ESTF2020

SPCTOR: Sensing-Policy Controller and OptimizeR

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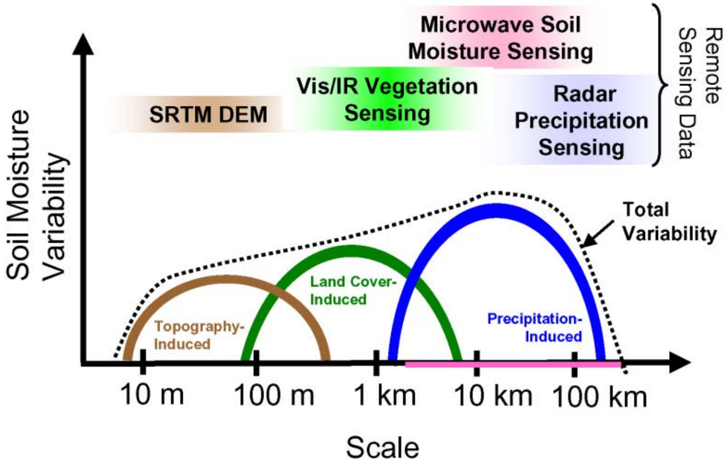
Program: AIST-18

Problem to Solve

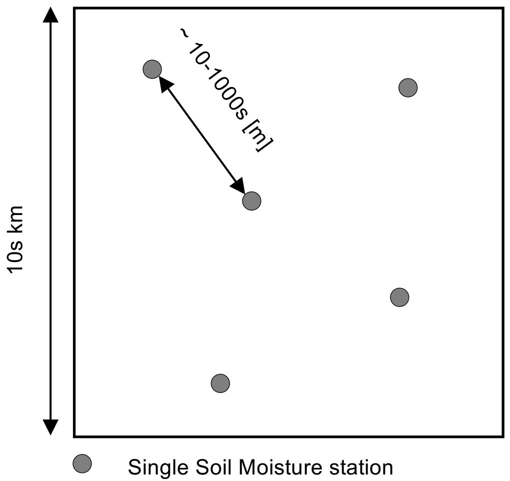
1. Soil moisture is highly variable at multiple scales across landscape and time
2. Landscape heterogeneity is "smeared" within antenna footprint
3. Observation technologies for soil moisture must be adaptive in space and time
4. Distributed wireless sensor networks (WSNs) within FOV will increase <u>representativeness</u>

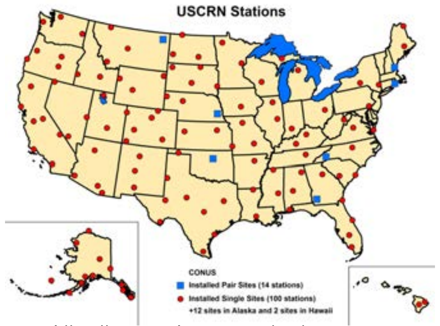
   Yet, WSN are "**static**"

   1. Network deployment considers representation of many different factors influencing soil moisture (topography, land cover, soil type, etc.)
   2. But conventional sensor networks have limitations in adequate sampling



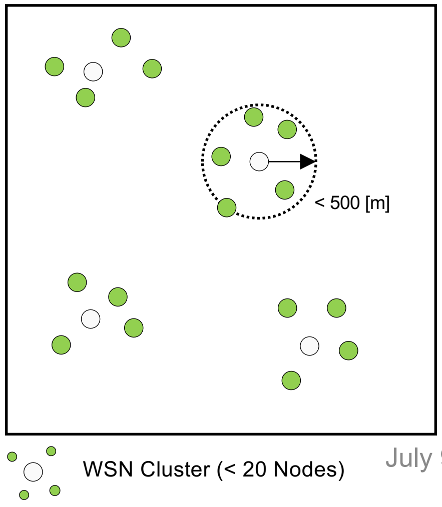
"Traditional" Approach



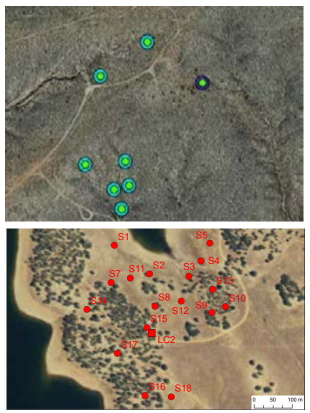


https://www.ncdc.noaa.gov/crn/

Wireless Sensor Networks (WSN)



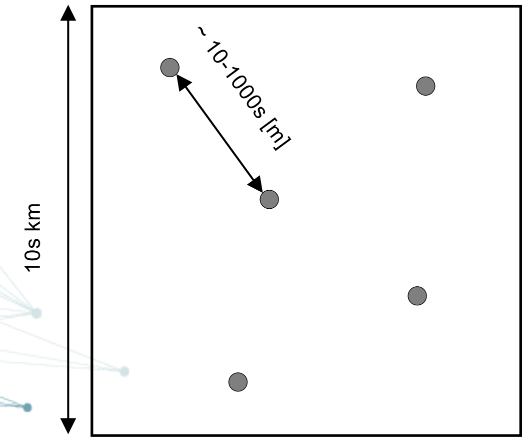
Example Sites in CA and AZ



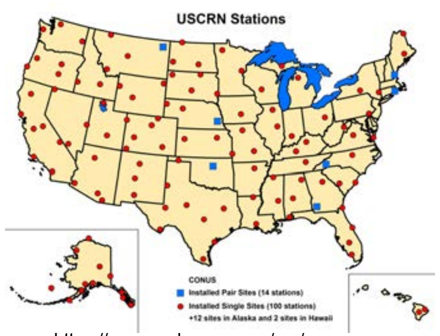
Solution

1. UAVs are mobile platforms which can "gap fill, expand, and complement in-situ WSN
2. Software Defined Radars (SDRadars) have reached a level of maturity that allows us to locally (~100s [m]) maps soil moisture beyond point observations
3. Technical challenge is coordinating WSN and UAV-SDRadar operations!

"Traditional" Approach



Single Soil Moisture station



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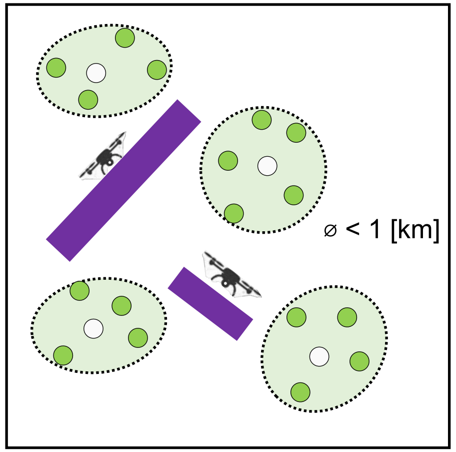

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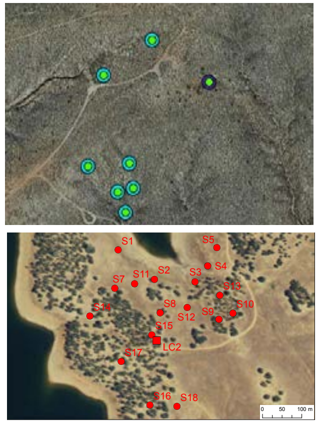


WSN Cluster (< 30 Nodes)

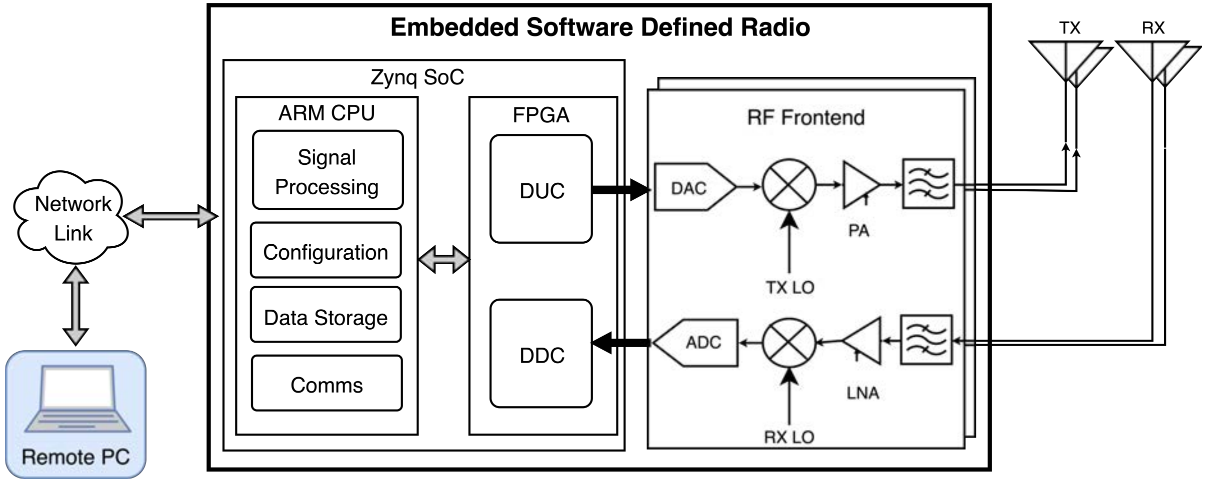
UAV Flight Path

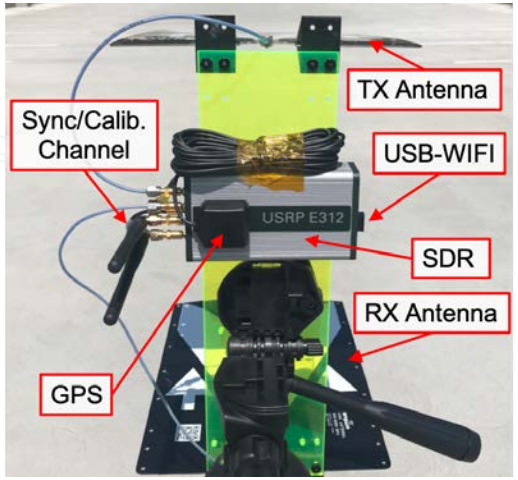
Objective 1: Develop a Sensing-Policy Controller (SPC) for multi-Agent observation strategy coordination and optimization (TRL - 2)

Objective 2: Develop and demonstrate integrated operations between in-situ WSN and networks of UAV-SDRadars based on SPC commands (TRL- 4)

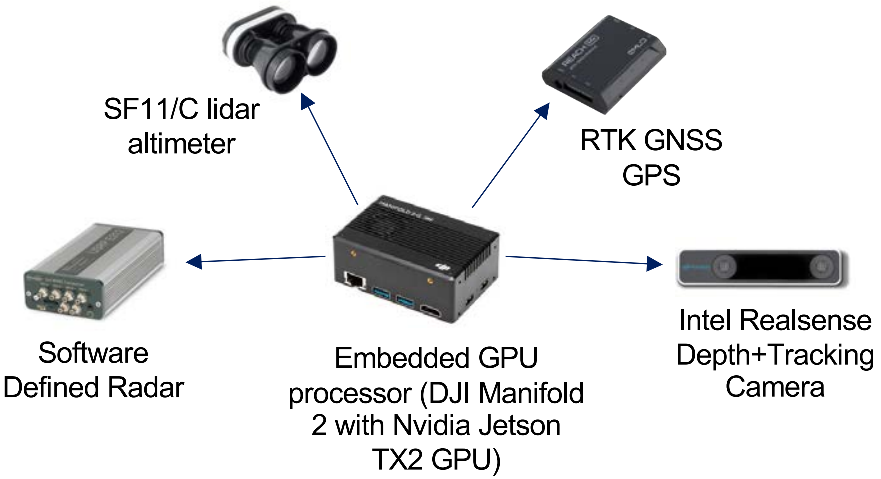
Technical Details (UAV-SDRadar)

- Single radar sensor that can be deployed across a wide range of environments with different characteristics and requirements
- Small, low-cost, and highly flexible hardware platform
- Real-time configuration and control
- *Potential to perform environmental monitoring tasks at higher spatial and temporal resolutions than space-borne counterparts and with larger area coverage than in-situ sensors*





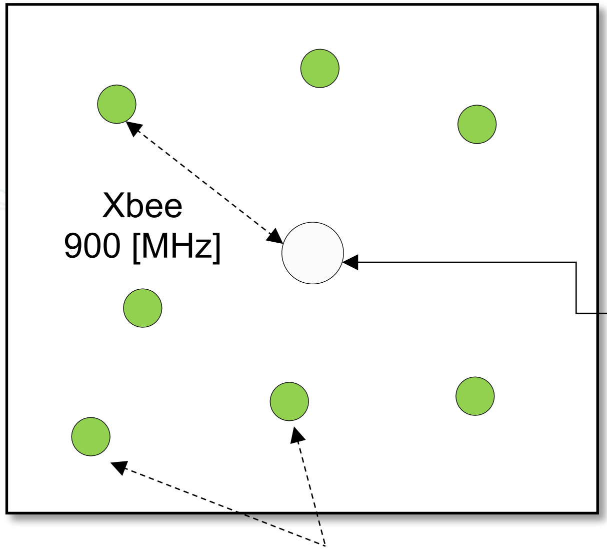
USC SDRadar prototype built using USRP E312 hardware



Technical Details (WSN + UAV)

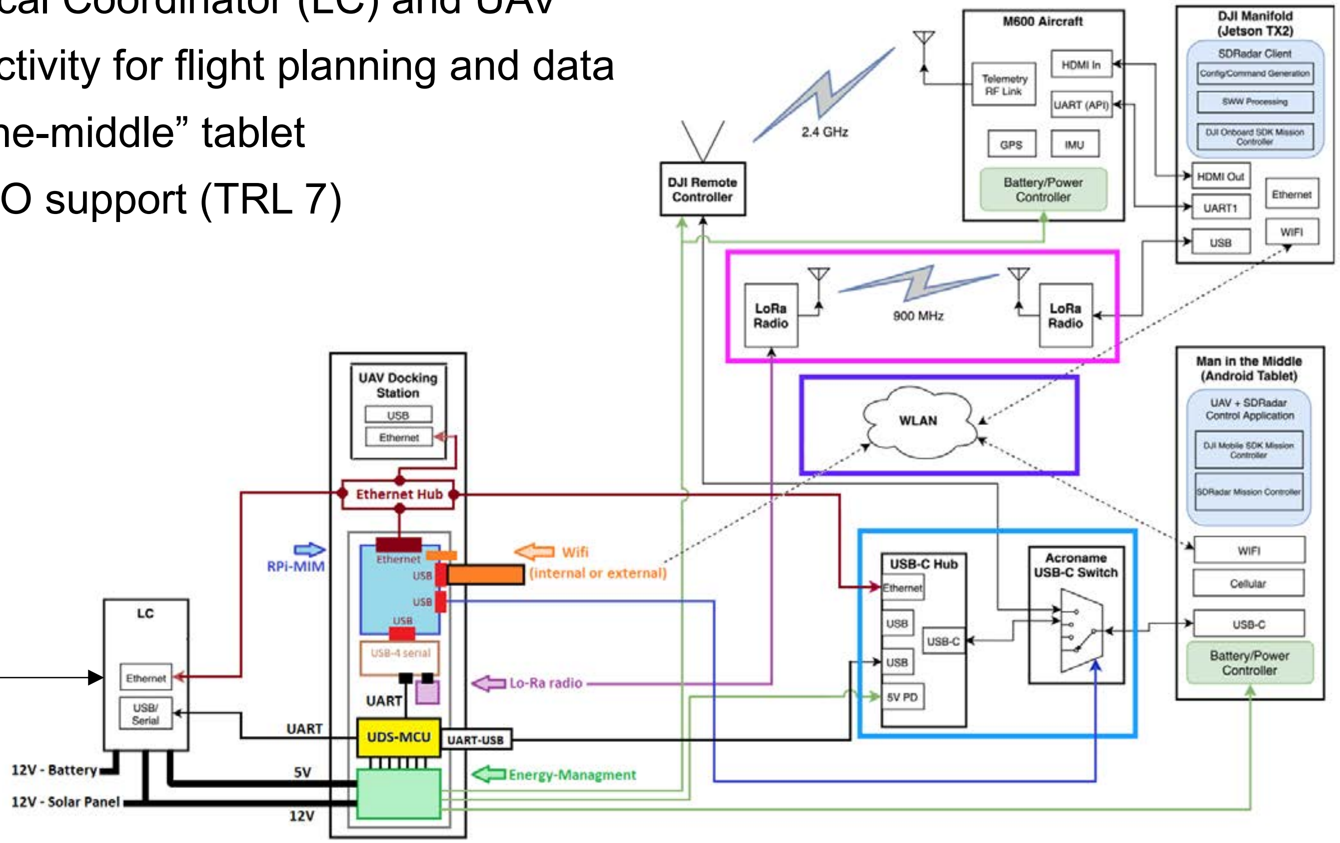
- Investigating and Implementing 3 solutions to enable 2-way data communication between WSN Local Coordinator (LC) and UAV
  - LoRa, WiFi, and USB connectivity for flight planning and data
  - Flight Software on “man-in-the-middle” tablet
- WSN LC available from prior ESTO support (TRL 7)

Wireless Sensor Network Domain



Wireless End-node
4-soil moisture sensors

UAV-SDRadar



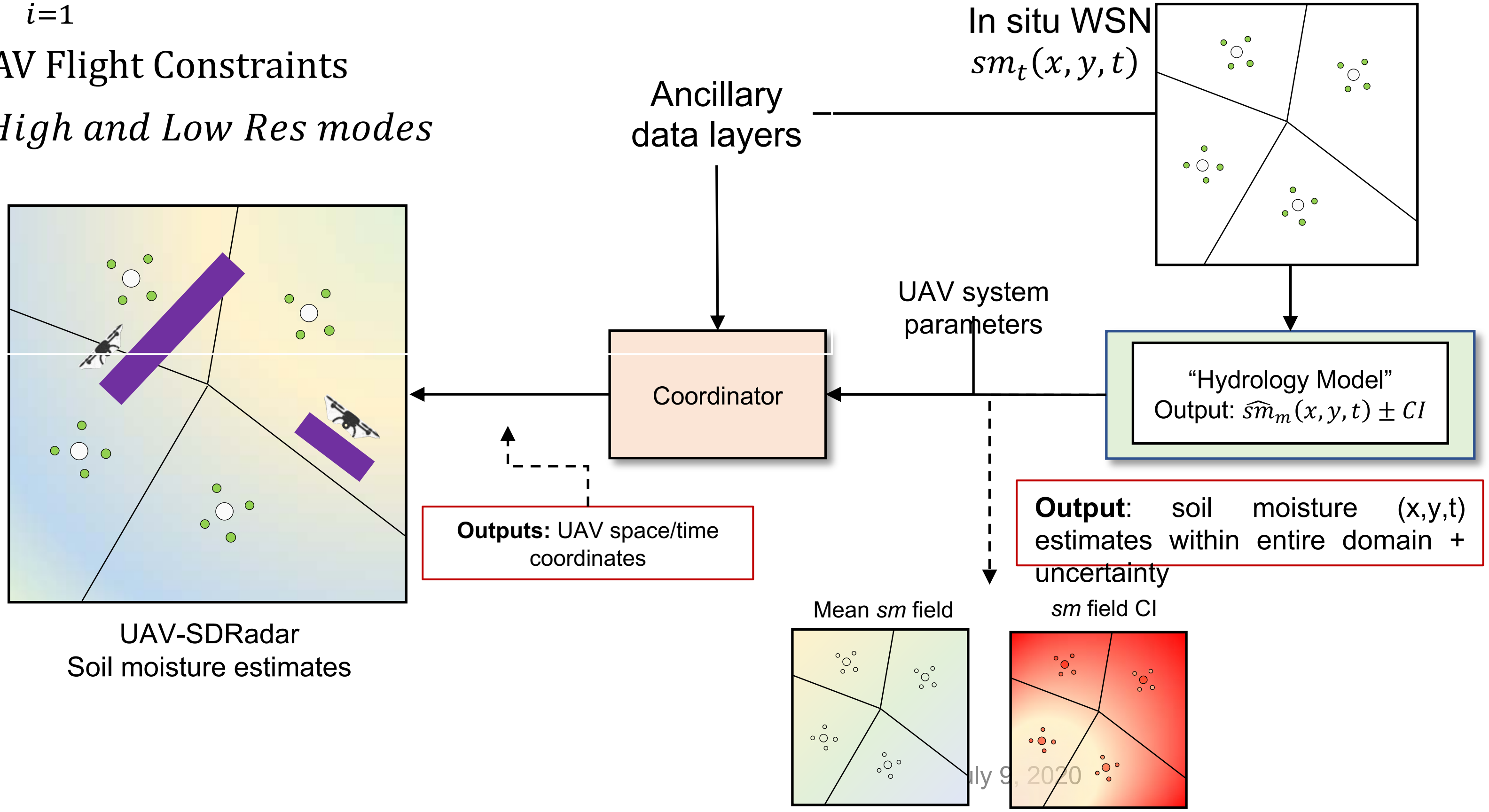
Technical Details (WSN-UAV Path planning and coordination)

- UAV-WSN planning is a Multi-Objective Optimization
- Maximize UAV flight coverage over background soil moisture uncertainty

$$\max_{x,y} \sum_{i=1}^{N} U\big(x(i), y(i)\big)$$

$$s.t.\,\text{UAV Flight Constraints}$$

$$SDRadar\ High\ and\ Low\ Res\ modes$$

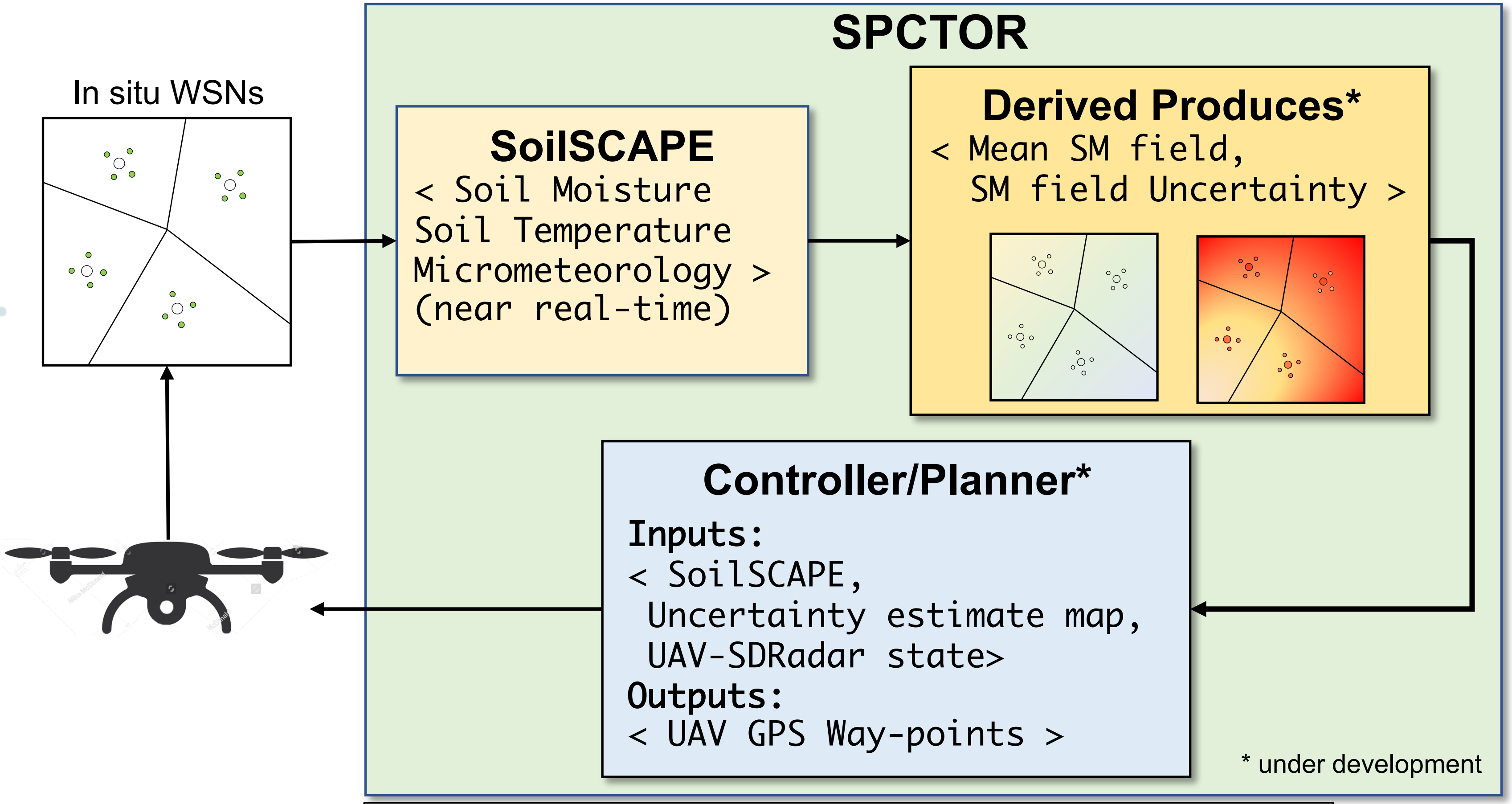


Next Steps / Contributions

- **On-going work:**
  a. SoilSCAPE in-situ WSN + UAV data and communication hardware design and implementation
     - Investigation of physical layer options (WiFi, LoRa, etc.)
  b. Development of Sensing Policy Controller (SPC)
     - UAV path planning optimization based on in-situ soil moisture knowledge from WSN
     - Development of Multi-agent Reinforcement Learning scheme for coordinated operation of WSN and UAC

- **Contributions to ESTO-AIST New Observation Strategies**:
  a. Evaluation/comparison of alternative observing [sensing] strategies (Obj. 1)
  b. Estimation of science value to enable comparison of observing strategies (Obj. 1)
  c. Integrated operation of different types of instruments or at different vantage points (Obj. 2)

Back Up Slides



- SoilSCAPE Soil Moisture, Temp. & Micro.Met Data
- Mean SM and Uncertainty estimate maps
- UAV GPS Way-points
- UAV-SDRadar swath(s)

NOS-T

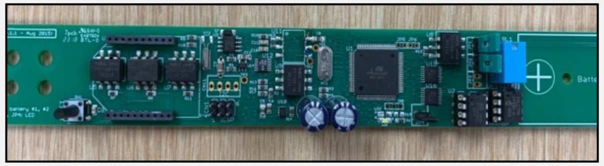
- Local Events and Alerts, e.g., flash floods, local precip., etc.
- Satellite/Airborne overpasses, and NRT observations.
- Domain Precipitation information.
- Similar SoilSCAPE/SPCTOR data from Neighboring clusters.
- Other.

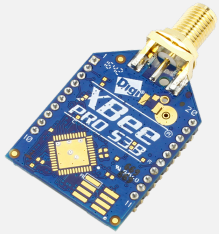
SoilSCAPE

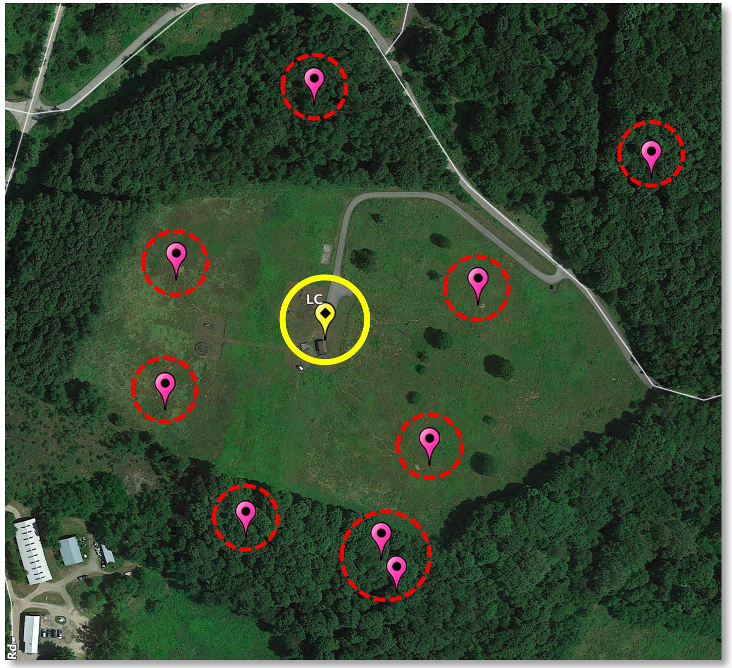
Network Architecture

Wireless End-Device (ED)

- Custom designed
- Xbee Transceiver
- 900 MHz ISM
- 4-Digital, 4-Analog probes



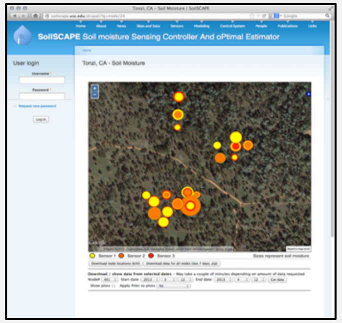




Local Coordinator (LC)

3G/LTE/Satellite

Data Server and Delivery



- Project Website
- SMAP
- AirMOSS
- CYGNSS
- ORNL DAAC