

# 6.808: Mobile and Sensor Computing

## Lecture 10: Bringing Connectivity “Everywhere”

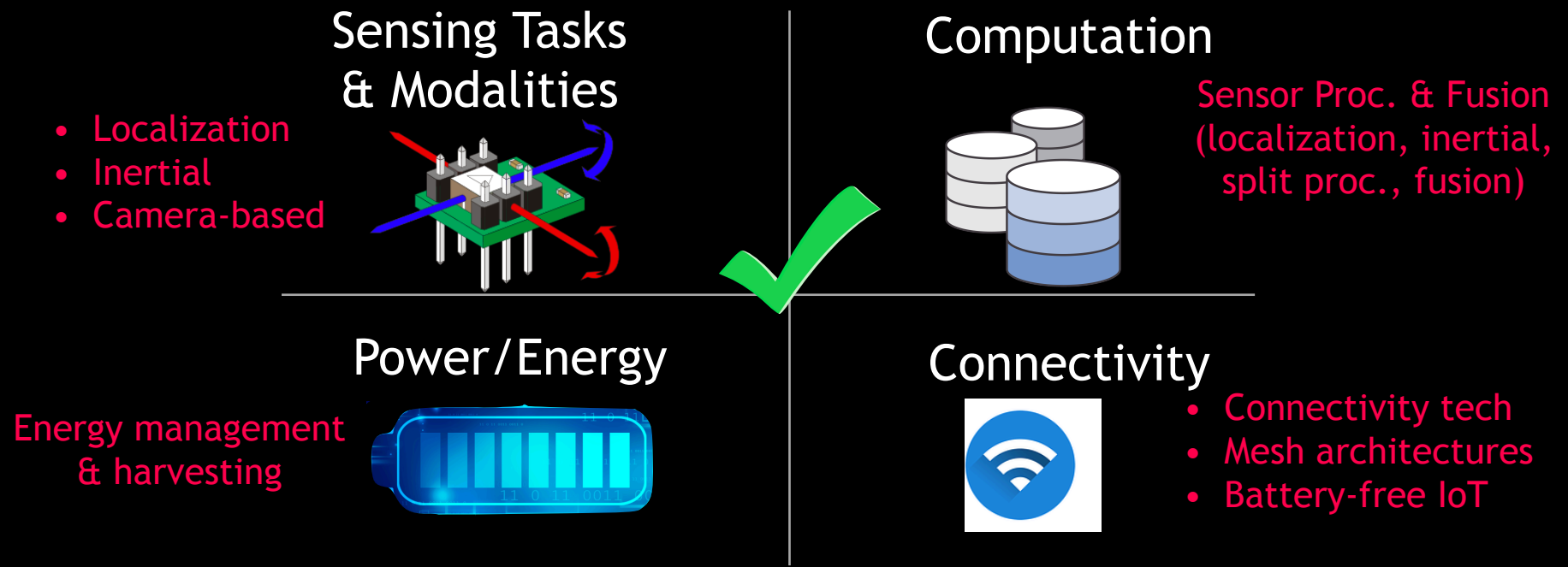
### Aerial-based Connectivity & Agriculture IoT



Some material adapted from Deepak Vasisht (UIUC/Microsoft)

# Class Timeline

## 4 Quadrants of IoT



## Emerging Application Domains & Cross-Cutting Topics

✓ **1. Transportation**

✓ **2. Health**

**3. Agriculture**

This lecture

**4. Oceans/Climate**

✓ **5. Security/Privacy**

# Aerial-based Connectivity for Remote Areas

X's Project Loon



Facebook's Project Aquila

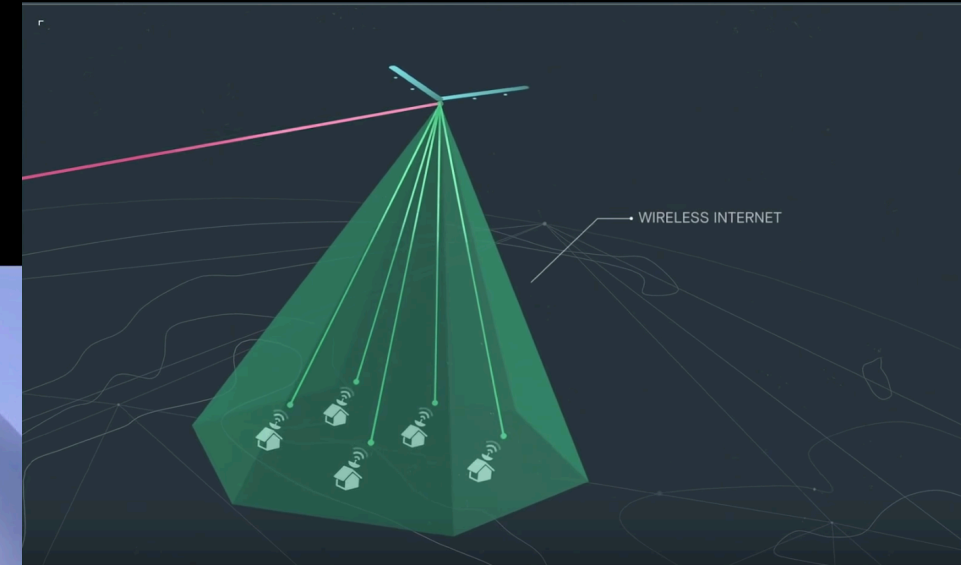


Others including Microsoft, Boeing, etc.

Goal: Bringing Connectivity to the Remote and Disconnected Areas of the Planet

# Goal: Bringing Connectivity to the Remote and Disconnected Areas of the Planet

- Bring connectivity to rural areas



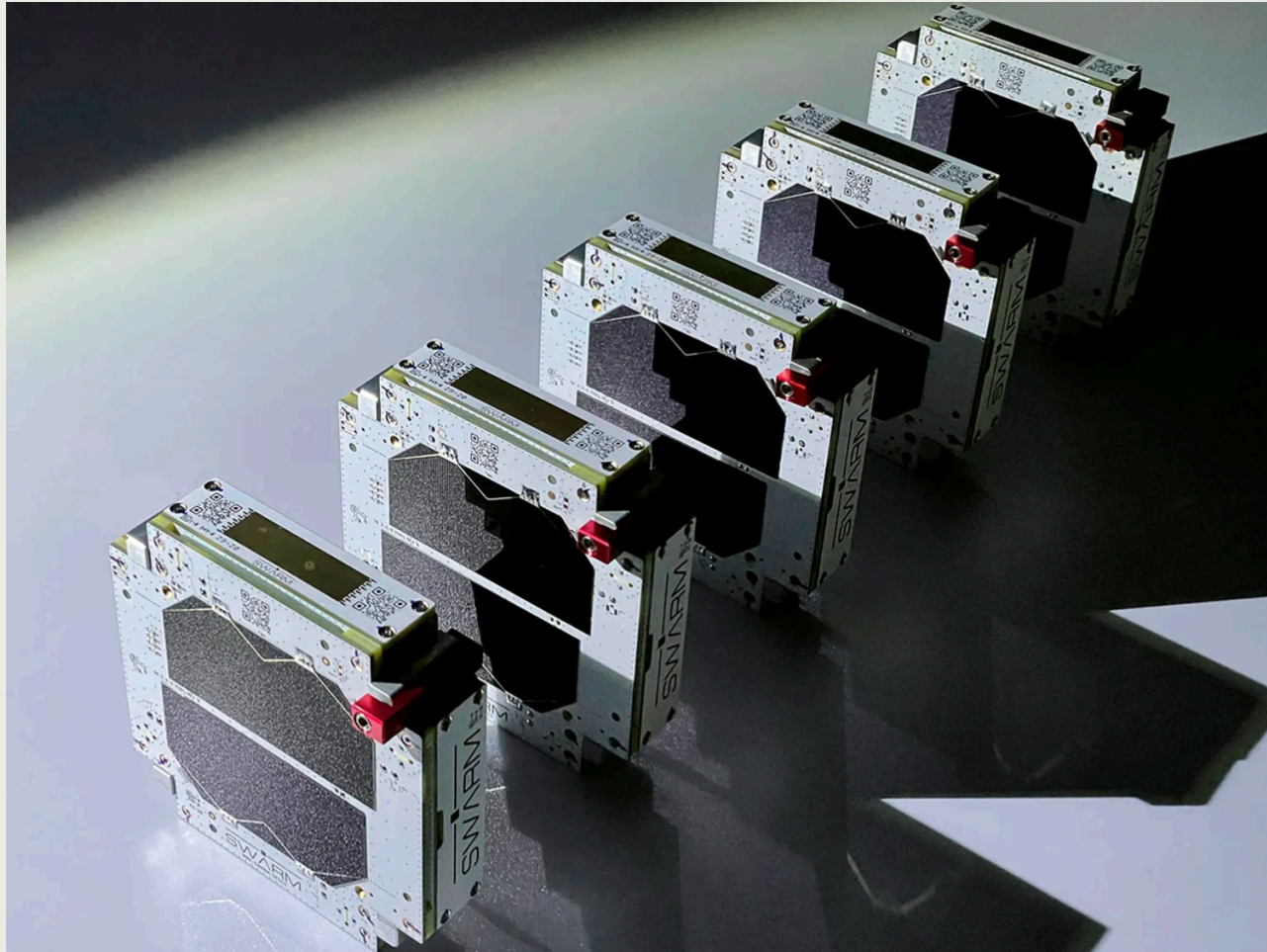
- Disaster Relief



Aquila was discontinued in 2018; Loon was discontinued in 2021

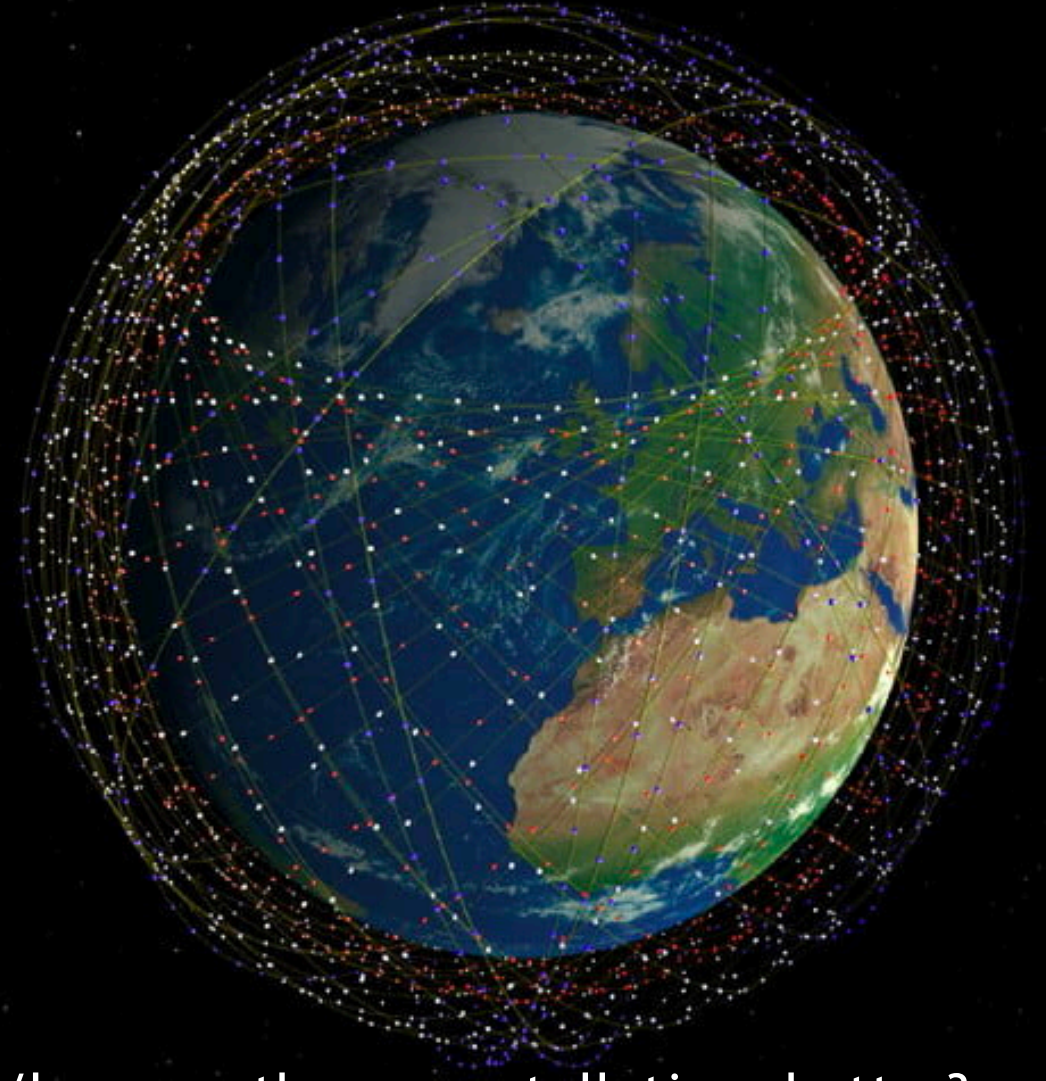
## Swarm Takes LoRa Sky-High > The satellite company has adapted the popular IoT technology for use in its constellation

BY MICHAEL KOZIOL | 23 MAR 2021 | 4 MIN READ | 



Each of Swarm's satellites is the size of a sandwich, but still has everything it needs to relay low-power signals from remote IoT networks to another point on the planet. PHOTO: SWARM

# SpaceX's Starlink



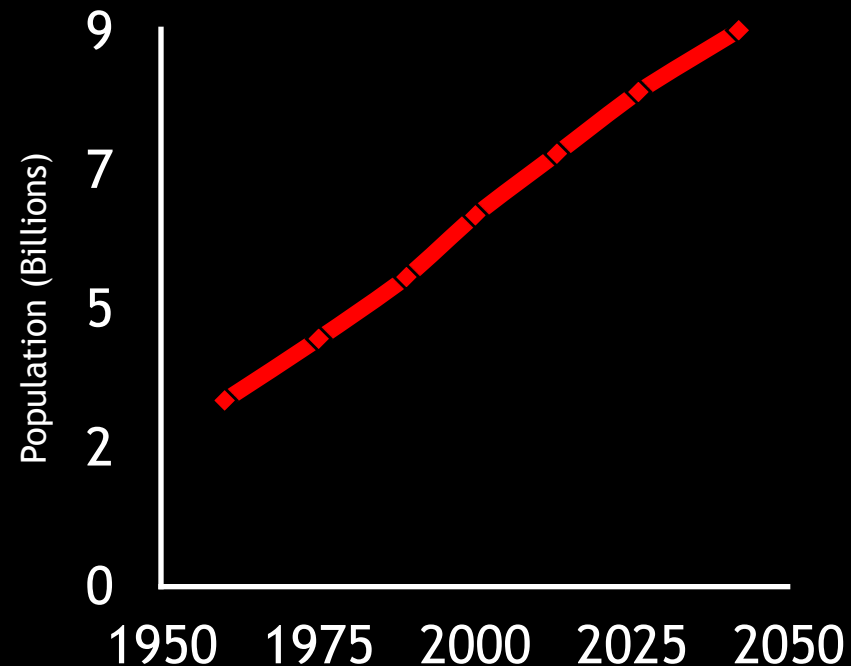
Satellite connectivity already exists (Iridium). Why/how are these constellations better?

# FarmBeats: An IoT System for Data-Driven Agriculture

NSDI 2017

# Why Agriculture?

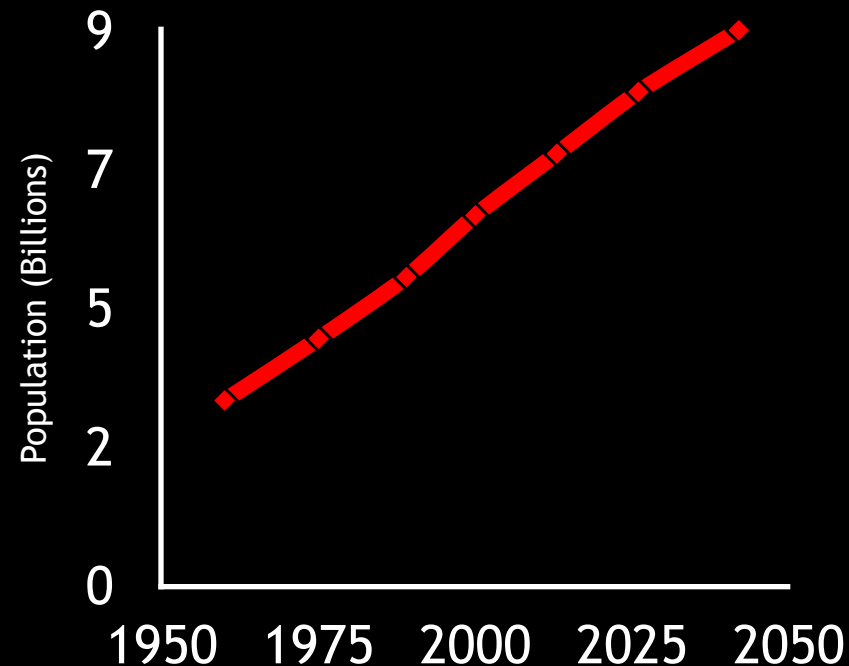
Agricultural output needs to **double by 2050** to meet the demands  
- United Nations<sup>1</sup>



<sup>1</sup>: United Nations Second Committee (Economic & Financial), 2009

# Why Agriculture?

Agricultural output needs to **double by 2050** to meet the demands  
- United Nations<sup>1</sup>



But...

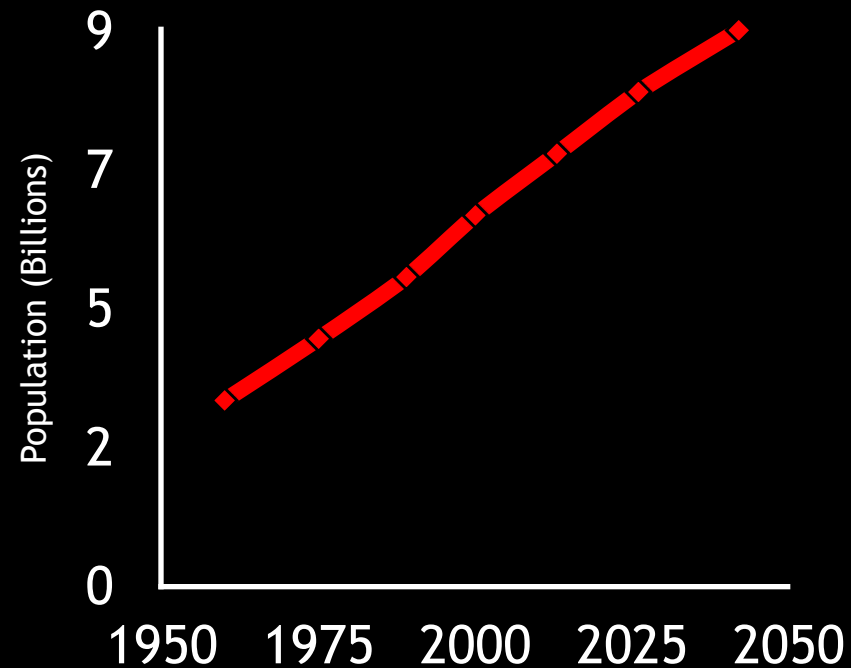
- Water levels are receding
- Arable land is shrinking
- Environment is being degraded

<sup>1</sup>: United Nations Second Committee (Economic & Financial), 2009

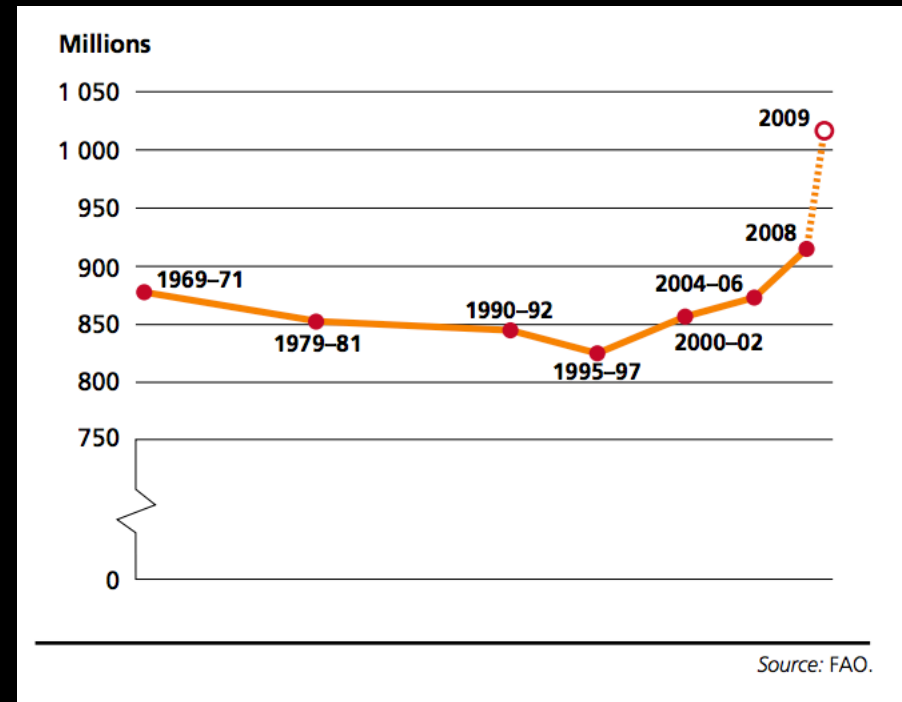


# Why Agriculture?

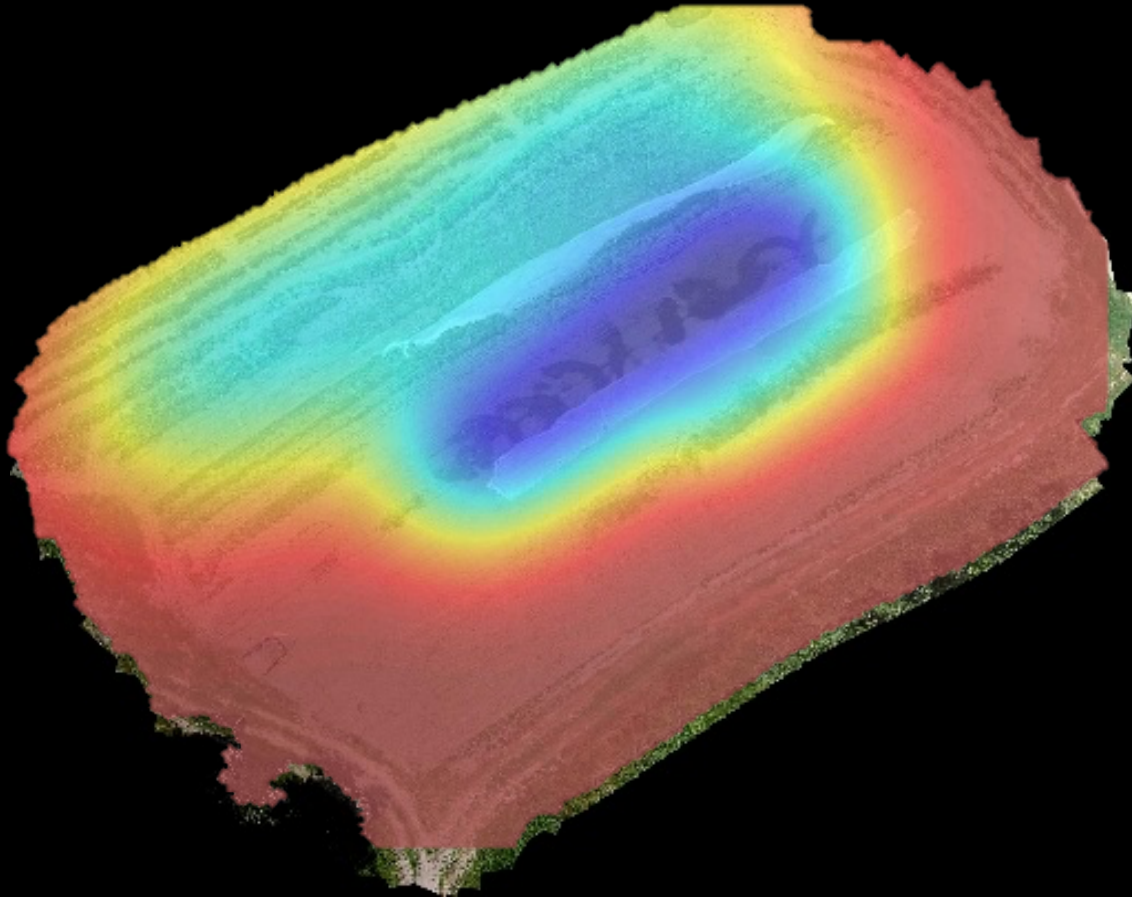
Agricultural output needs to **double by 2050** to meet the demands  
- United Nations



## Number of World's Hungry People



# Solution: Data-Driven Agriculture



Traditional vs Data-driven approach

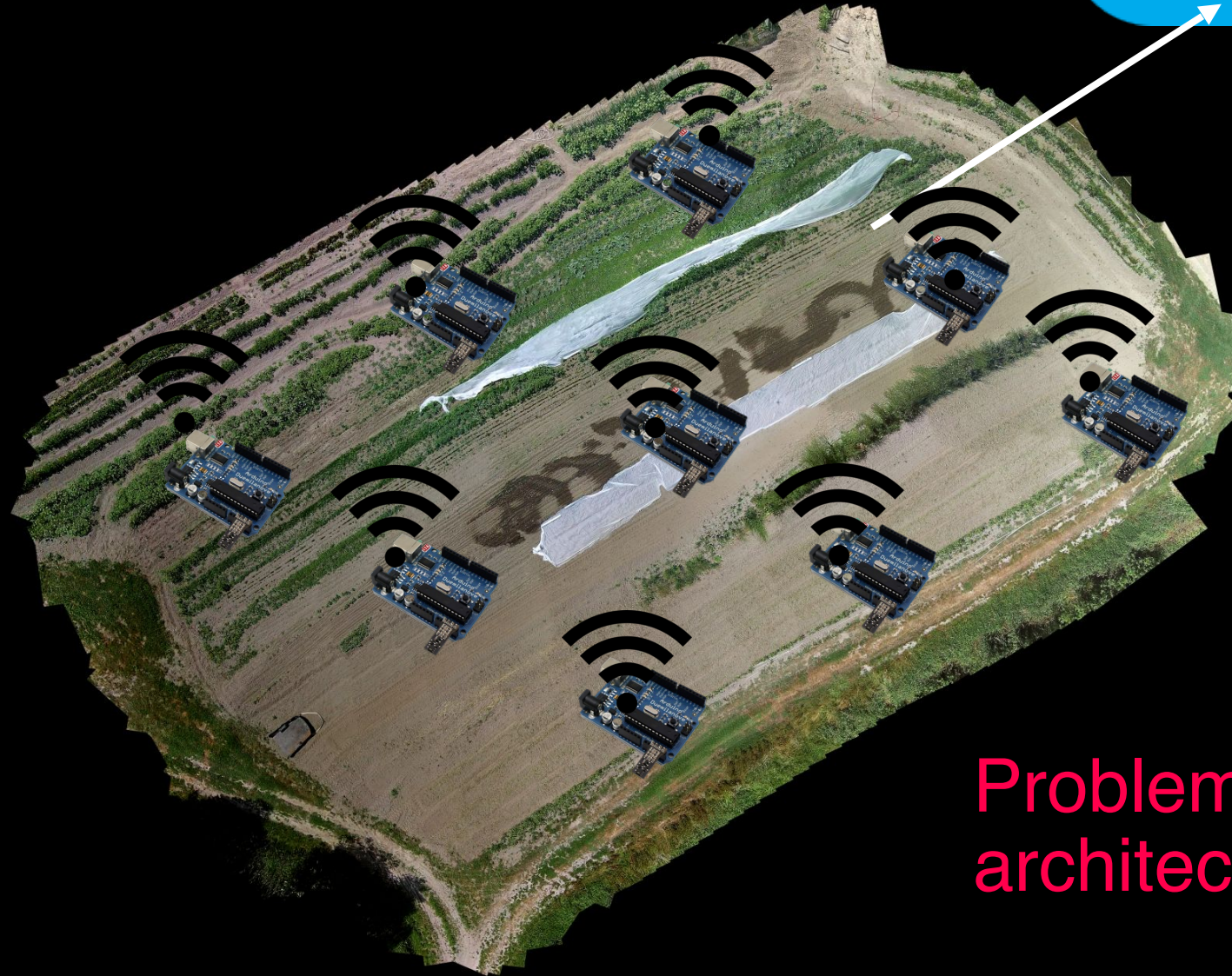
Ag researchers have shown that it:

- 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



Problems with this architecture?

# 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

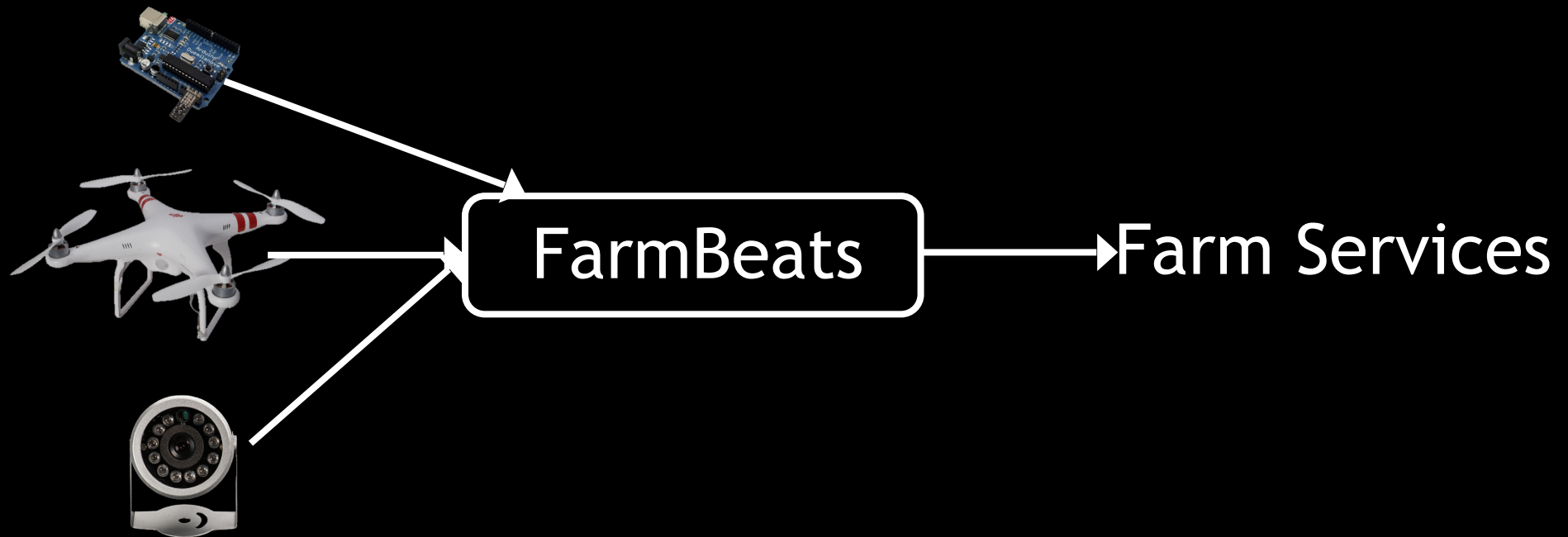
# Problem 3: Limited Resources

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

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

# Rest of this lecture

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

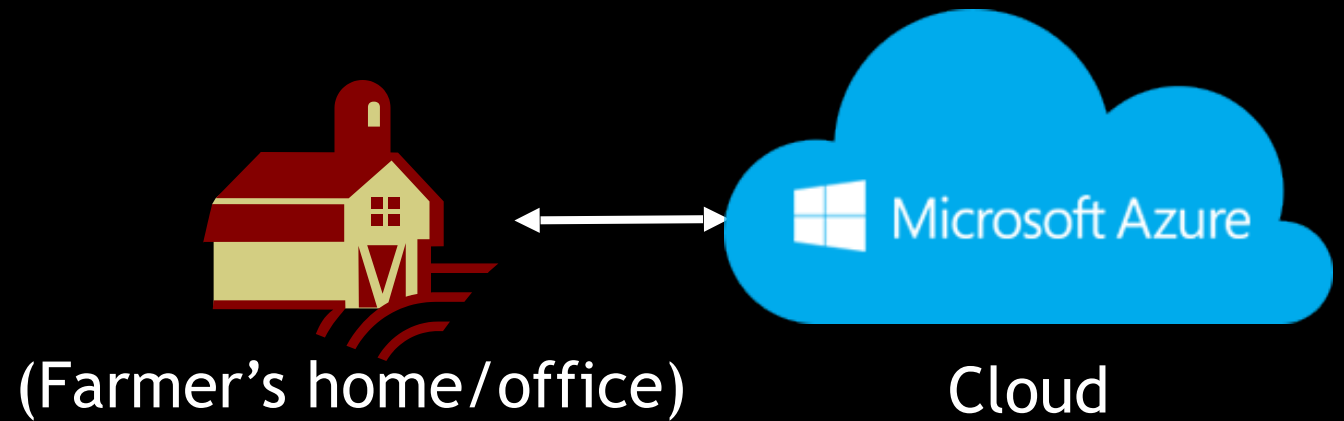




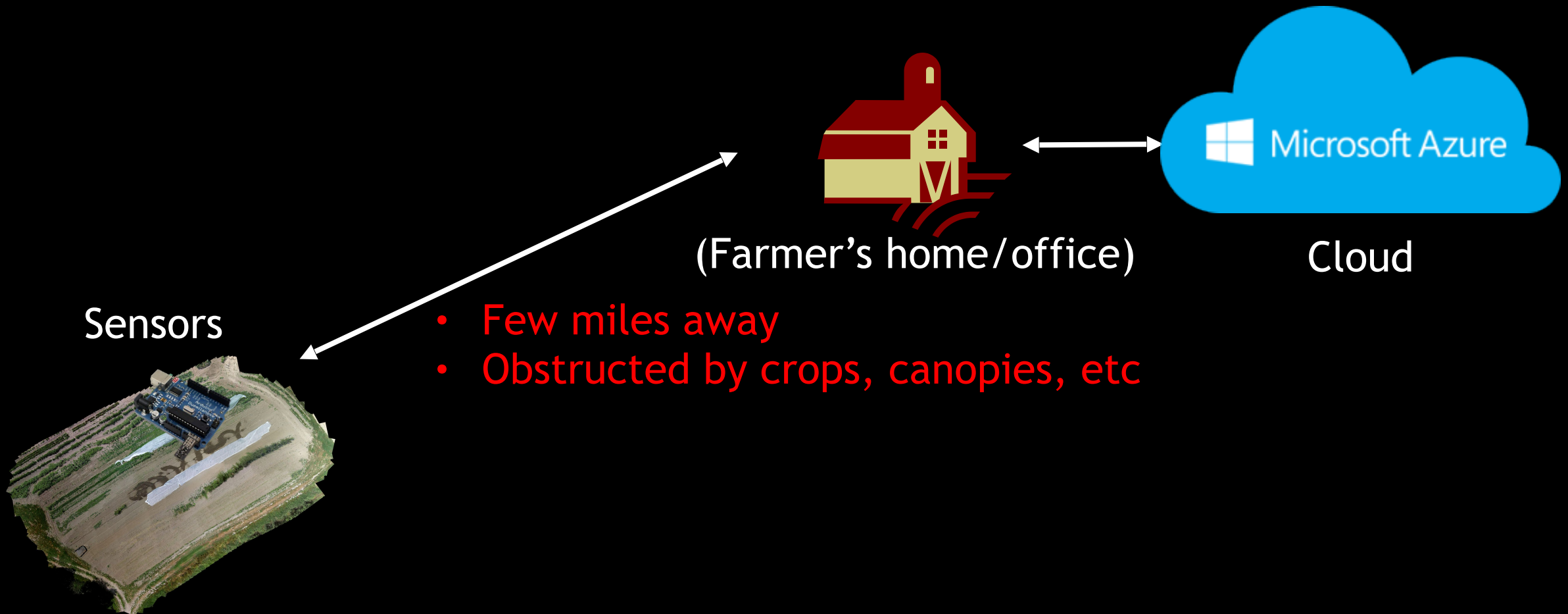
# Rest of this lecture

- 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



# Approach: Use TV White Spaces

- Can provide long-range connectivity (10 miles)
- 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



Wi-Fi, BLE



Sensors

TV White Spaces

←→  
Few miles



(Farmer's home/office)

- Weak Connectivity
- Prone to outages

Microsoft Azure

Cloud

# Approach: Compute Locally and Send Summaries

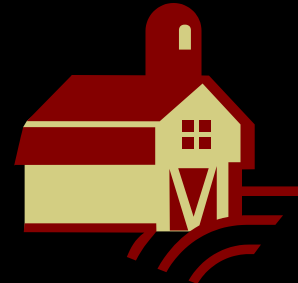
- PC on the farm delivers time-sensitive services locally
- Combines all the sensor data into summaries
- 2-3 orders of magnitude smaller than raw data
- Cloud delivers long-term analytics and cross-farm analytics

# FarmBeats Design

Base Station



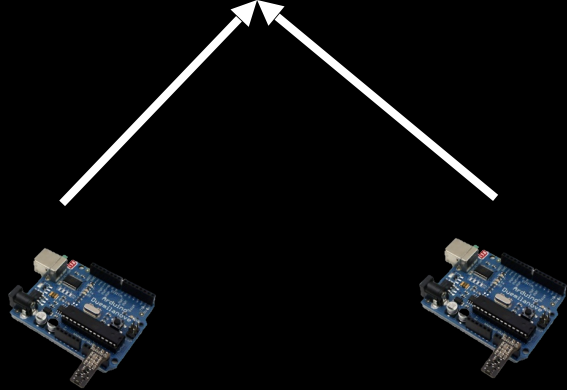
TV White Spaces  
←→  
Few miles



Gateway PC  
(Farmer's home/office)



Cloud



Sensors

# In this lecture

- FarmBeats: An end-to-end IoT system that enables seamless data collection for agriculture
- Solves three key challenges:
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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?

# Approach: 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

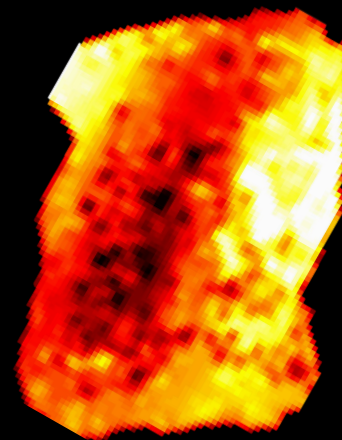
# Idea: Use Drones to Enhance Spatial Coverage



Drone Video



Panoramic Overview



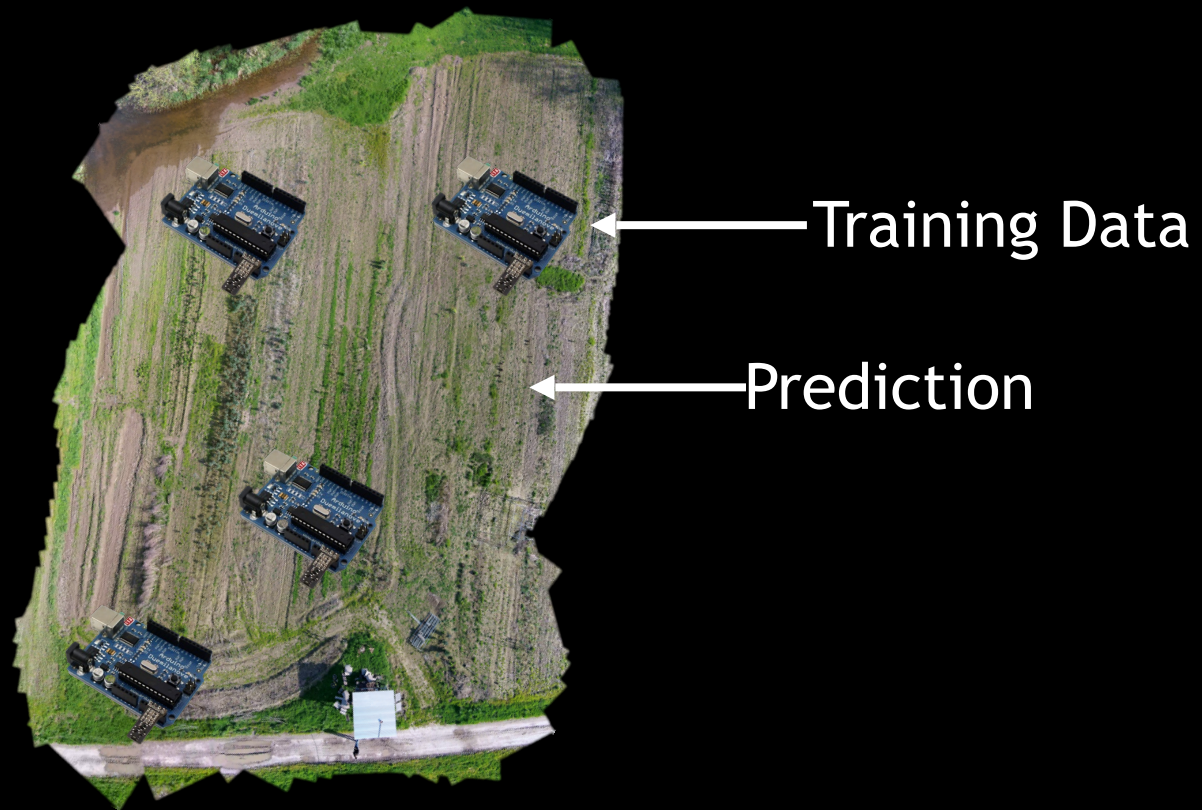
Precision Map



Sparse Sensor Data



# Formulate as a Learning Problem



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



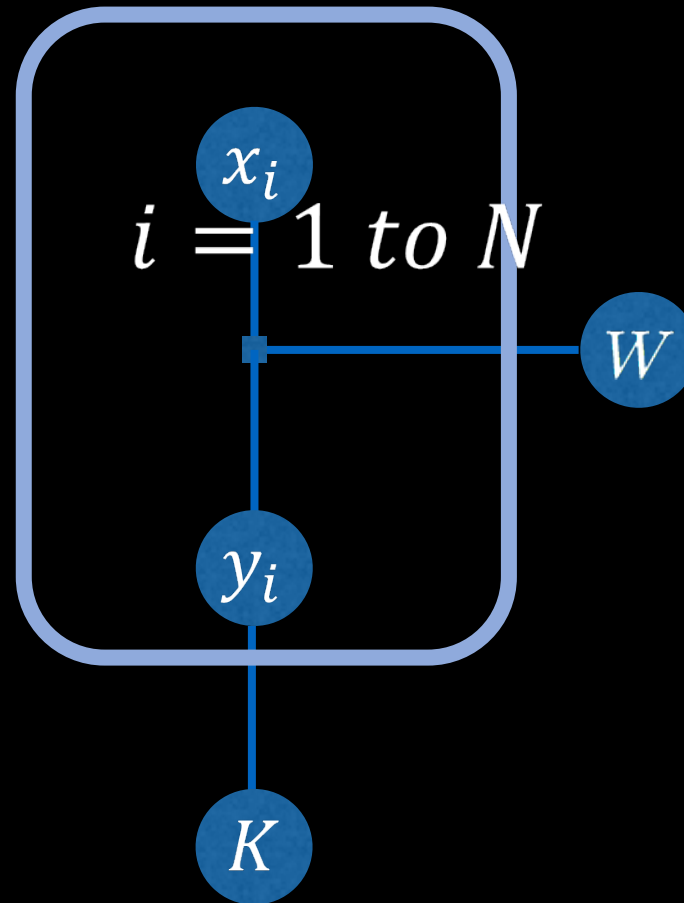
# Model: Gaussian Processes

Features (visual)

Kernel (Model  
visual similarity)

Output (say, moisture)

Spatial Smoothness



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

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

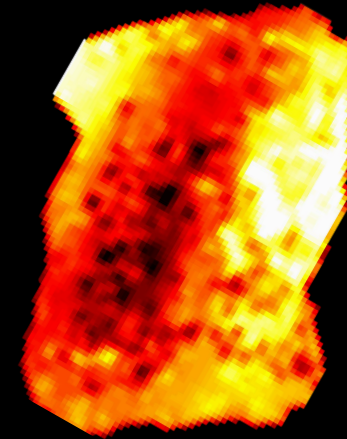
# Using Sparse Sensor Data



Drone Video



Panoramic Overview



Precision Map

100 kB summary



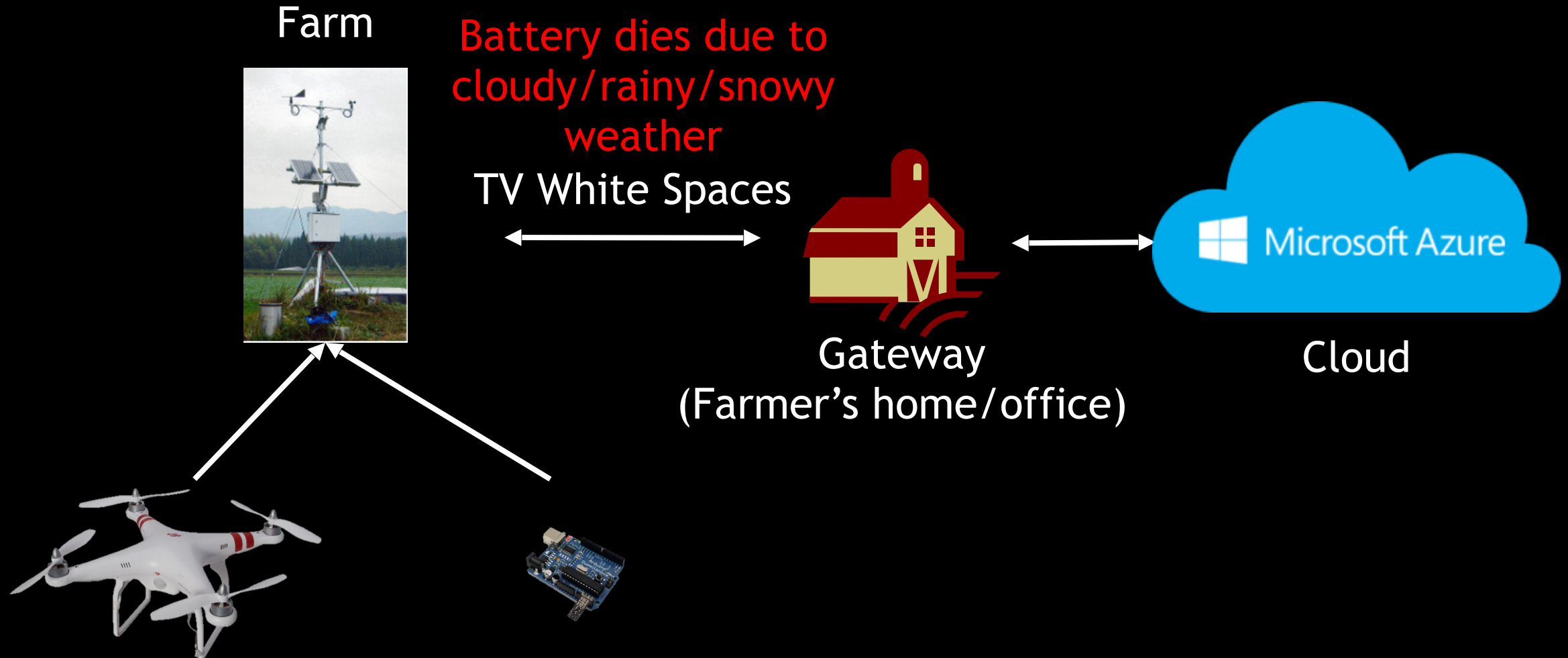
FarmBeats can use drones to expand the sparse sensor data and create summaries for the farm

# In this talk

- FarmBeats: An end-to-end IoT system that enables seamless data collection for agriculture
- Solves three key challenges:
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  - ✓ Limited Sensor Placement
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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?

# Approach: Weather is Predictable

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

# Idea: Weather is Predictable

- $\gamma$ : Duty Cycle ratio,  $T_{on}$ : On time in each cycle,  $T_{off}$ : Off time

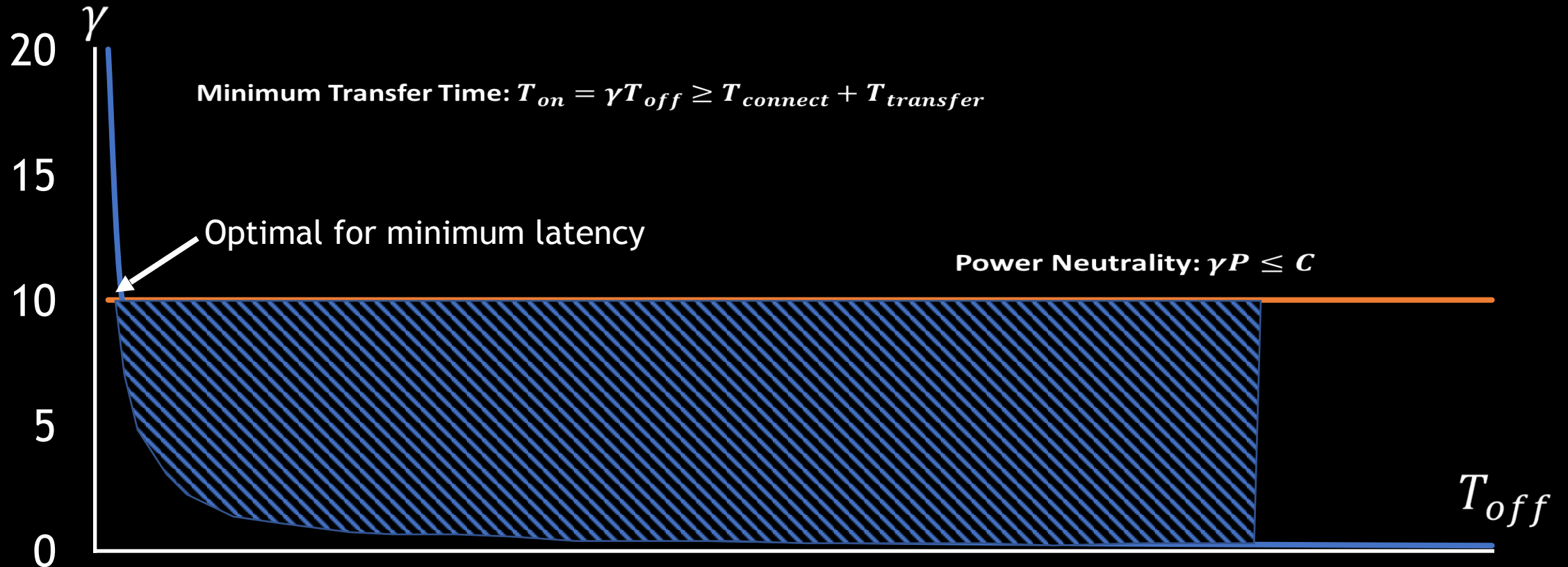
- $\gamma = \frac{T_{on}}{T_{off}}$

- Constraints:

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

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

# Solution: Weather is predictable



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

# In this lecture

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

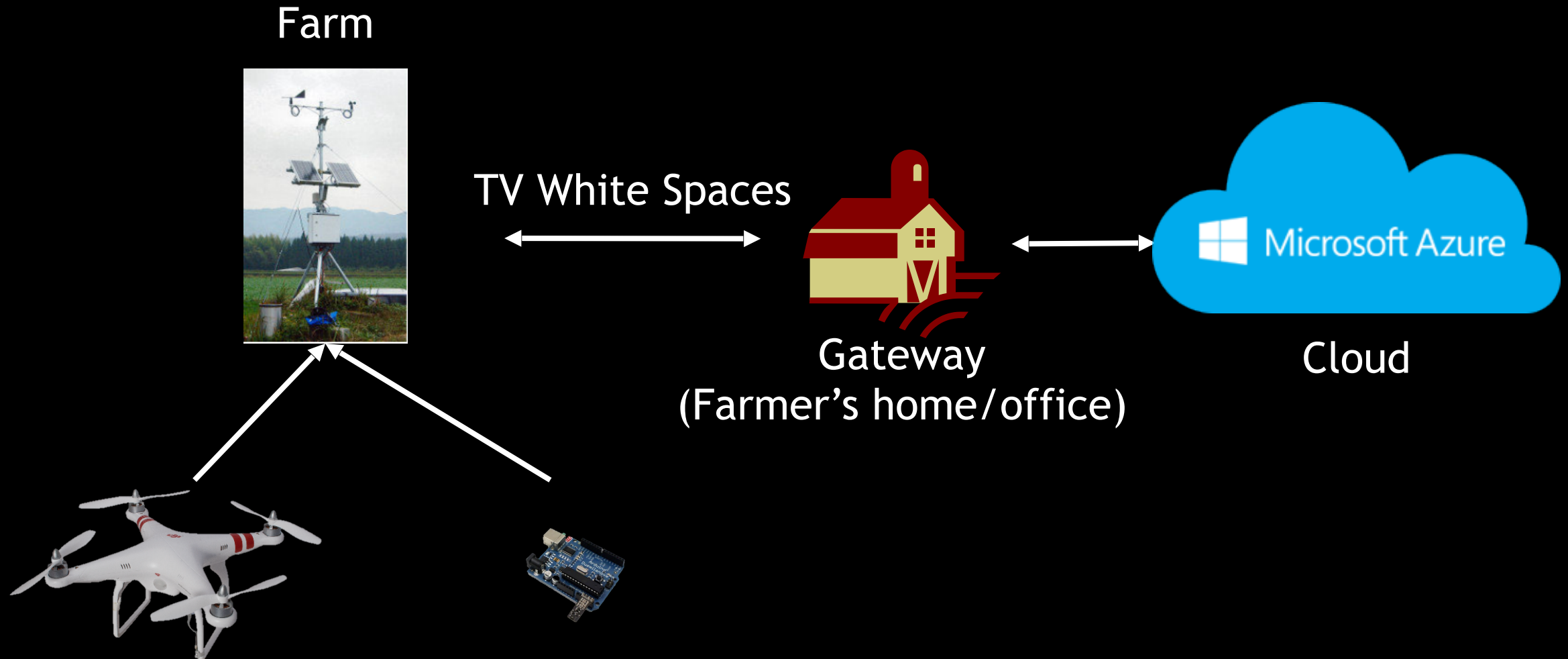


# Deployment Statistics

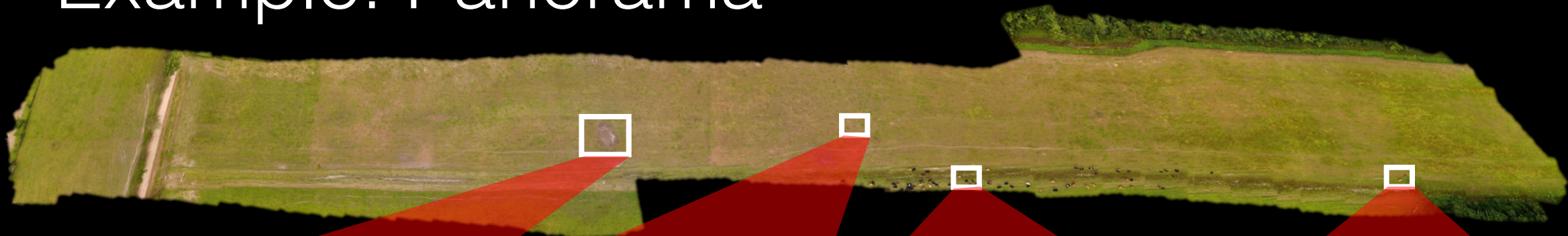
- Used 10 sensor types, 3 camera types and 3 drone versions
- Deployed >100 sensors and ~10 cameras
- Collected >10 million sensor measurements, >0.5 million images, 100 drone surveys
- Resilient to week long outage from a thunderstorm



# FarmBeats: Usage



# Example: Panorama



Water puddle



Cow excreta



Cow Herd

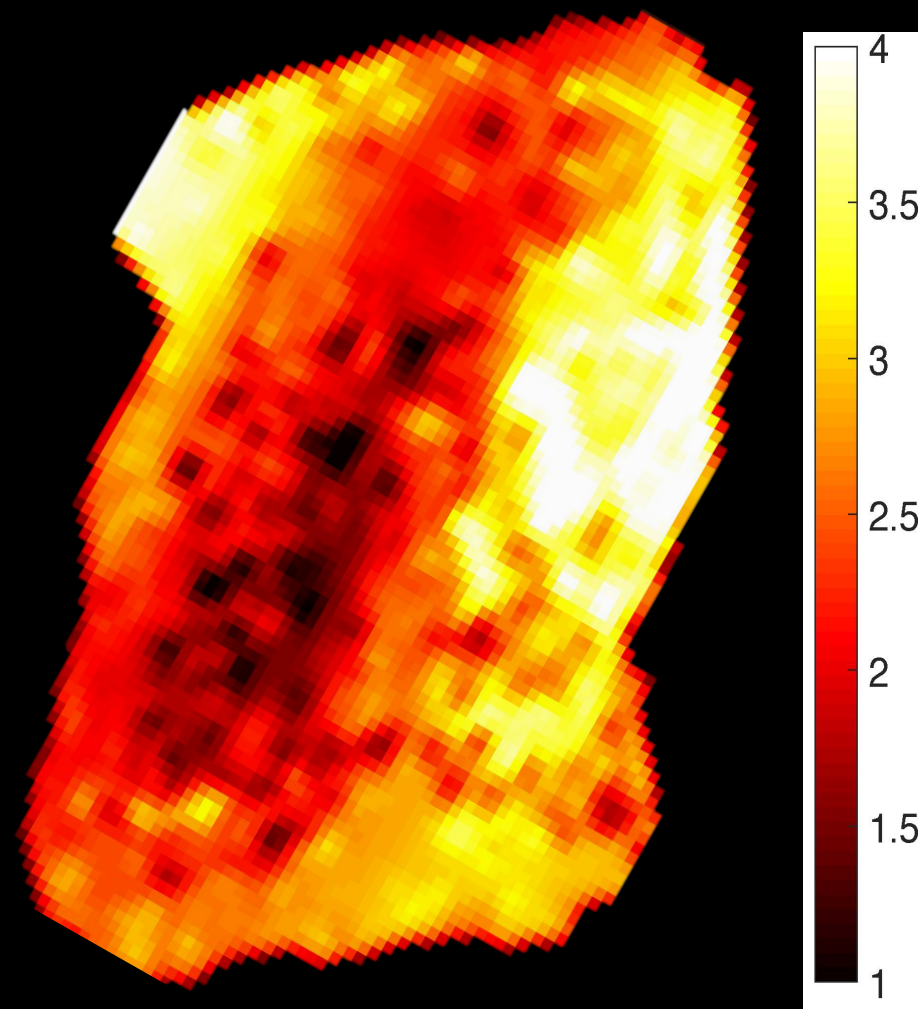


Stray cow

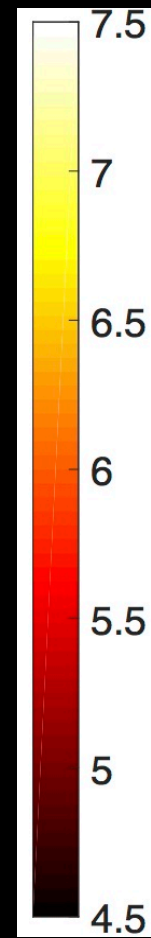
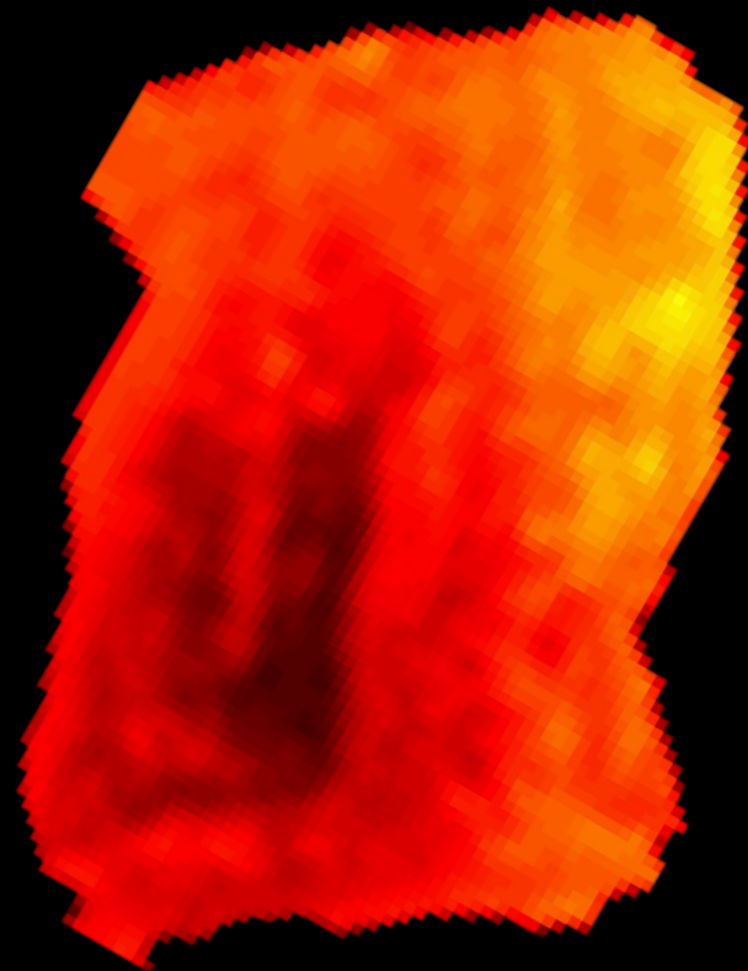
# Precision Map: Panorama Generation



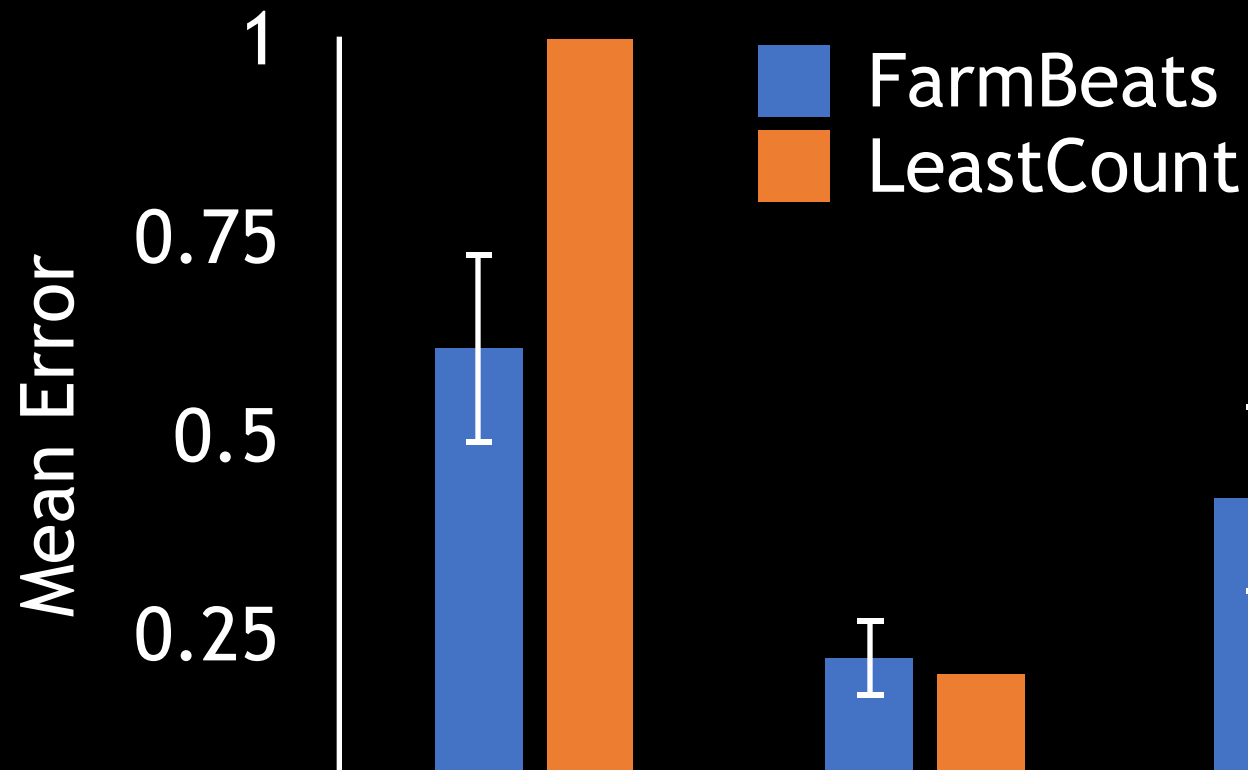
# Precision Map : Moisture



# Precision Map : pH

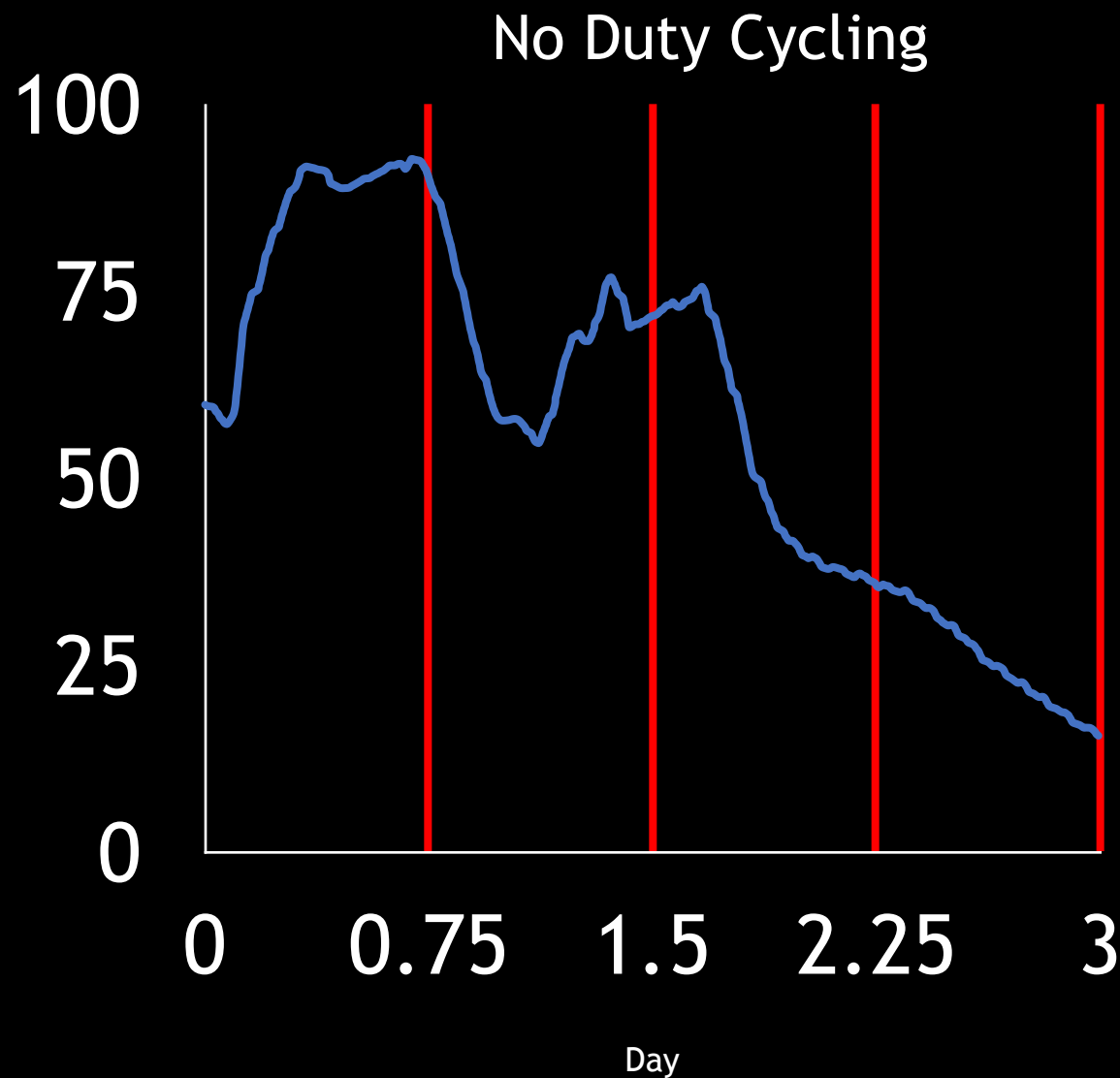
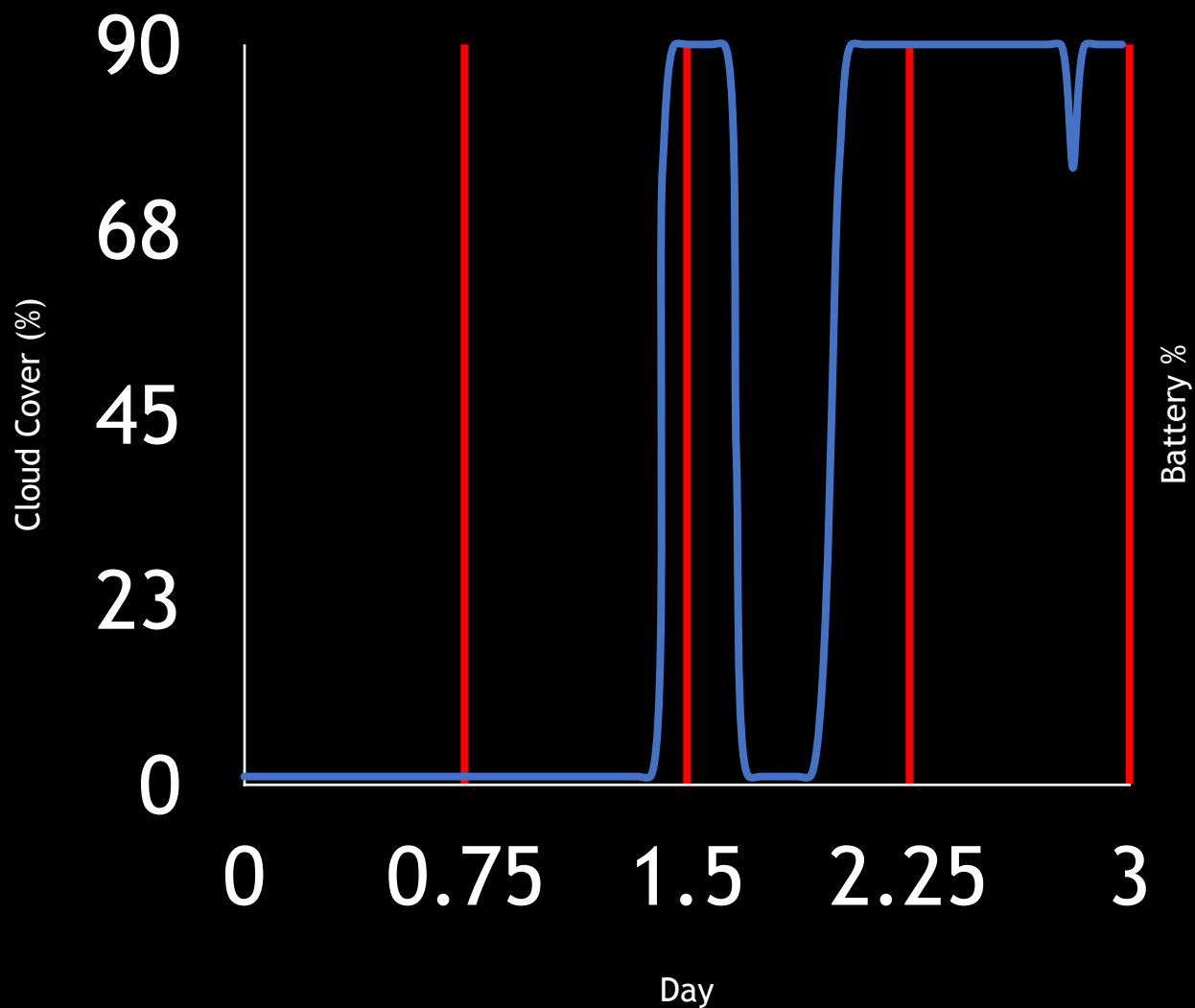


# Precision Map: Accuracy

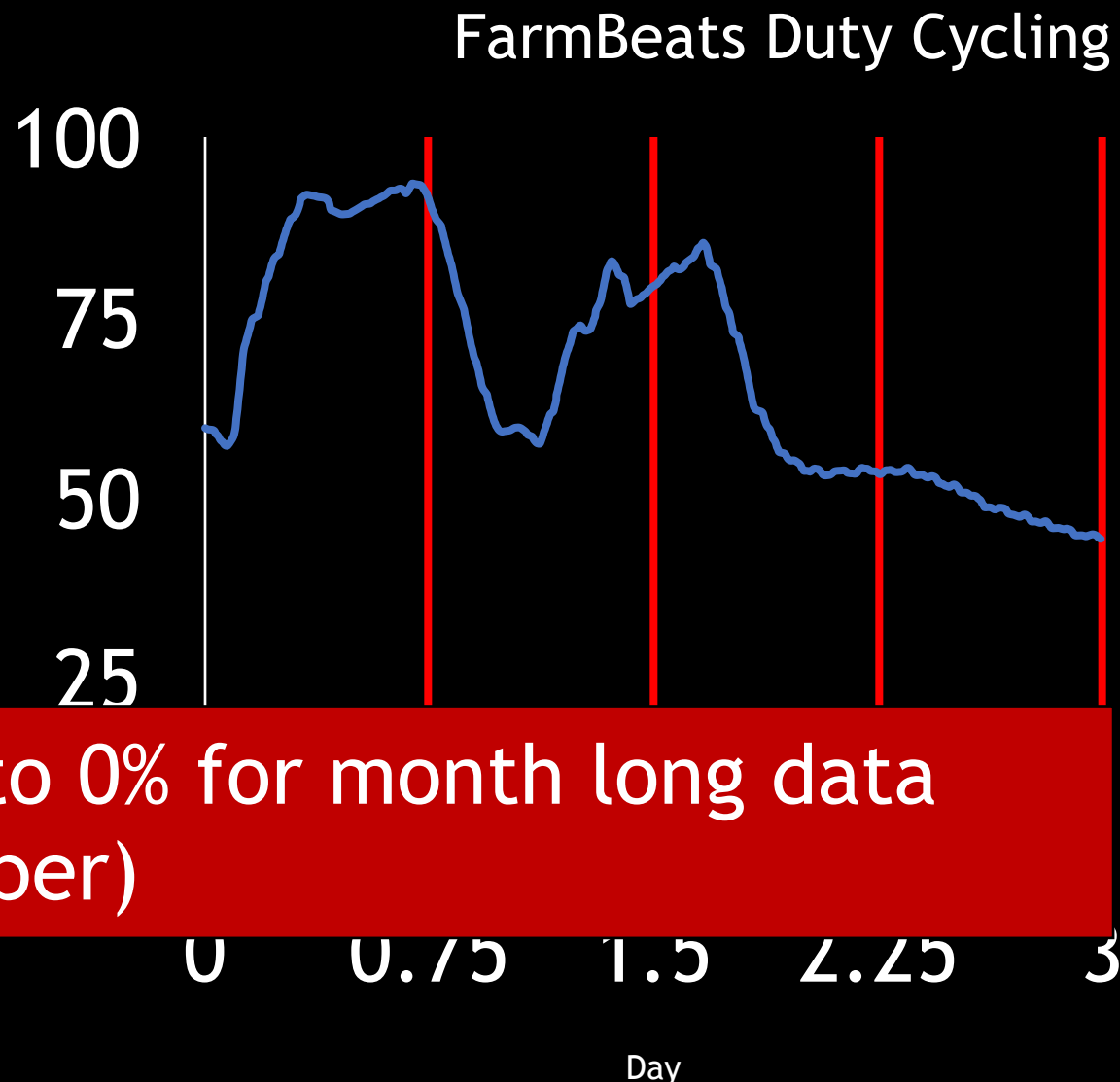
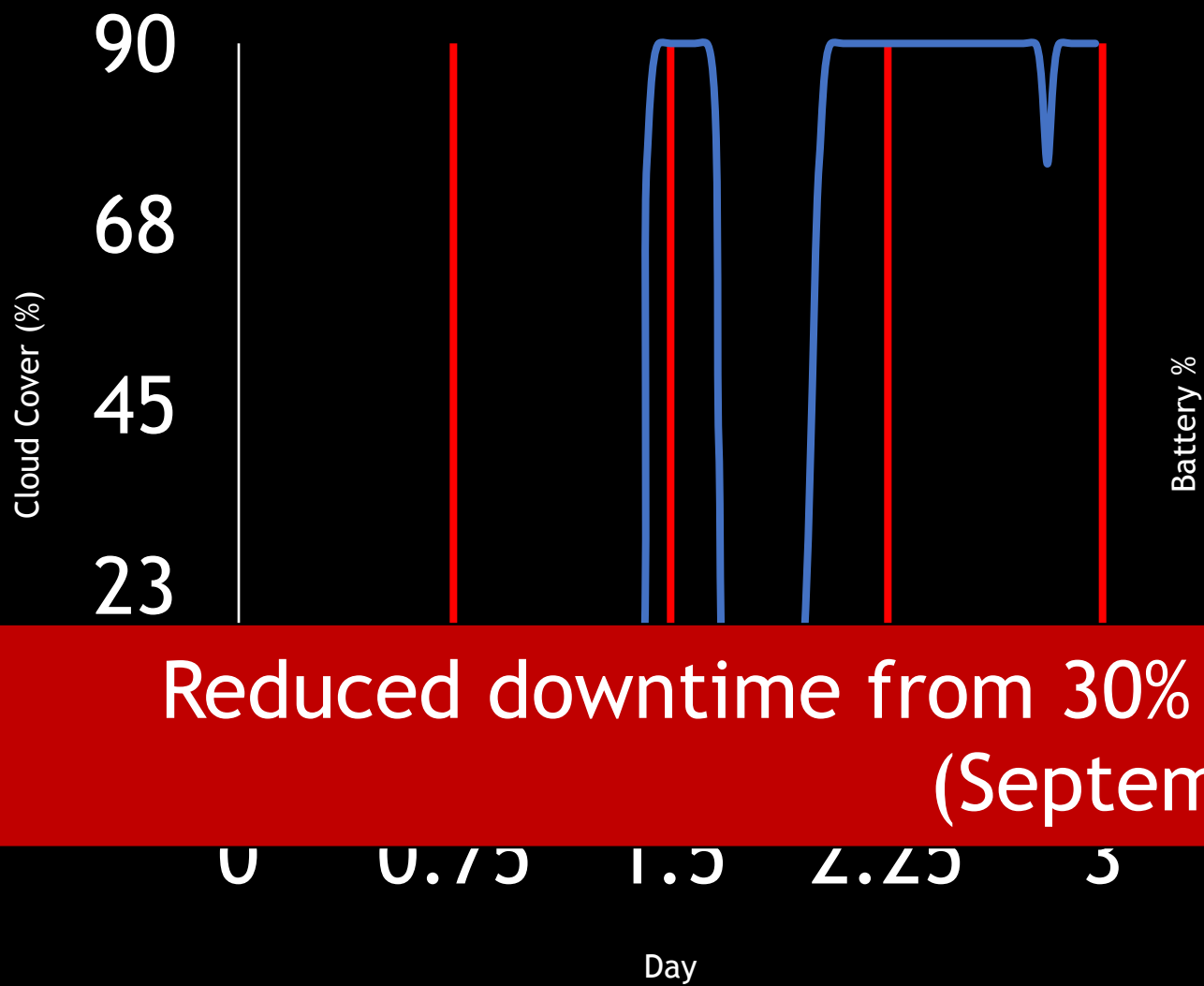


FarmBeats can accurately expand coverage by orders of magnitude using a sparse sensor deployment

# Weather-Aware Duty Cycling



# Weather-Aware Duty Cycling



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





# Other Related Works

- **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)

# Summary

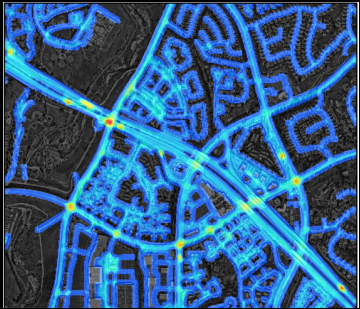
- Aerial-based Connectivity (Loon, Aquila) & Agriculture IoT
- Challenges: Power, Control, Communication Range, Bandwidth, Weather
- Opportunities: Duty cycling, sparse sampling, weather prediction, thermodynamics, learning and sensor fusion, Drones
- Farmbeats: End-to-end IoT system for Farming

# Remainder of the Class

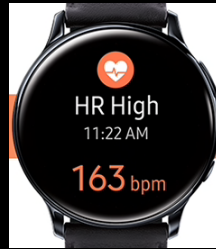
## Emerging Application Domains & Cross-Cutting Topics



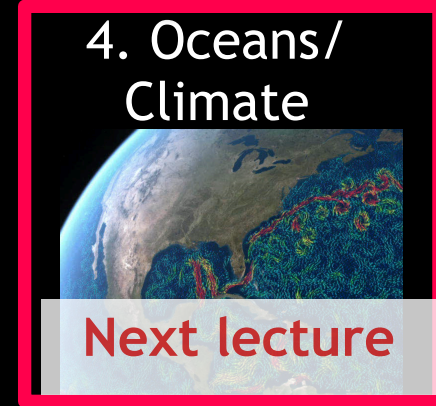
1. Transportation



2. Health



3. Agriculture



5. Security/  
Privacy



## TODO:

- 1- Project Proposals due TODAY
- 2- Lab 4 out; due March 30
- 3- PSet 2 due April 4
- 4- Grades will be out this week