SoilSCAPE and SCPTOR

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ESTO AIST New Observing Strategies (NOS) Workshop
Washington DC
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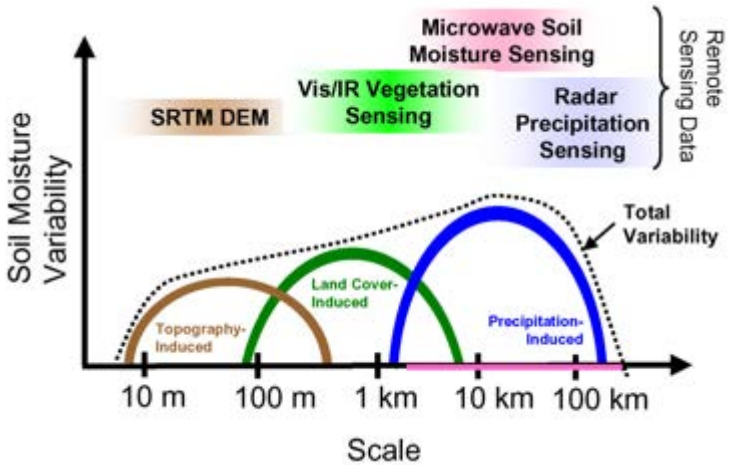
Presentation Overview

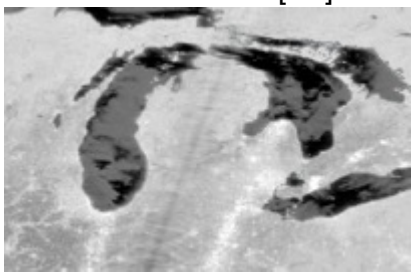
- Projects
  - SoilSCAPE → *in situ* Wireless Soil Moisture Sensor Networks
  - SPCTOR → Sensing-Policy Controller and Optimizer
- Project Technical Overview
- Relation to NOS Concepts

Satellite Soil Moisture Product Validation

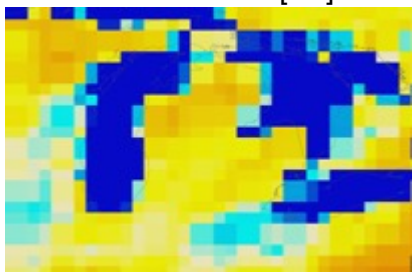
1. Soil moisture highly variable across the land-scape.
2. Satellite/Instrument FOV and resolution → land-scape heterogeneity is "averaged" within antenna footprint.



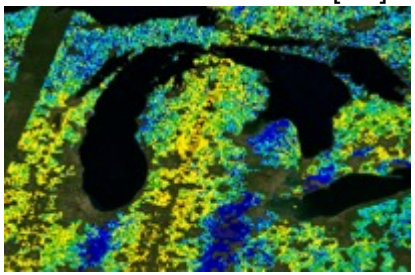
SMAP SAR 3 [km]



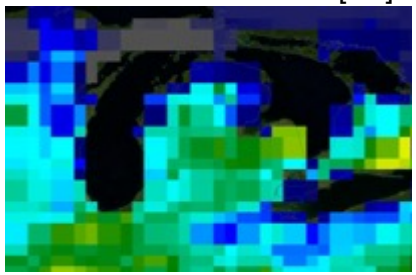
SMAP TB 36 [km]



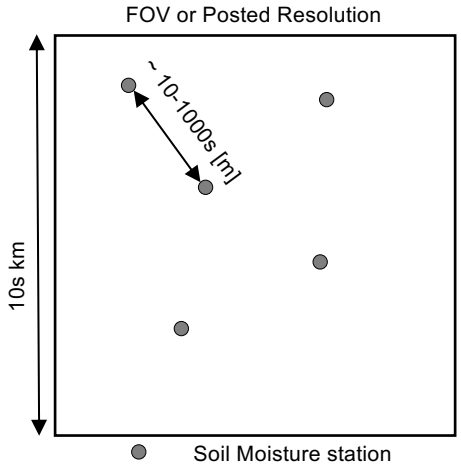
SMAP Soil Moisture 3 [km]



SMAP Soil Moisture 36 [km]



- *"**Representative**" number of in situ ground stations within FOV or posted resolution.*
- *Upscale in situ sensors and compare to satellite observation*



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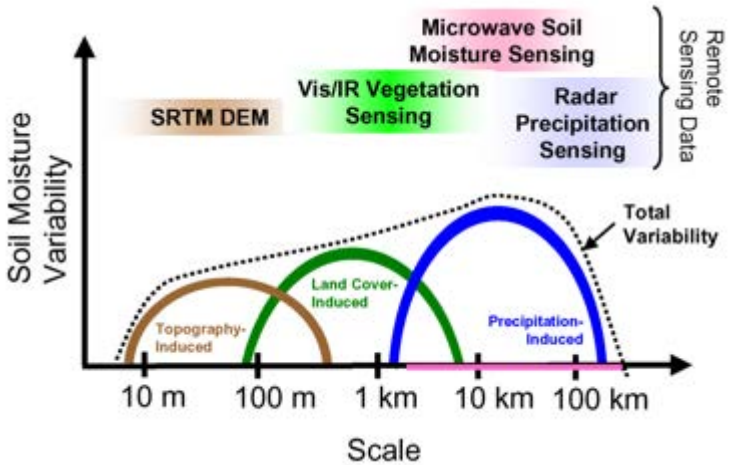
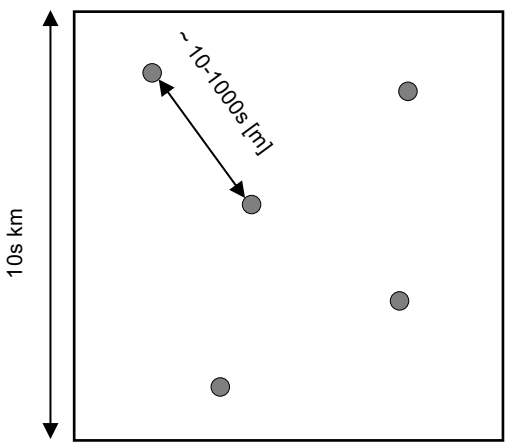


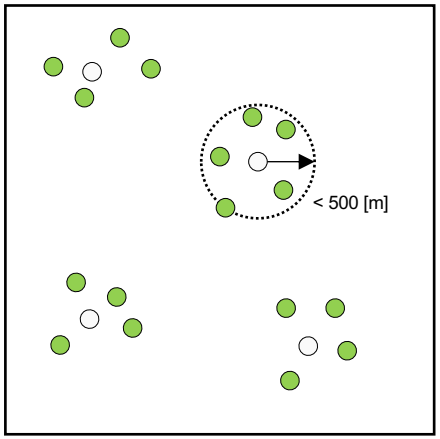
"Traditional" Approach



Single Soil Moisture station

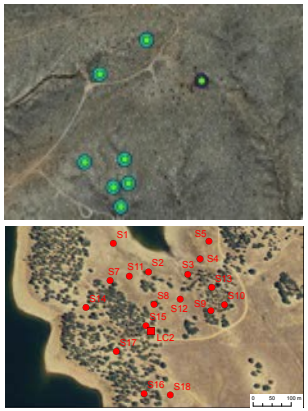
https://www.ncdc.noaa.gov/crn/

Wireless Sensor Networks (WSN)



WSN Cluster (< 20 Nodes)

Example Sites in CA and AZ



SoilSCAPE
Soil Moisture Sensing Controller and Optimal Estimator (TRL7)

What?

Clusters of medium-scale (< 500 [m]) *in situ* **Wireless Sensor Networks** (WSN)

Function?

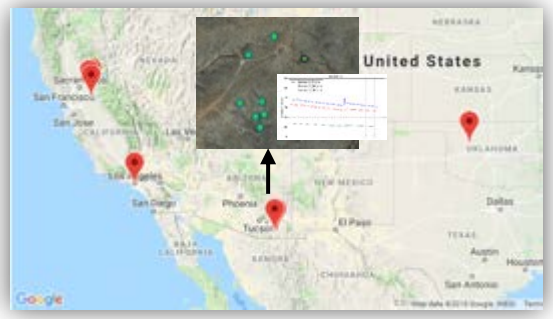
Measure and report near real-time surface-to-root zone soil moisture (surface down to ~100 [cm])

Why?

1. Advancement in low-power wireless sensing technologies.
2. *Ground truth soil moisture for NASA Earth Science missions.*
   (SMAP, AirMOSS, *recently CYGNSS*)
3. Data at ORNL DAAC (https://daac.ornl.gov/LAND_VAL/guides/SoilSCAPE.html)

How?

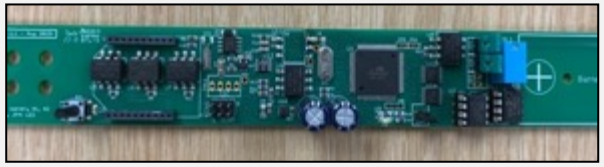
- Custom made low-power "wireless dataloggers"
- Wireless network communication protocols and data-delivery

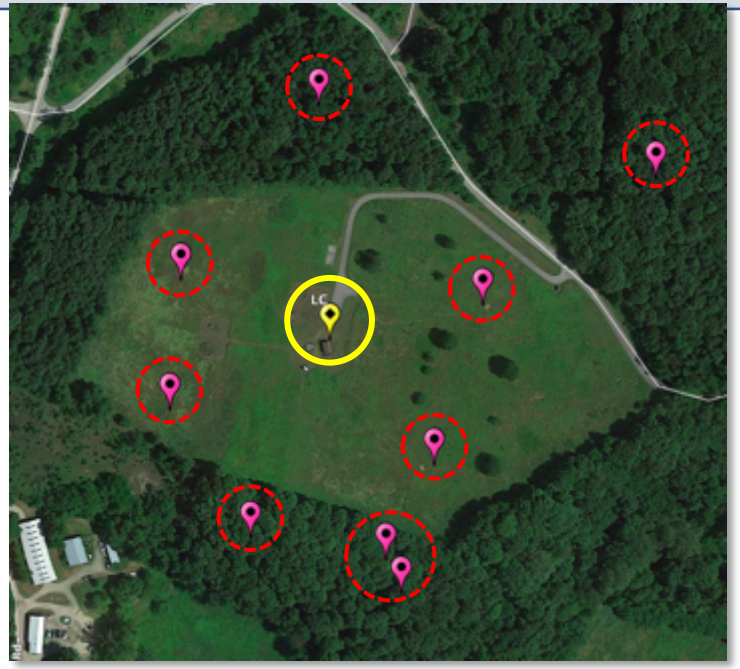


SoilSCAPE
Wireless Network Architecture Overview

Wireless End-Device (ED)

- 4-Digital, 4-Analog probes
- PVC Enclosures
- 900 MHz ISM Xbee Transceiver





Local Coordinator (LC)

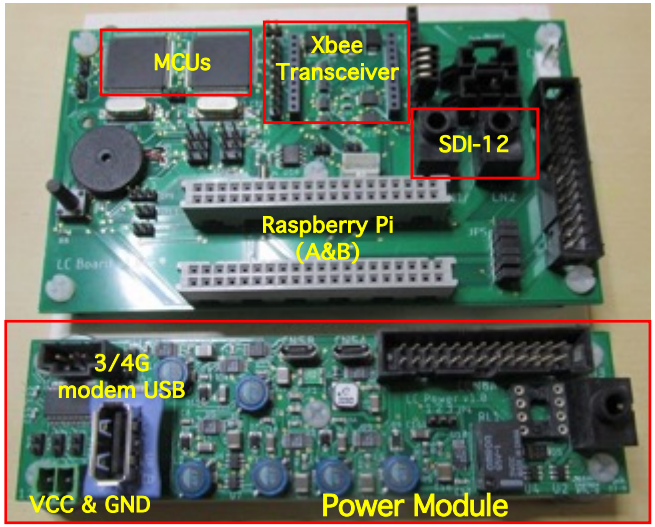
3G/LTE/Satellite

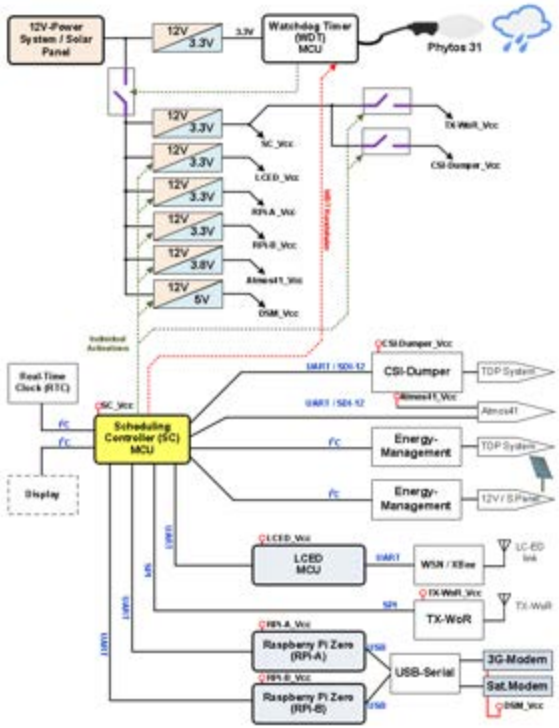
Data Server and Delivery

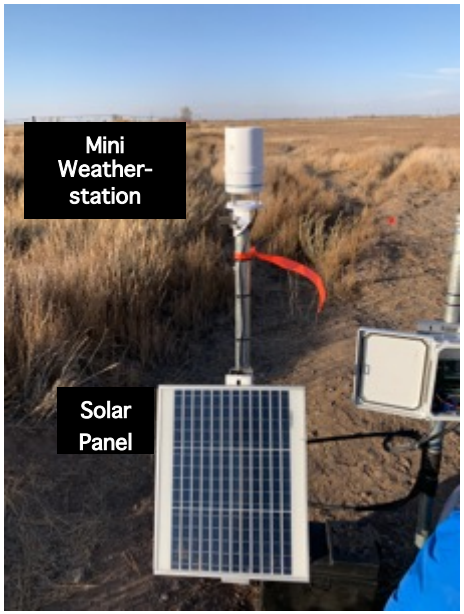
- Project Website
- SMAP
- AirMOSS
- CYGNSS
- ORNL DAAC

SoilSCAPE
Key Hardware Components: Local Coordinator (LC)

- Central "node" coordinating all wireless sensors
- Dedicated power module w/ isolated power lines
- Raspberry Pi microcomputer
- Data server connection options:
  - Commercial Verizon, AT&T, or Iridium modems
- SDI-12 interfaces for peripheral devices
  - Weather station, Sap-flow system, leaf-wetness sensors

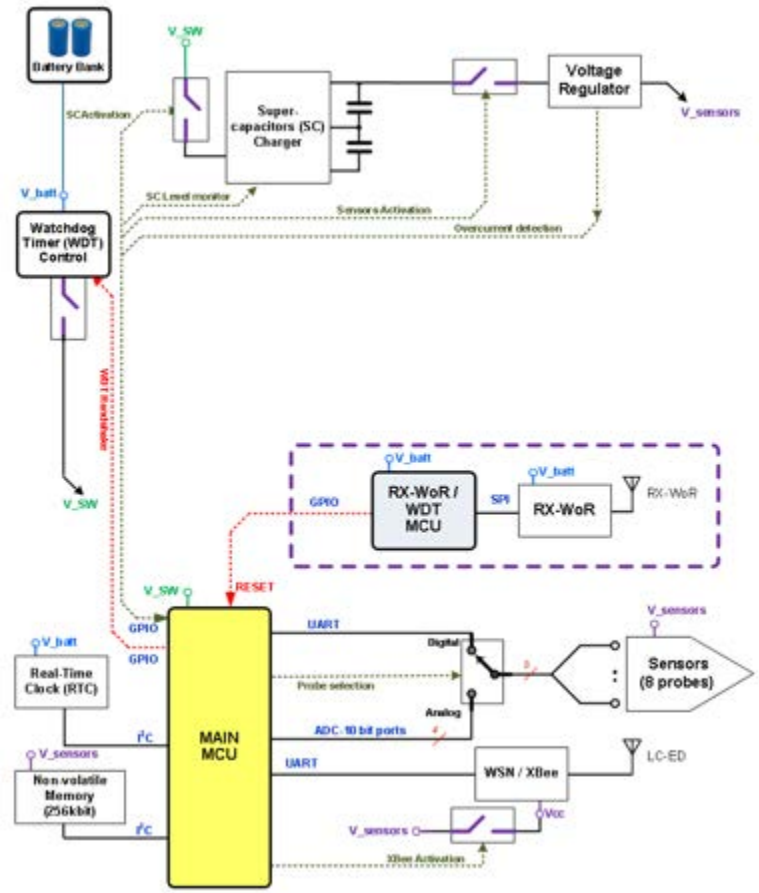


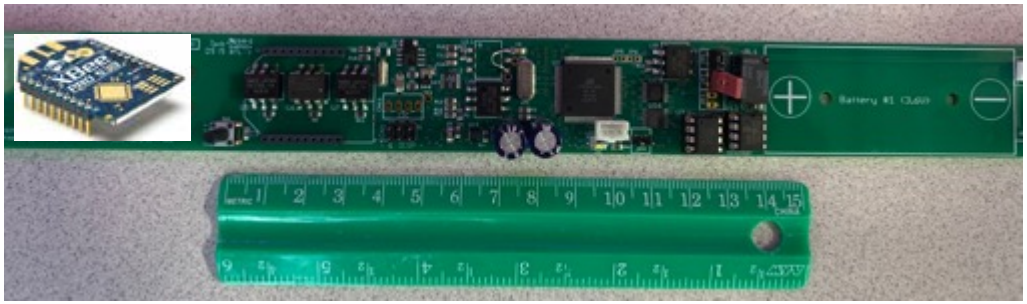


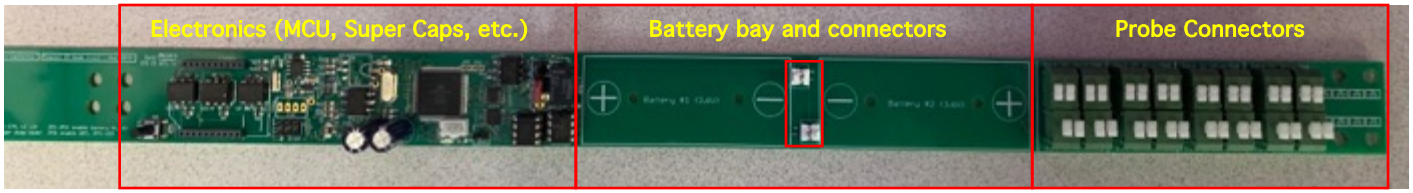


SoilSCAPE
Key Hardware Components: Wireless End-Device (ED)

- Wireless "datalogger"
- Designed in-house
- Non-rechargeable batteries (2x 19000 mAh)
- 4 Digital and 4 Analog probes
- Low-duty cycle (mostly in sleep mode)
- Power-gating and power-matching techniques to increase energy efficiency (~1.8-2 years)
- "Emergency mode" if no ED-LC communication







Presentation Overview

- Project Objectives
  - SoilSCAPE → *in situ* Wireless Soil Moisture Sensor Network
  - SPCTOR → Sensing-Policy Controller and Optimizer
- Project Technical Overview
- Relation to NOS Concepts

SPCTOR
Sensing-Policy Controller and Optimizer (AIST-18)
(Start Date: Jan'20)

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)

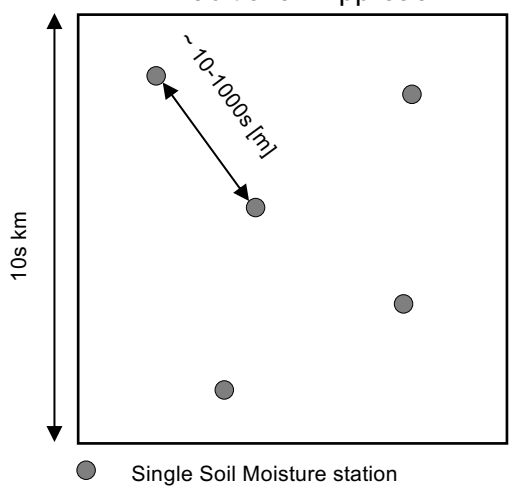
Both address **ESTO-AIST-NOS objectives**:

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).

SPCTOR
Sensing-Policy Controller and Optimizer (AIST-18)

- Observation technologies for soil moisture need to be spatiotemporally adaptive.
- Distributed WSNs within FOV will increase representativeness. Yet, WSN are "static."
  - Network deployment considers many different factors (topography, land cover, etc.)
  - Limited capabilities in wide-spread sensor networks that adequately cover and measure heterogenous landscape soil moisture
- UAV-SDRadar are mobile and can "gap fill"/complement WSN.
  - Technical challenge: coordinating UAV and WSN operations.

"Traditional" Approach



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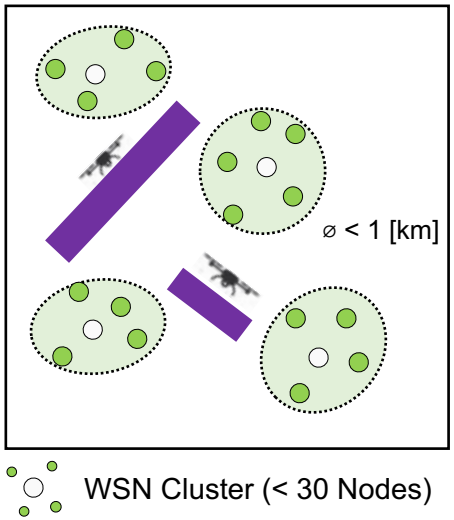

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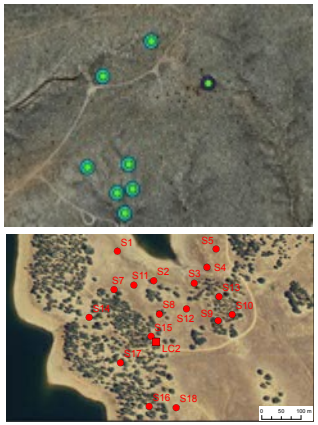
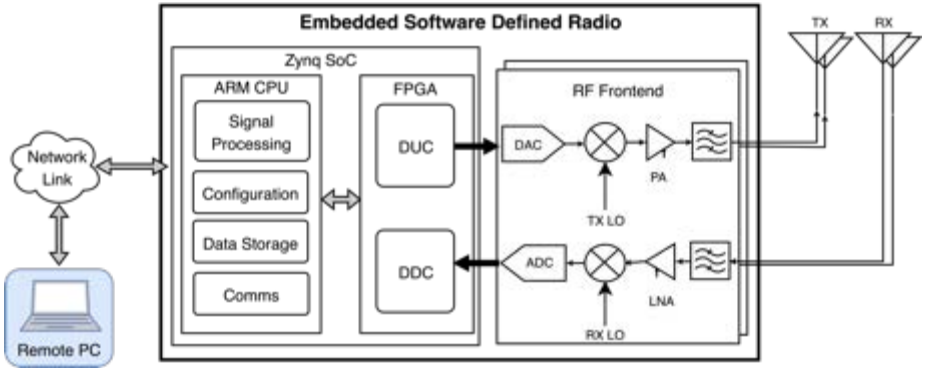
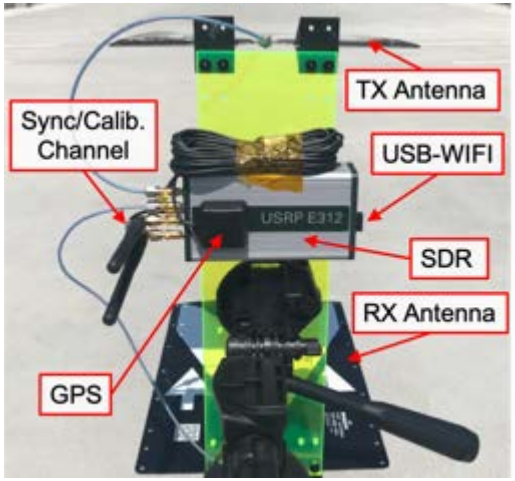


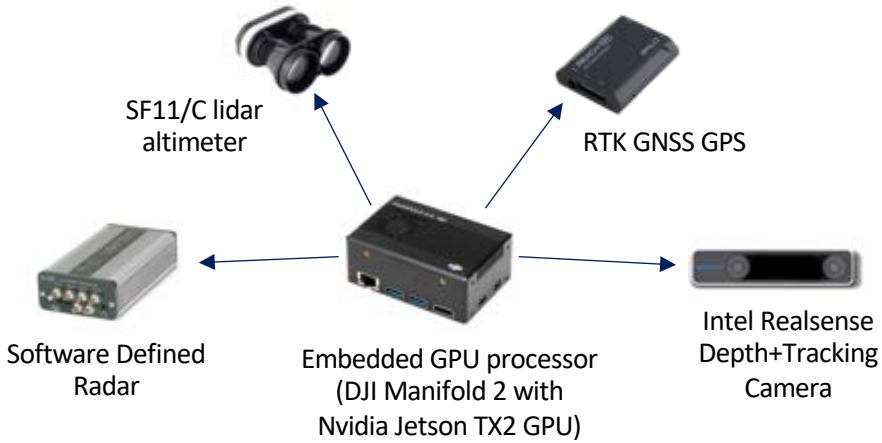
SPCTOR
Software Defined Radar (SDRadar)

- 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 are coverage than in-situ sensors.*





USC SDRadar prototype built using USRP E312 hardware



UAV-SDRadars Current State (1)

- Previous work at MiXIL has demonstrated synthetic ultra-wideband operation of SDRadar up to 5 GHz bandwidth, 3 [cm] resolution
- Multiple field experiments conducted demonstrating capability of SDRadar to perform sub-surface radar imaging and sounding.

Snow Penetrating Radar Test

- Near Mammoth Lakes, CA
- 2.5 GHz synthesized bandwidth (600 MHz-3.1 GHz)
- Single sensor moved in .5m steps

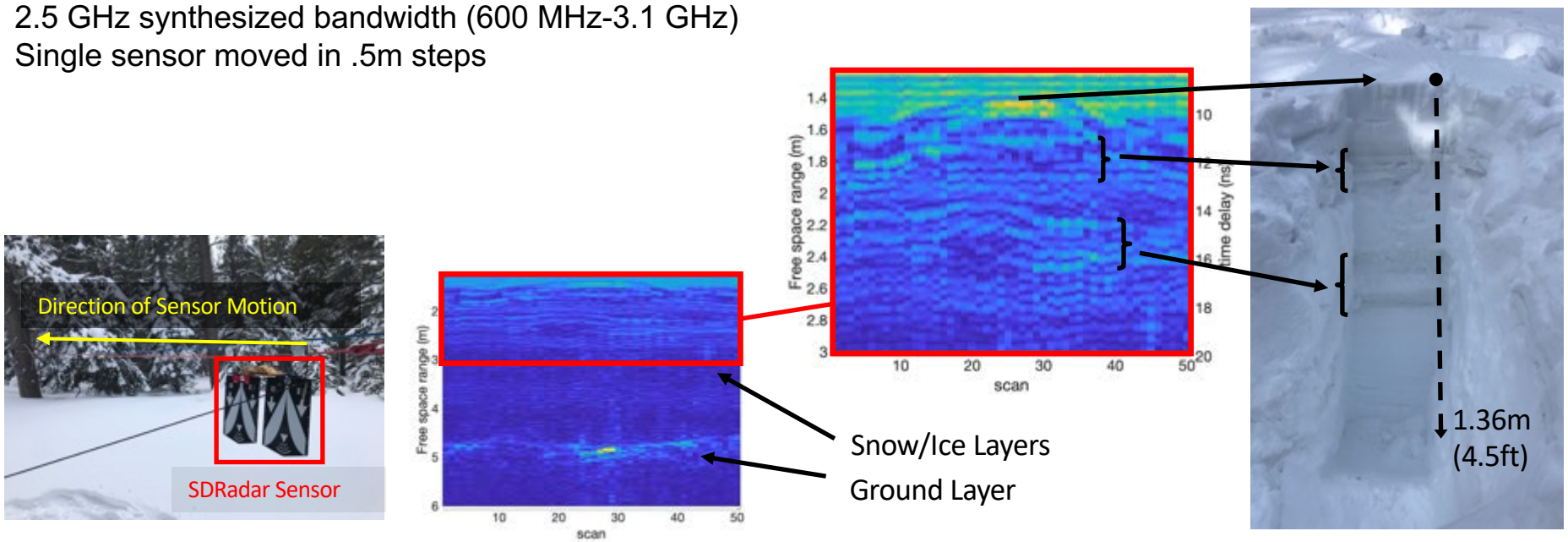


Figure 3. 2.5 GHz SWW SDRadar Snow/Ice Penetrating radar experiment

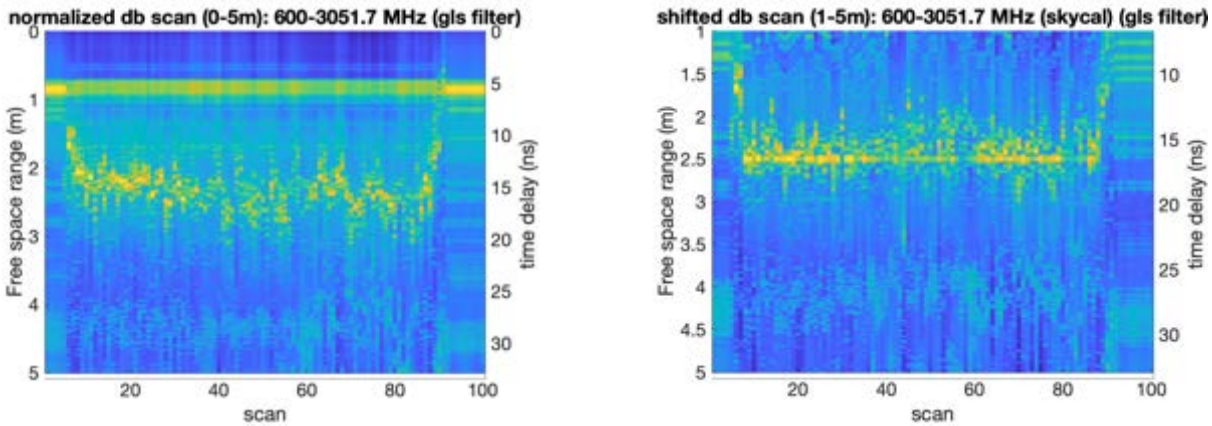
UAV-SDRadars Current State (2)

- Preliminary flight tests performed with the SDRadar sensor integrated on DJI M600 drone
- Motion compensation performed using estimated positional data and radar surface return

Figure 4. UAV-SDRadar

Indoor Flight Test Over Sand Pit

- UAV flown in indoor test facility over 30cm deep sand pit
- 2.5 GHz synthesized bandwidth (600 MHz-3.1 GHz)
- Pulse repetition interval (PRI) of 1 second



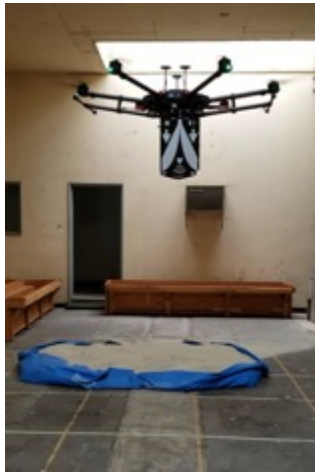
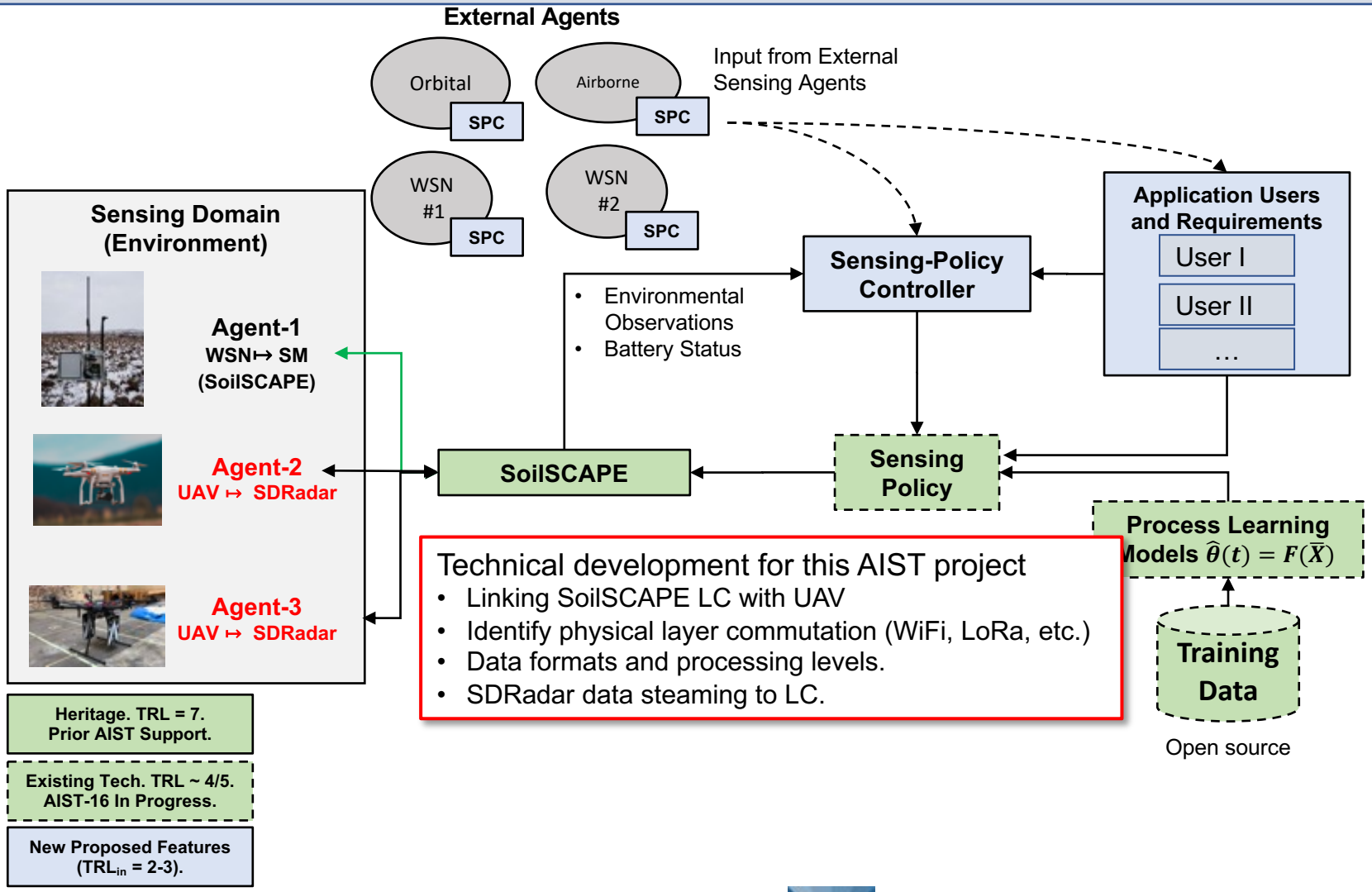


Figure 5. 2.5 GHz SWW test flight data without range correction (left) and with range correction (right)

SPCTOR
Sensing-Policy Controller and Optimizer (AIST-18)



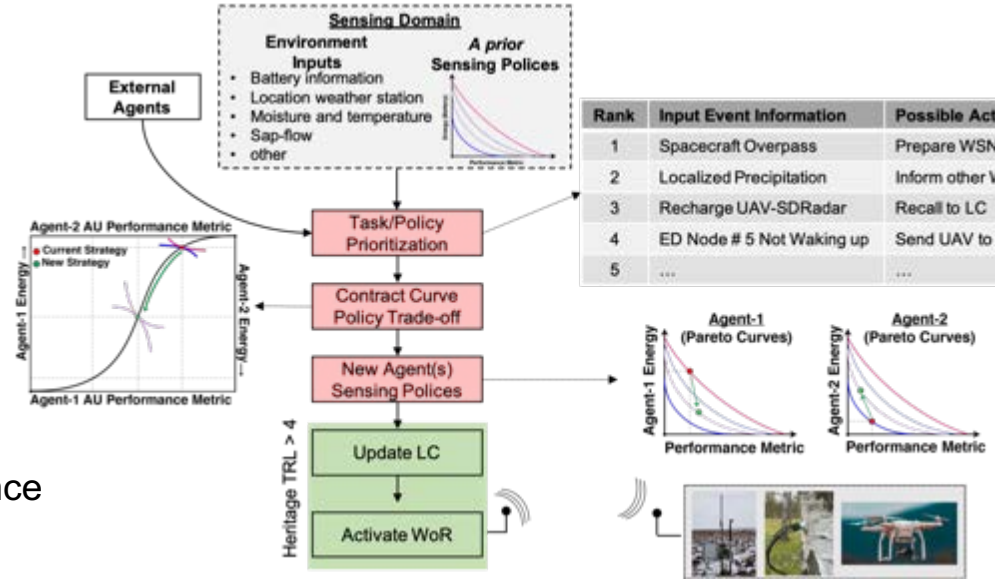
WSN: Wireless Sensor Network
SM: Soil Moisture
UAV: Unmanned aerial vehicle
SDRadar: Software Defined Radar

SPCTOR
Policy Coordination

- ✓ Science Applications and Requirements
- ✓ Agents' Sensing Policies
- ✓ Task/Action (or Policy) **Prioritization**
  1. Identify Action
  2. Update Agents' polices
  3. Execute actions

Key constraint

- All Actions are considered Optimal.
- Satisfy energy/battery contains and performance metrics.



Rank	Input Event Information	Possible Action(s)
1	Spacecraft Overpass	Prepare WSN
2	Localized Precipitation	Inform other WSNs
3	Recharge UAV-SDRadar	Recall to LC
4	ED Node # 5 Not Waking up	Send UAV to location
5	...	...

Implementation: "Multi-Agent Reinforcement Learning"

- Sequential Decision making involving multiple agents
- Each agent has its own long-term reward to optimize → in our context, individual performance metrics.
- State evolution is not always influenced by joint actions/agents.
- Need to investigate whether Agents' actions affect each other (and optimum policy)

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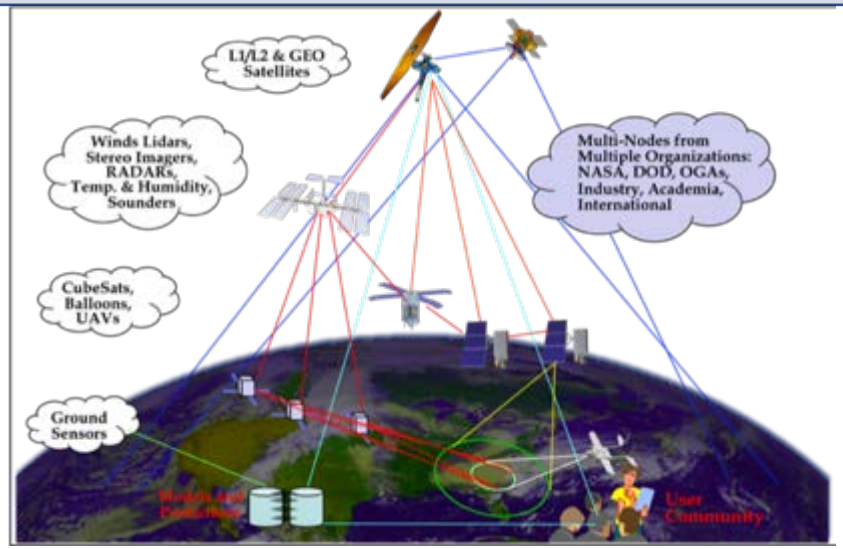
SoilSCAPE and SPCTOR
Relation to NOS Concepts

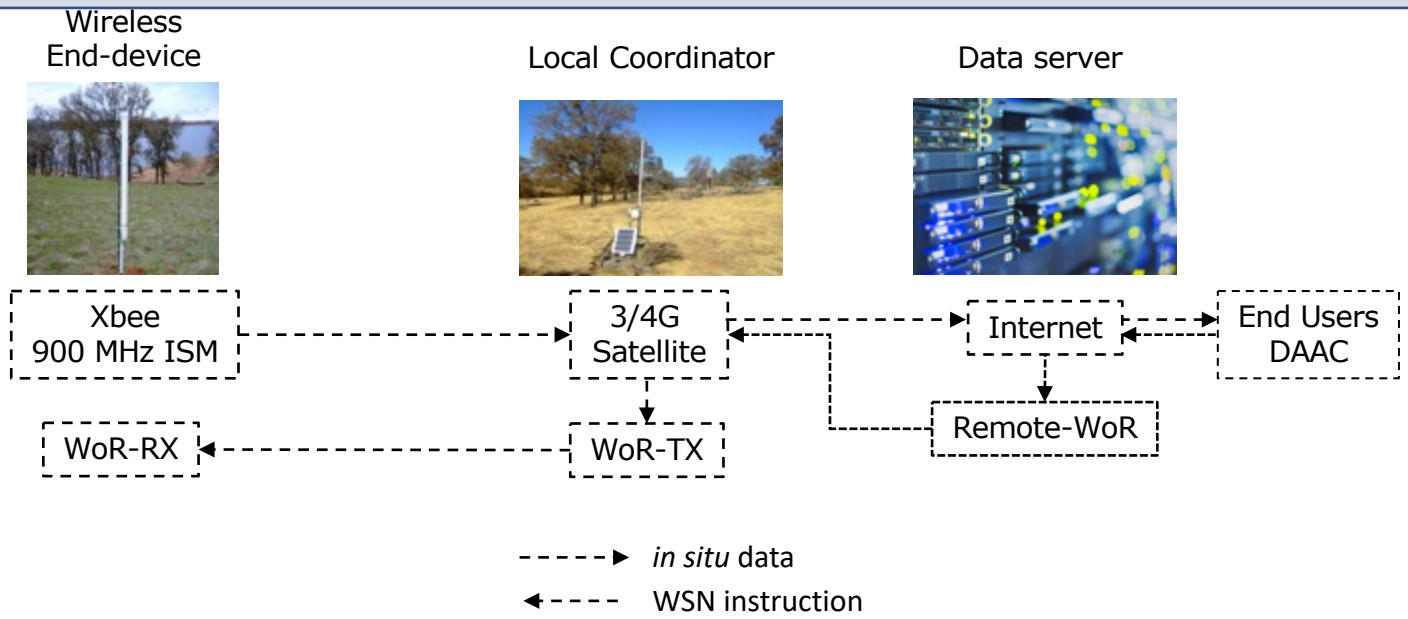
Technology Concepts

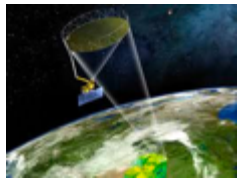
- In situ wireless sensors networks
  - Sensor Automation (AIST-16, TRL 3).
  - Intra-WSN communication (AIST-18, TRL 2).
- UAV-WSN operations (AIST-18, TRL 2-4)
  - UAV communication with WSN LC.
  - Multi-Agent coordination and planning.
- SoilSCAPE + SPCTOR open the possibility for coordination between ground networks and airborne/spacecraft remote sensing systems.



Science Use Cases

- Primarily Terrestrial Hydrology.
- Near-real time Root-zone soil moisture measurements.
- Satellite Cal/Val support.


Wireless End-device
Local Coordinator
Data server
Xbee 900 MHz ISM
3/4G Satellite
Internet
End Users DAAC
Remote-WoR
WoR-RX
WoR-TX
in situ data
WSN instruction



Thank you!

Background: NOS Workshop Focus

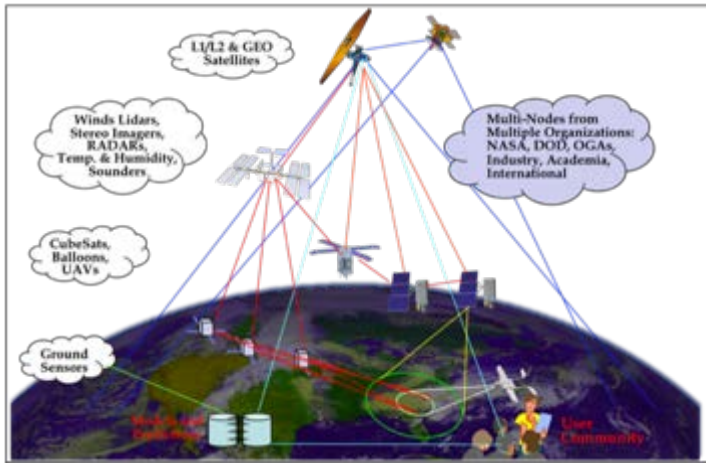
The workshop is one of the first steps in developing NOS reference concepts and use cases as well as in identifying corresponding technologies that will guide the development of a NOS roadmap.

Technology advances have created an opportunity to make new measurements to augment and complement current measurements in a less costly or more productive manner. Future science measurements will include capabilities such as smallsats equipped with science-quality instruments, distributed spacecraft missions and generalized sensor-webs, machine learning techniques enabling processing of large data volumes and real-time, onboard decision making. Along with these capabilities, technologies such as:

- well-defined and standardized interfaces,
- inter-spacecraft/inter-node secure communications systems,
- generic metadata and ontologies,
- onboard processing,
- intelligent data understanding and decision making

will also be necessary to fully exploit the power of distributed, heterogeneous and coordinated observing systems. These capabilities and technologies will enable seamless interaction of NASA assets as well as those from other organizations, e.g., academia, industry, and Other Government Agencies (OGAs).

The goals of the workshop are to:
•Define the general NOS concept,
•Investigate potential applications and corresponding use cases,
•Identify the required technologies to implement future NOS concepts,
•And inform the development of the NOS Testbed framework



New Observing Strategies:

- Multiple collaborative sensor nodes producing measurements integrated from multiple vantage proins and in multiple dimensions (spatial, spectral, temporal, radiometric)
- Provide a dynamic and more complete picture of physical processes or natural phenomena

Science Use Case Domains:

- Atmospheric
- Carbon / Ecosystems
- Earth Surface & Interior
- Snow / Ice / Energy
- Oceans