

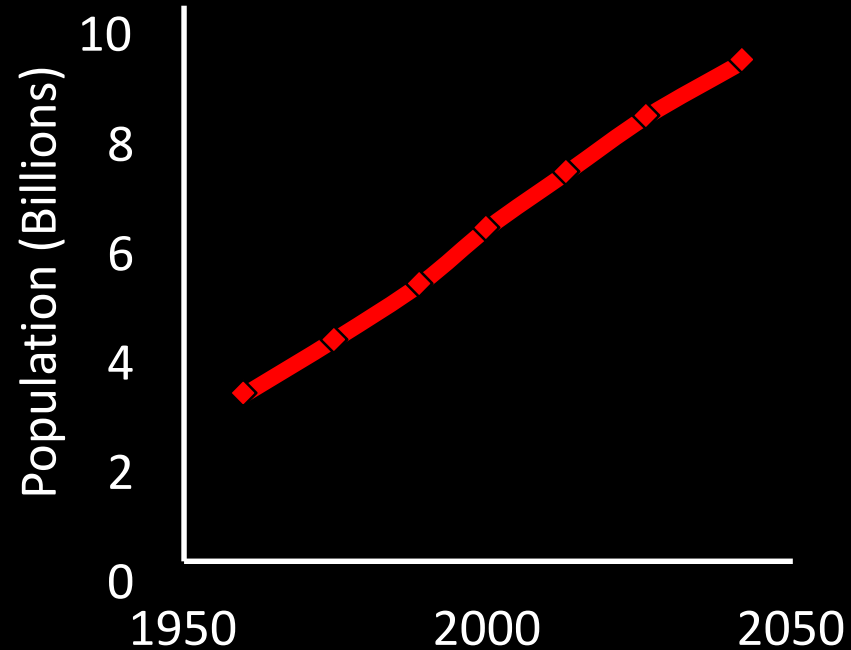
FarmBeats: An IoT System for Data-Driven Agriculture

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



Why Agriculture?

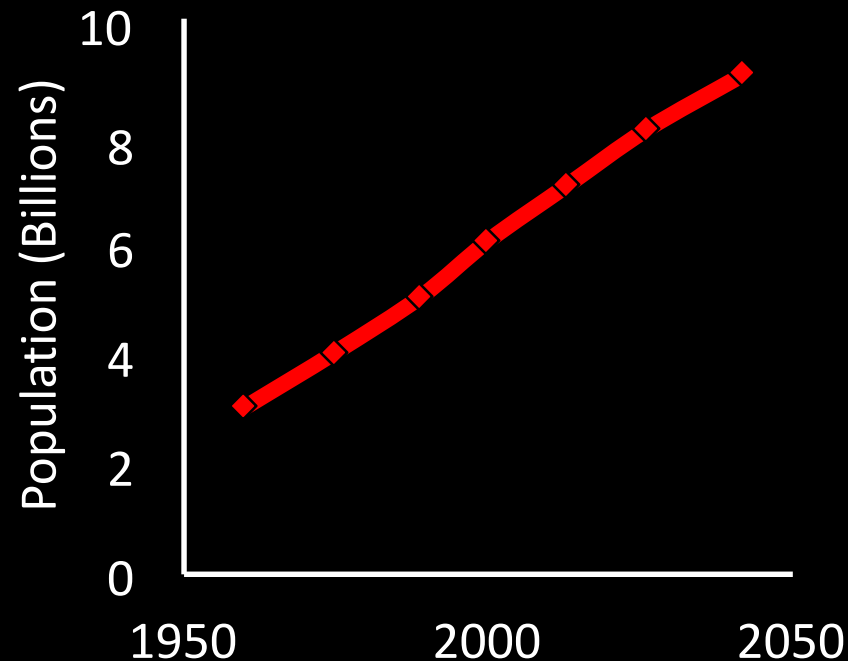
Agricultural output needs to **double By 2050** to meet the demands
– United Nations¹



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

Why Agriculture?

Agricultural output needs to **double By 2050** to meet the demands
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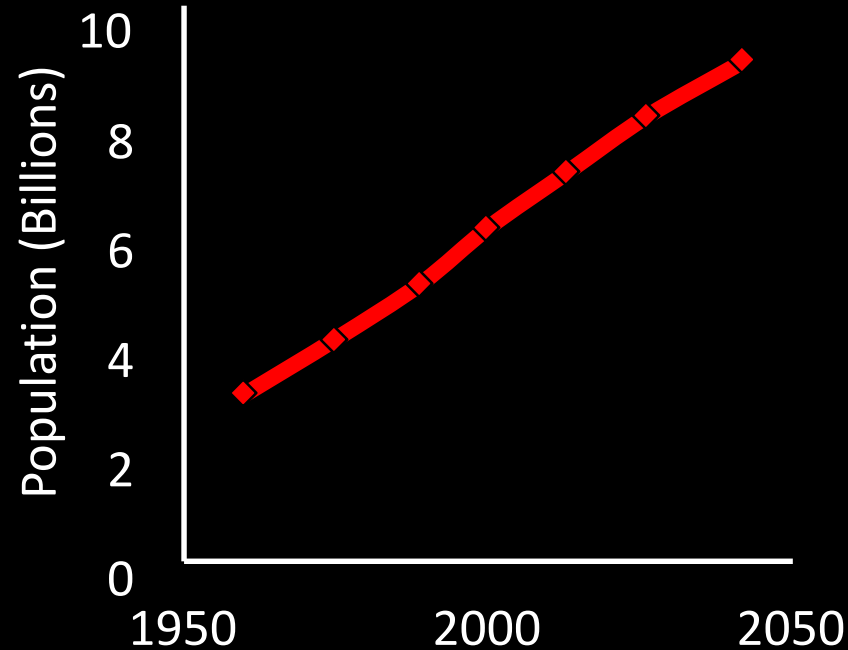


But...

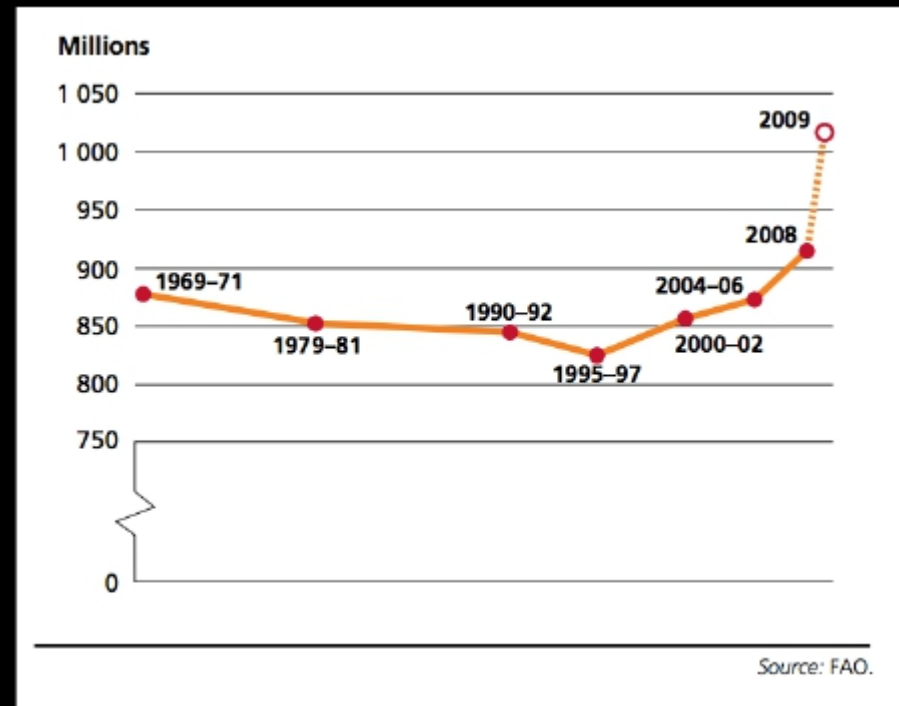
- Water levels are receding
- Arable land is shrinking
- Environment is being degraded

Why Agriculture?

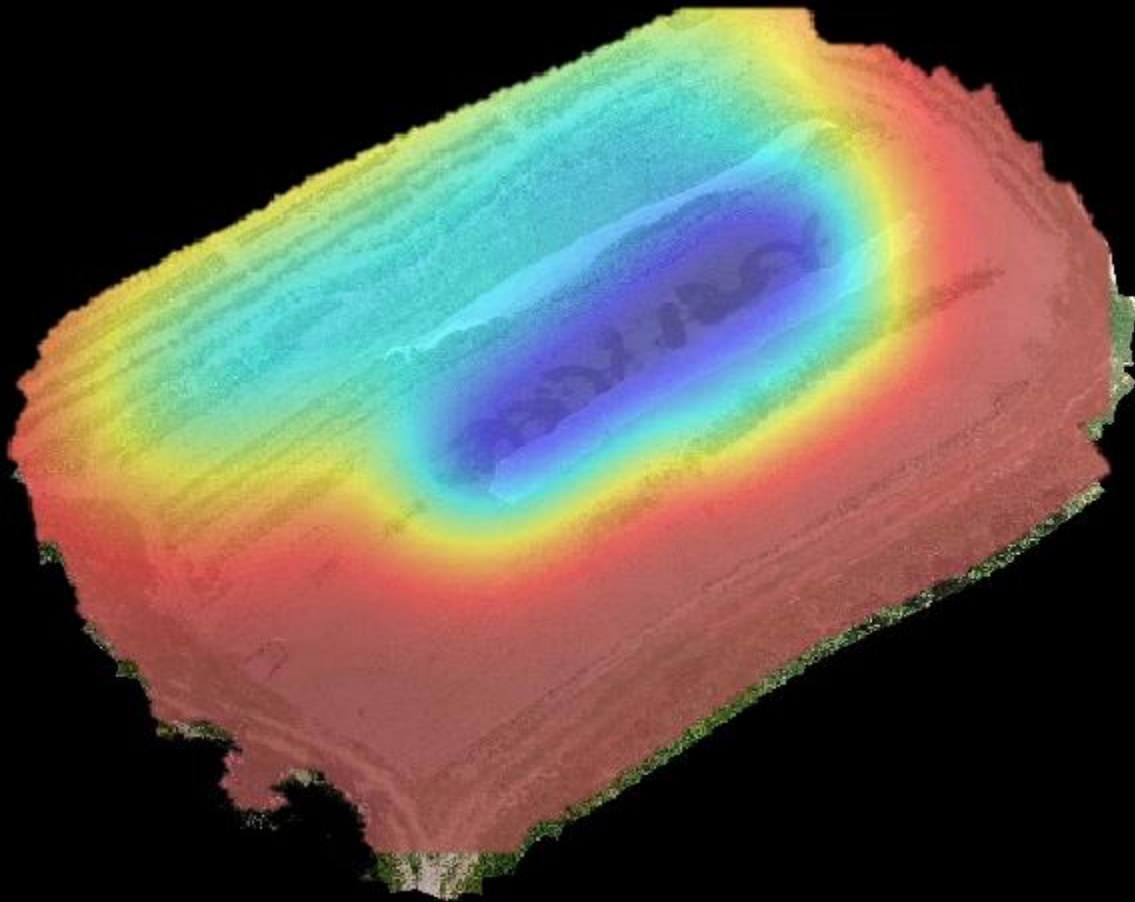
Agricultural output needs to **double By 2050** to meet the demands
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Number of World's Hungry People



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

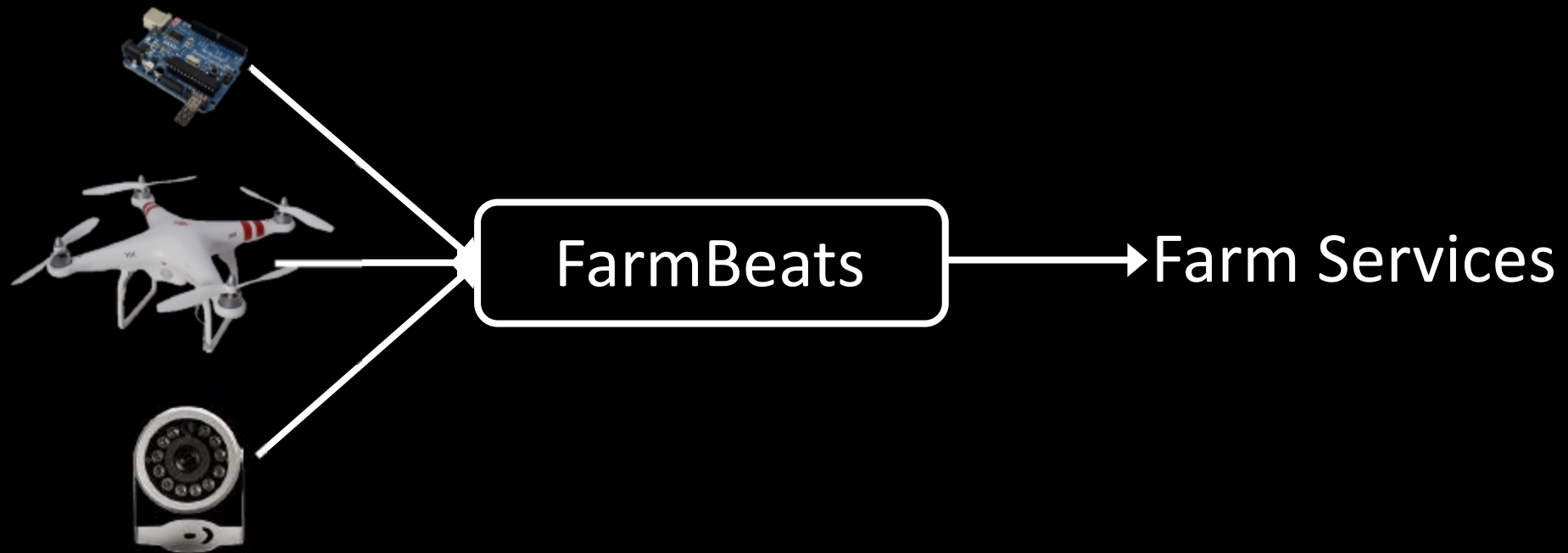


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How can one design an IoT system in challenging resource-constrained environments?

In this talk

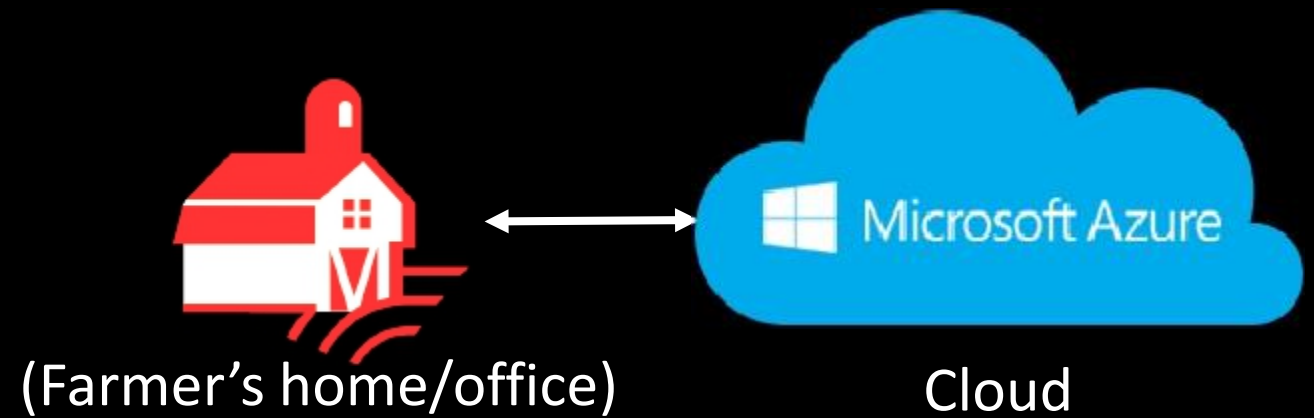
- FarmBeats: An end-to-end IoT system that enables seamless data collection for agriculture



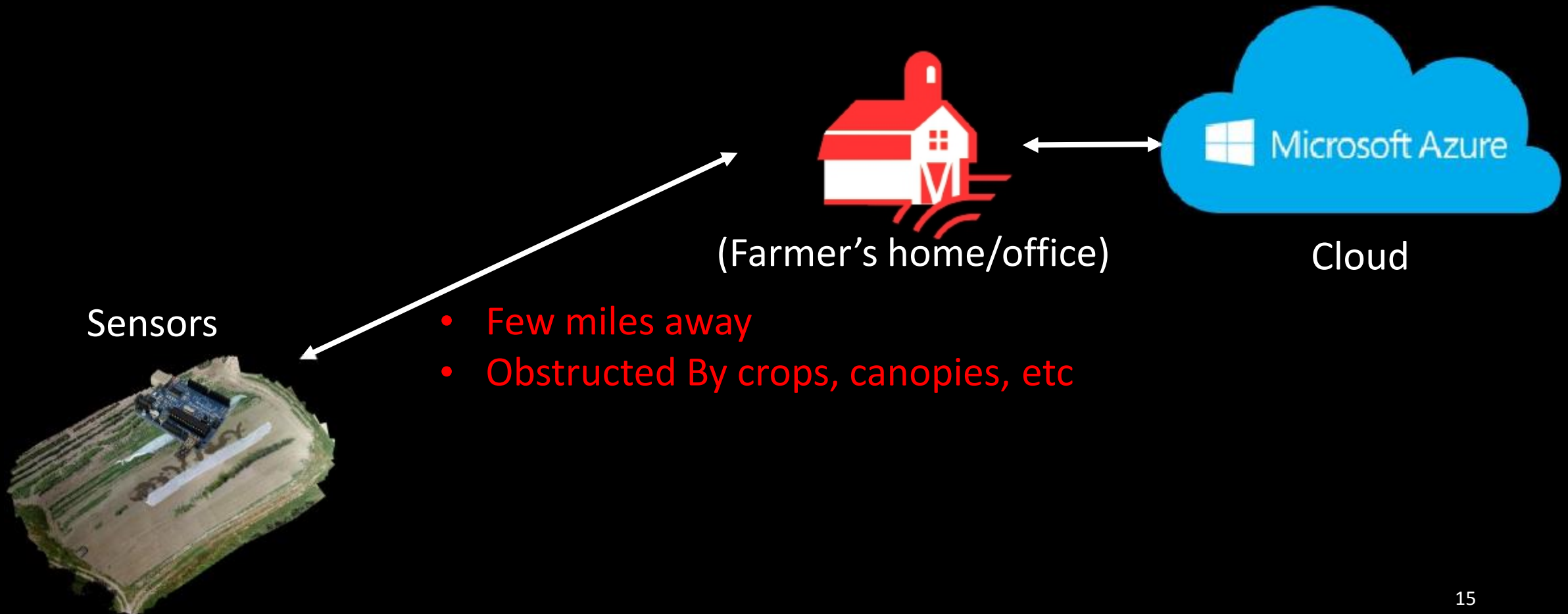
In this talk

- 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



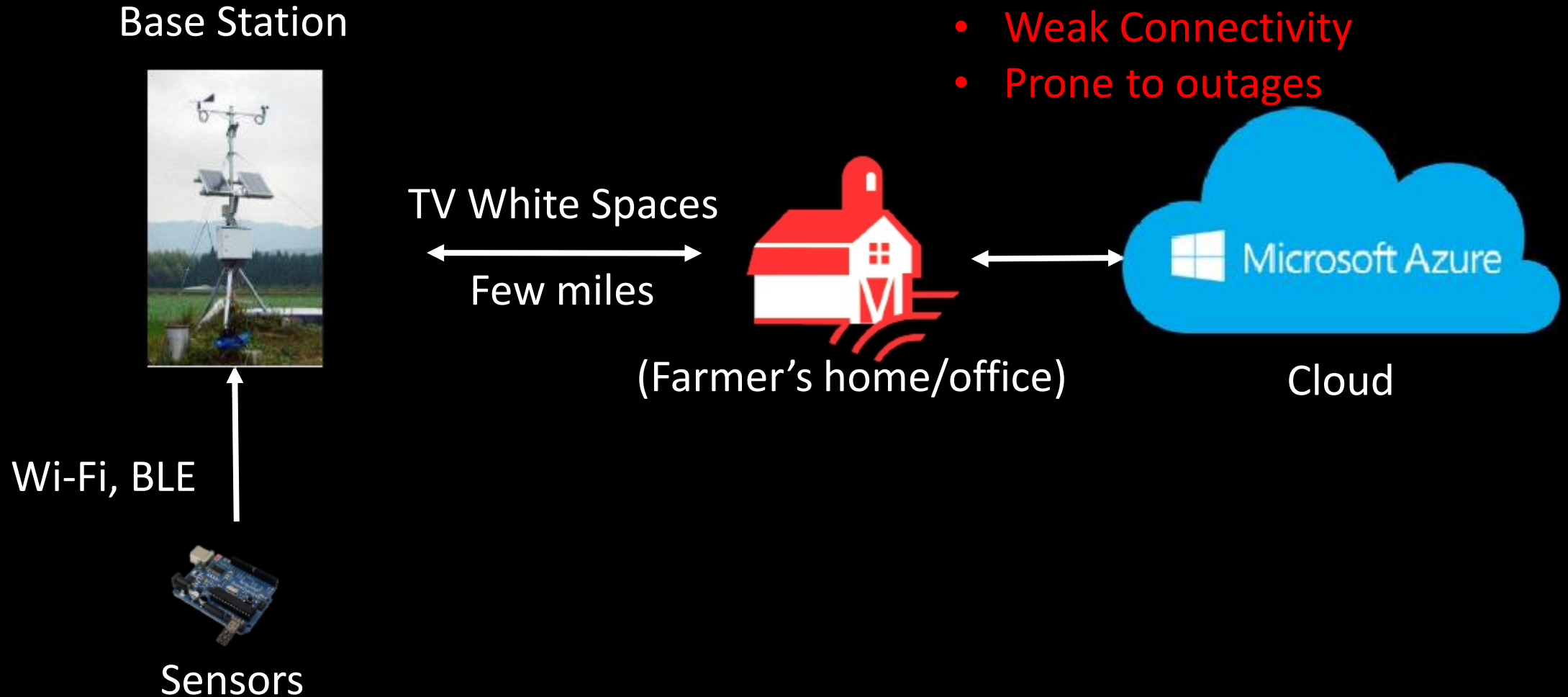
Challenge: Internet Connectivity



Idea: Use TV White Spaces

- Can provide long-range connectivity
- Can travel through crops and canopies, Because of low frequencies
- With existing infrastructures

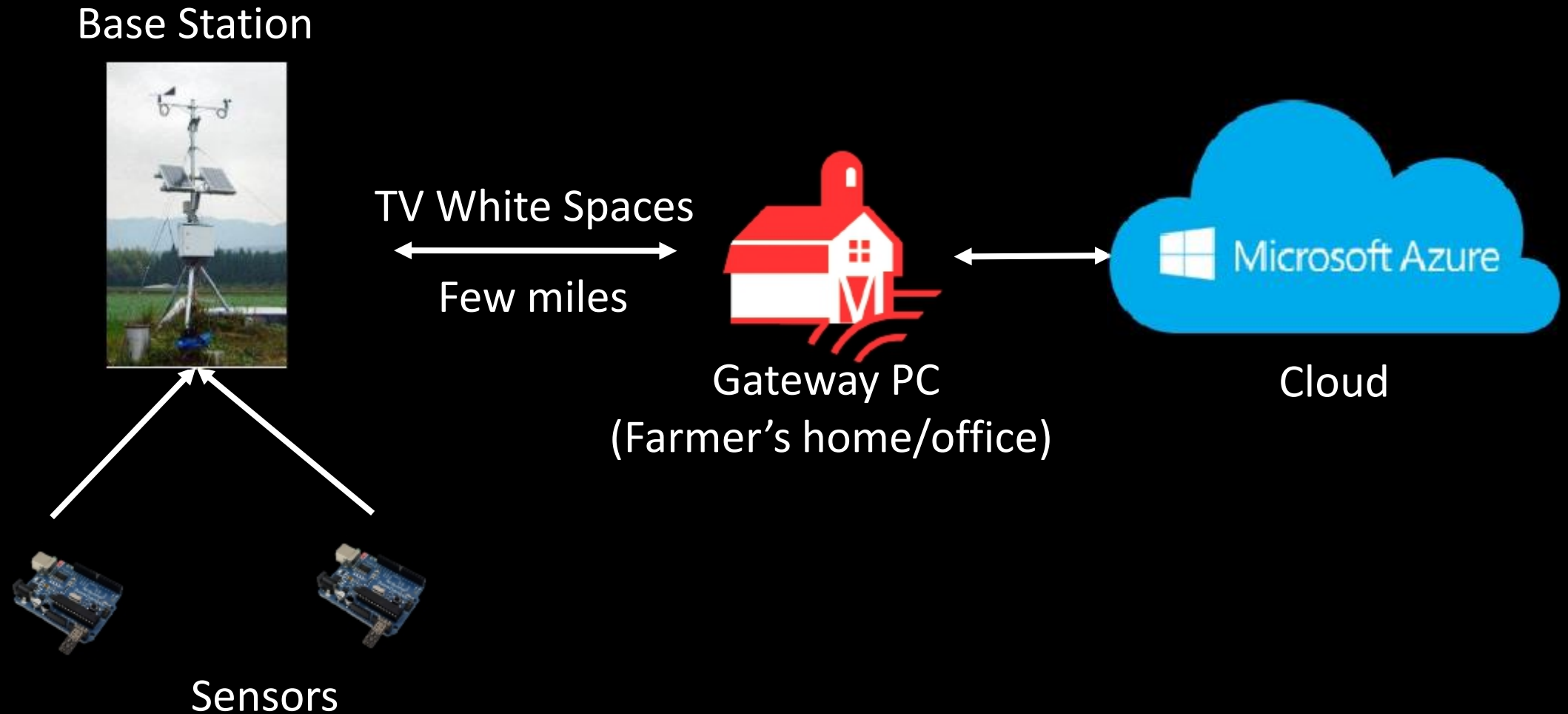
Idea: Use TV White Spaces



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



In this talk

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

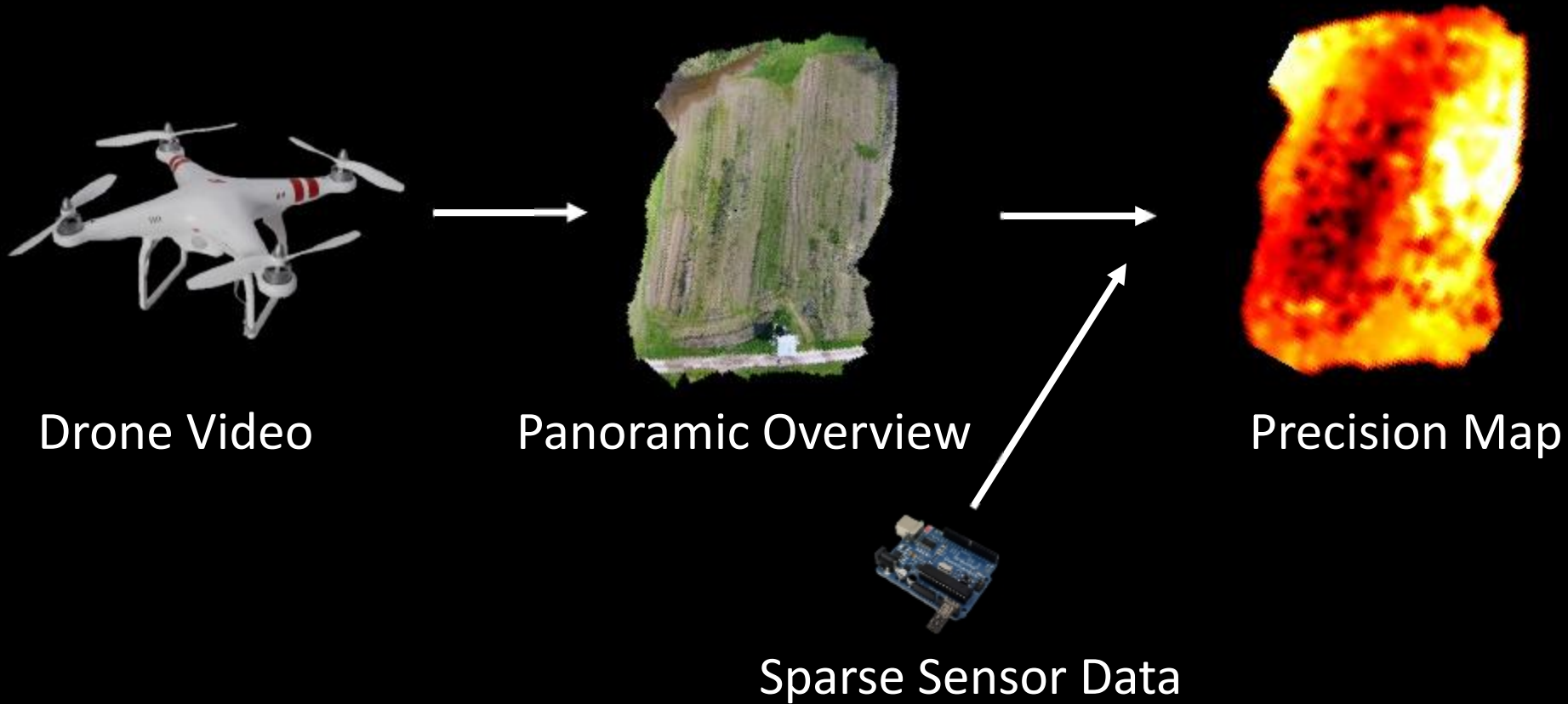
- Need to work with sparse sensor deployments
 - Physical constraints due to farming practices
 - Too expensive to deploy and maintain
- How do we get coverage with a sparse sensor deployment?

Idea: Use Drones to Enhance Spatial Coverage

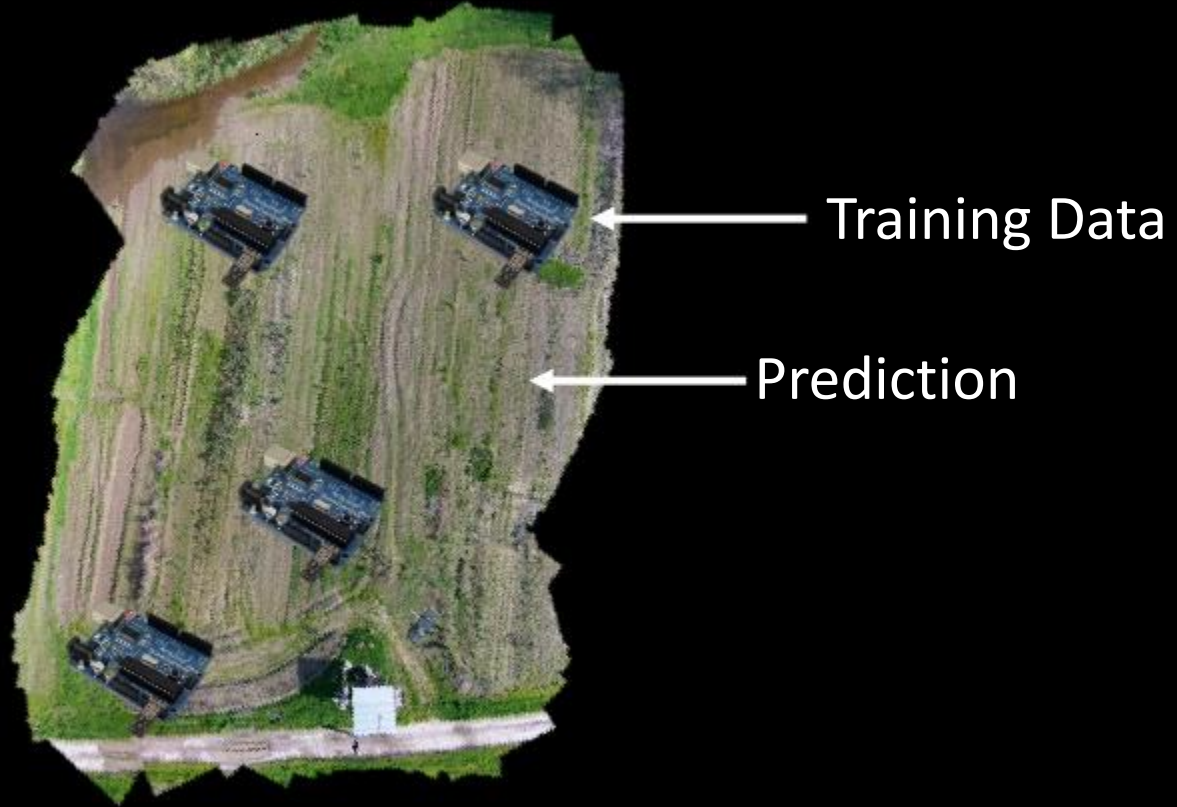
- Drones are cheap and automatic
- Can cover large areas quickly
- Can collect visual data

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



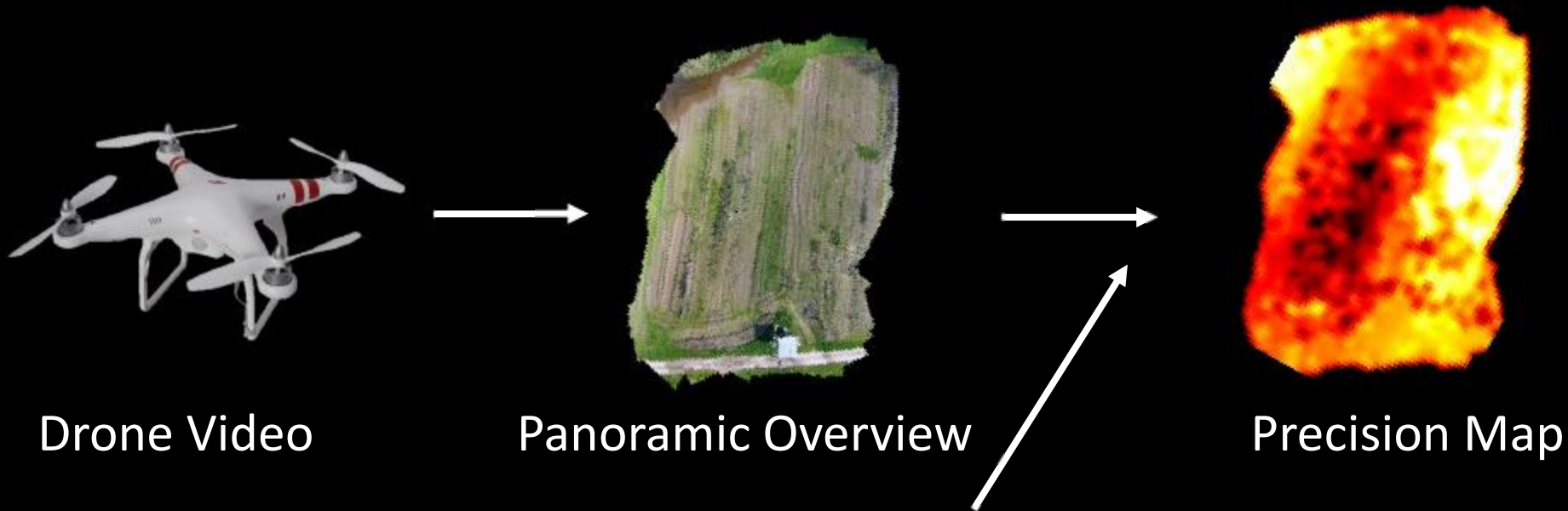
Panoramic Overview

Model Insights

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



Idea: Use Drones to Enhance Spatial Coverage

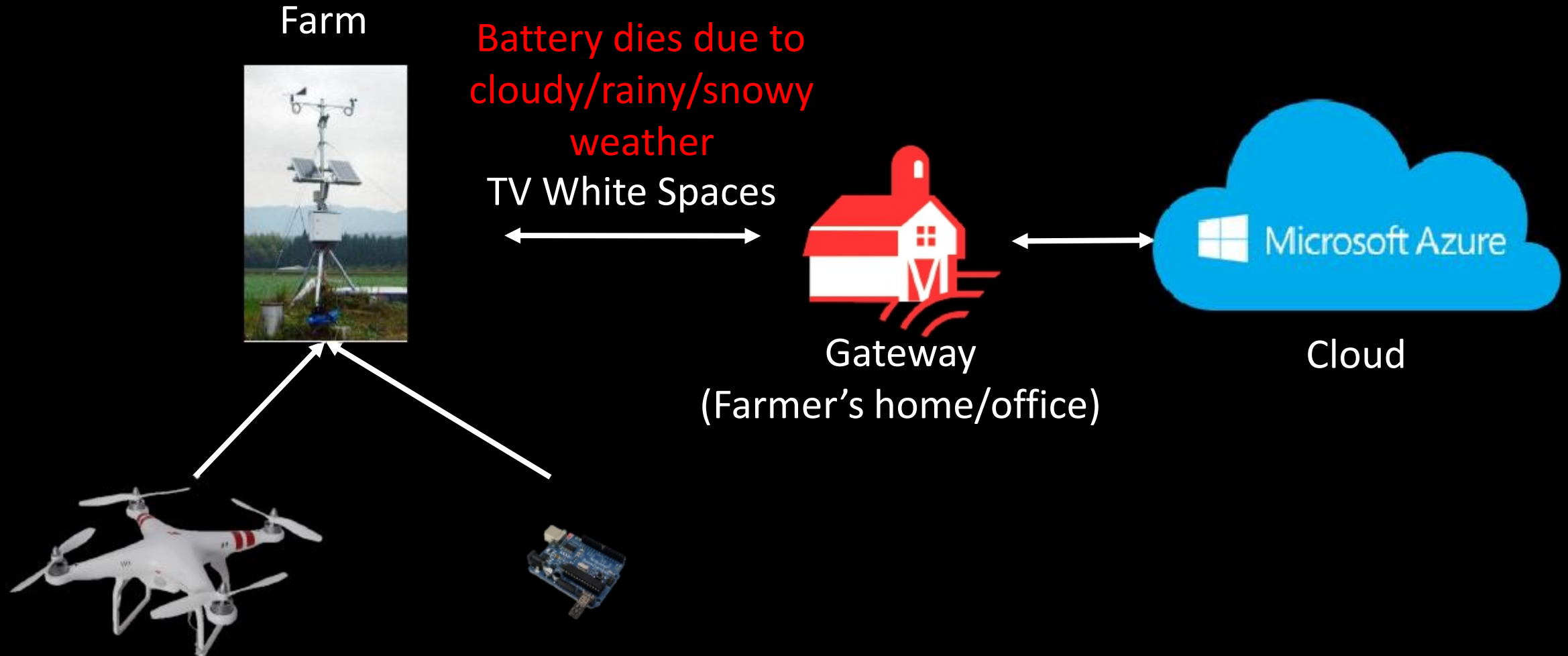


FarmBeats can use drones to expand the sparse sensor data and create summaries for the farm

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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

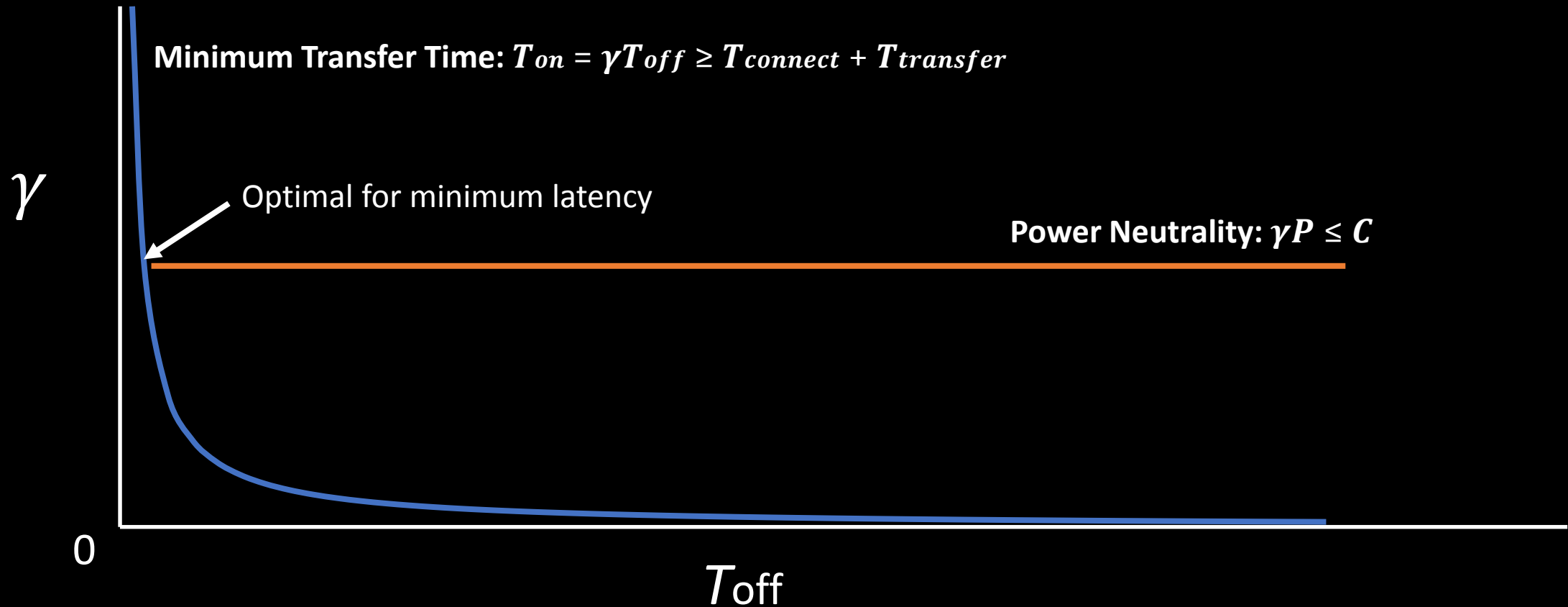
- $\gamma = \frac{T_{on}}{T_{off}}$

- Constraints:

- **Power Neutrality:** $\gamma P \leq C$

- **Minimum Transfer Time:** $T_{on} \geq T_{connect} + T_{transfer}$

Solution: Weather is predictable



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Deployment

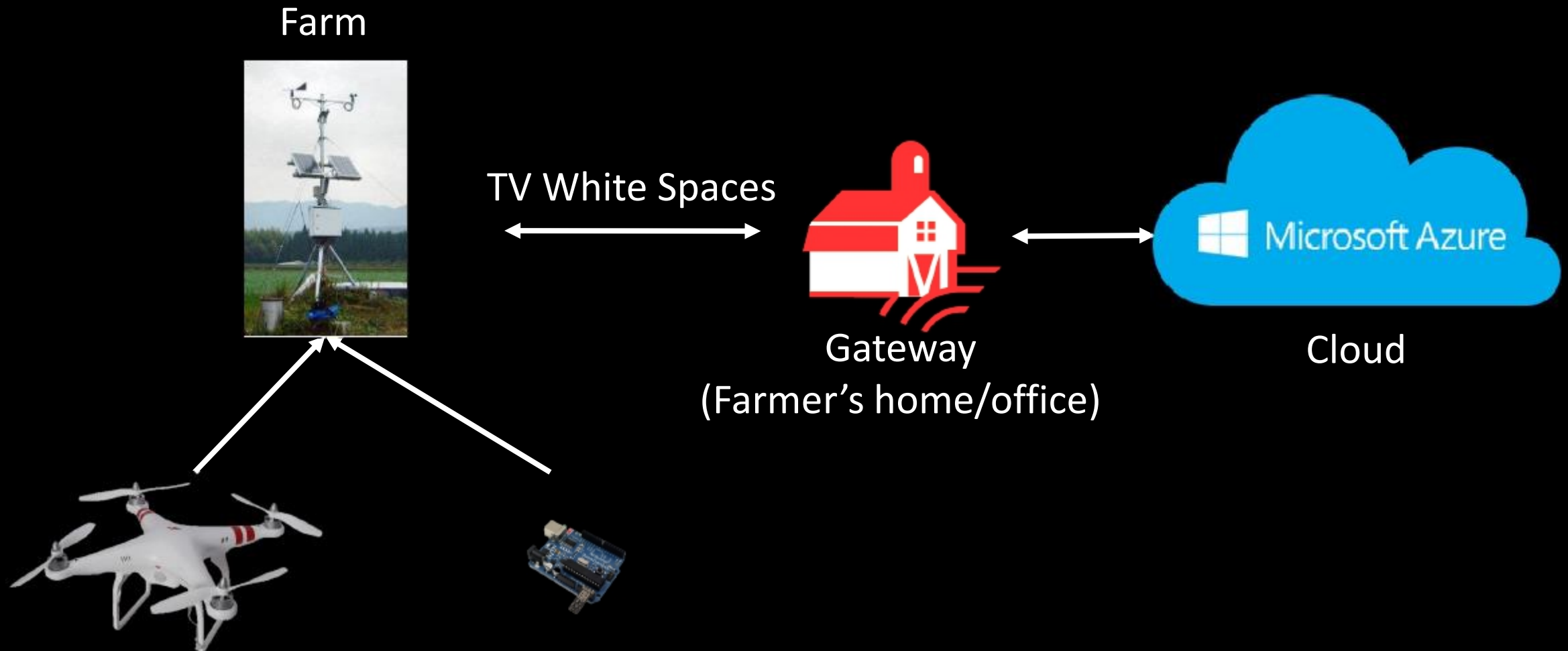
- Six months deployment in two farms: Upstate NY (Essex), WA (Carnation)
- The farm sizes were 100 acres and 5 acres respectively
- Sensors:
 - DJI Drones
 - Particle Photons with Moisture, Temperature, pH Sensors
 - IP Cameras to capture IR imagery as well as monitoring
- Cloud Components: Azure Storage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



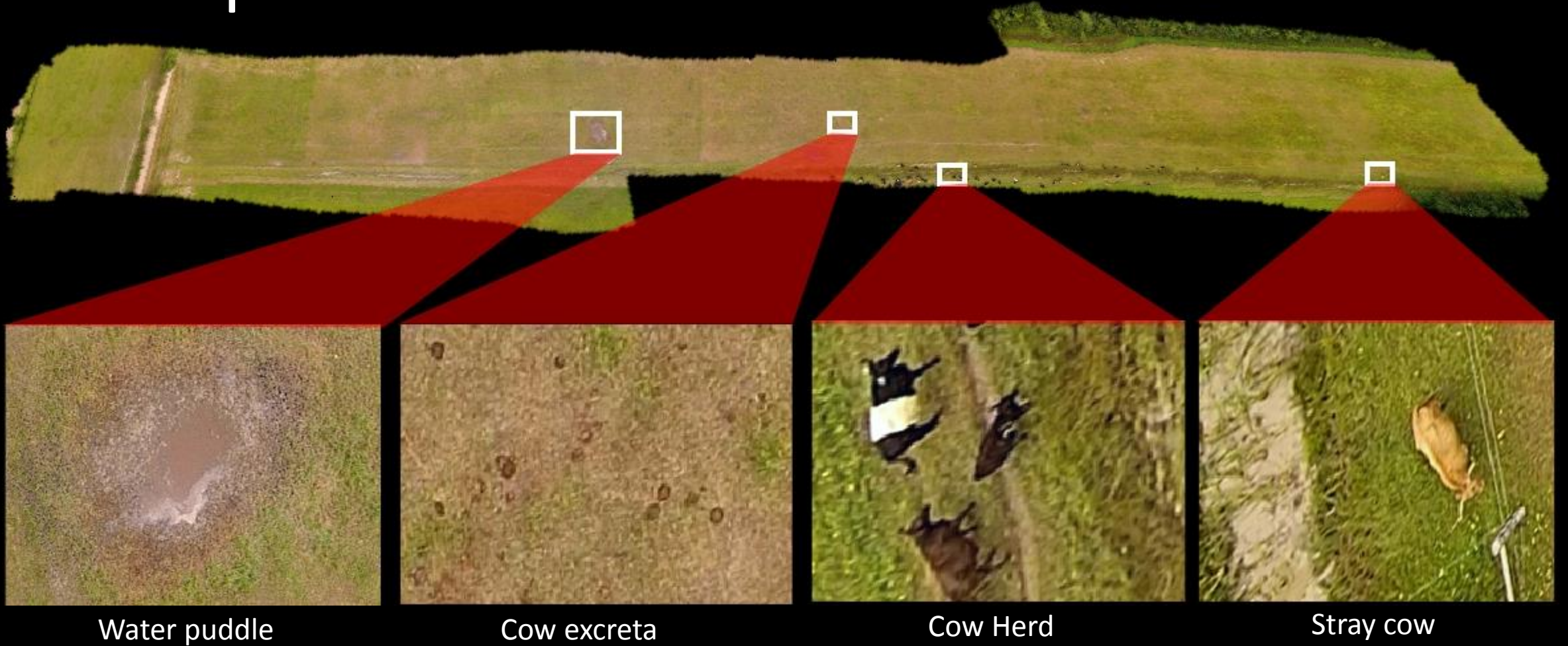
Deployment Statistics

- 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



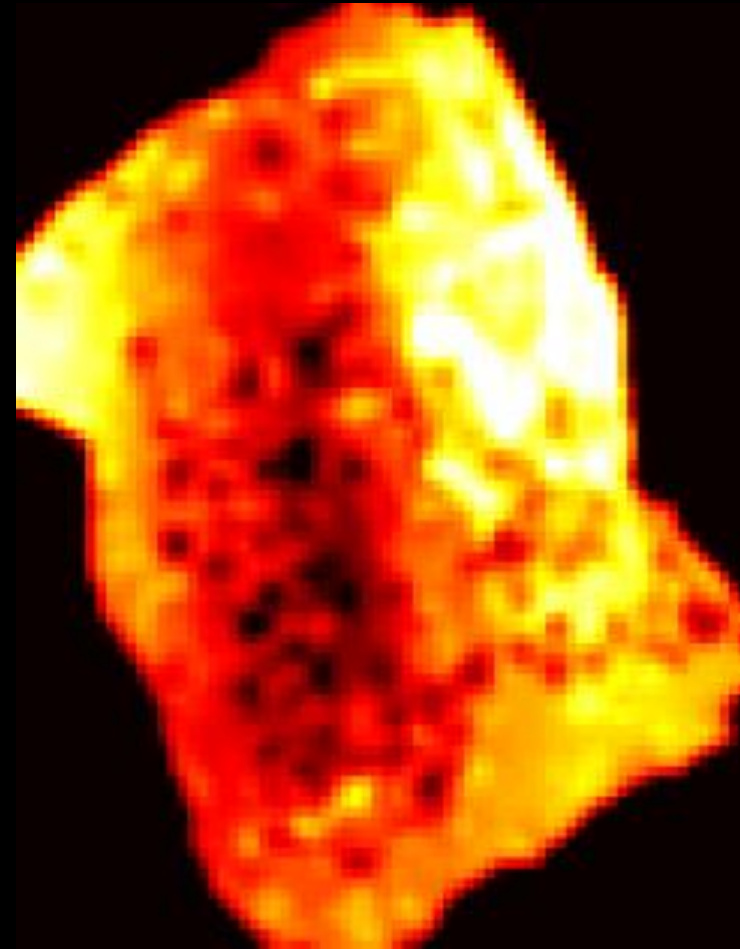
Example: Panorama



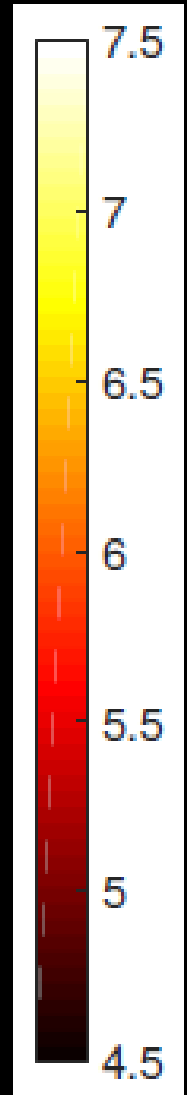
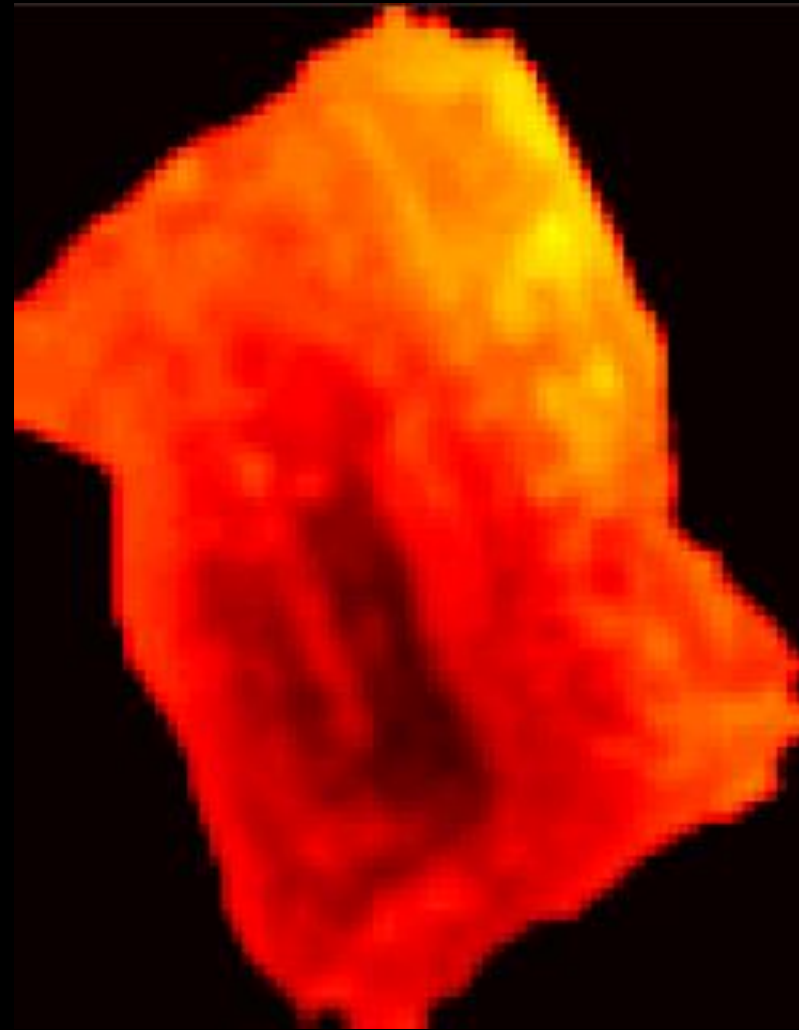
Precision Map: Panorama Generation



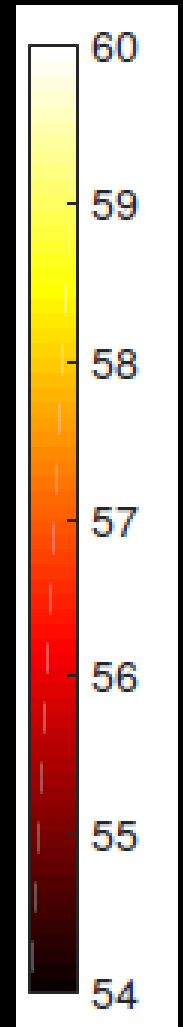
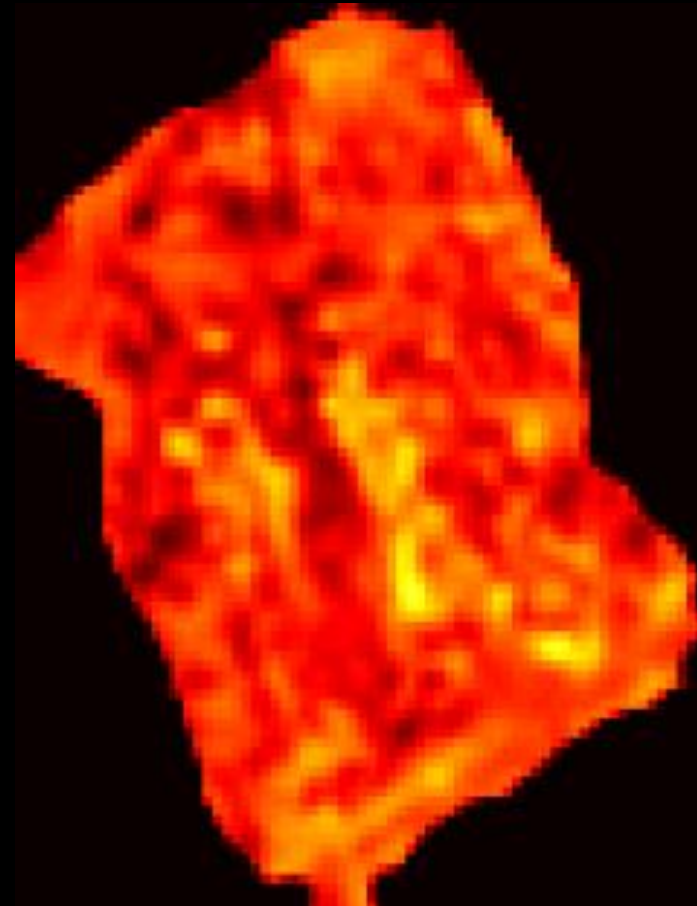
Precision Map : Moisture



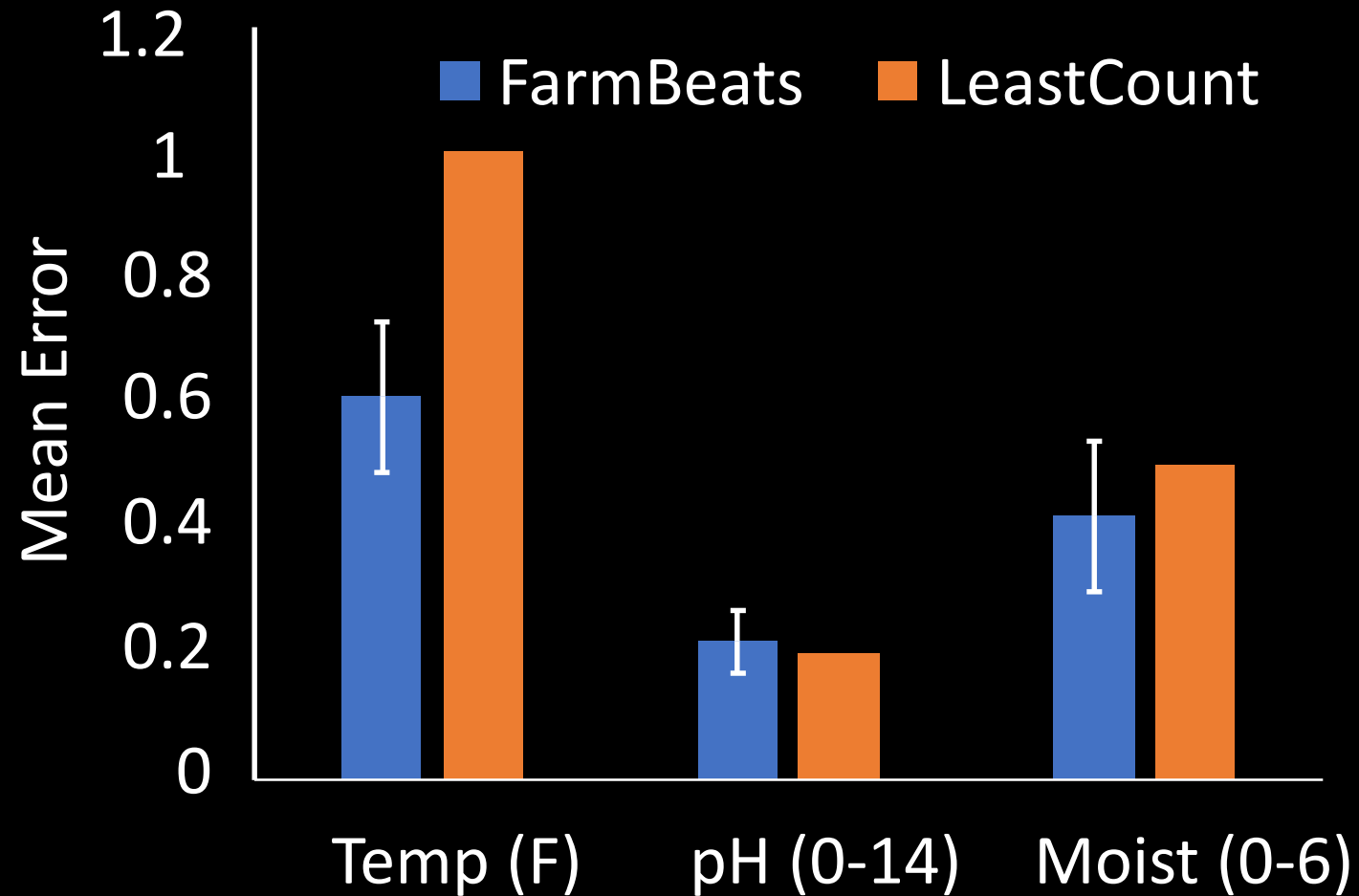
Precision Map : pH



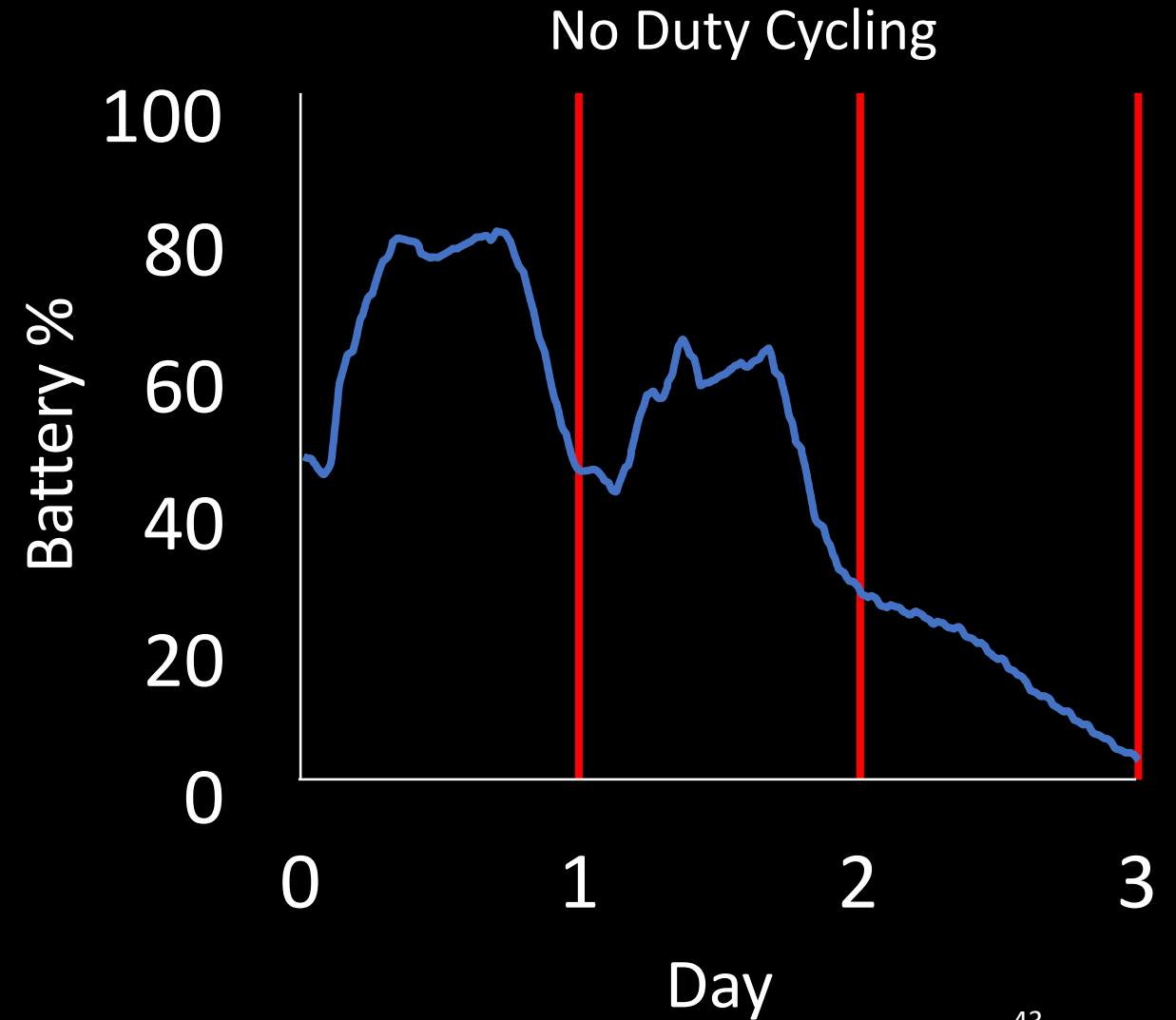
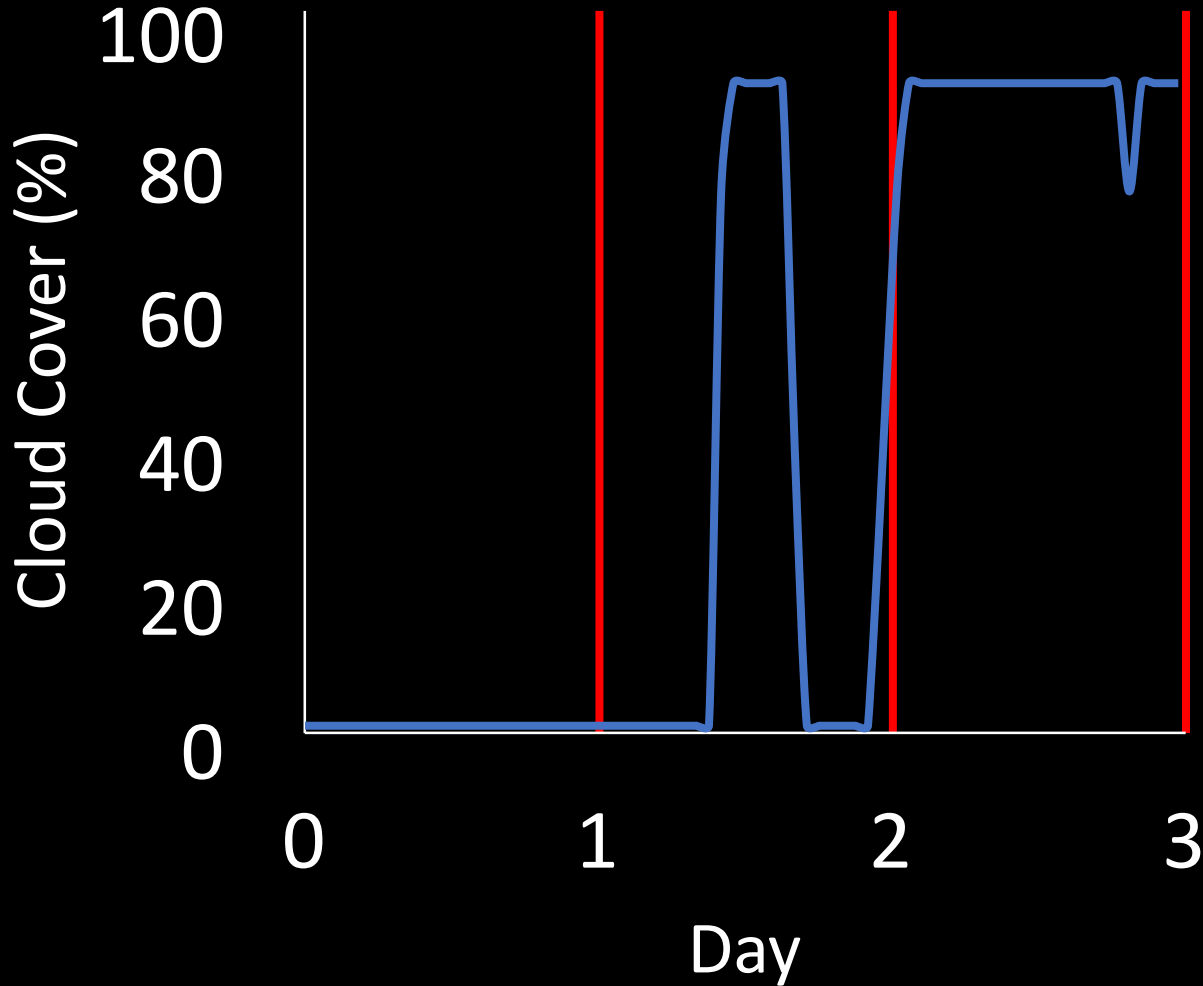
Precision Map : Temperature



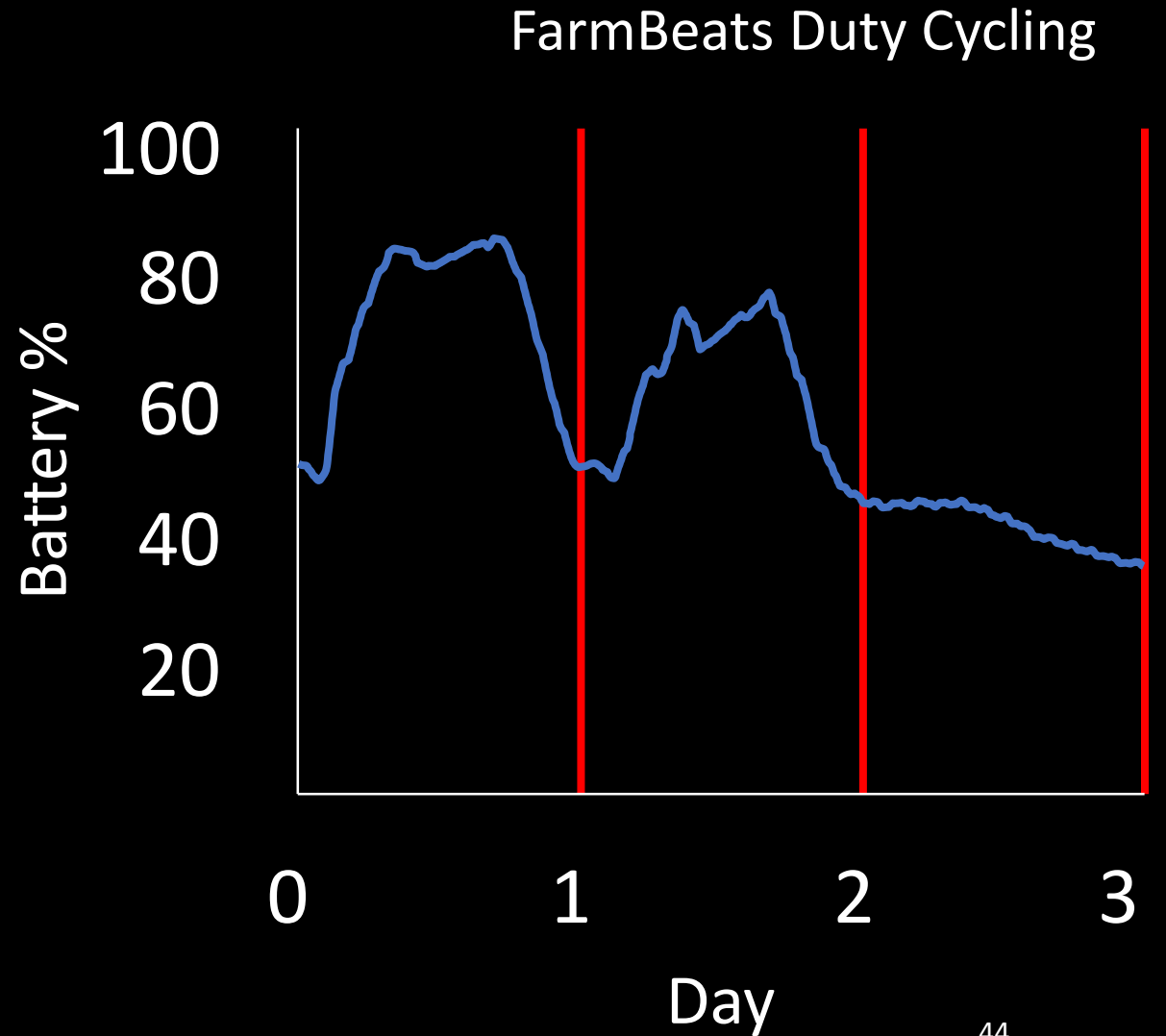
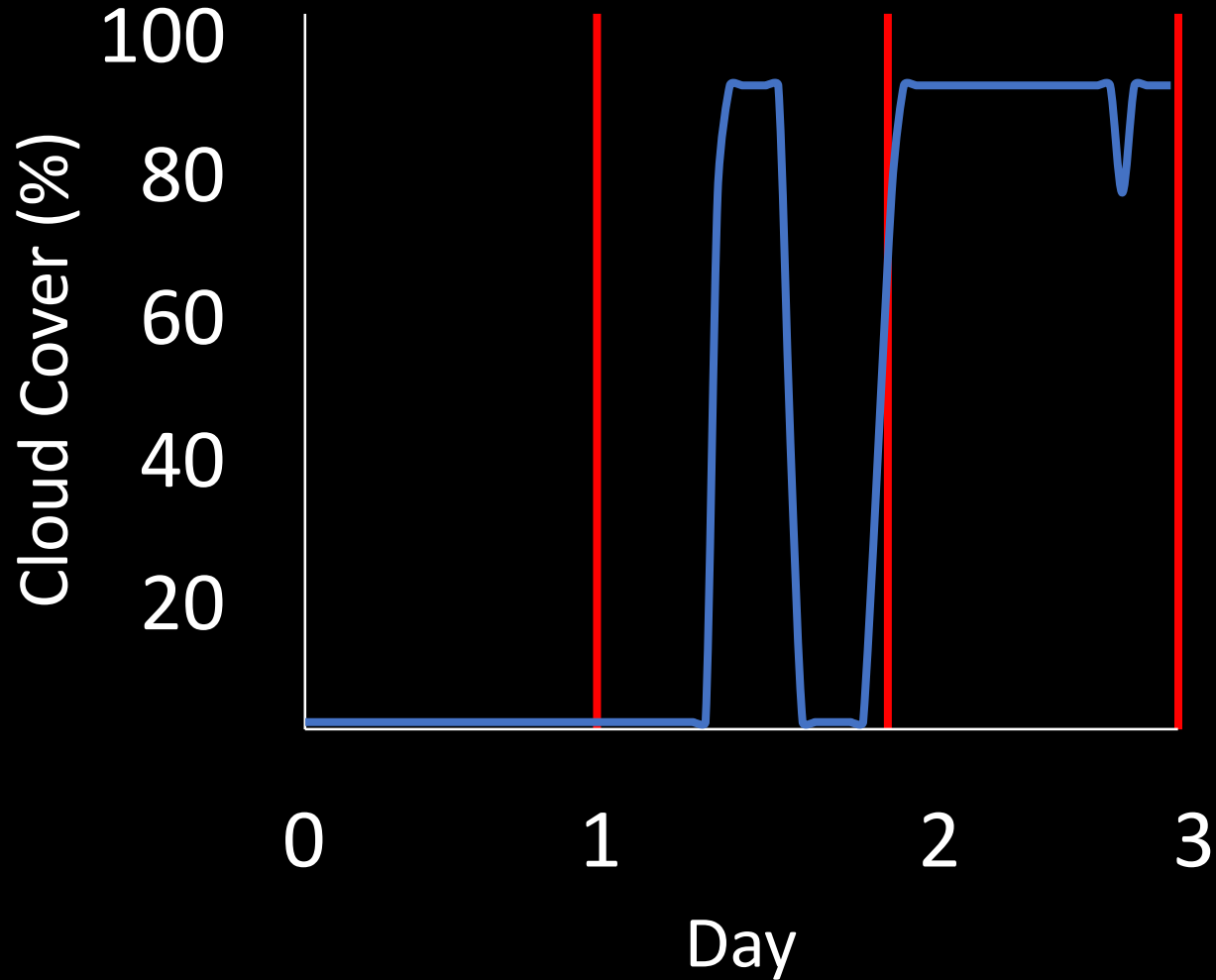
Precision Map: Accuracy



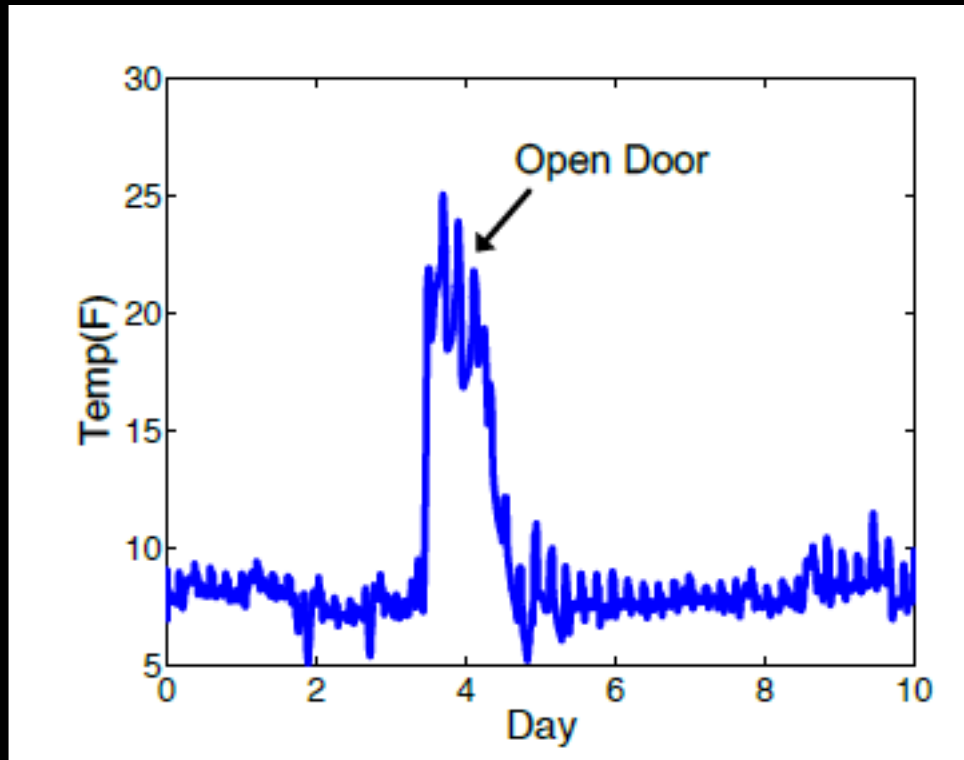
Weather-Aware Duty Cycling



Weather-Aware Duty Cycling



Expanded application



Storage temperature



Cow shed monitoring

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

What can we learn?

- Problem-based
 - Limited power
 - Limited connectivity
 - Limited sensor deployment
- Attach to real-life situations
 - TV White Space
 - Weather-aware design
 - Spatial-temporal analysis

Thank you!

Sean Stratman, Dancing Crow Farm, WA



Mark & Kirstin KimBall, Essex Farm, NY

