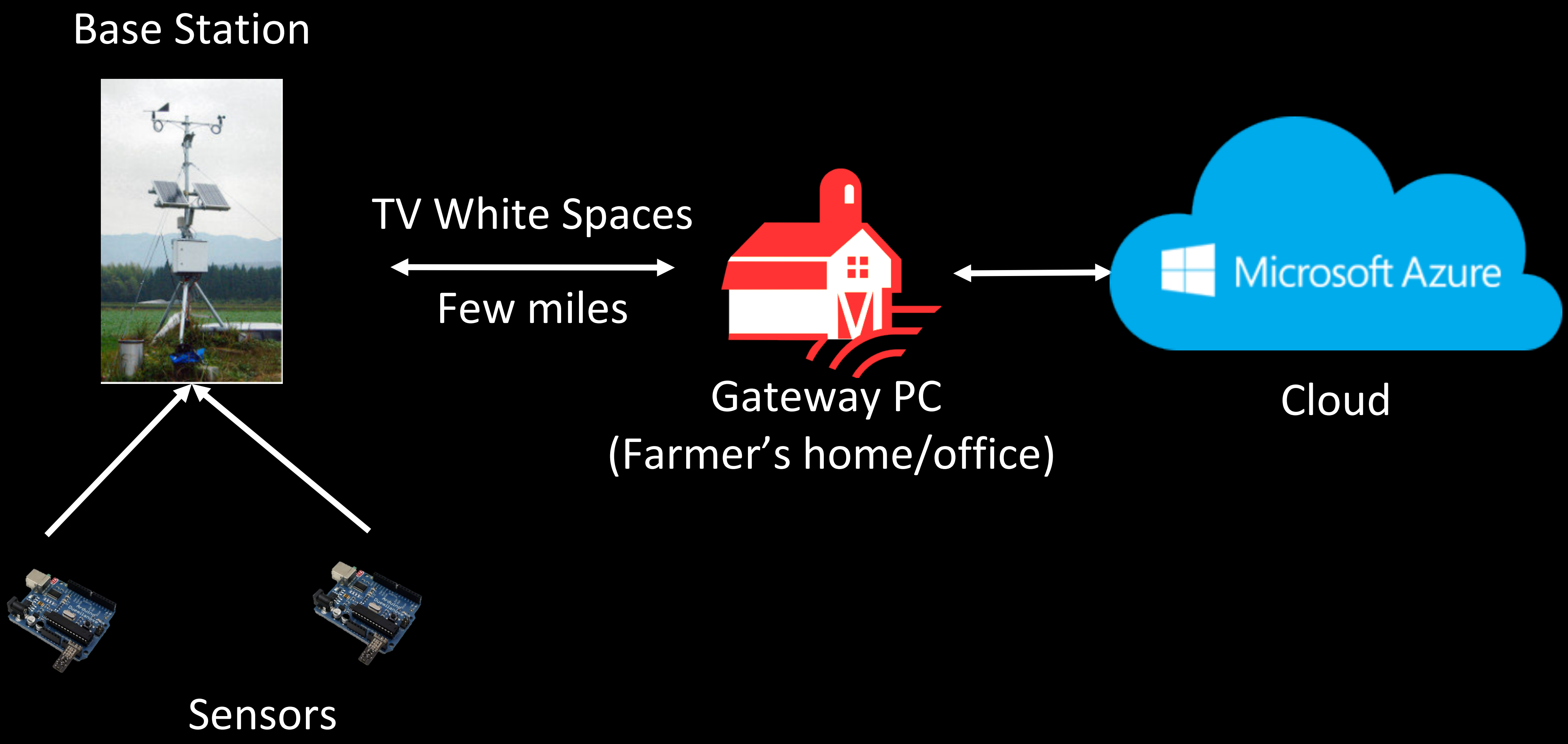
Wi-Fi, BLE

Sensors

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 Design



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Challenge: 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 Drones to Enhance Spatial Coverage

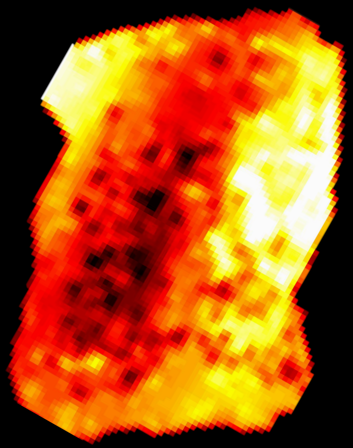
- Drones are cheap and automatic
- Can cover large areas quickly
- Can collect visual data

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

Idea: Use Drones to Enhance Spatial Coverage

Drone Video

Panoramic Overview



Precision Map

Sparse Sensor Data

Formulate as a Learning Problem

Training Data

Prediction

Panoramic Overview

Model Insights

- **Spatial Smoothness:** Areas close to each other have similar sensor values
- **Visual Smoothness:** Areas that look similar have similar sensor values values

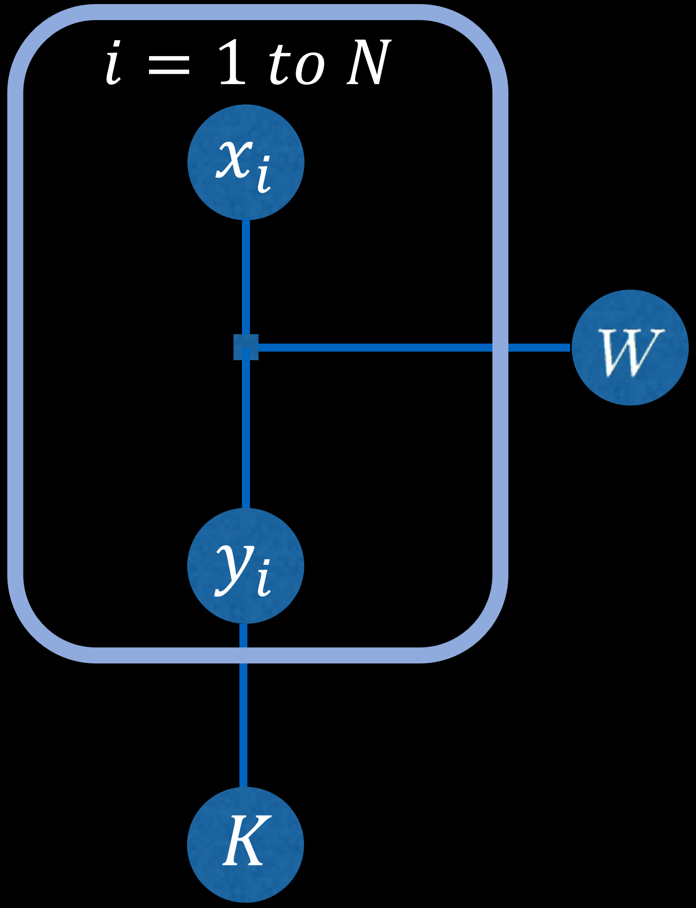
Model

Features (visual)

Kernel (Model visual similarity)

Output (say, moisture)

Spatial Smoothness



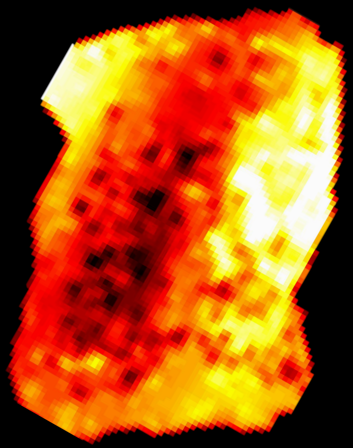
- **Training Phase:** Learn K and W

- **Test Phase:** Generate outputs for unknown areas

Using Sparse Sensor Data

Drone Video

Panoramic Overview



Precision Map

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

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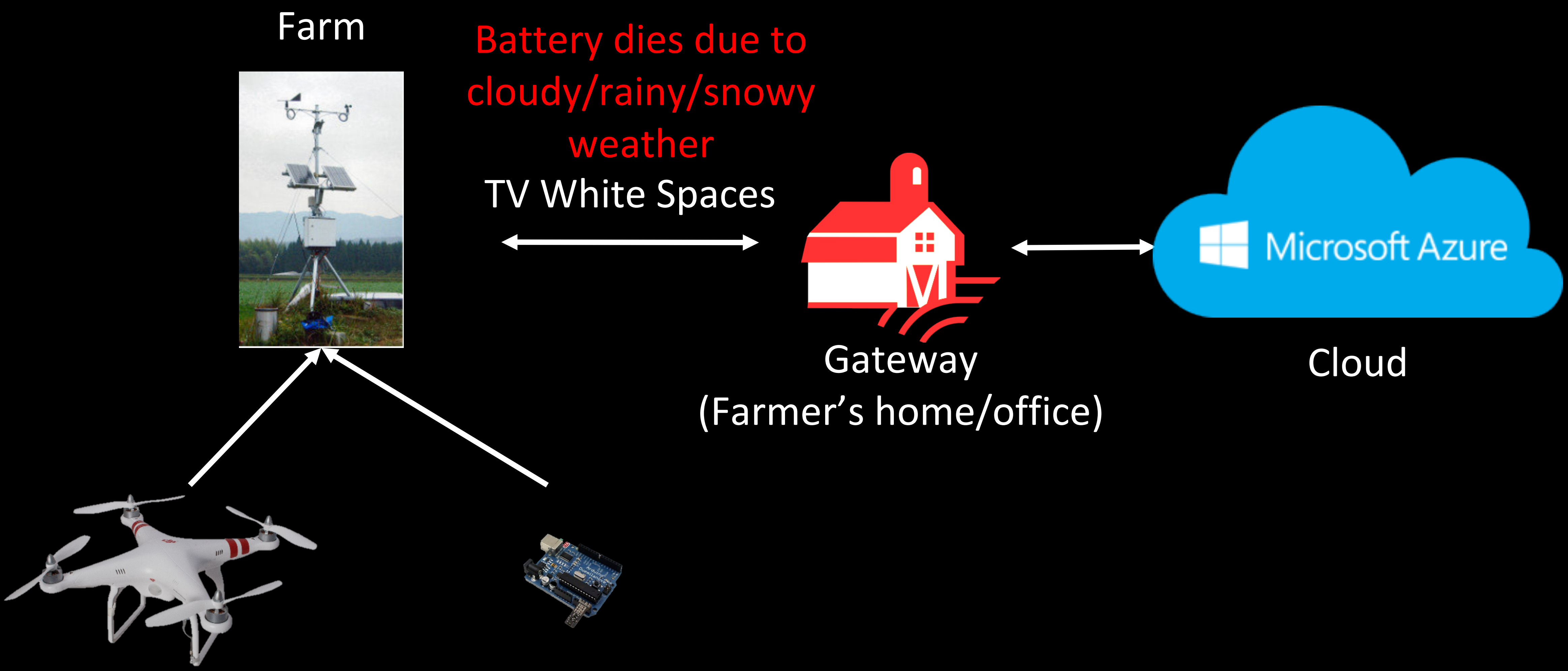
Challenge: Power Availability is Variable



Challenge: Power Availability is Variable

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

How do we deal with weather-based power variability?

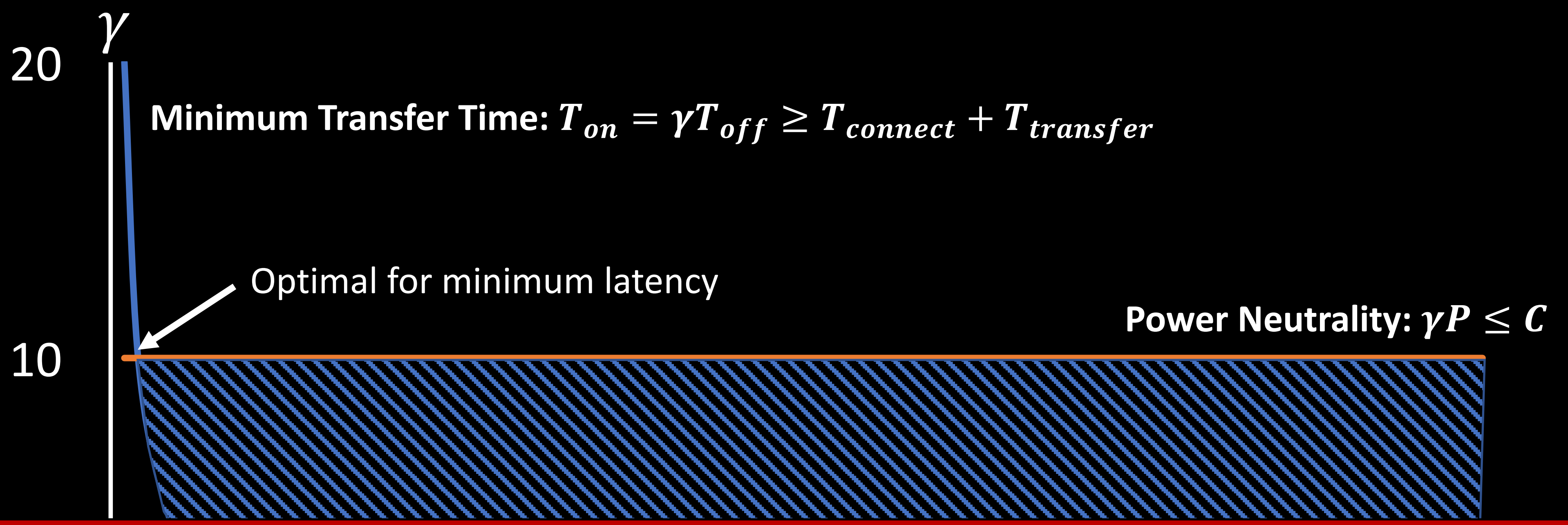
Idea: Weather is Predictable

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

Idea: Weather is Predictable

- γ: Duty Cycle ratio, T_{on}: On time in each cycle, T_{off}: Off time
- $\gamma = \frac{T_{on}}{T_{off}}$
- Constraints:
  - **Power Neutrality:** $\boldsymbol{\gamma P \leq C}$
  - **Minimum Transfer Time:** $\boldsymbol{T_{on} \geq T_{connect} + T_{transfer}}$

Solution: Weather is predictable



FarmBeats can use weather forecasts to duty cycle the base station, with minimum latency

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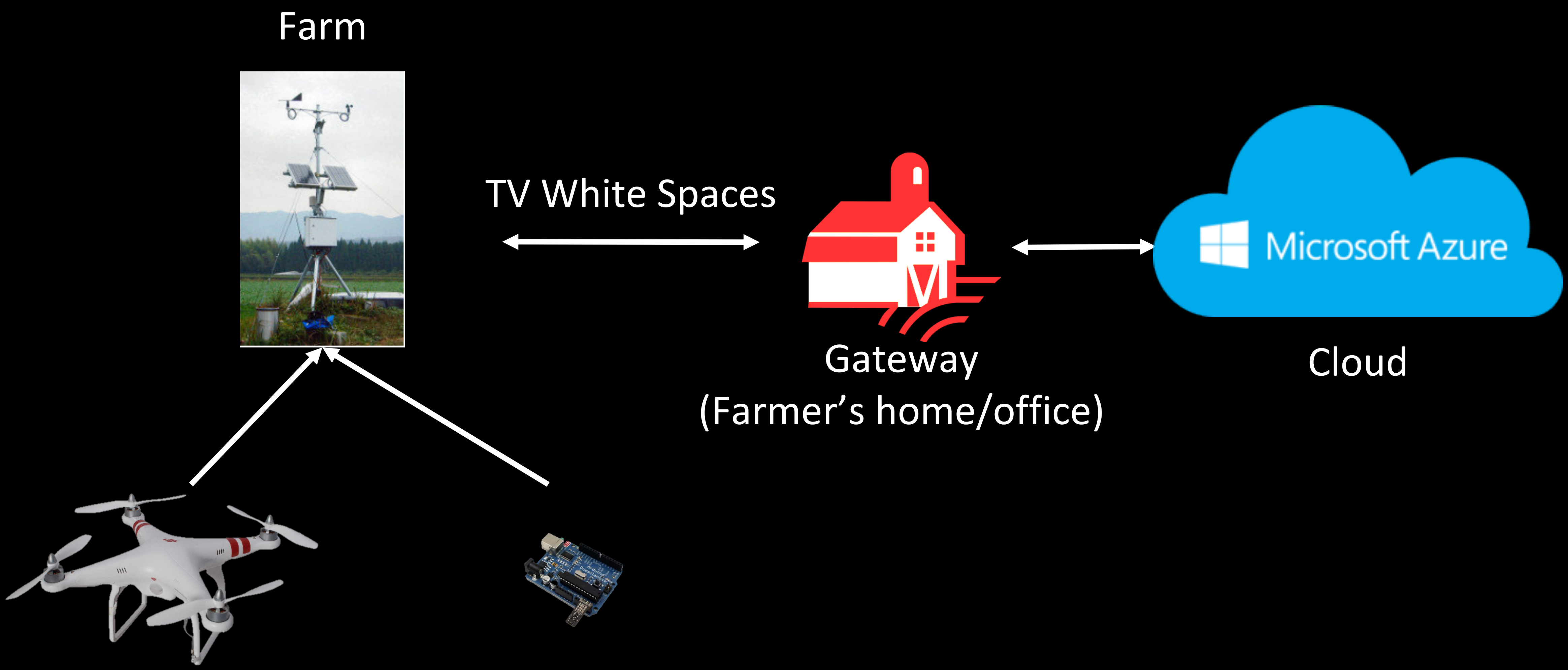
Deployment

- Six months deployment in two farms: Upstate NY (Essex), WA (Carnation)
- The farm sizes were 100 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

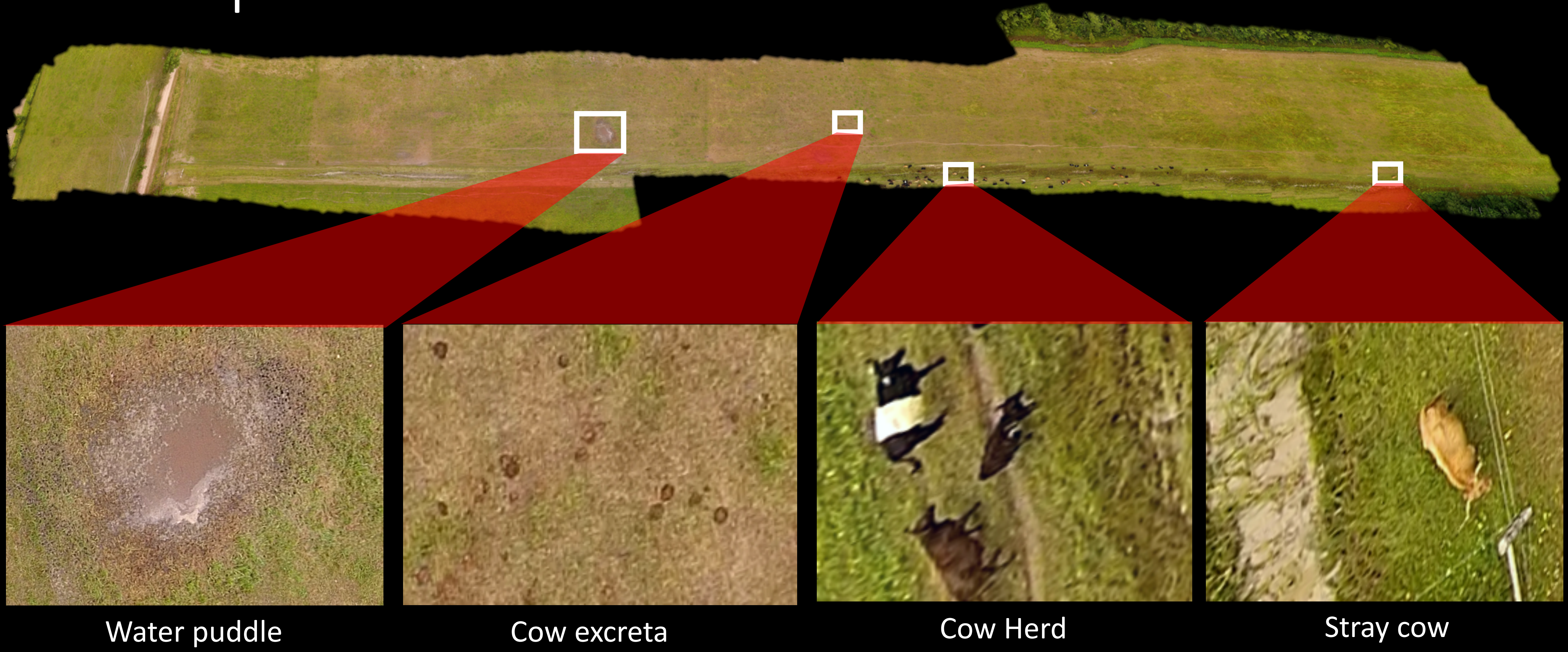
Deployment Statistics

- Used 10 sensor types, 3 camera types and 3 drone versions
- Deployed >100 sensors and ~10 cameras
- Collected >10 million sensor measurements, >0.5 million images, 100 drone surveys
- Resilient to week long outage from a thunderstorm

FarmBeats: Usage

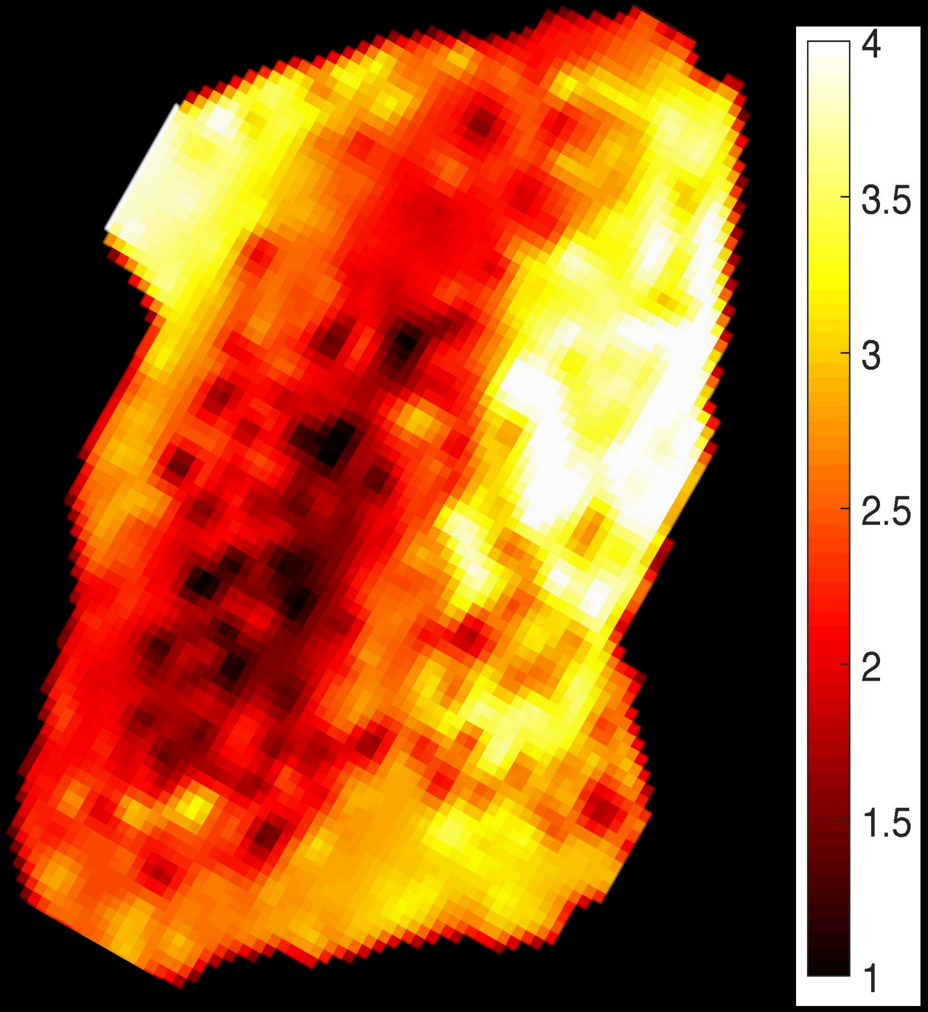


Example: Panorama

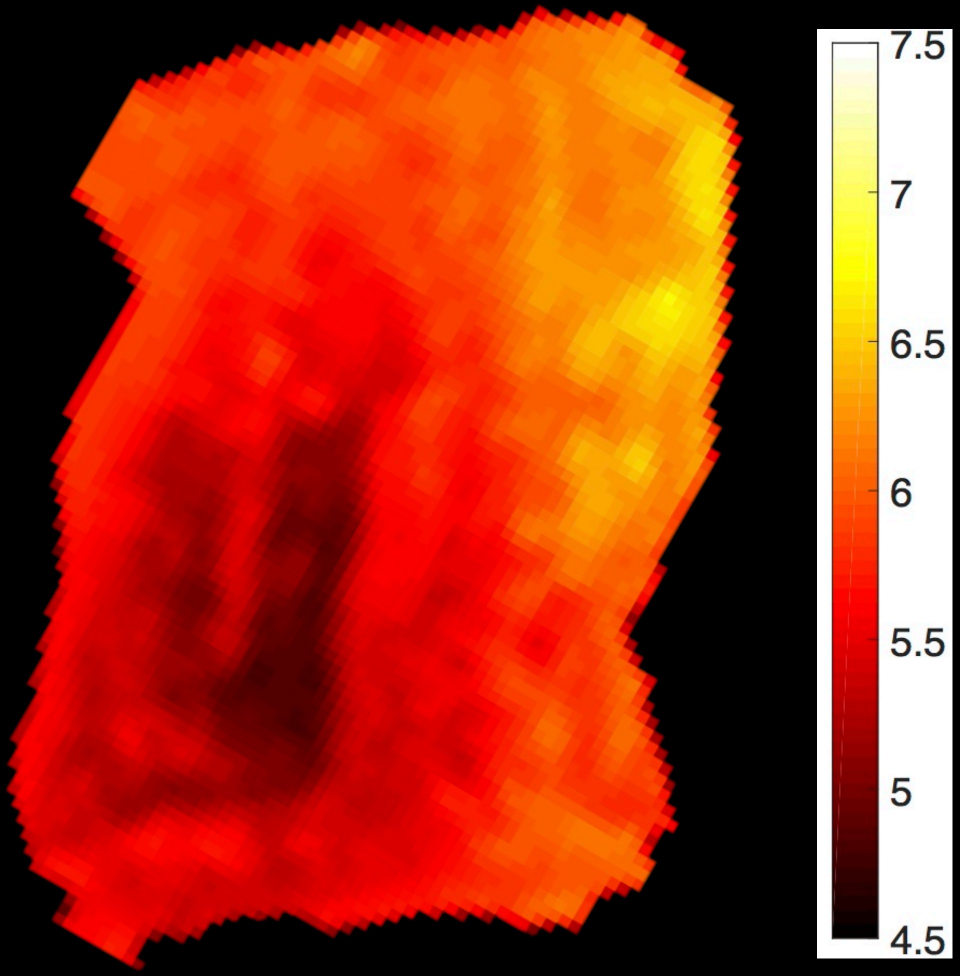


Precision Map: Panorama Generation

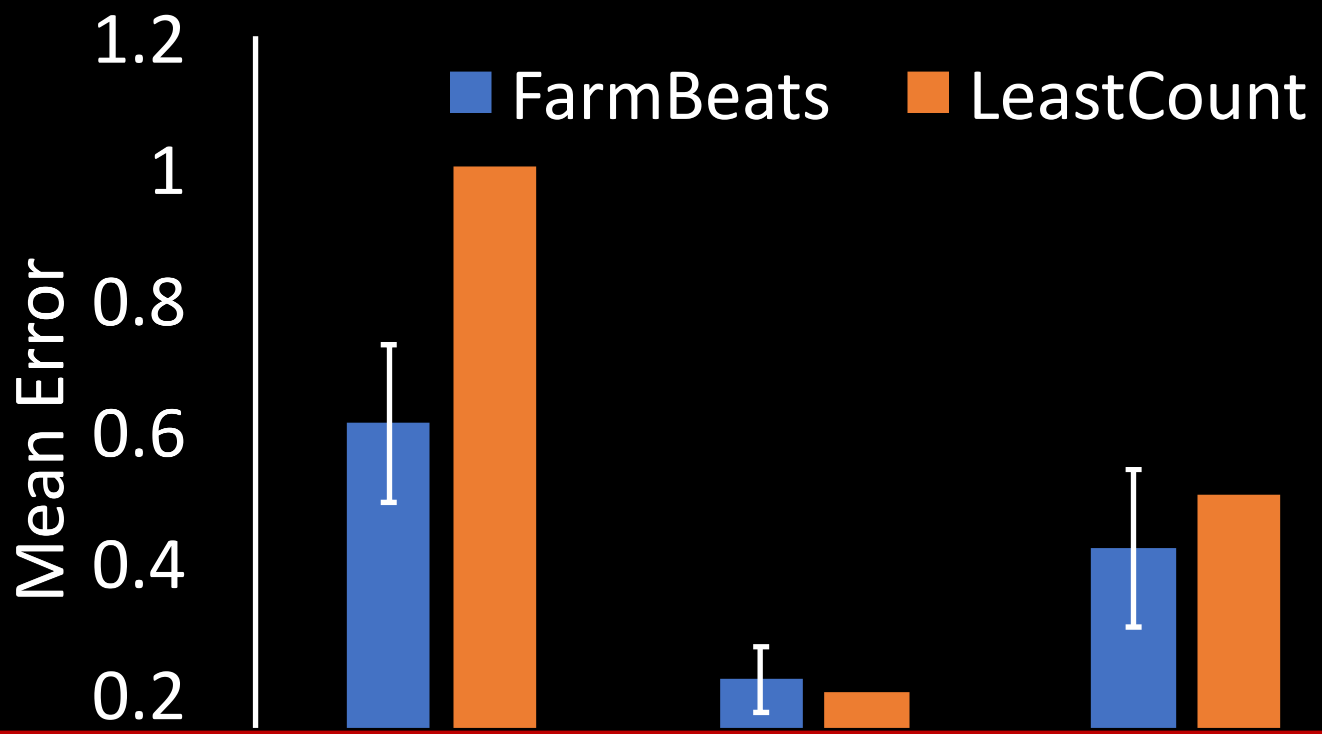
Precision Map : Moisture



Precision Map : pH

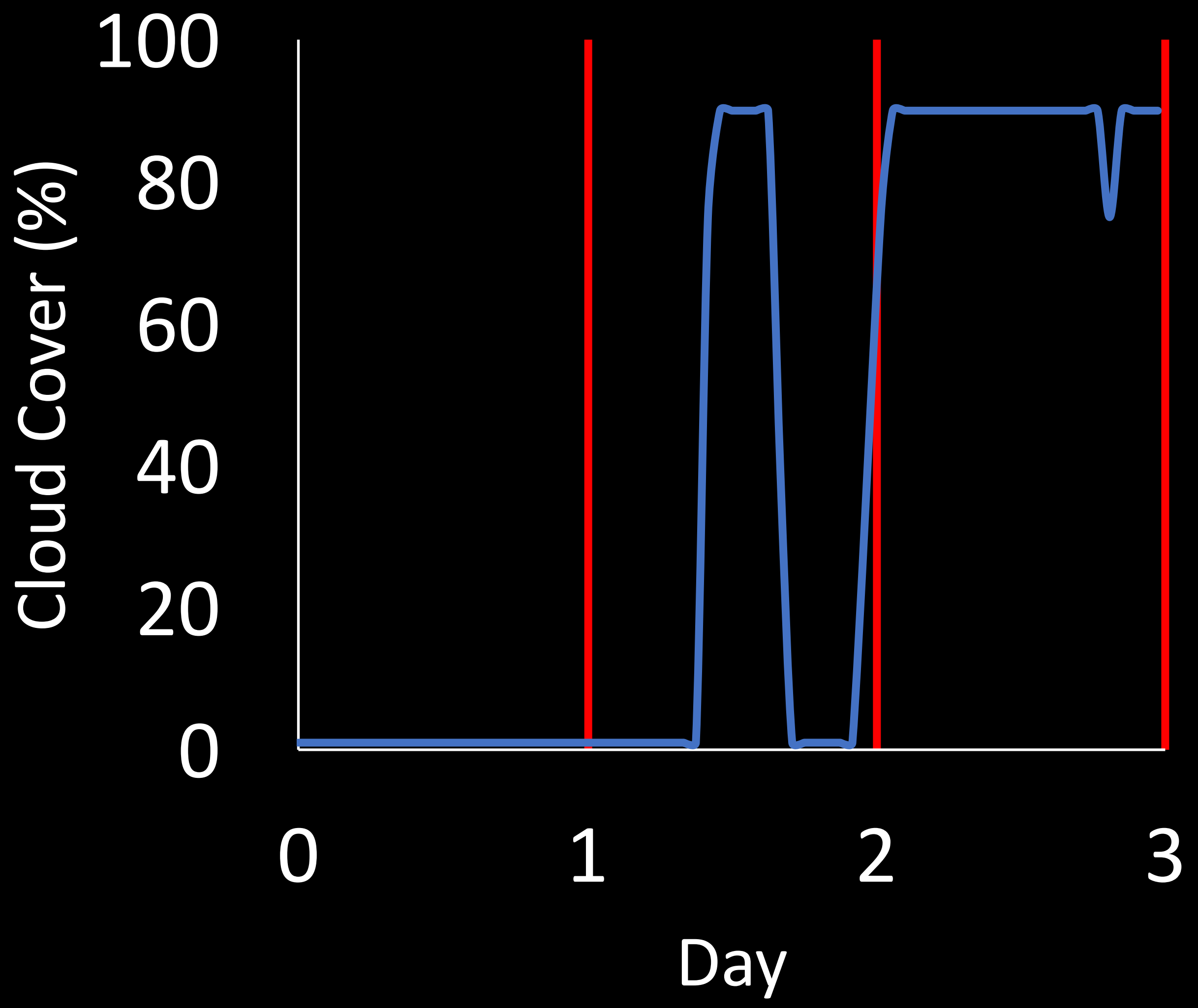


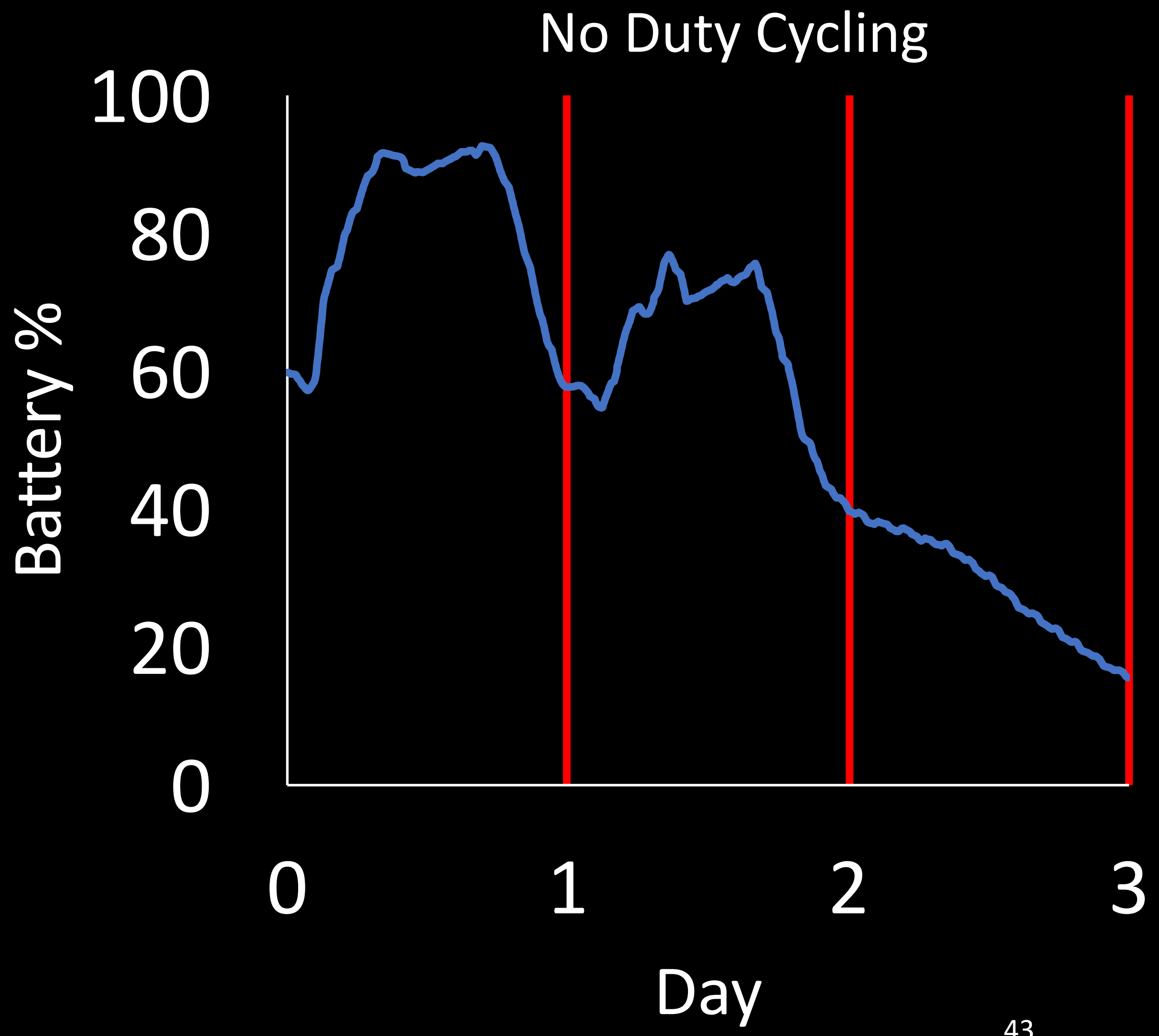
Precision Map: Accuracy



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

Weather-Aware Duty Cycling





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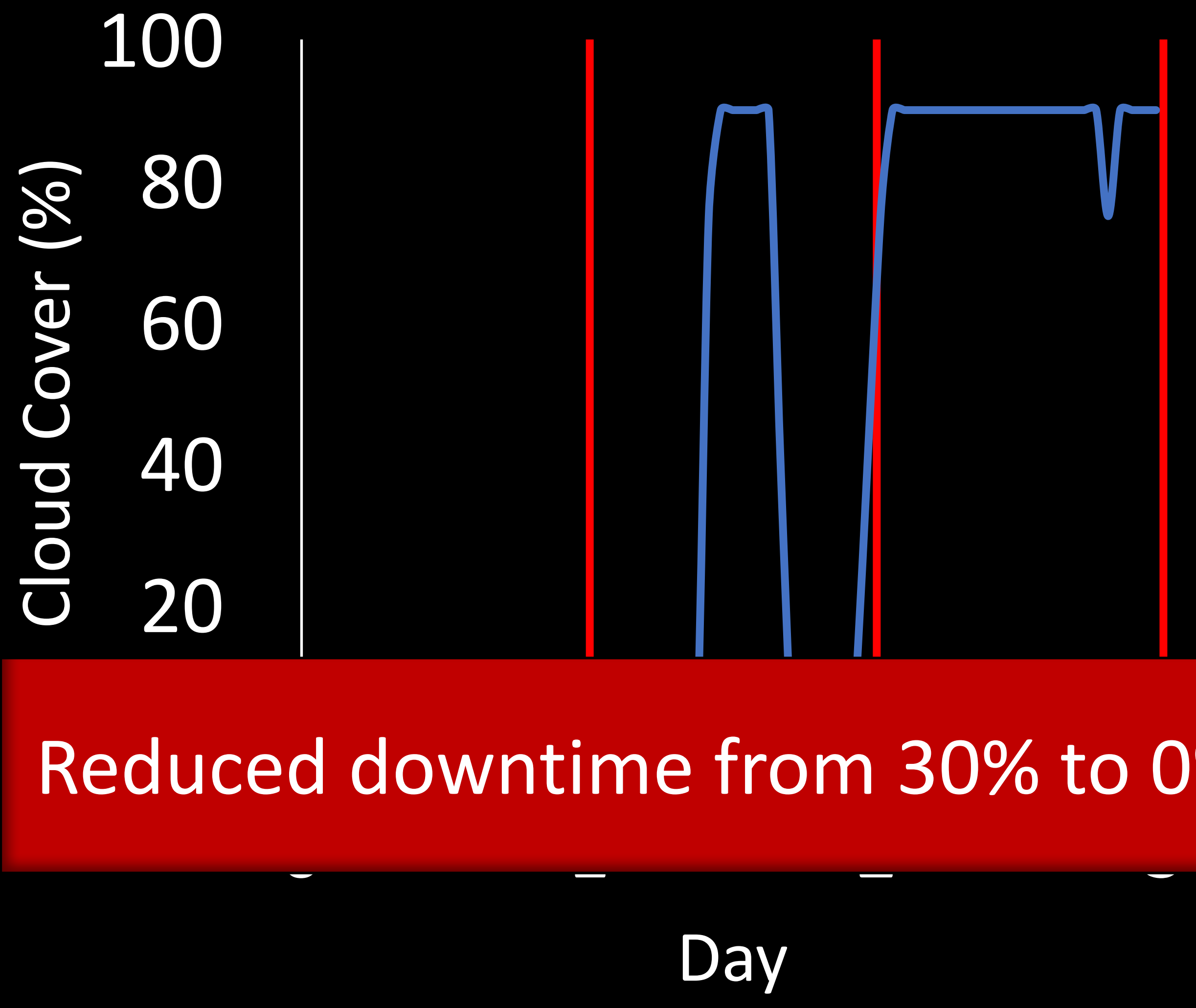

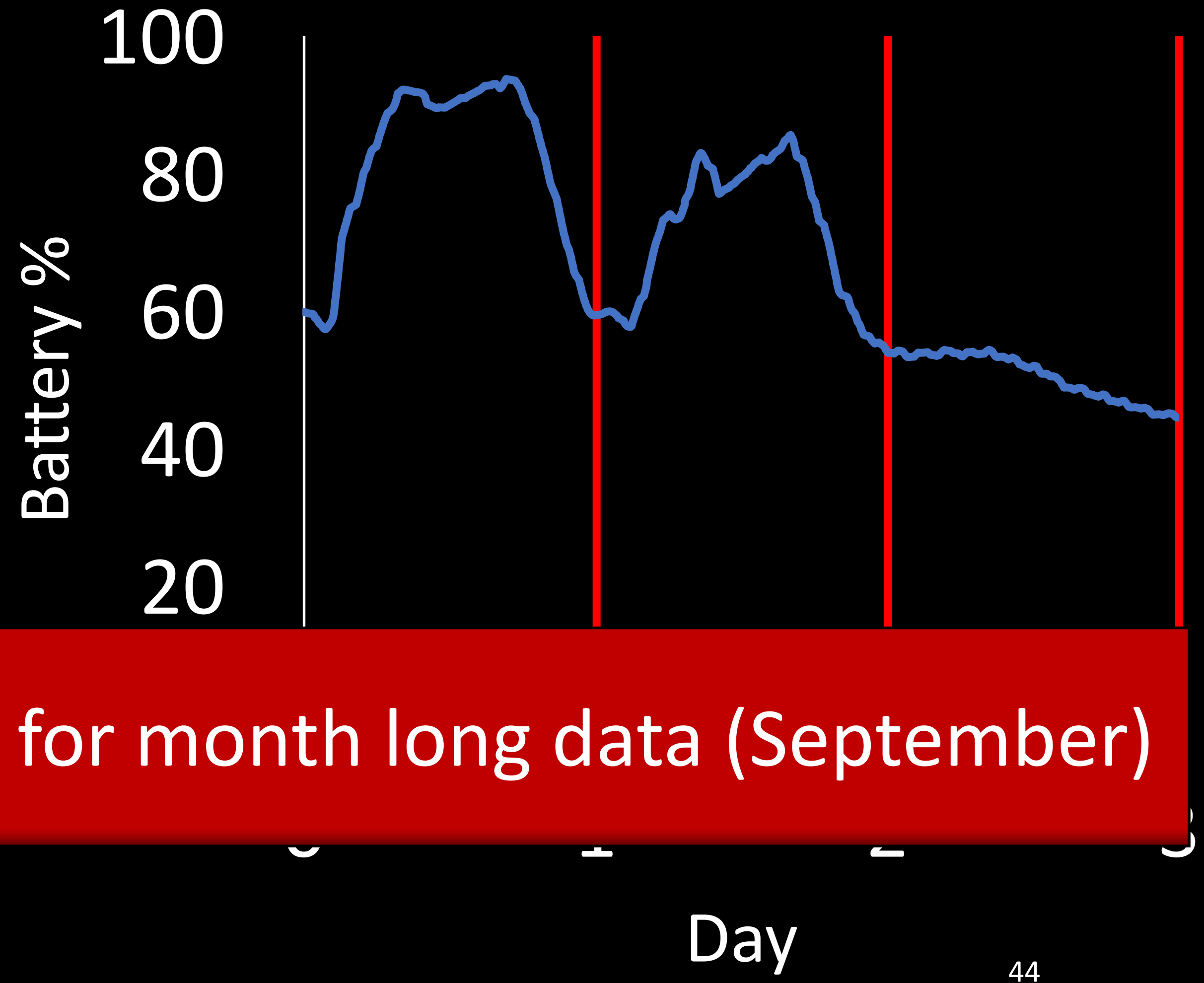

Reduced downtime from 30% to 0% for month long data (September)

Related Work

- **Wireless Sensor Networks:** Sensor networks for agriculture (Baggio `05, Sanchez et al `11, Lee et al `10,…), LPWAN technologies (LoRA, SIGFOX, …)
- **Agriculture:** Precision agriculture (Bratney et al `99, Mueller et al `12, Cassman et al `99,..), Nutrient measurement (Kim et al `09, Hanson et al `07)
- **ICTD:** Information access and user interfaces (Zhao et al `10, Doerflinger et al 2012)

Conclusion

- FarmBeats: First end to end IoT system for environments constrained by:
  - Limited internet connectivity
  - Power Variability
  - Sparse Sensor Deployment
- Acts as a tool to enhance farm and farmer productivity
- Used by farmers for applications beyond precision farming

Thank you!

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Mark & Kirstin Kimball, Essex Farm, NY