

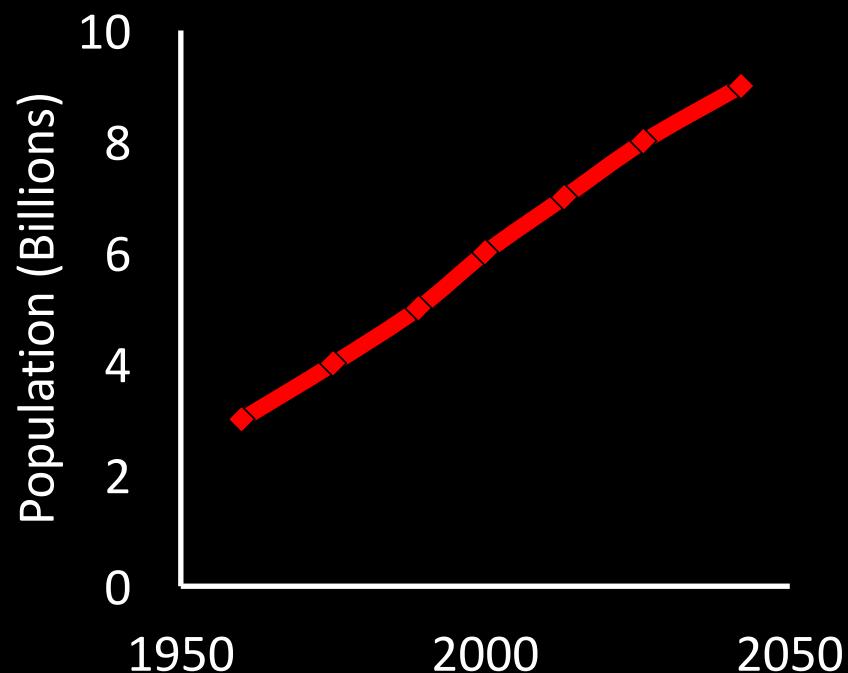
FarmBeats: An IoT System for Data-Driven Agriculture

Deepak Vasisht, Zerina Kapetanovic, Jong-ho Won, Xinxin Jin,
Ranveer Chandra, Ashish Kapoor, Sudipta N. Sinha, Madhusudhan Sudarshan, Sean Stratman



Why Agriculture?

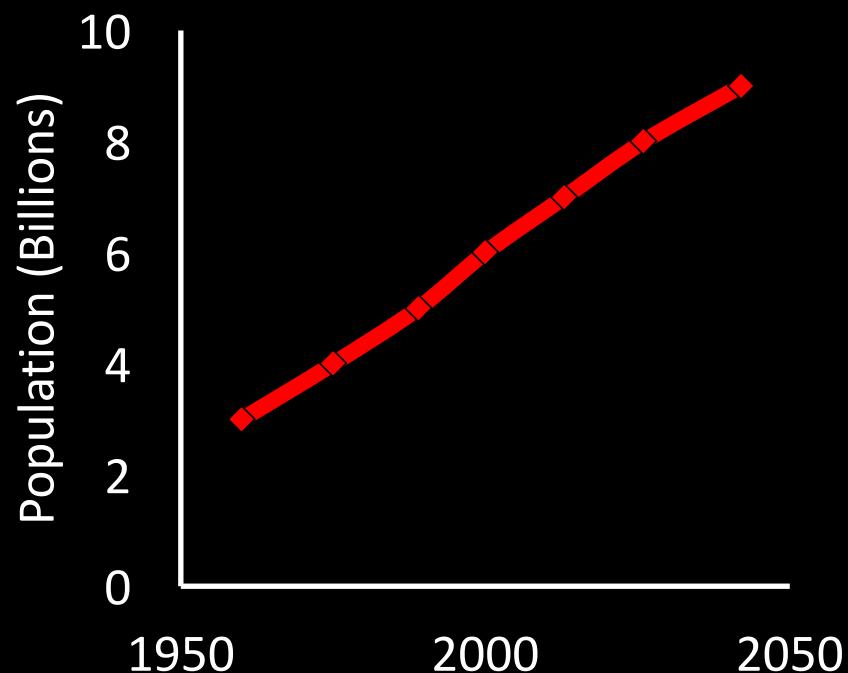
Agricultural output needs to **double** by 2050 to meet the demands
– United Nations¹



¹: United Nations Second Committee (Economic & Financial)², 2009

Why Agriculture?

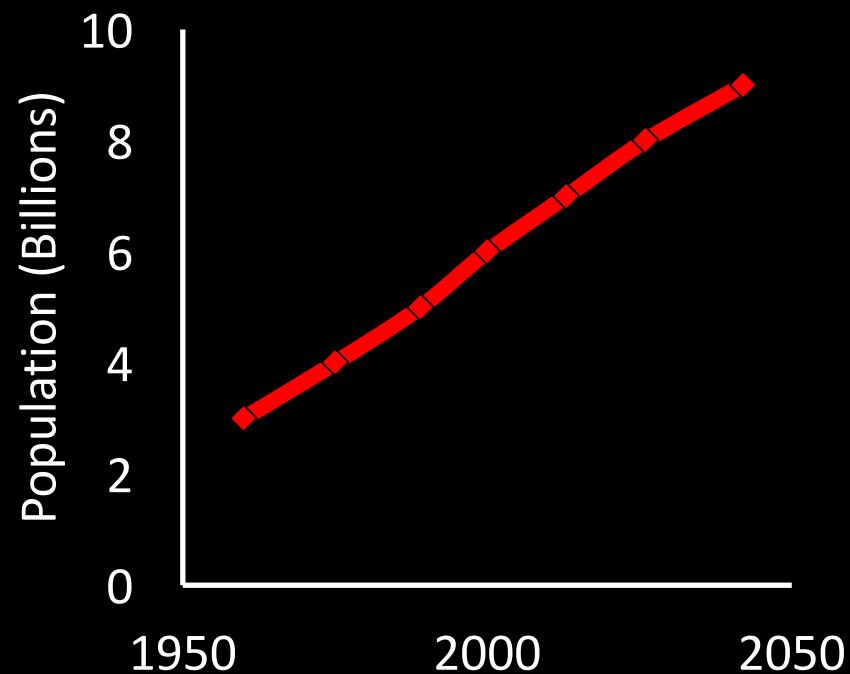
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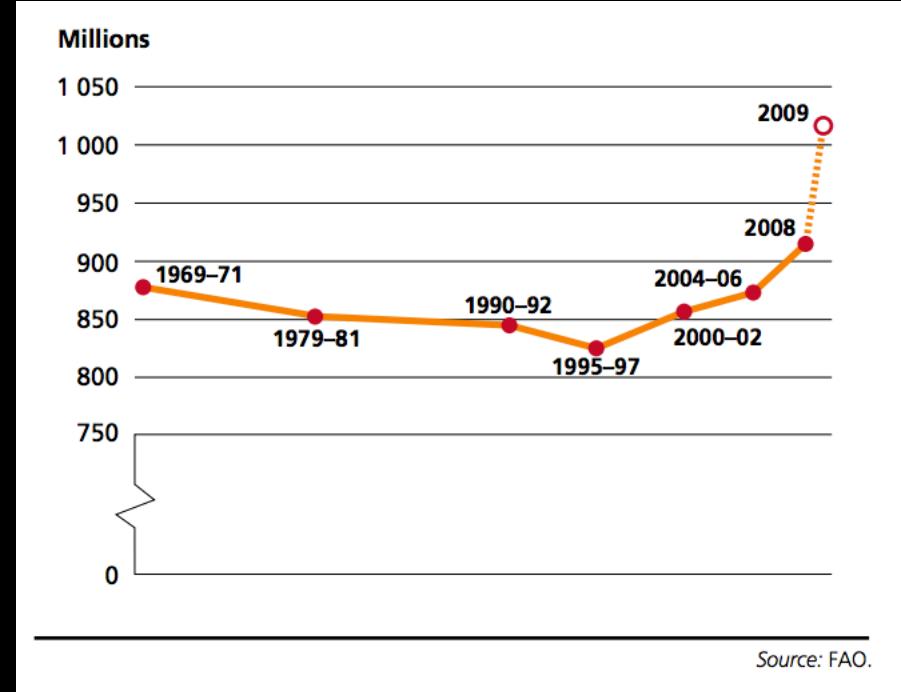
- But...
- Water levels are receding
 - Arable land is shrinking
 - Environment is being degraded

Why Agriculture?

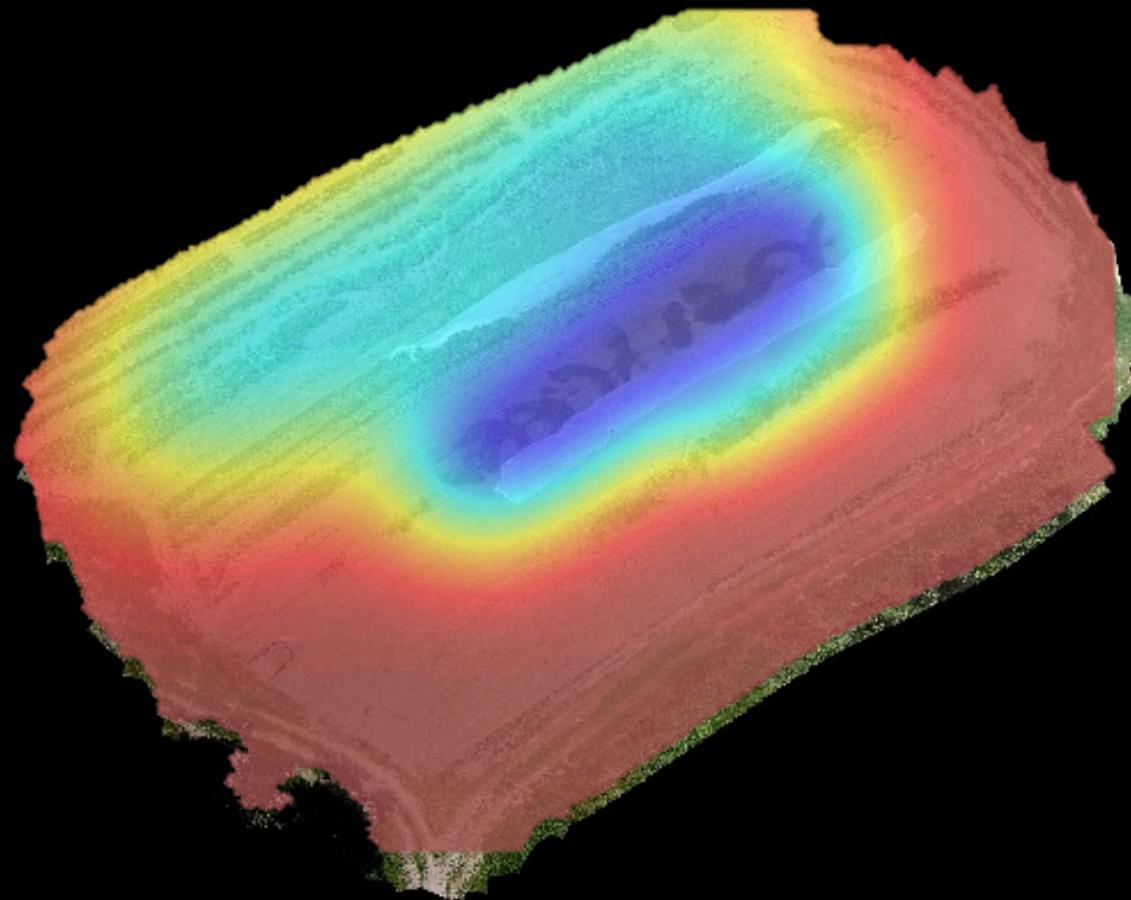
Agricultural output needs to **double** by 2050 to meet the demands
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Number of World's Hungry People



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



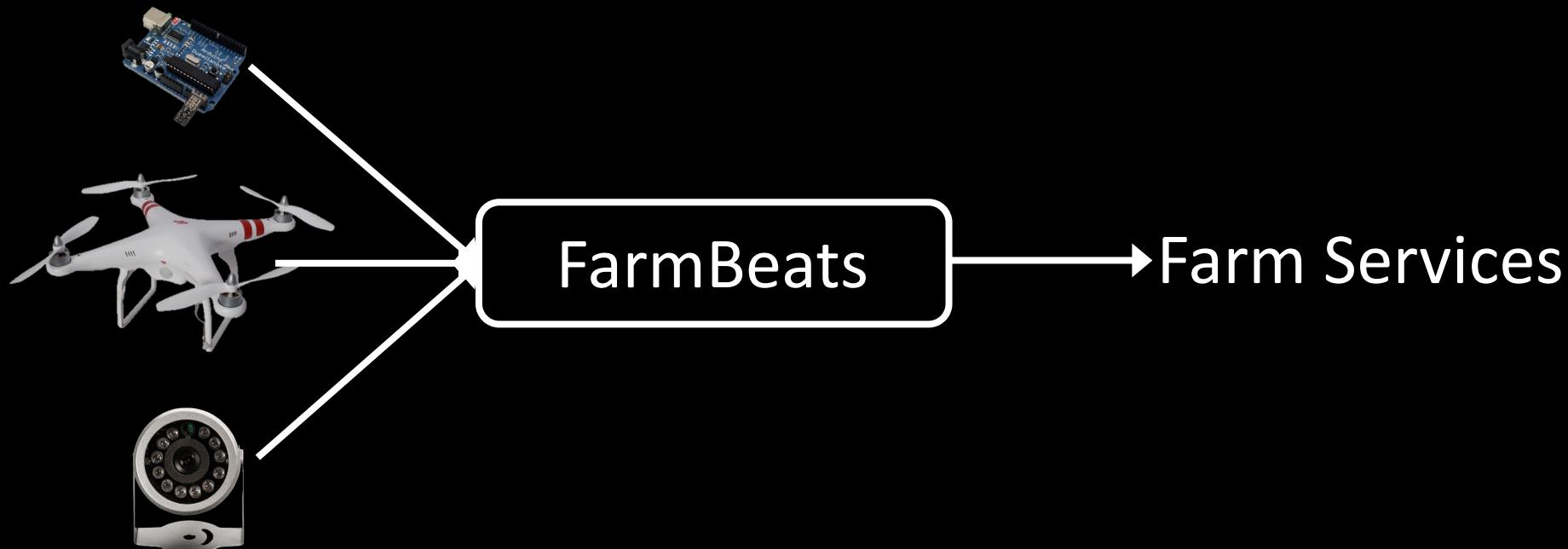
Oil Fields



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

In this talk

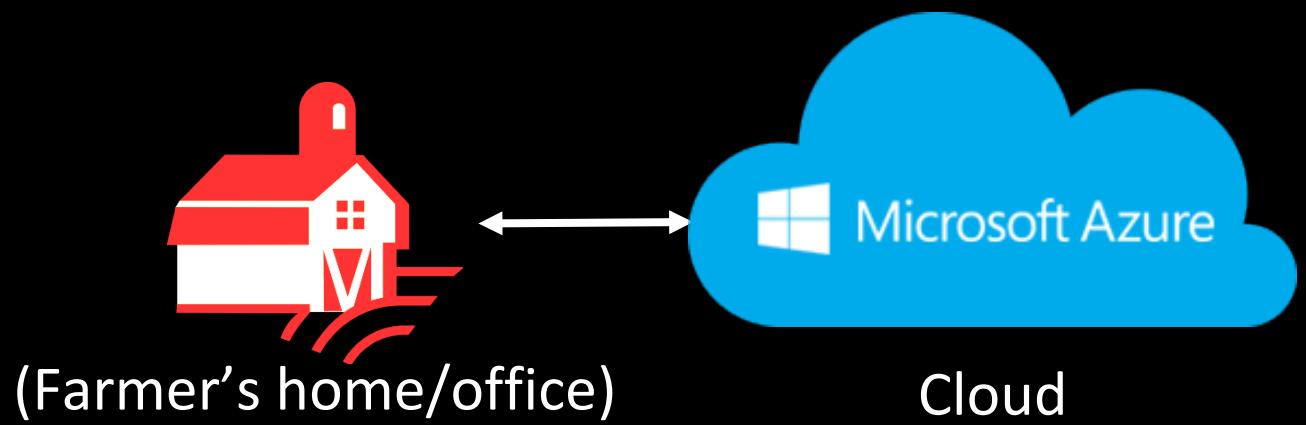
- FarmBeats: An end-to-end IoT system that enables seamless data collection for agriculture



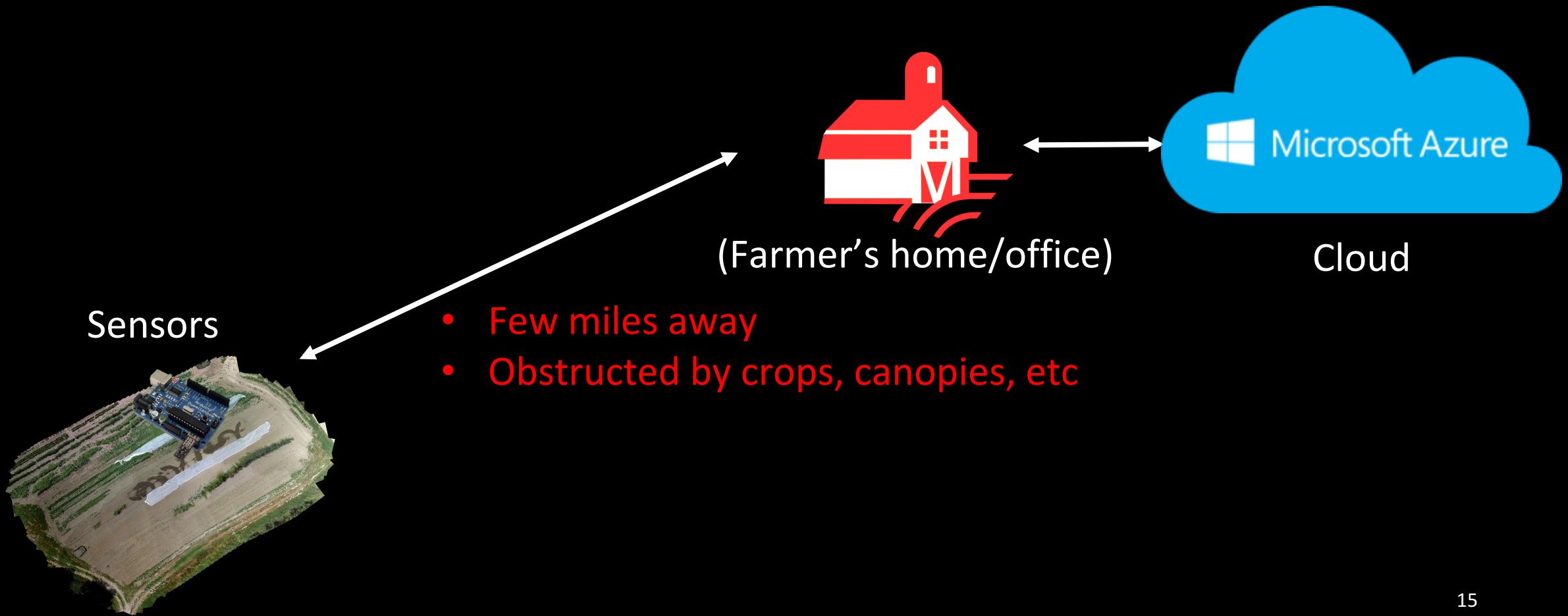
In this talk

- 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



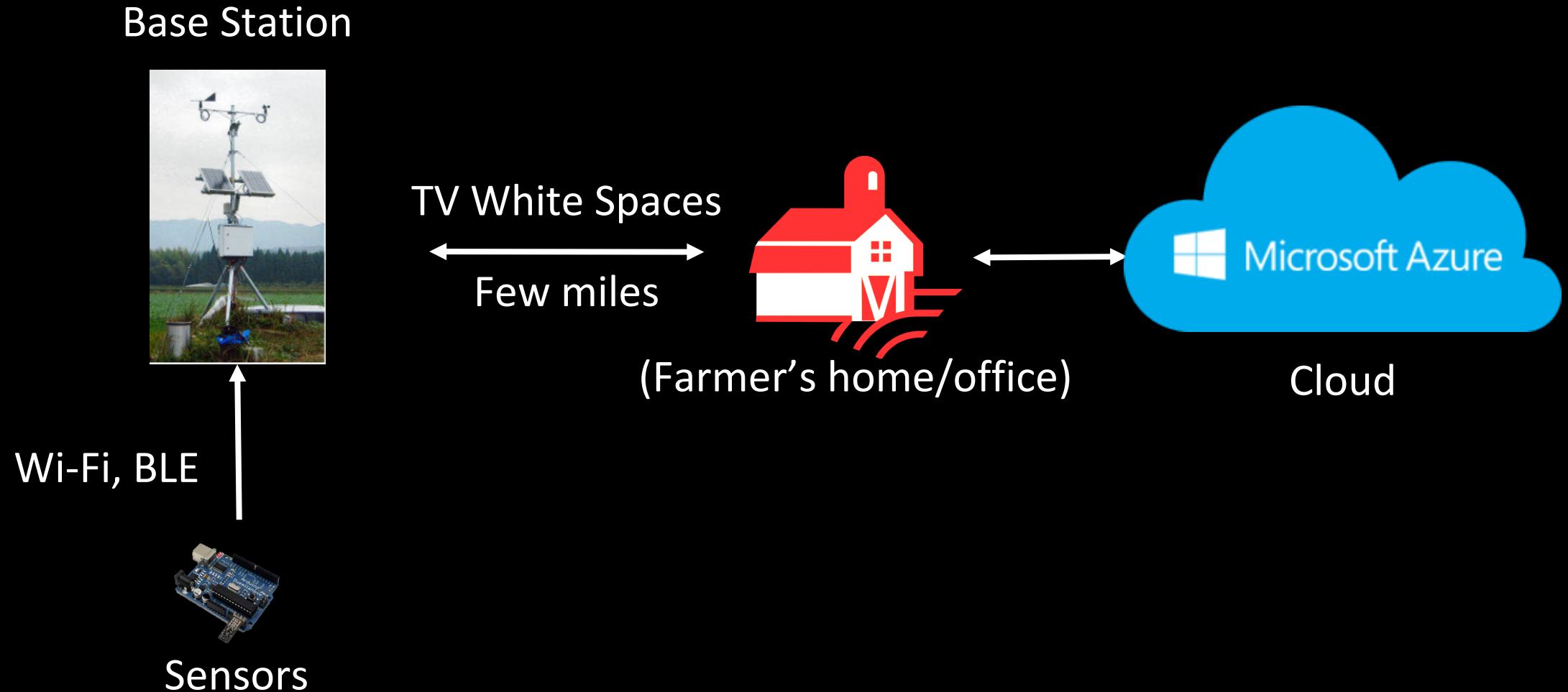
Challenge: Internet Connectivity



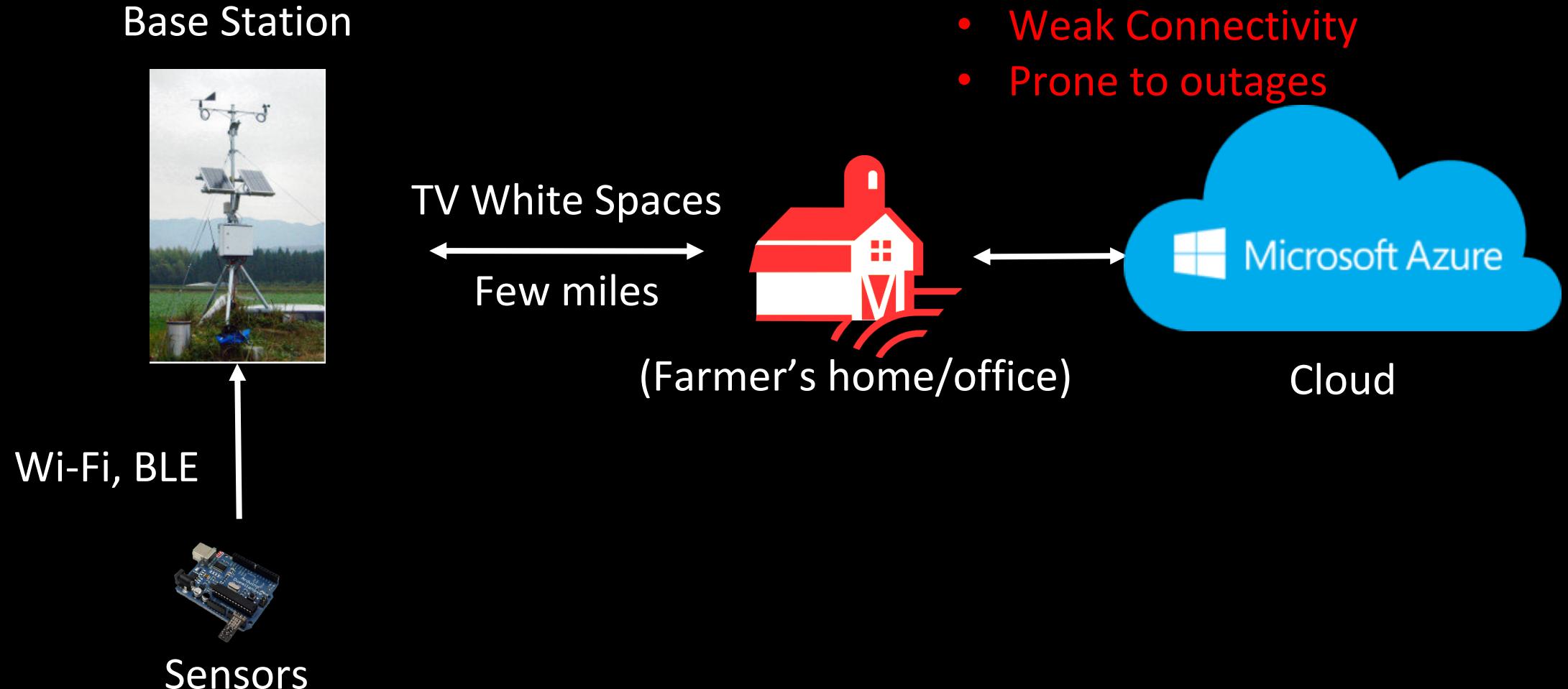
Idea: Use TV White Spaces

- 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



Idea: Use TV White Spaces



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

Base Station



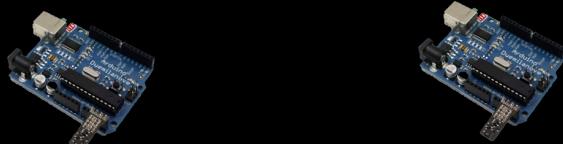
TV White Spaces
↔
Few miles



Gateway PC
(Farmer's home/office)



Cloud



Sensors

In this talk

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Challenge: Limited Resources

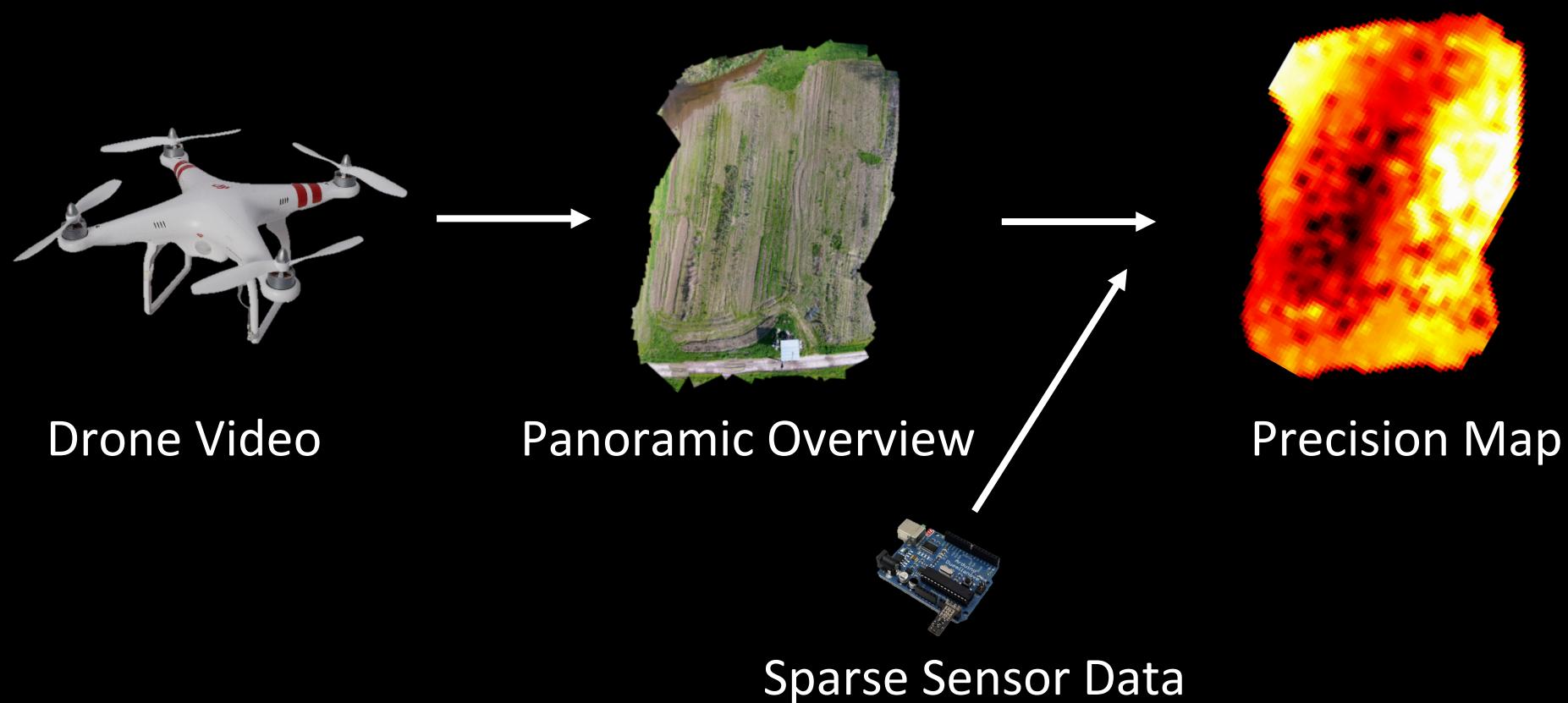
- Need to work with sparse sensor deployments
 - Physical constraints due to farming practices
 - Too expensive to deploy and maintain
- How do we get coverage with a sparse sensor deployment?

Idea: Use Drones to Enhance Spatial Coverage

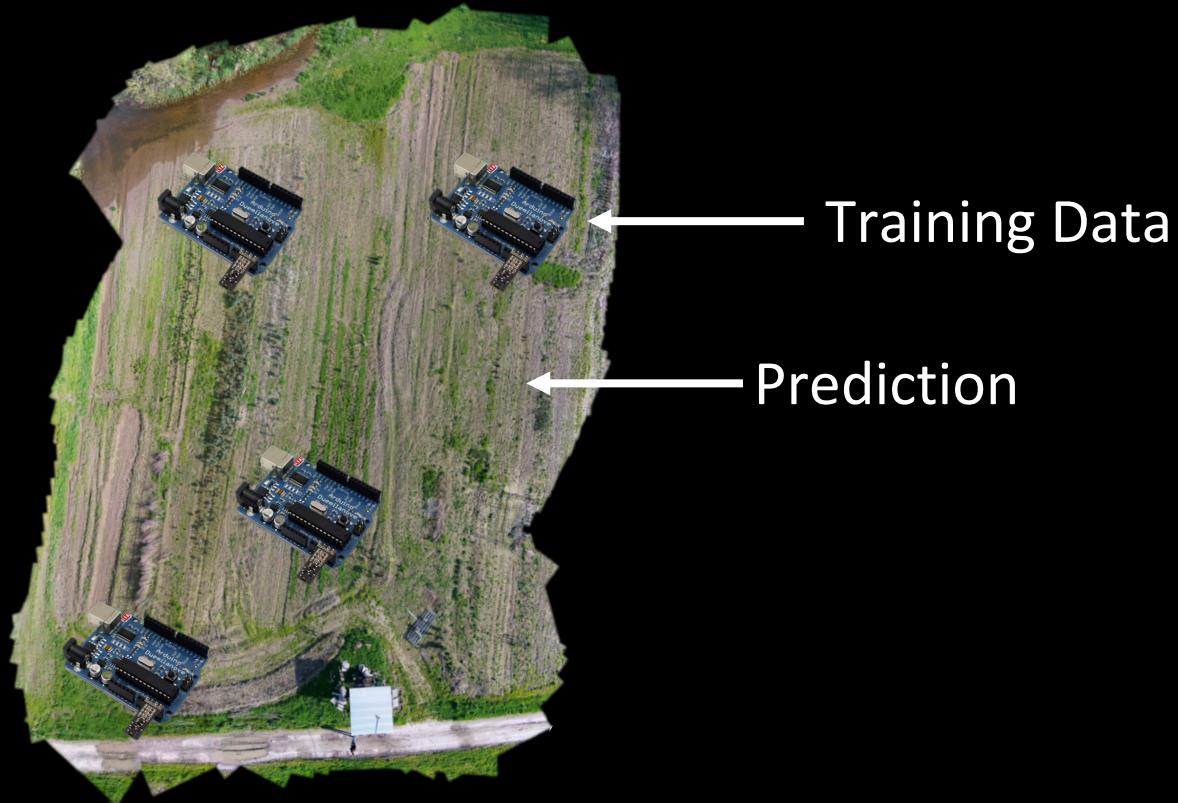
- Drones are cheap and automatic
- Can cover large areas quickly
- Can collect visual data

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

Idea: Use Drones to Enhance Spatial Coverage



Formulate as a Learning Problem



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



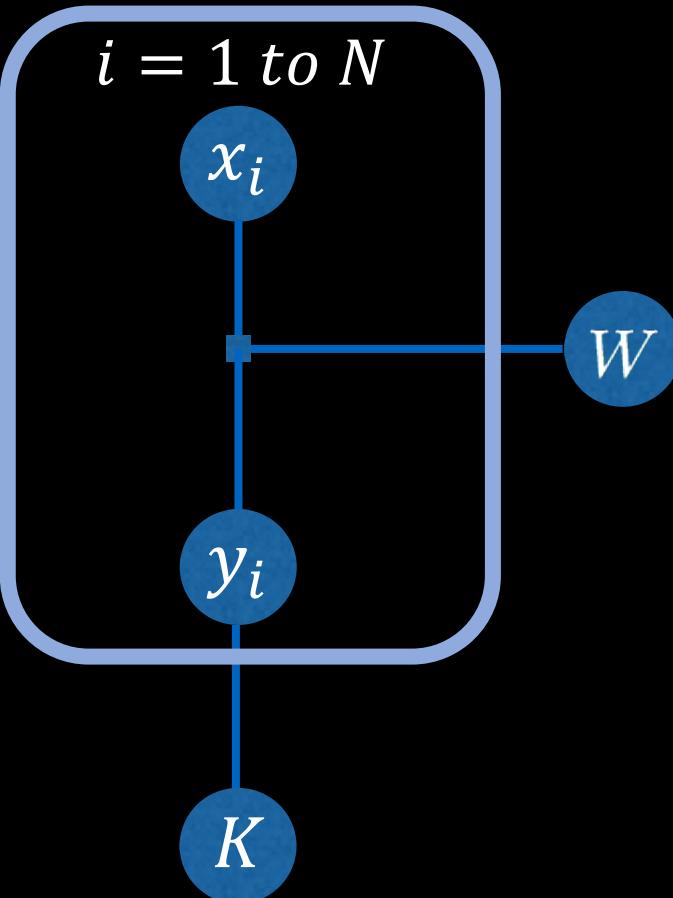
Model

Features (visual)

Kernel (Model visual similarity)

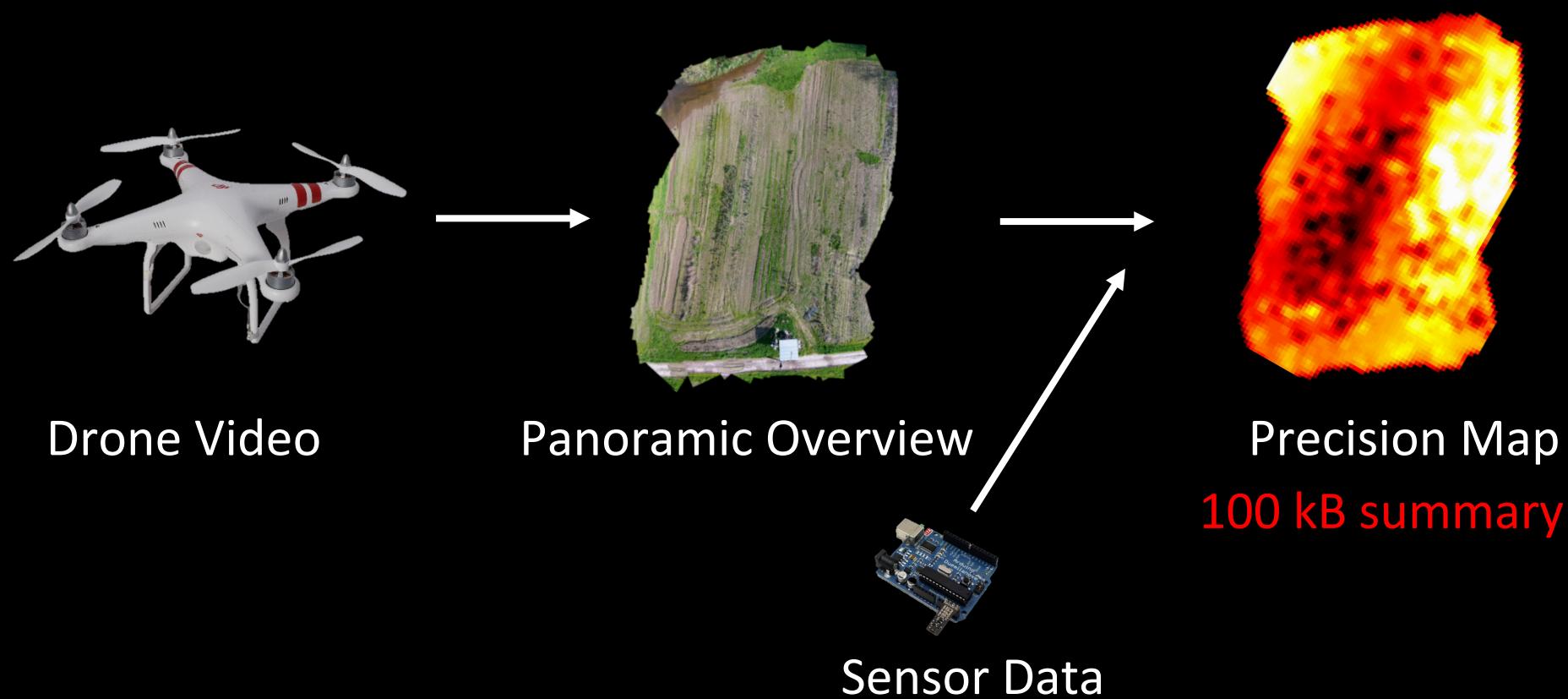
Output (say, moisture)

Spatial Smoothness

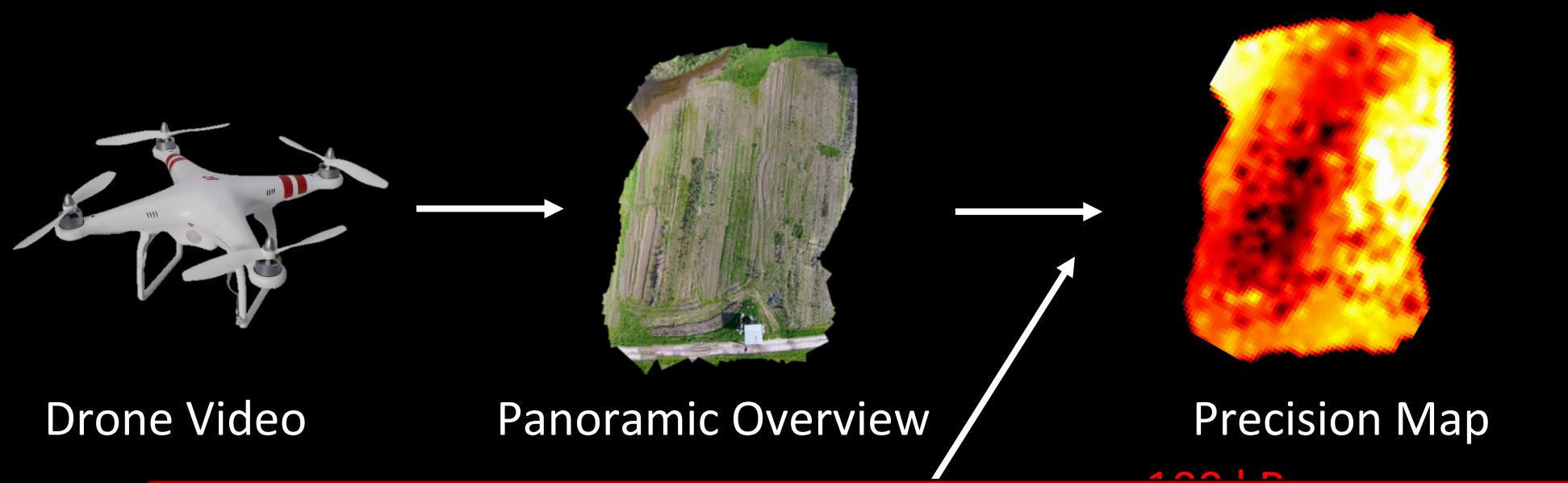


- **Training Phase:** Learn K and W
- **Test Phase:** Generate outputs for unknown areas

Using Sparse Sensor Data



Using Sparse Sensor Data

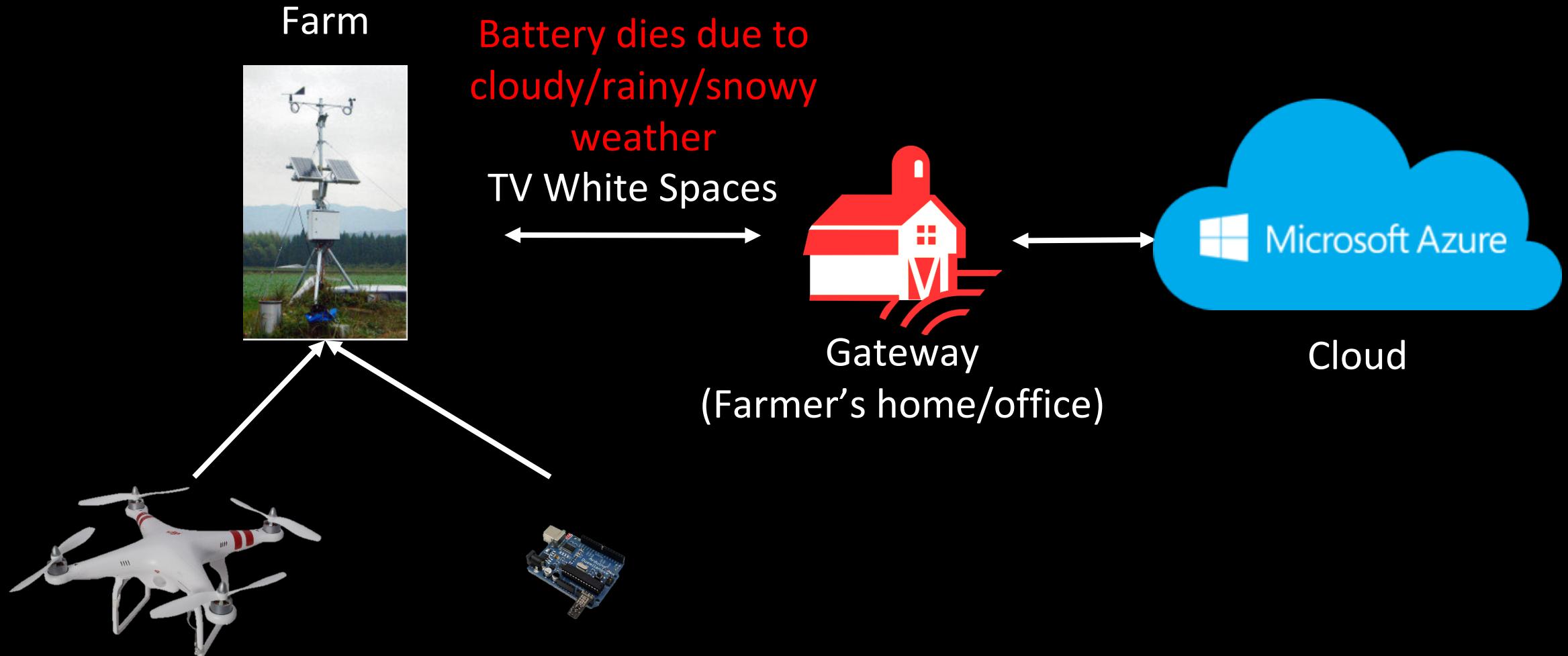


FarmBeats can use drones to expand the sparse sensor data and create summaries for the farm

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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?

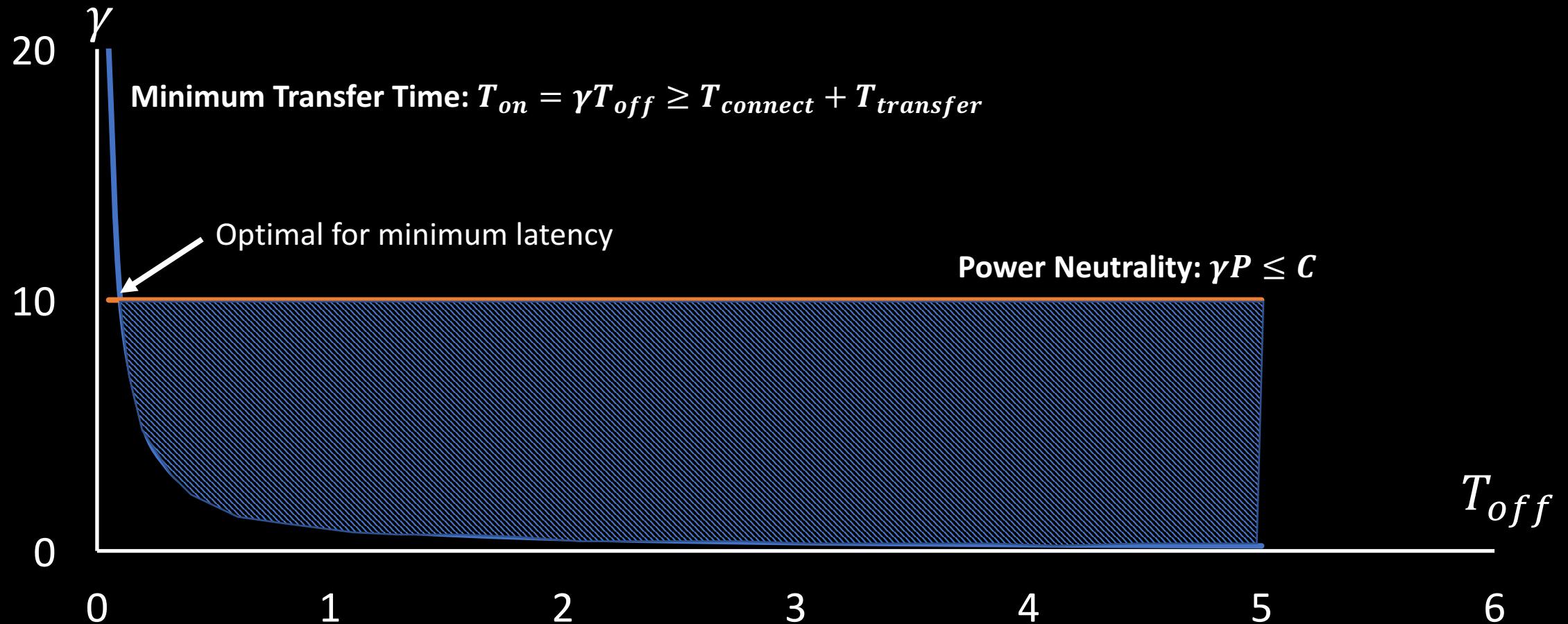
Idea: Weather is Predictable

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

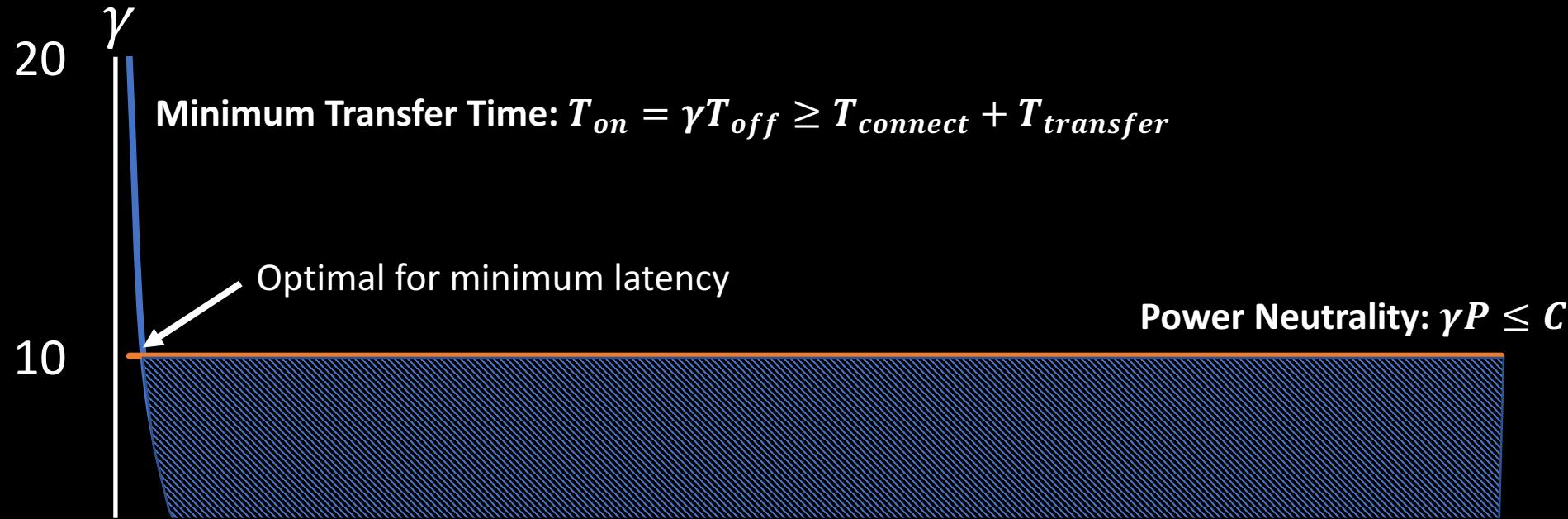
Idea: Weather is Predictable

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

Solution: Weather is predictable



Solution: Weather is predictable



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

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Deployment

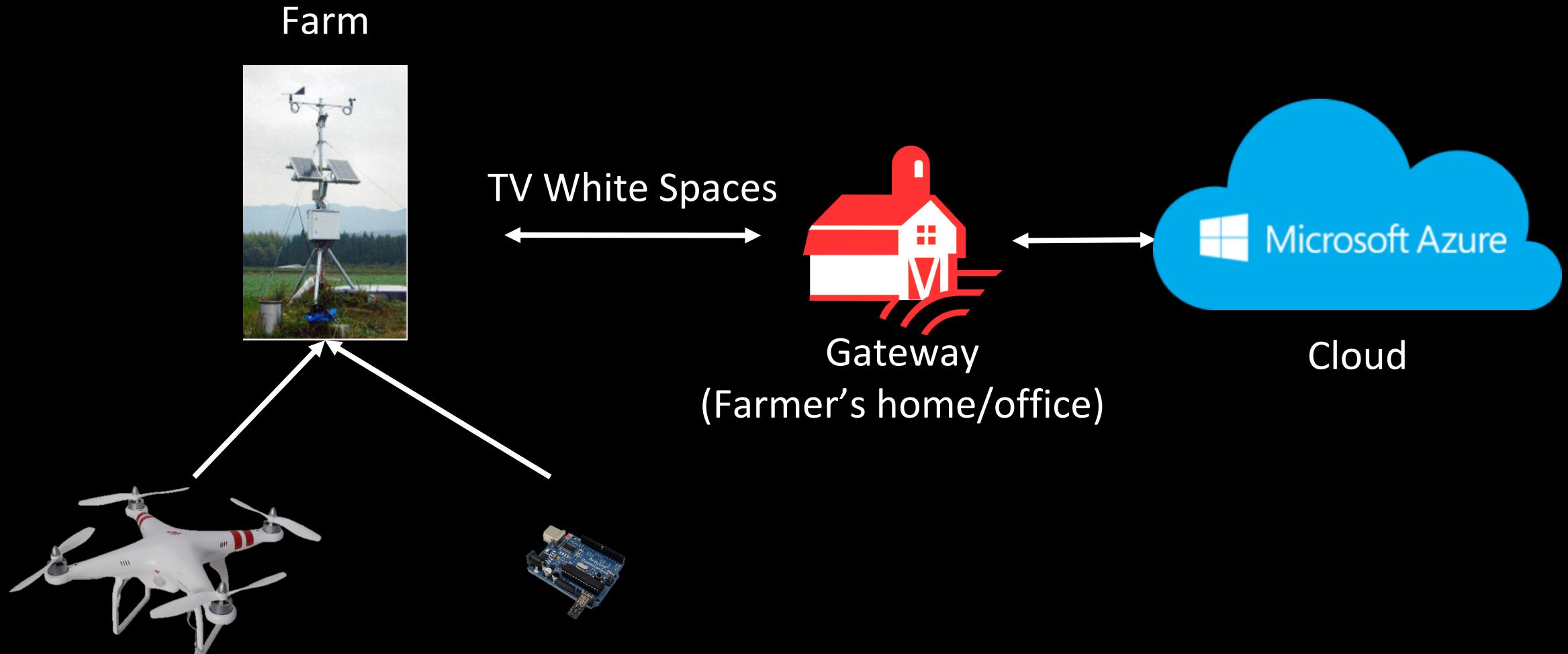
- Six months deployment in two farms: Upstate NY (Essex), WA (Carnation)
- The farm sizes were 100 acres and 5 acres respectively
- Sensors:
 - DJI Drones
 - Particle Photons with Moisture, Temperature, pH Sensors
 - IP Cameras to capture IR imagery as well as monitoring
- Cloud Components: Azure Storage and IoT Suite



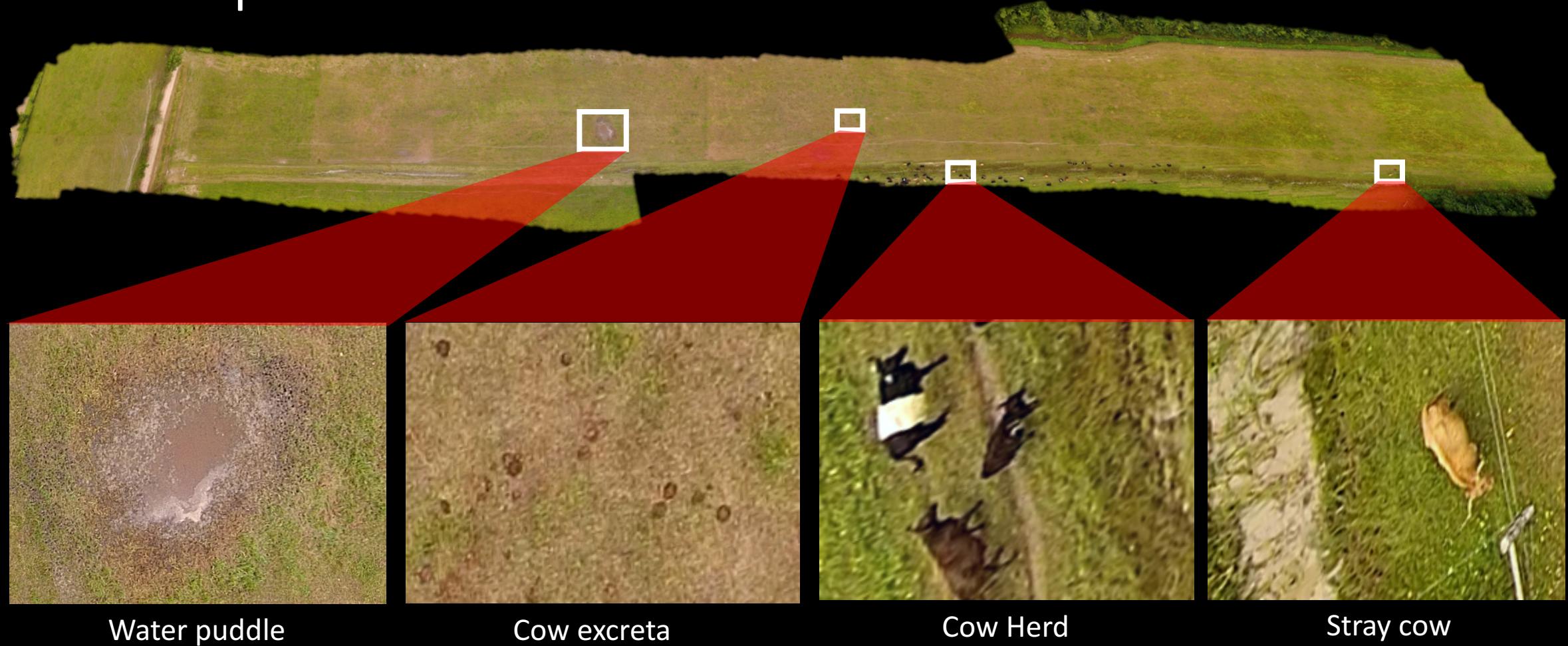
Deployment Statistics

- 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

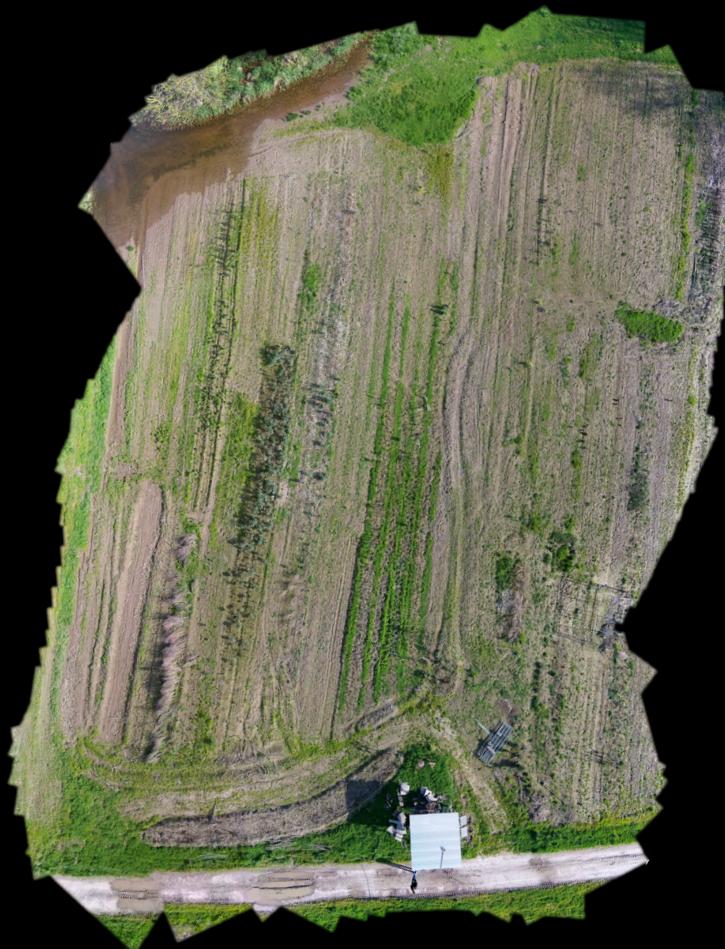
FarmBeats: Usage



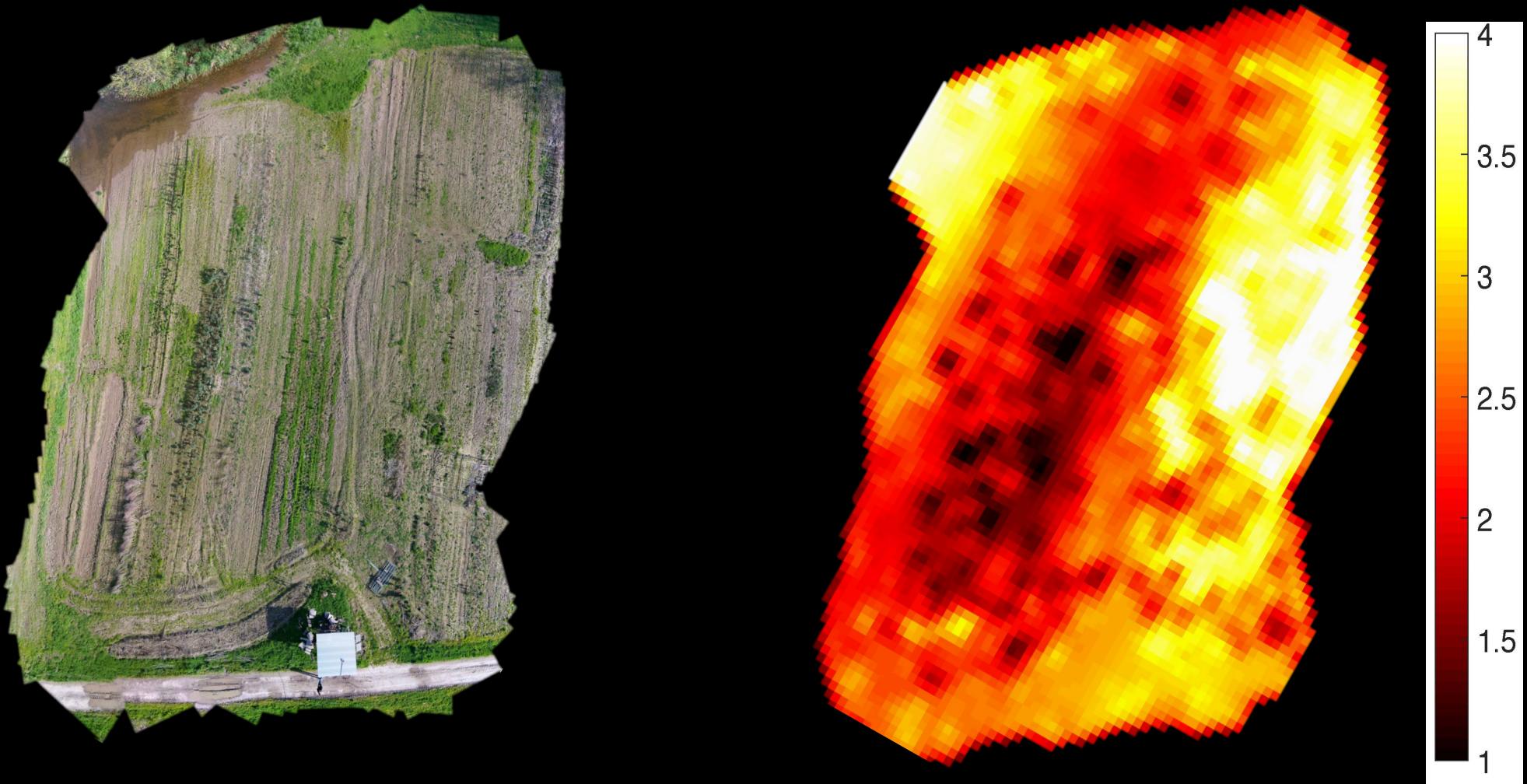
Example: Panorama



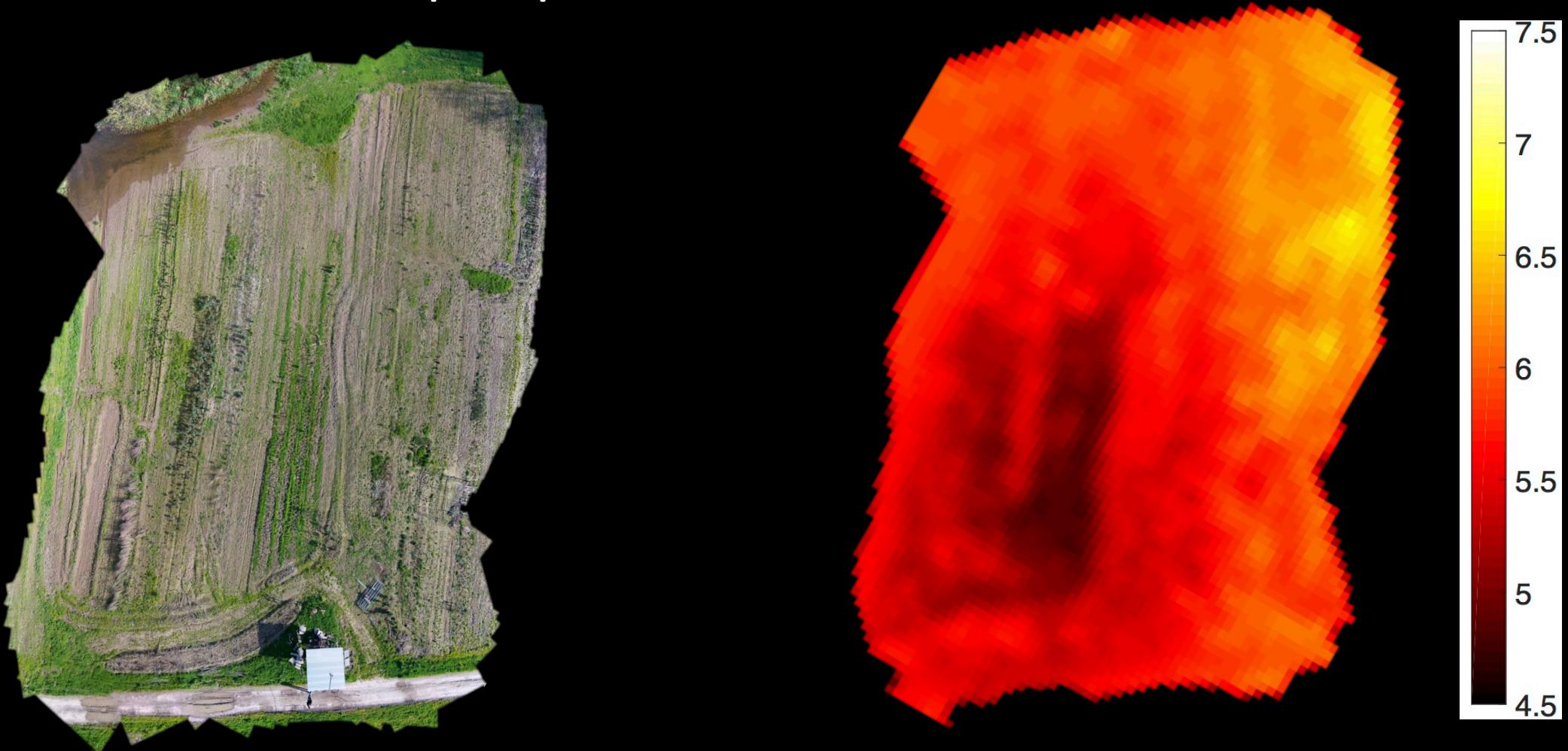
Precision Map: Panorama Generation



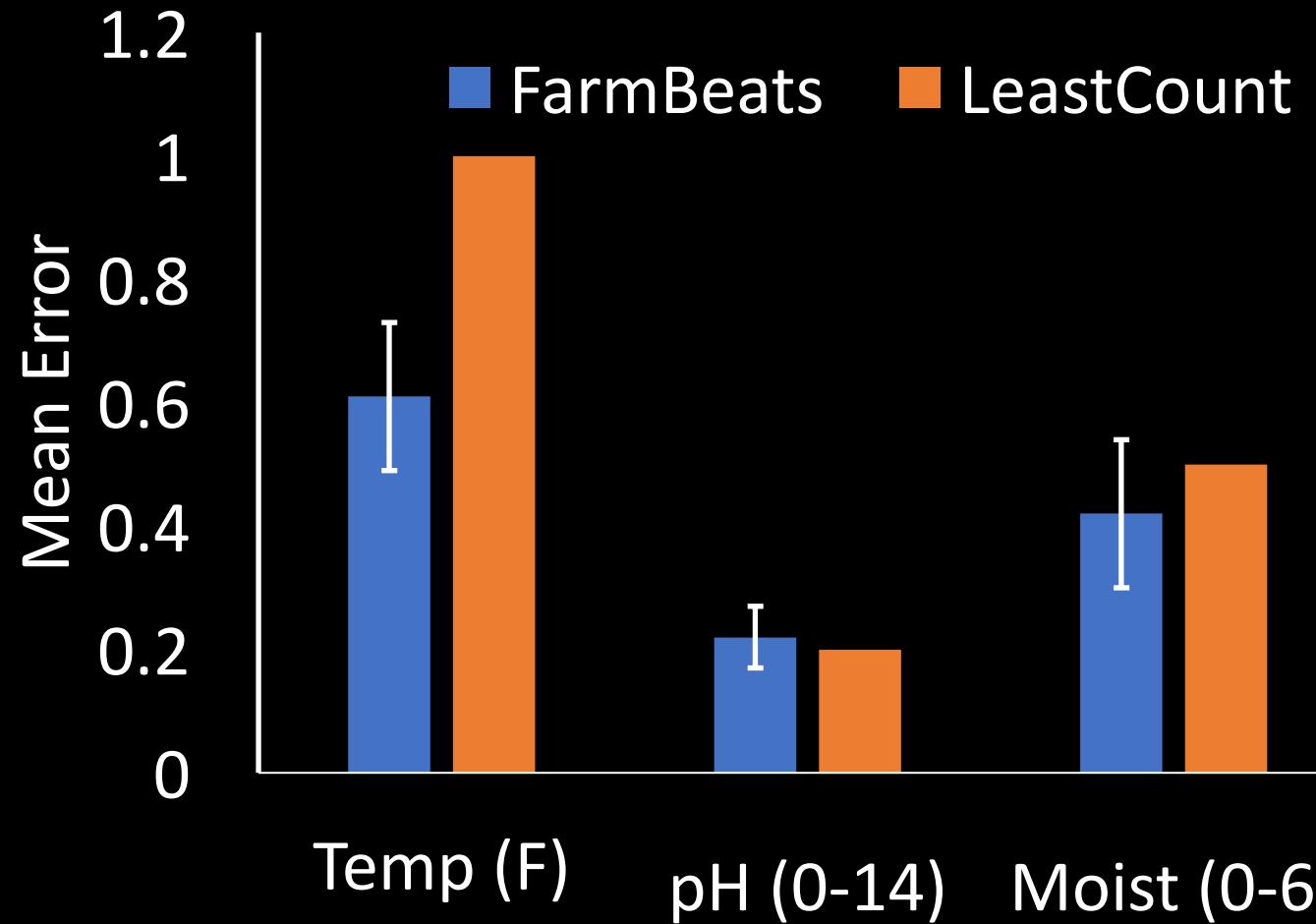
Precision Map : Moisture



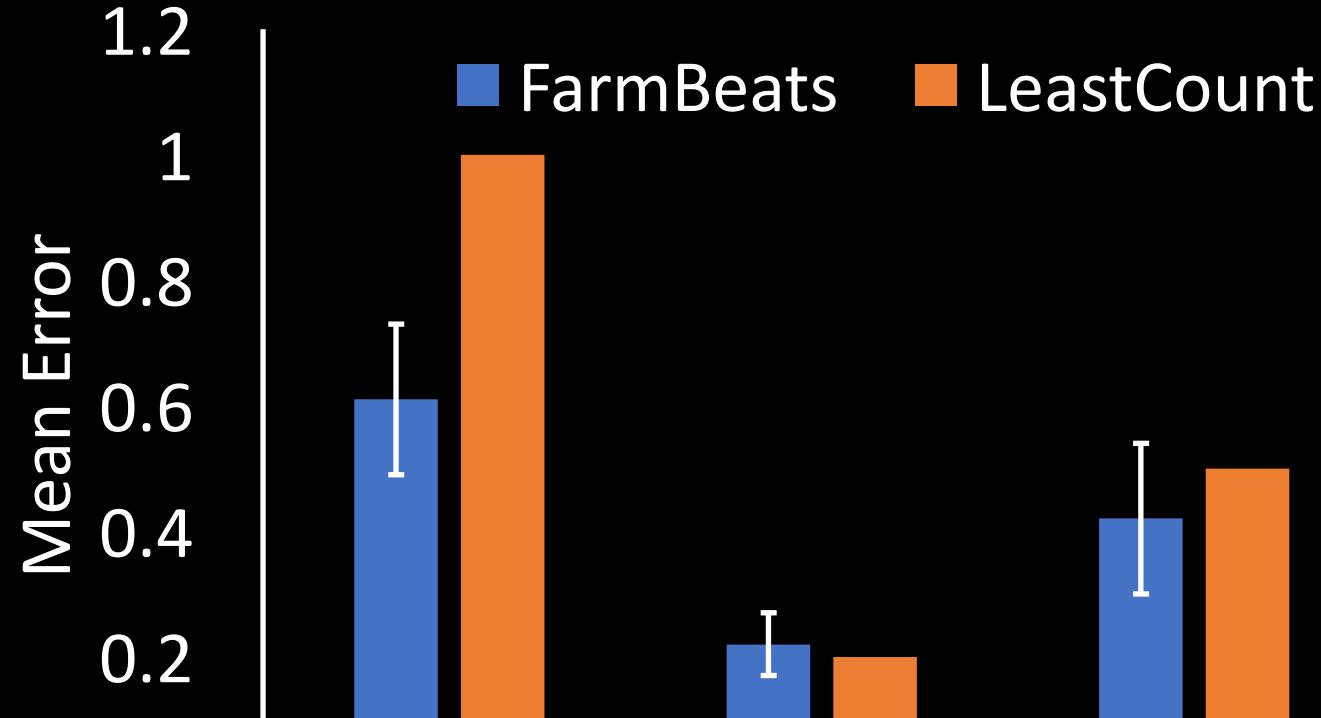
Precision Map : pH



Precision Map: Accuracy

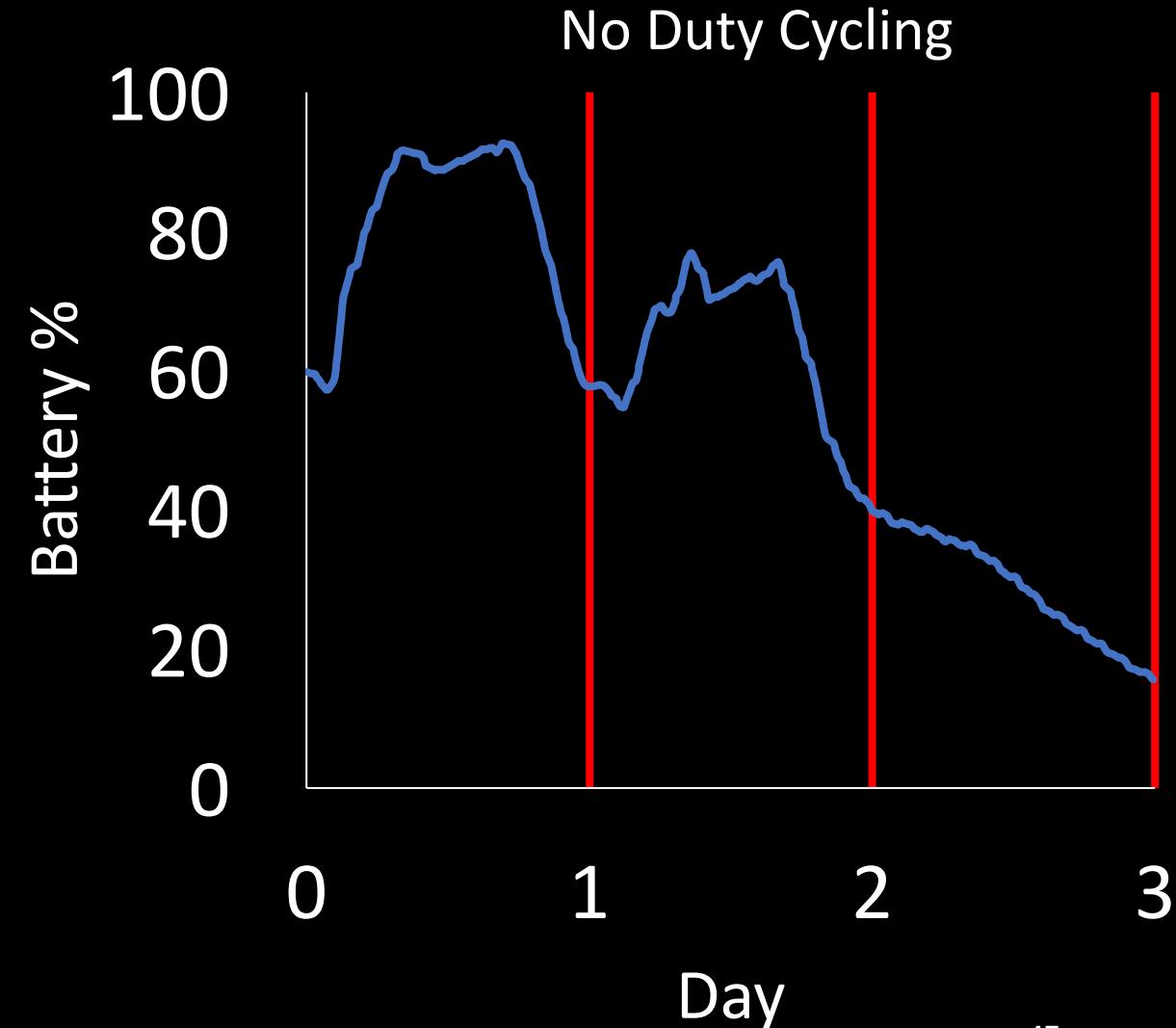
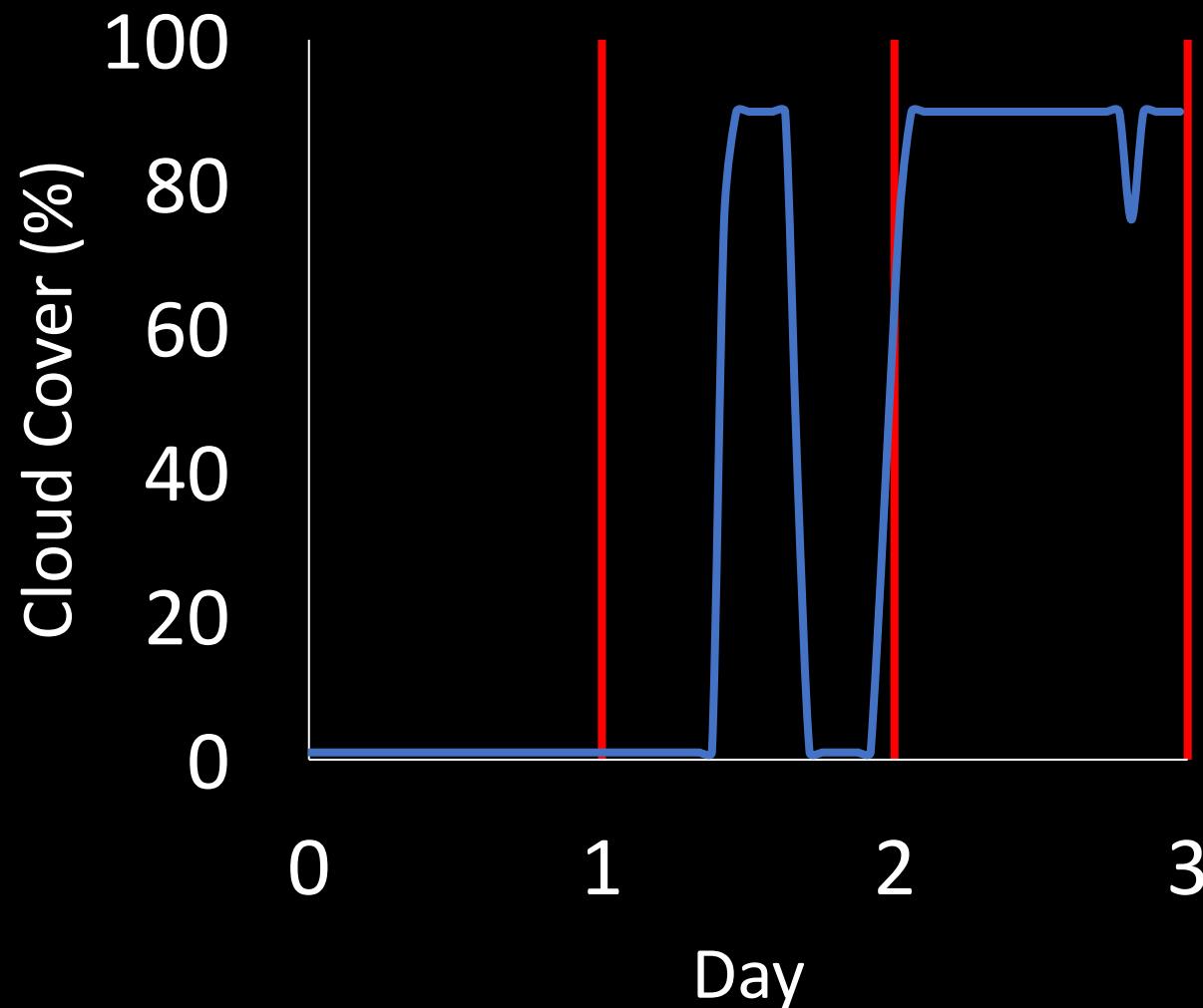


Precision Map: Accuracy

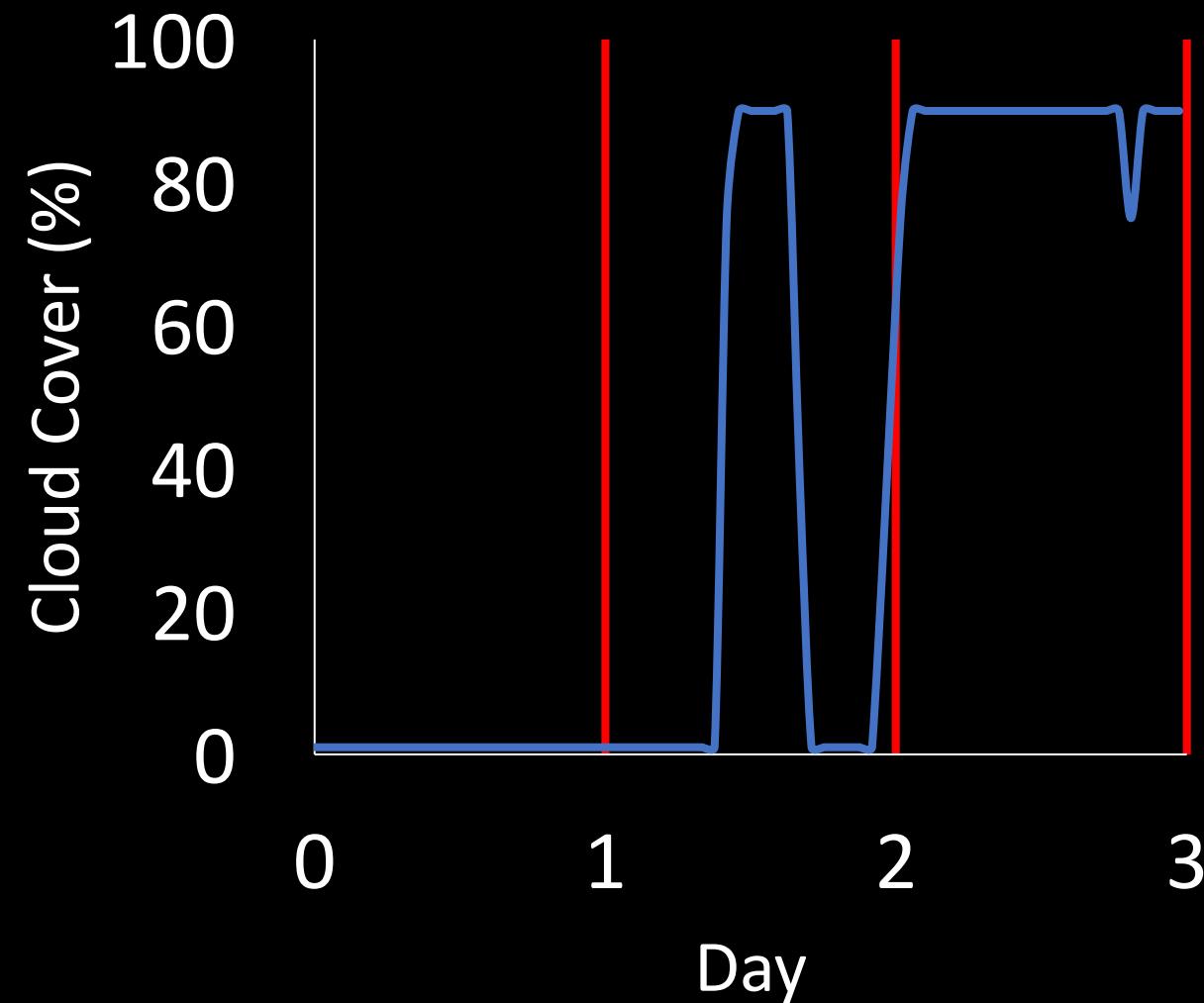


FarmBeats can accurately expand coverage by orders of magnitude using a sparse sensor deployment

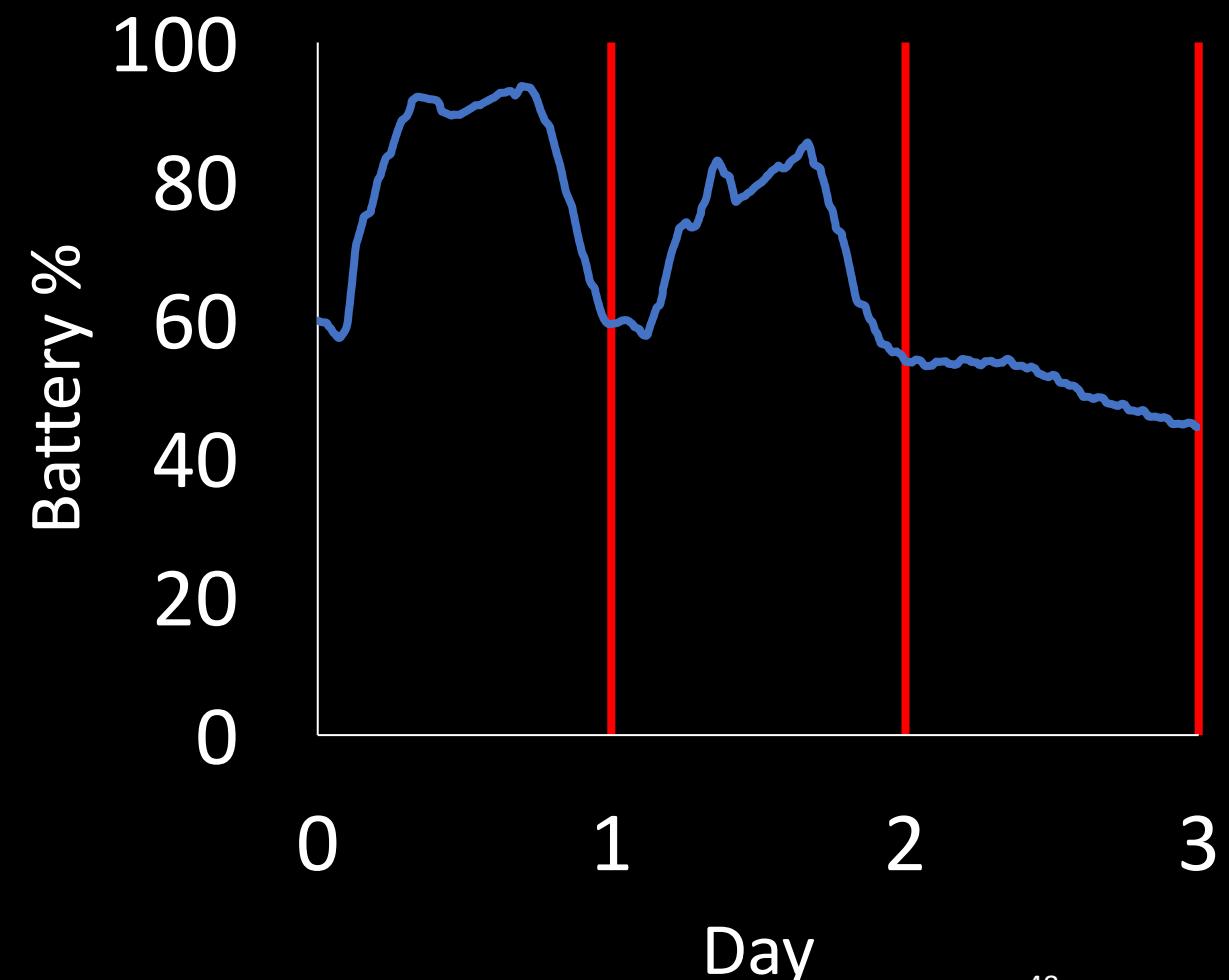
Weather-Aware Duty Cycling



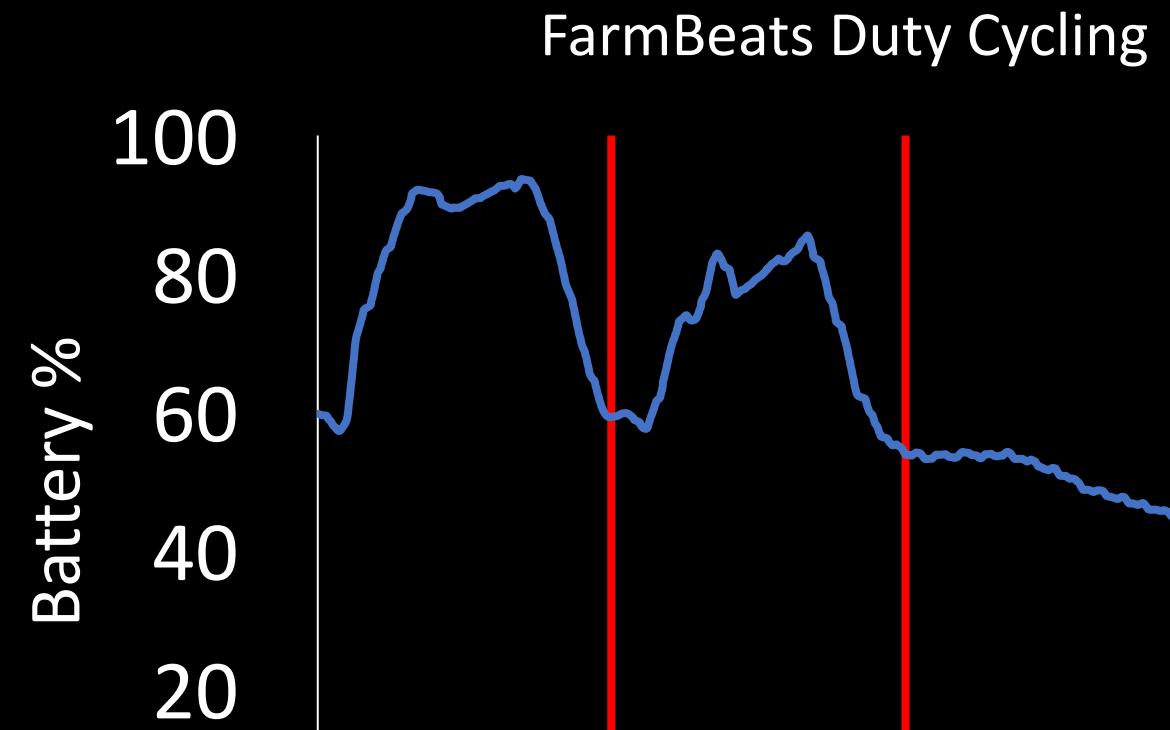
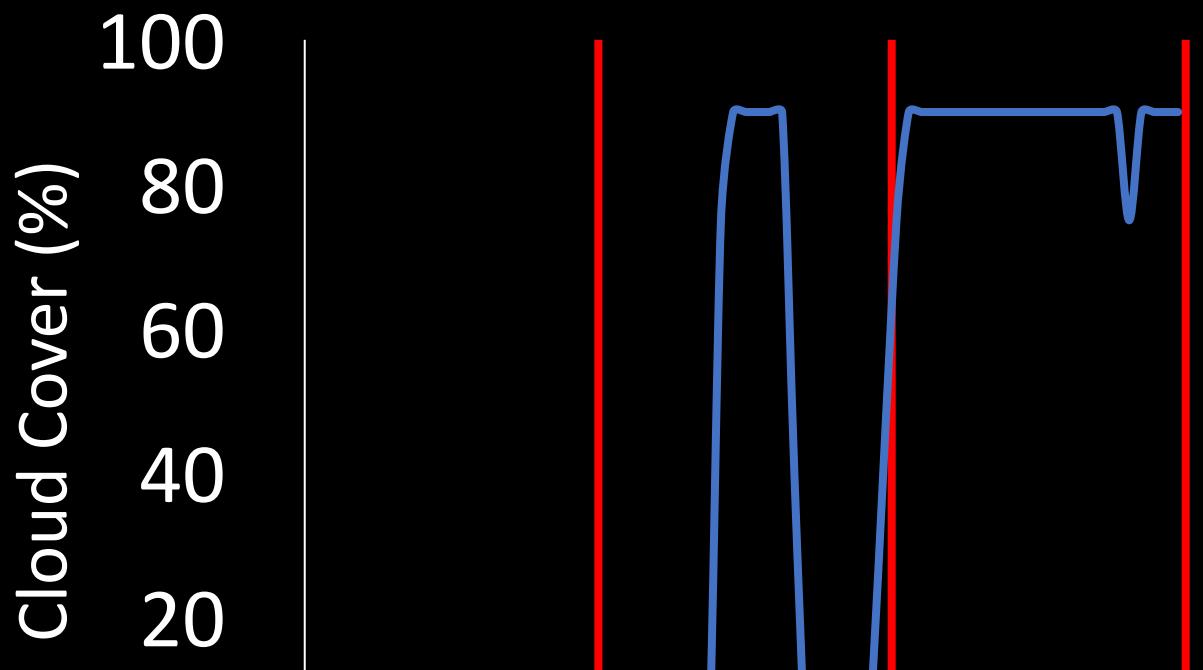
Weather-Aware Duty Cycling



FarmBeats Duty Cycling



Weather-Aware Duty Cycling



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

Day

Day

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!

Sean Stratman, Dancing Crow Farm, WA



Paula Thomas
PHOTOGRAPHY

Mark & Kirstin Kimball, Essex Farm, NY

