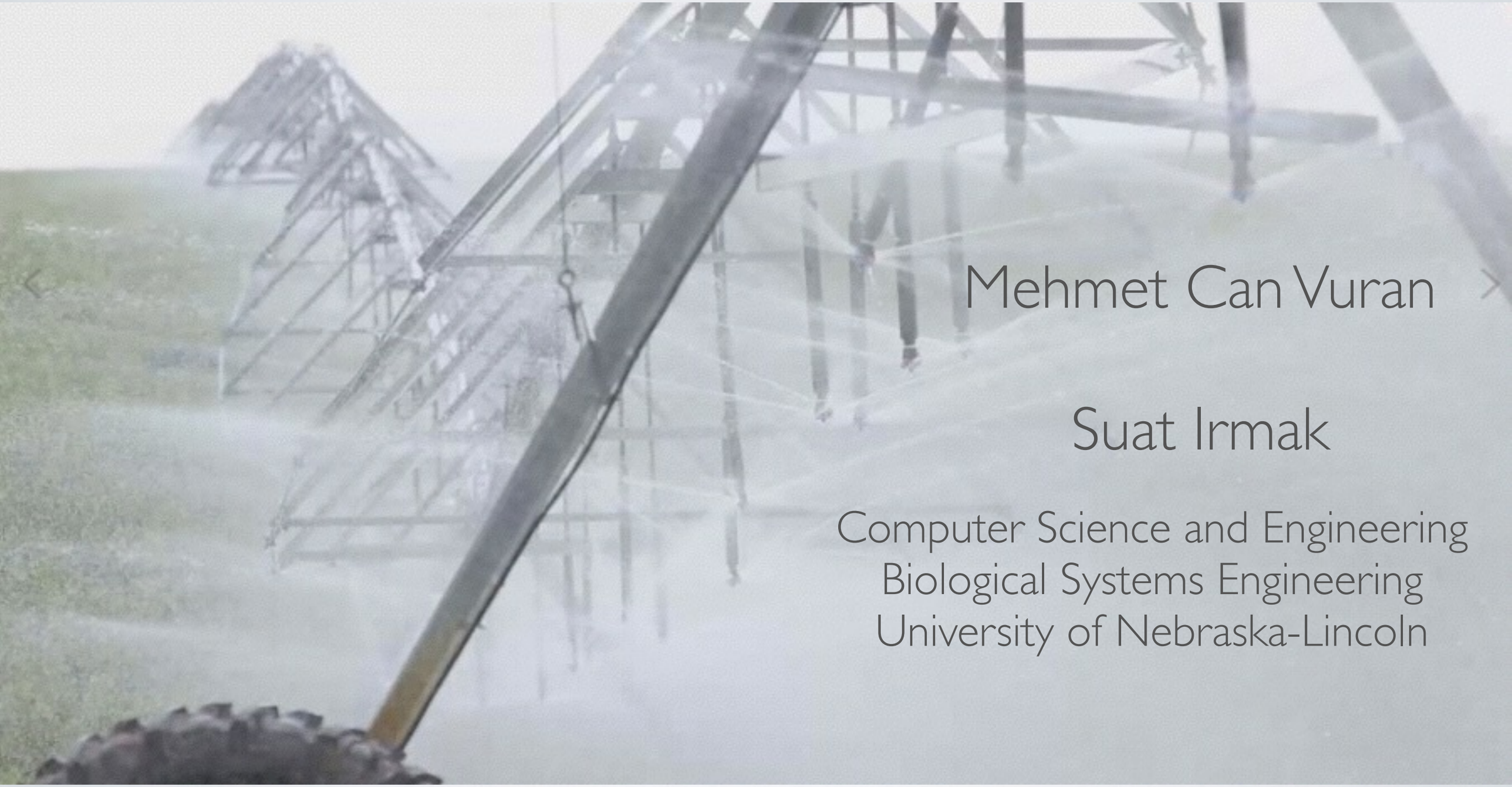
WIRELESS UNDERGROUND SENSOR NETWORKS FOR OBSTRUCTION-FREE AND PERMANENT SOIL MOISTURE MONITORING



Mehmet Can Vuran

Suat Irmak

Computer Science and Engineering
Biological Systems Engineering
University of Nebraska-Lincoln

CYBER-PHYSICAL NETWORKING LAB

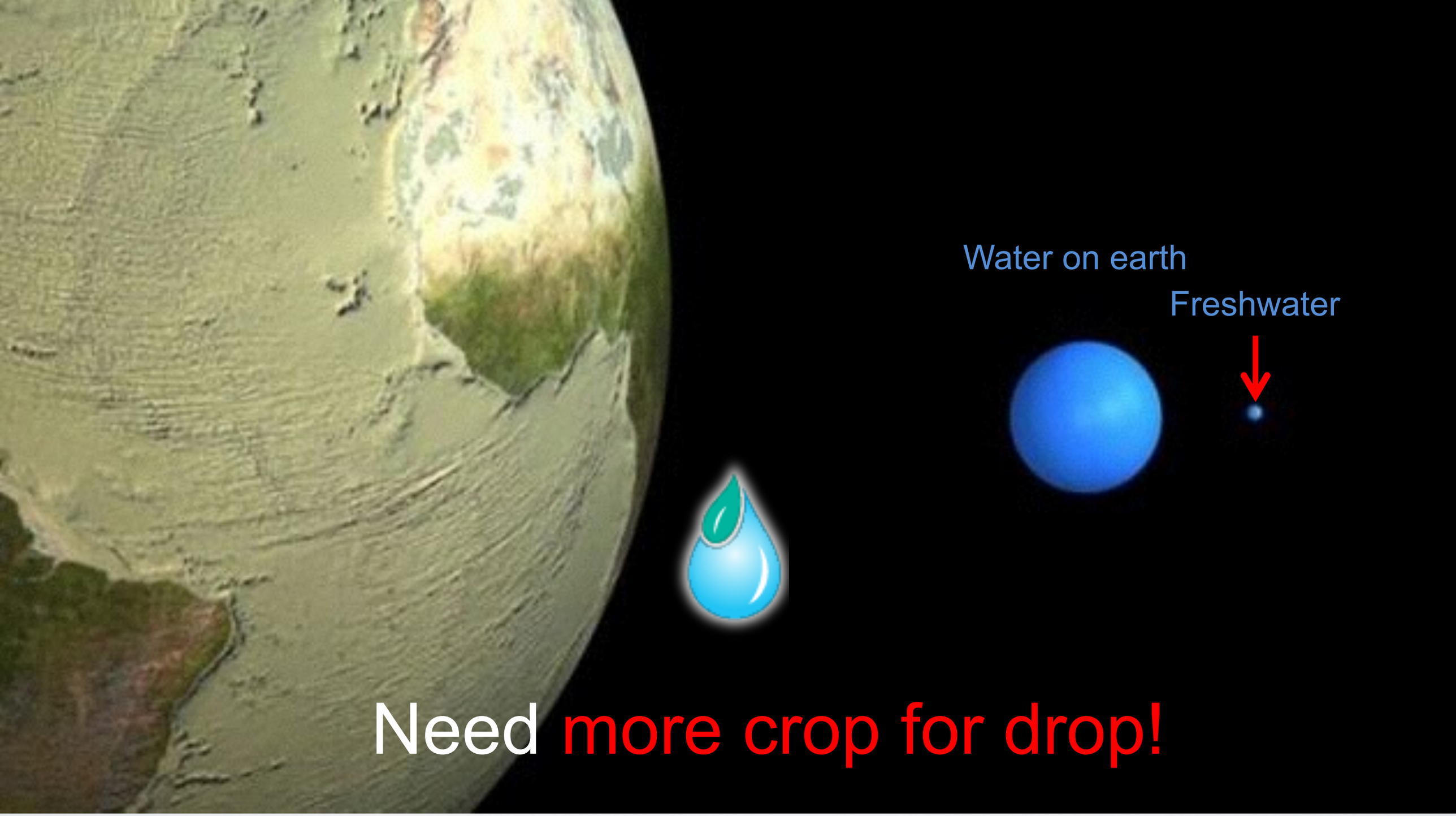
- Founded in 2007
- Current members: 5 Ph.D, 1 M.S., 1 UG student
- Graduates: 3 Ph.D, 6 M.S., 8 UG (1 M.S.)
- Graduates: Microsoft, Nvidia, Garmin, National Instruments
- Collaborators: CSE, BSE, SNR, CBA, Int. Crane Found., Ohio State

40% population increase by 2050, doubling the demand for food and feed

70% of all freshwater withdrawals are for agriculture

THE PROBLEM: WATER SCARCITY

Credit: waterforfood.nebraska.edu



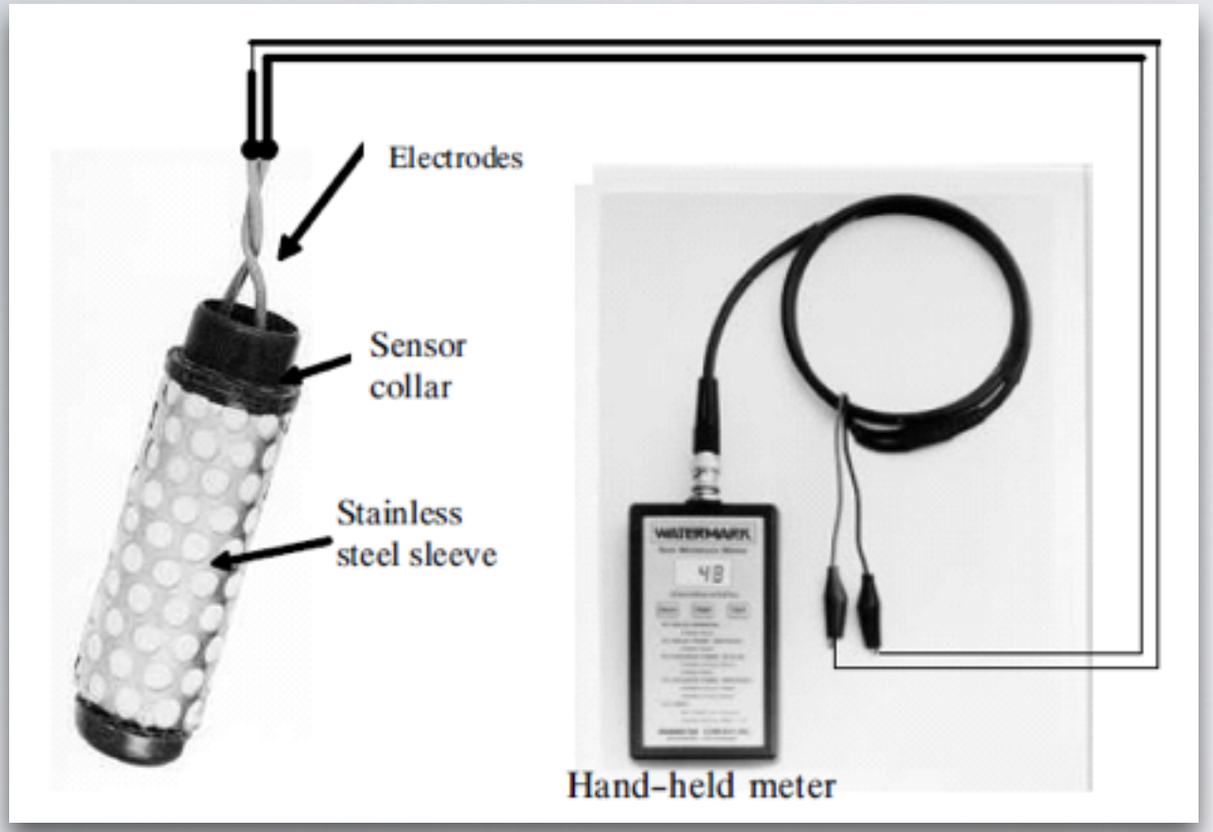
THE PROBLEM: WATER SCARCITY

Credit: usgs.org

MAKING SOIL TALK

1. Understand (sensors)
2. Communicate (wireless)

SENSOR-GUIDED IRRIGATION MANAGEMENT

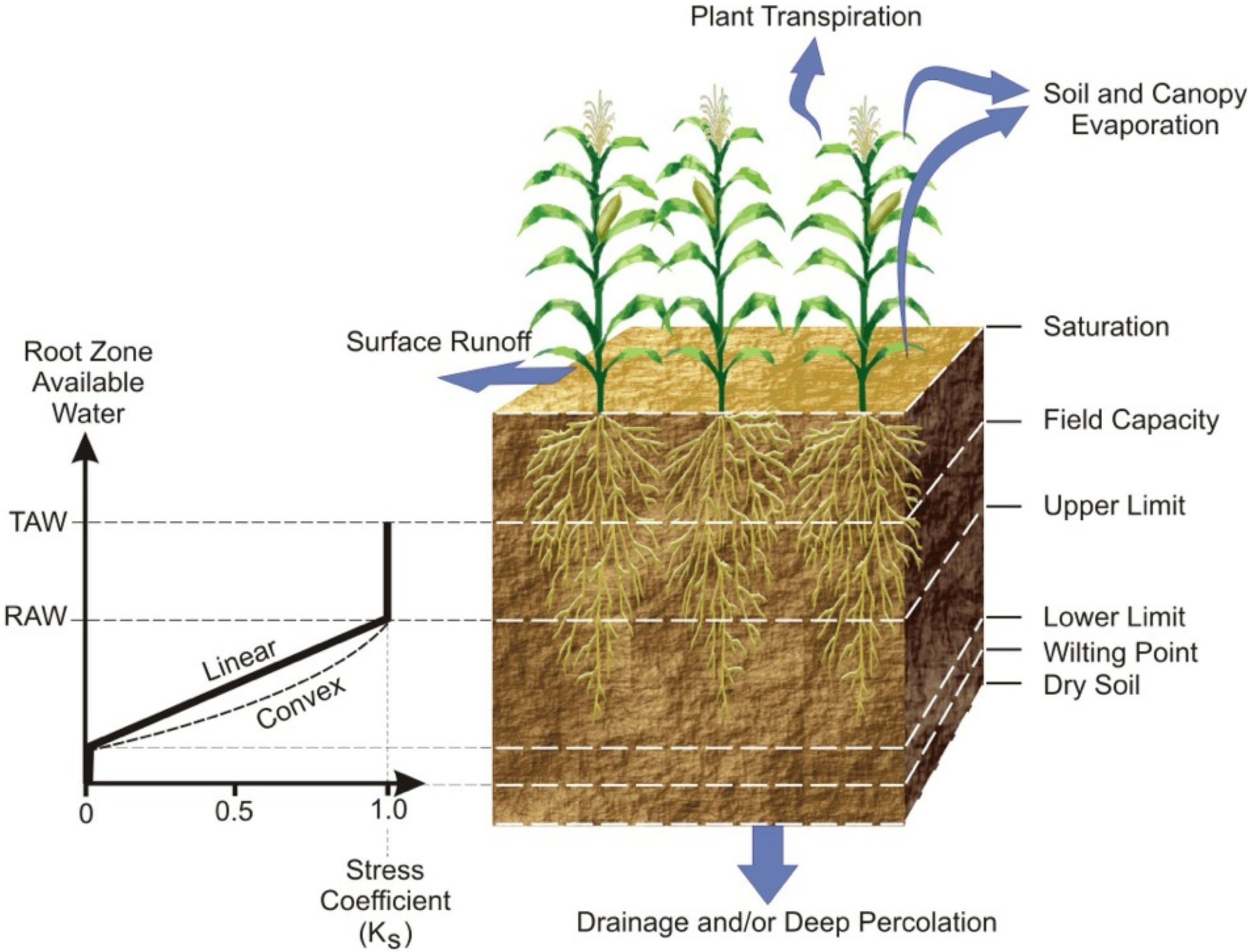


Up to 40% improvement in water use efficiency is possible with in-situ soil water content measurements

S. Irmak, et.al., ``Watermark granular matrix sensor to measure soil matric potential for irrigation management," *University of Nebraska-Lincoln Extension Circular*, EC783, 2006.

HOW DO WE MEASURE SOIL WATER CONTENT?

- Gravimetric sampling (direct, standard!)
- Electrical resistance units (granular matrix sensors-Watermarks)
- Pseudo transit time
- Neutron probe (standard!)
- Gamma ray attenuation
- TDR (Time-domain reflectometry)
- FDR (Frequency-domain reflectometry-capacitance sensors)
- Heat dissipation
- Filter paper technique
- Remote sensing


Plant Transpiration
Soil and Canopy Evaporation
Surface Runoff
Root Zone Available Water
TAW
RAW
Linear
Convex
0
0.5
1.0
Stress Coefficient (K_s)
Saturation
Field Capacity
Upper Limit
Lower Limit
Wilting Point
Dry Soil
Drainage and/or Deep Percolation

CAPACITANCE SENSOR

TIME DOMAIN REFLECTOMETER SENSORS

FREQUENCY DOMAIN REFLECTOMETER SENSORS

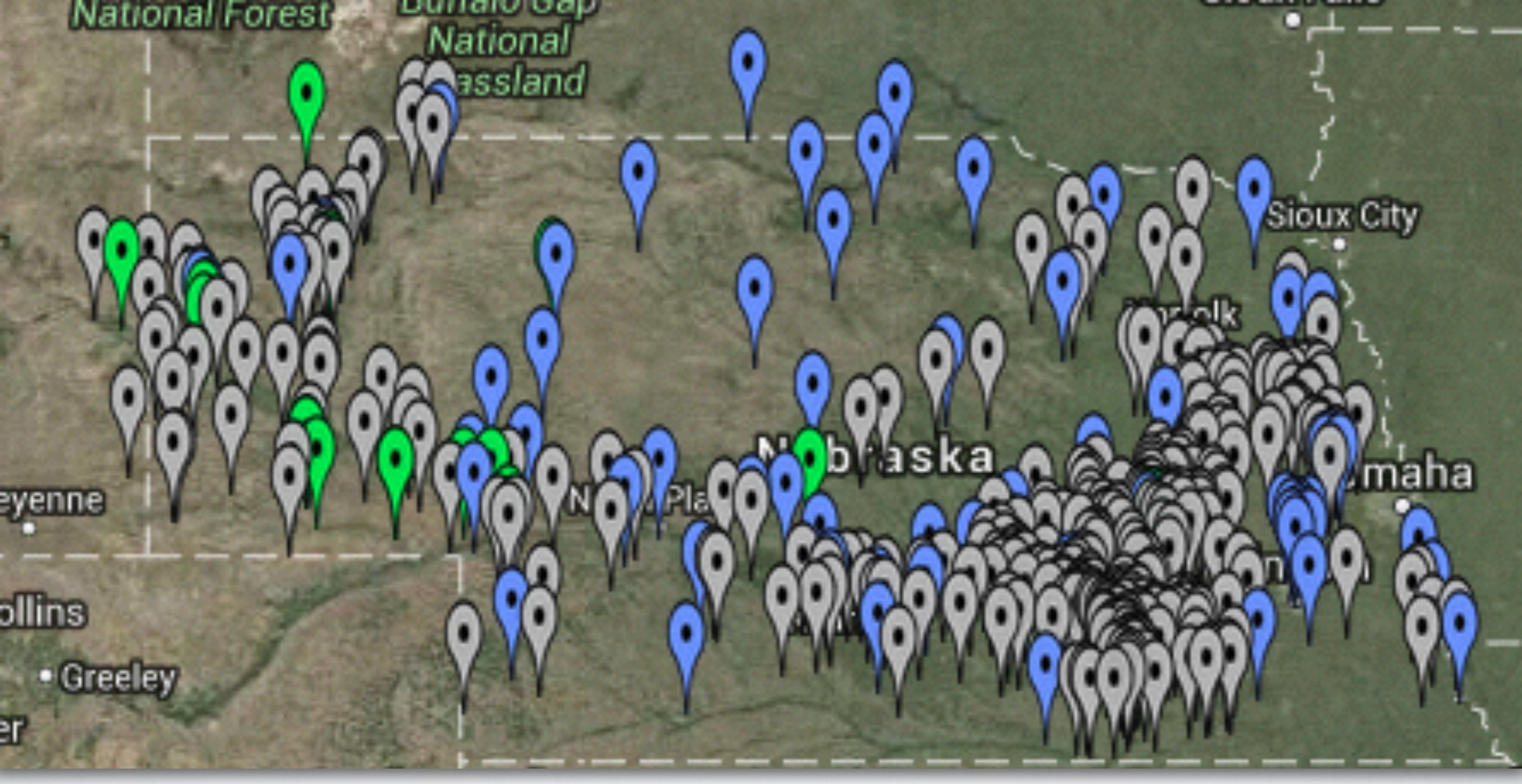
NEUTRON ATTENUATION PROBE

The most accurate soil moisture sensing method exist today!

GRANULAR MATRIX SENSORS

SCAL

PROBABLY HAS MORE SOIL MOISTURE SENSING DEVICES PER UNIT AREA THAN ANY OTHER PLACE!

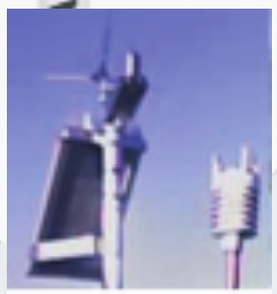


NAWMN DEMONSTRATION AND TECHNOLOGY IMPLEMENTATION SITES

Irmak et al. (2008) Statewide soil moisture monitoring locations

HOW DO WE GET THE DATA… OUT?

PureSense



AquaSpy

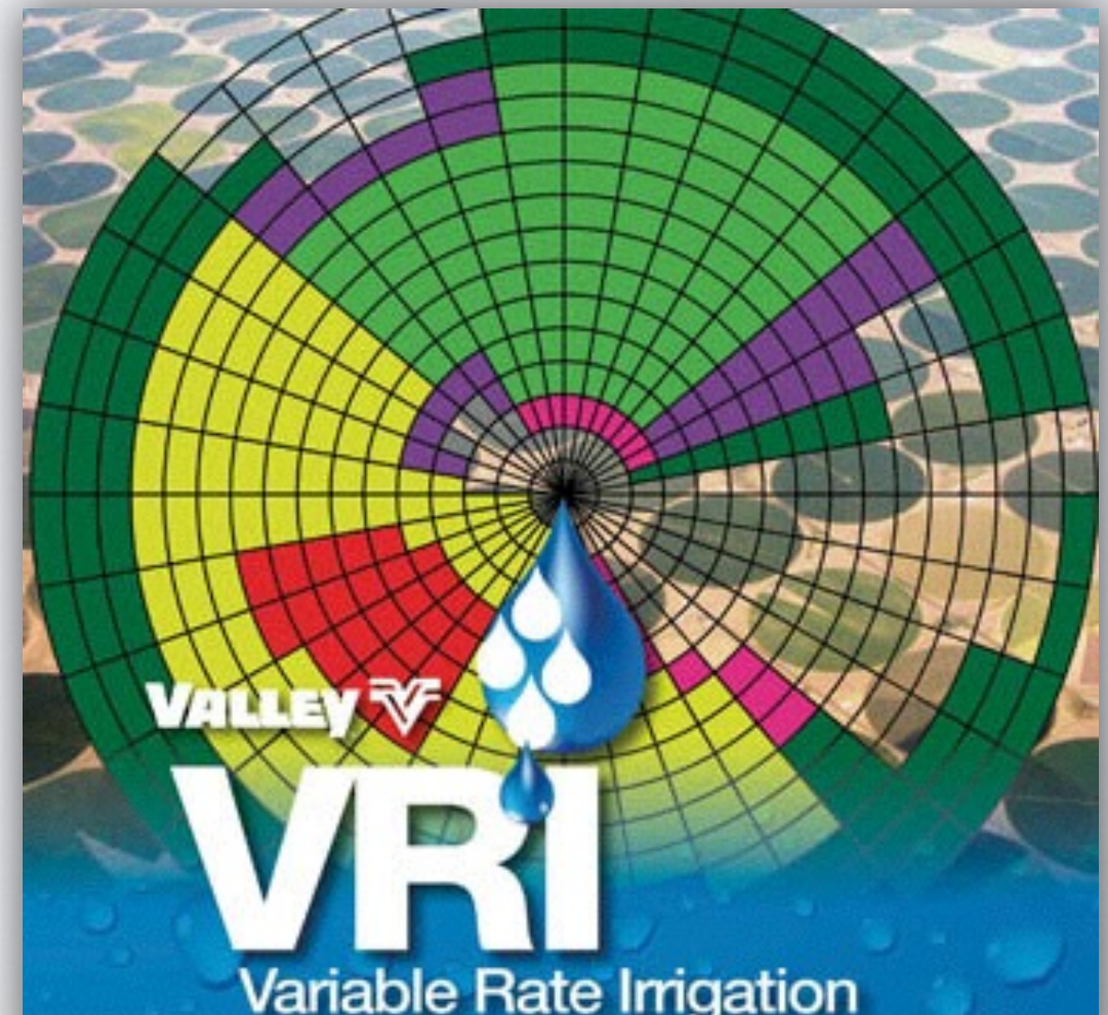
FieldConnect
(John Deere)

SmartField

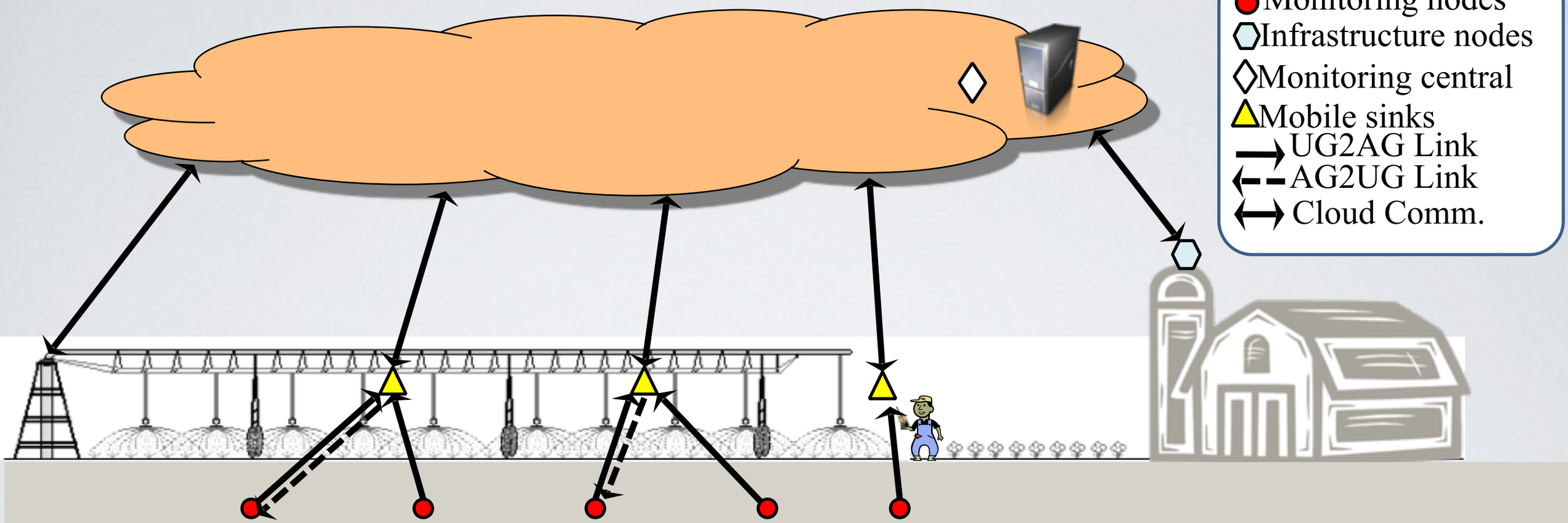
AquaView

SOIL MOISTURE MONITORING TECHNOLOGIES

- Monitor single location (a single root)
  - Cannot capture field variability (soil type, runnoff, topology, etc)
  - VRI → high cost



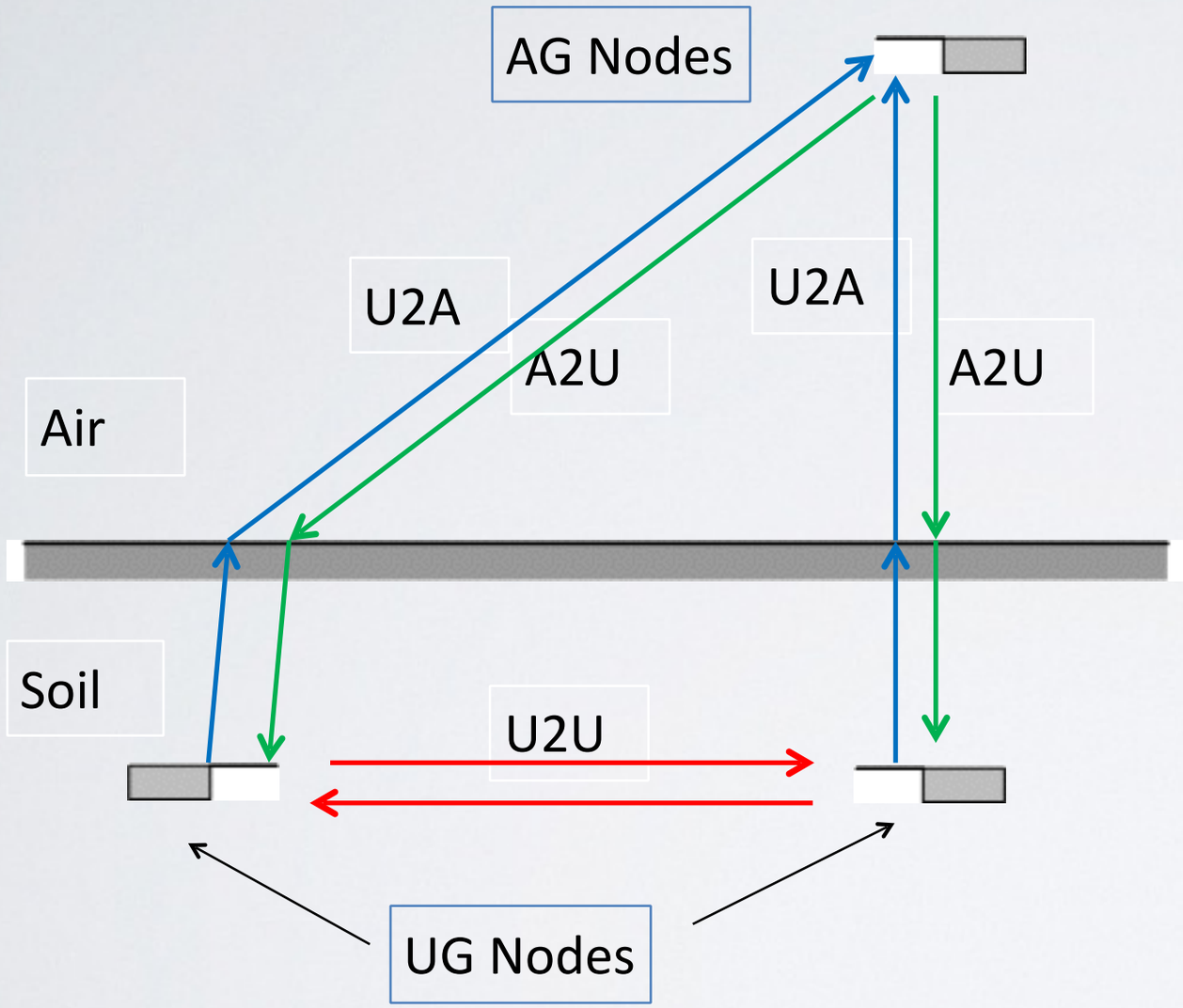
WIRELESS UNDERGROUND SENSOR NETWORKS
A NEW FRONTIER



- On-board sensing capabilities (soil moisture, temperature, salinity,)
- Communication through soil
- Real-time information about soil and crop conditions
- Inter-connection of heterogeneous machinery and sensors
- Complete autonomy on the field

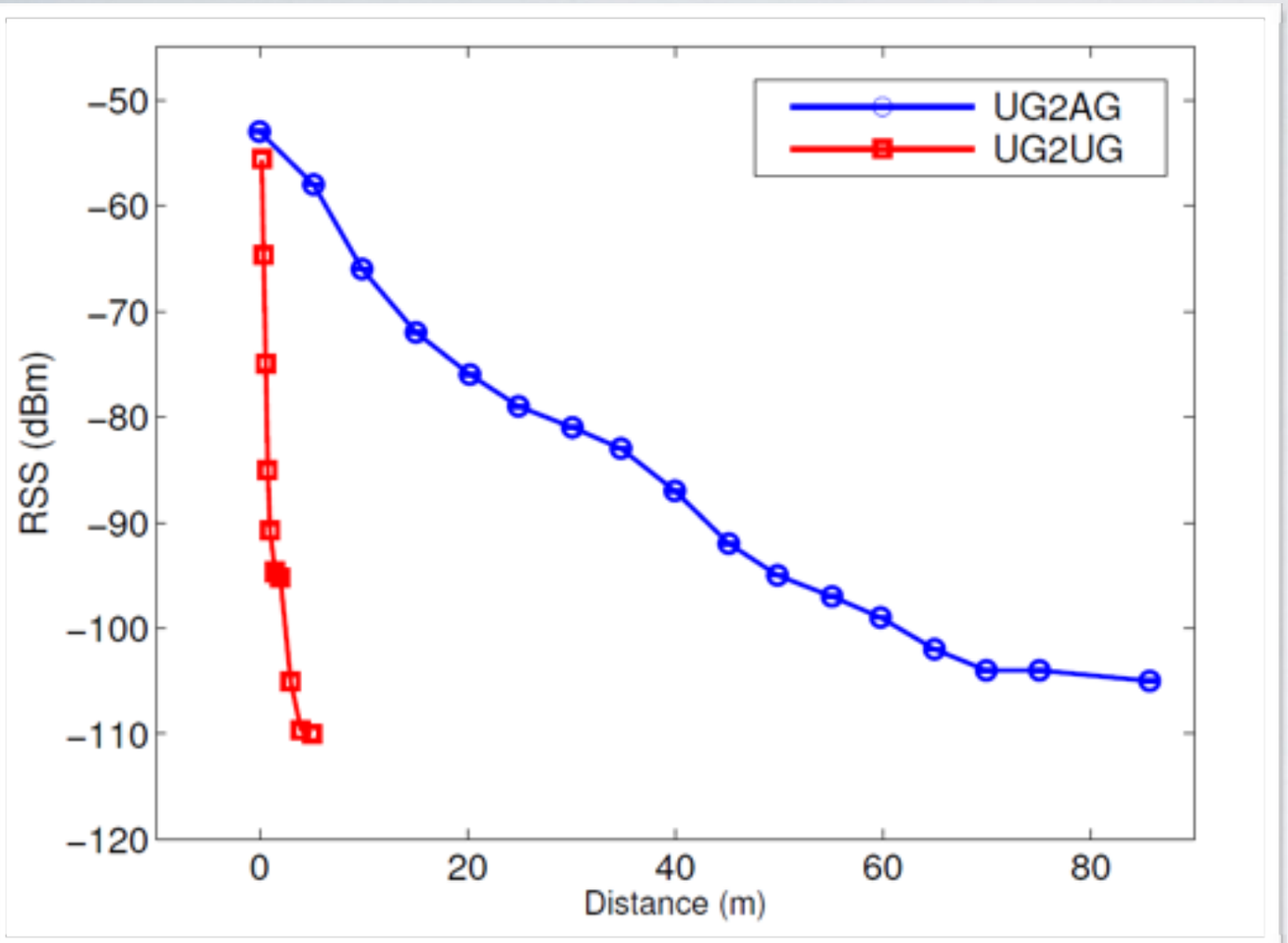
I. F. Akyildiz and E. P. Stuntebeck, "Wireless underground sensor networks: Research challenges," Ad Hoc Networks Journal (Elsevier), vol. 4, pp. 669–686, July 2006.

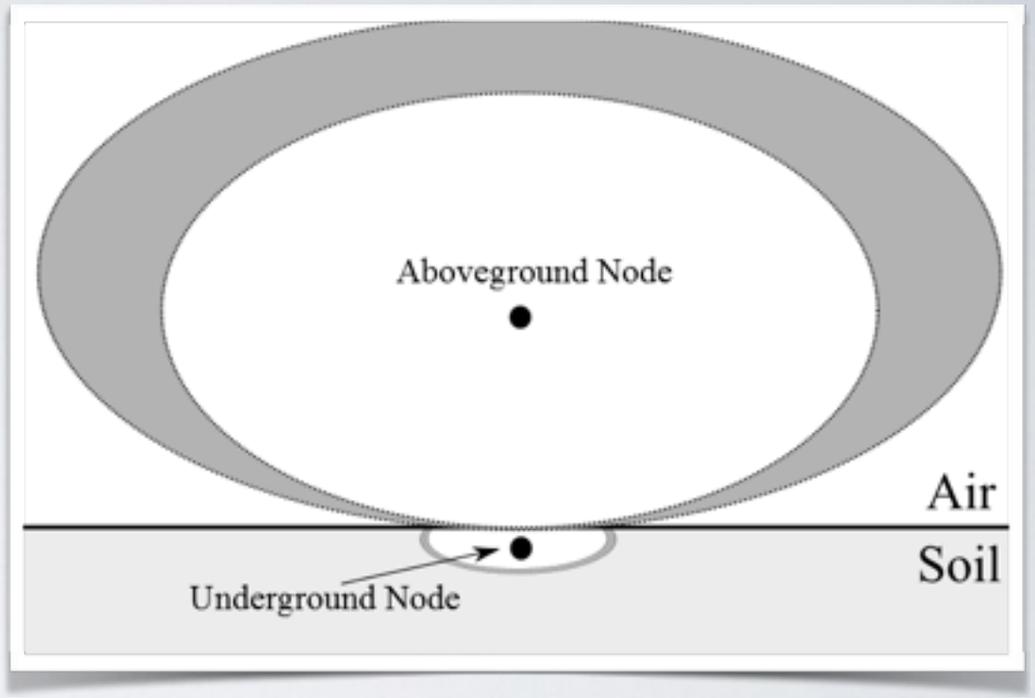
WIRELESS UNDERGROUND CHANNEL



- Two types of nodes
  - Underground nodes
  - Aboveground nodes
- Three channels [1,2]
  - Underground-to-underground (U2U)
  - Aboveground-to-underground (A2U)
  - Underground-to-aboveground (U2A)

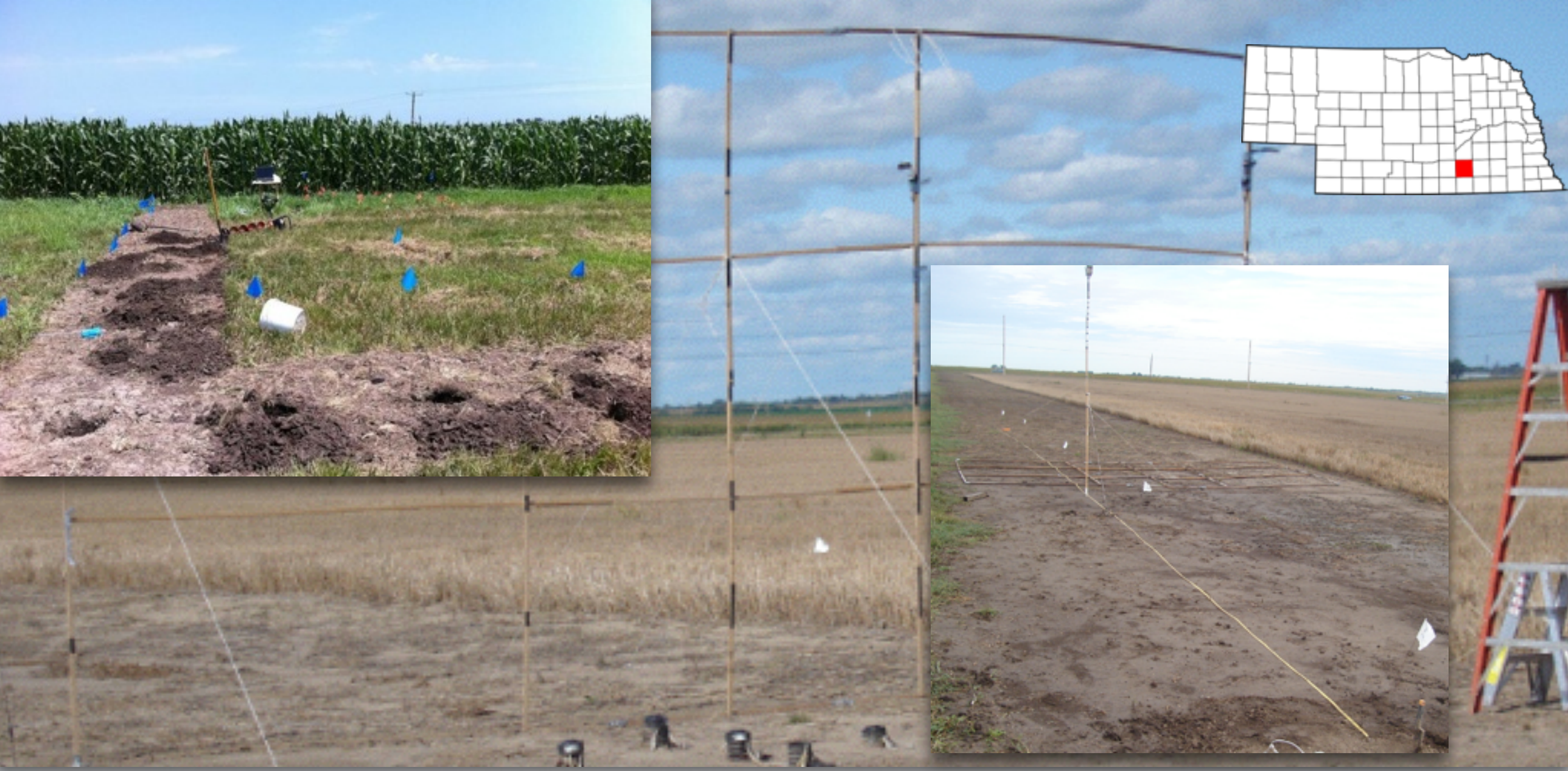
[1] M. C. Vuran and I. F. Akyildiz, “Channel model and analysis for wireless underground sensor networks in soil medium,” Physical Communication, vol. 3, no. 4, pp. 245–254, December 2010.
[2] X. Dong, M. C. Vuran, and S. Irmak, “Autonomous Precision Agriculture Through Integration of Wireless Underground Sensor Networks with Center Pivot Irrigation Systems,” **Ad Hoc Networks (Elsevier),** vol. 11, no. 7, pp. 1975-1987, Sept. 2013.





X. Dong and M. C. Vuran, “Environment Aware Connectivity in Wireless Underground Sensor Networks,” in **Proc. IEEE INFOCOM ‘13**, Torino, Italy, April 2013.

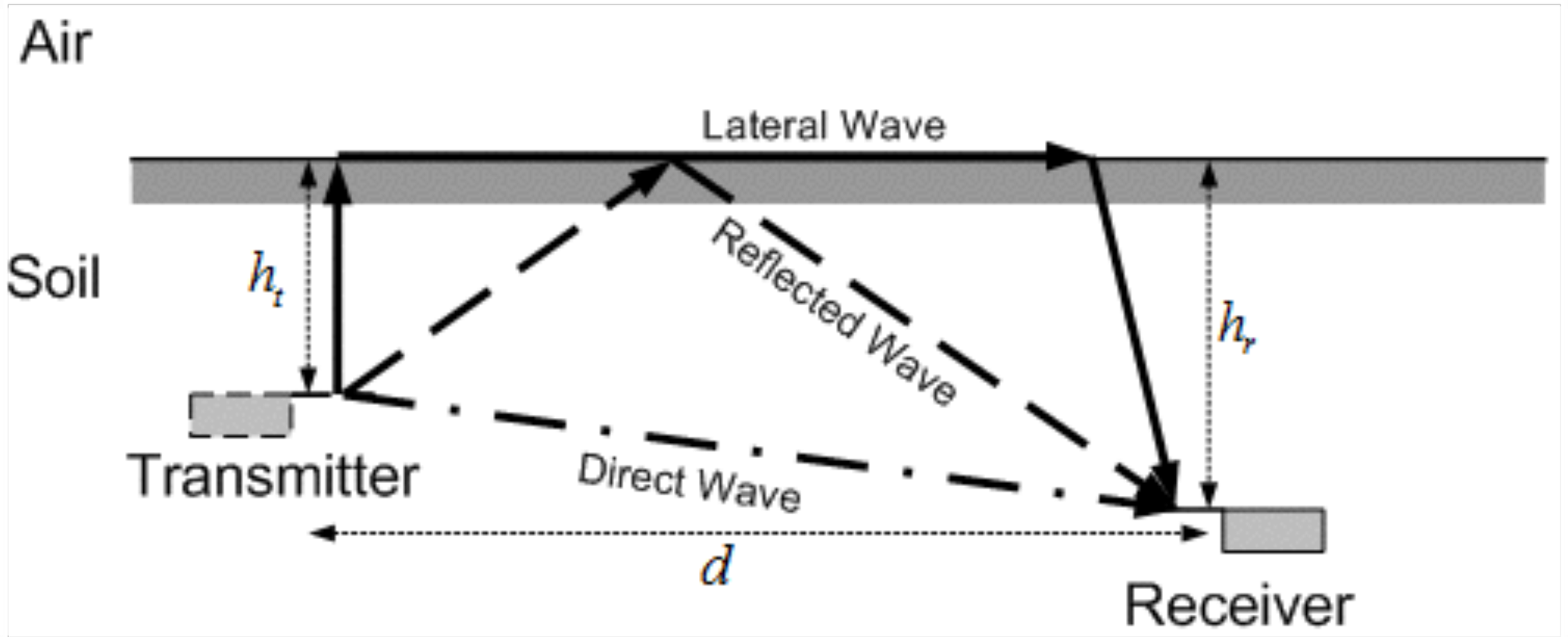
WIRELESS UNDERGROUND CHANNEL



A. Silva and M. C. Vuran, ``Development of a Testbed for Wireless Underground Sensor Networks,'' EURASIP Journal on Wireless Communications and Networking, 2010.

UNL-SCAL UNDERGROUND SENSING AND COMMUNICATION TESTBED

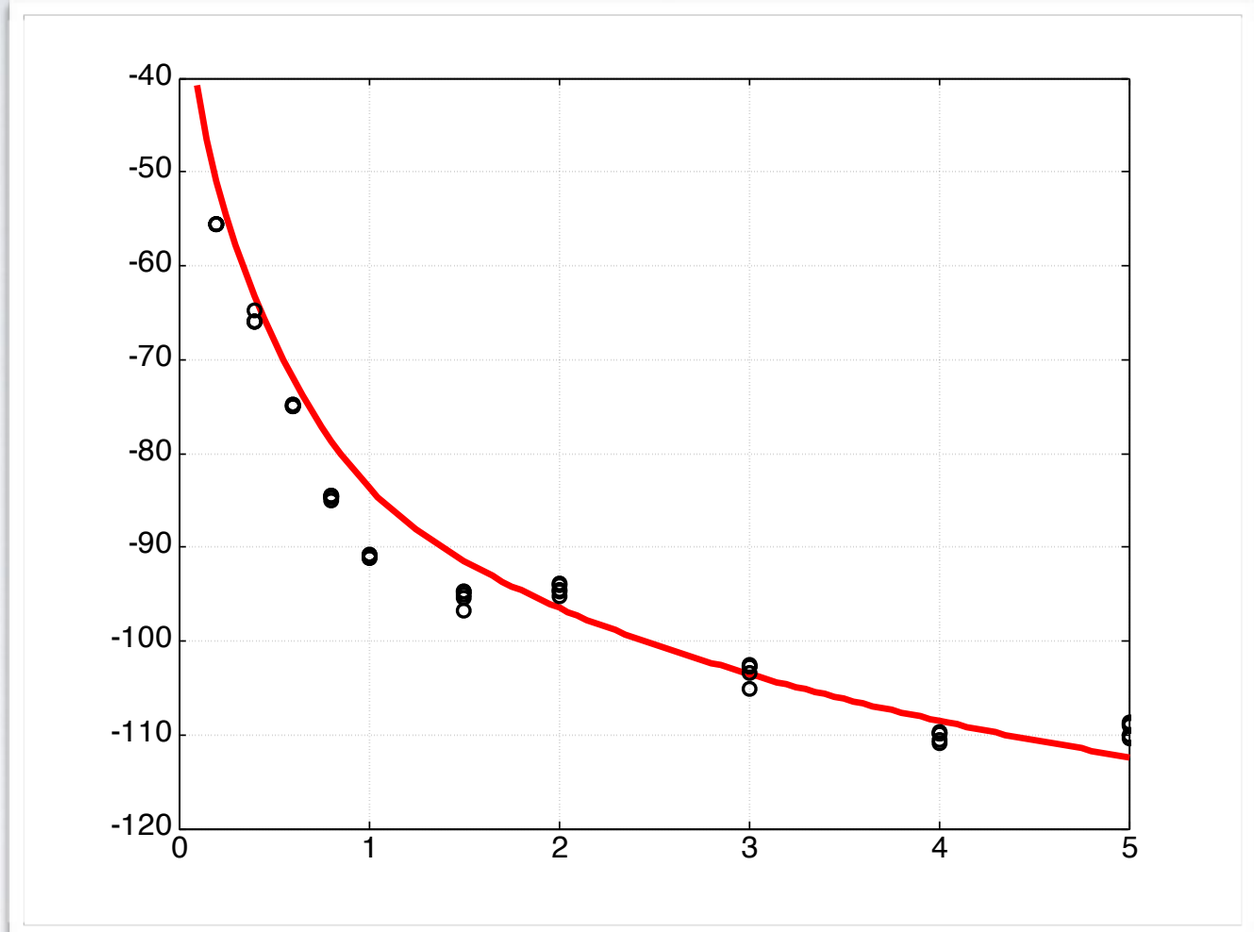
Characterizing Wireless Underground Communications…



X. Dong and M.C. Vuran, "A channel model for wireless underground sensor networks using lateral waves," in Proc. IEEE Globecom '11, Dec. 2011

IN SPACE…

Closed-form model for underground-to-underground communication



X. Dong and M.C. Vuran, "A channel model for wireless underground sensor networks using lateral waves," in Proc. **IEEE Globecom '11**, Dec. 2011

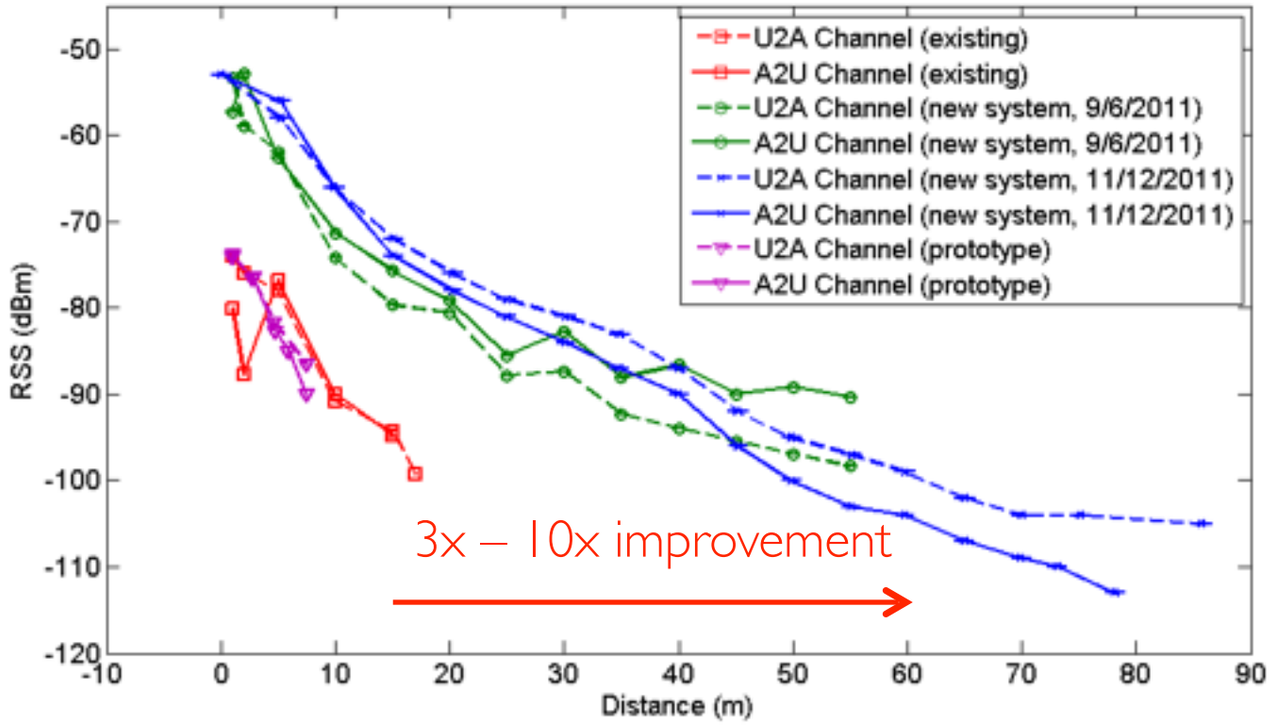
IN SPACE…

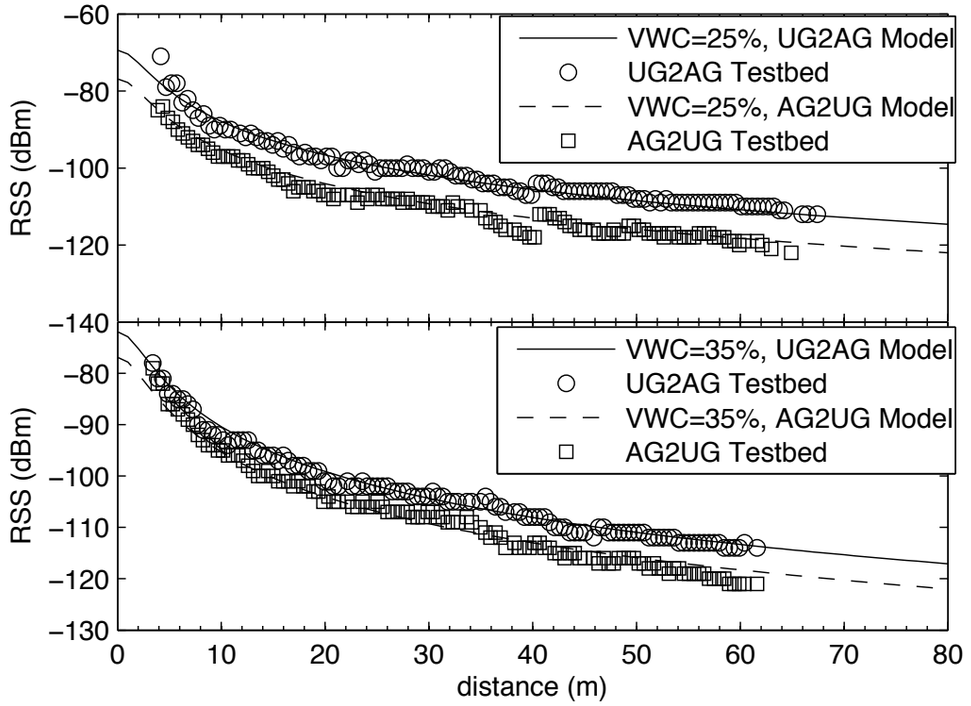
Model validation with empirical results

A. Silva and M. C. Vuran, ``Communication with Aboveground Devices in Wireless Underground Sensor Networks: An Empirical Study, Proc. **IEEE ICC '10**, Cape Town, South Africa, May 2010.

IN SPACE…

Communication from Soil

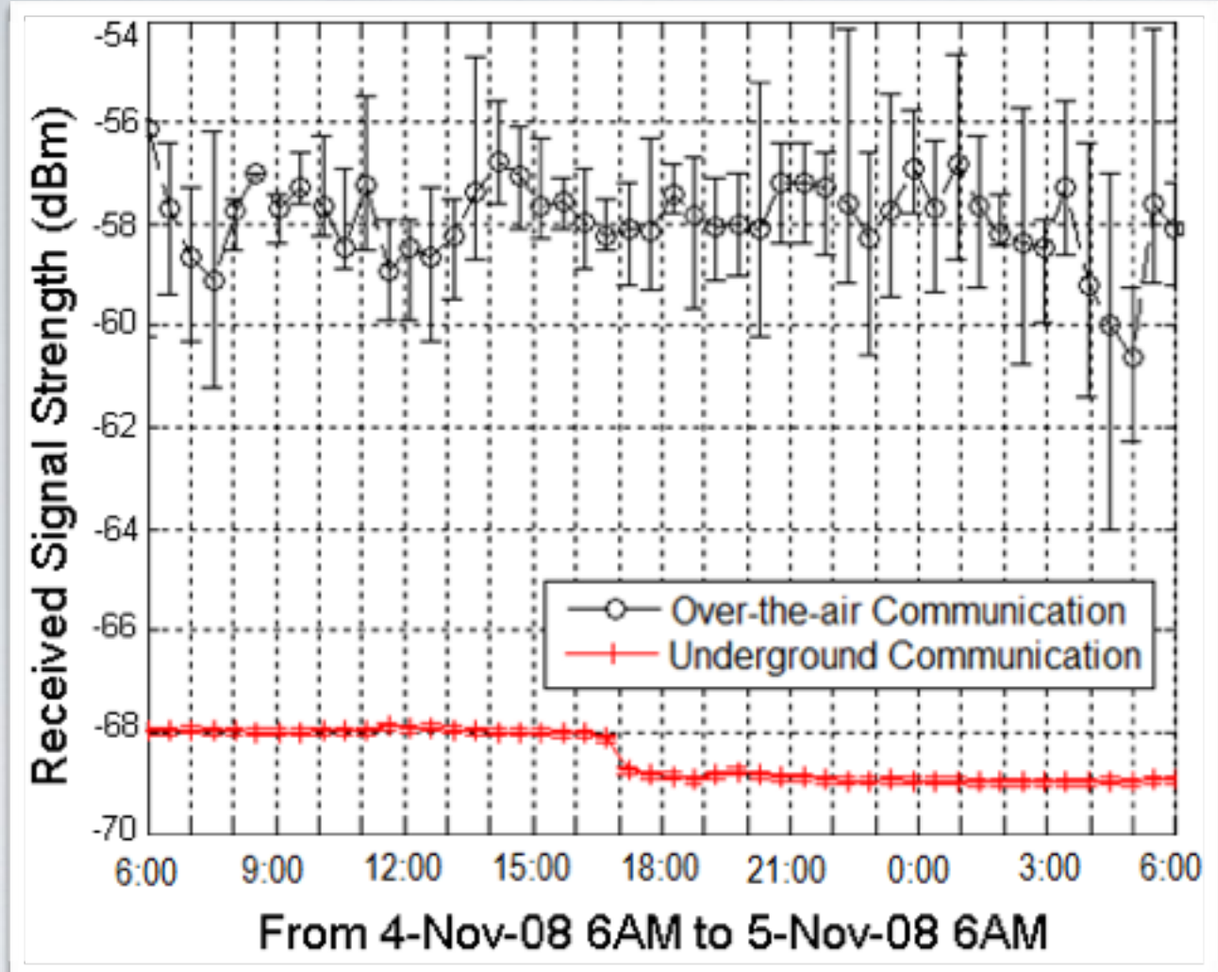


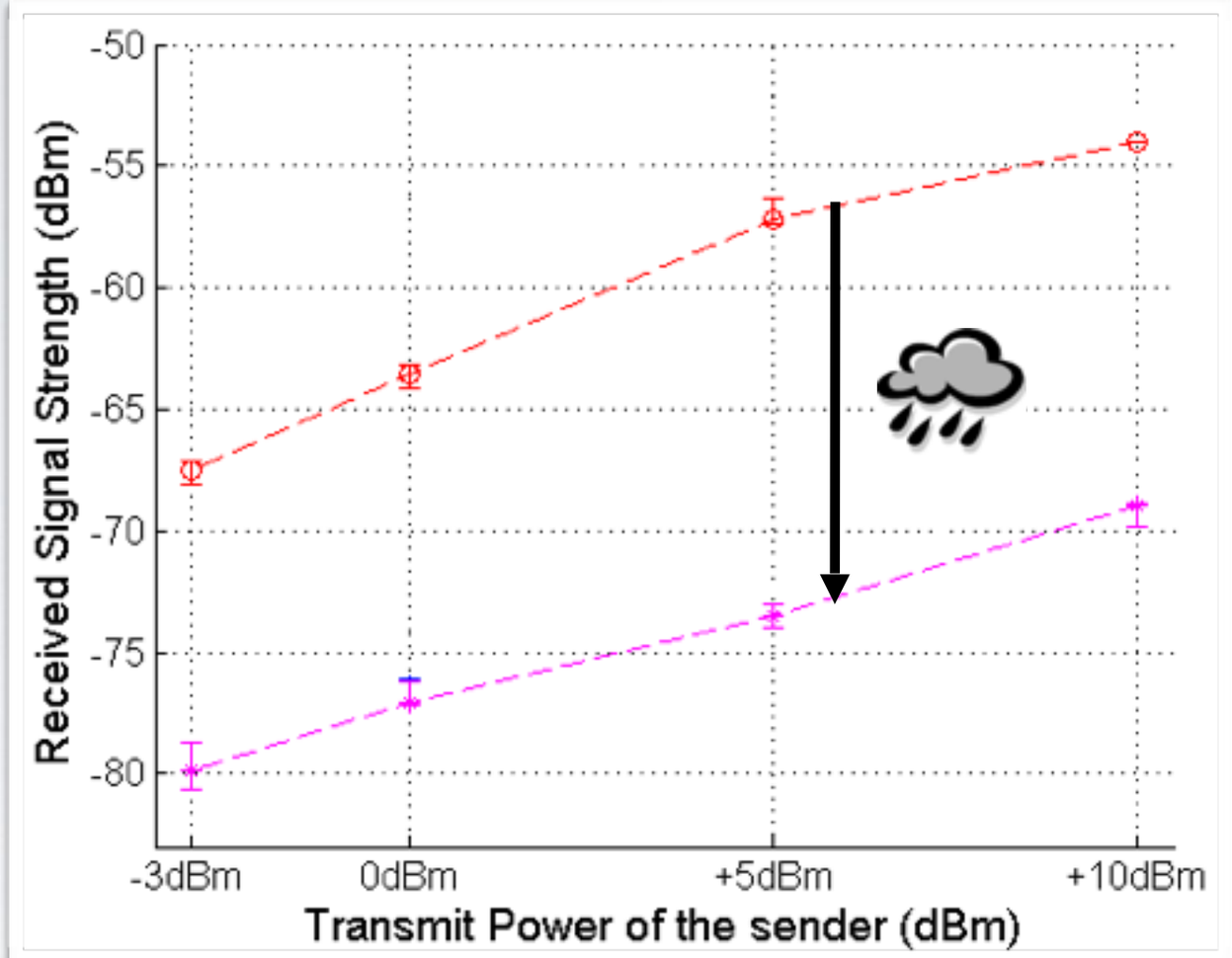


X. Dong, M. C. Vuran, and S. Irmak, "Autonomous Precision Agriculture Through Integration of Wireless Underground Sensor Networks with Center Pivot Irrigation Systems," **Ad Hoc Networks Journal,** vol. 11, no. 7, pp. 1975-1987, Sept. 2013.

IN SPACE…

Communication from Soil



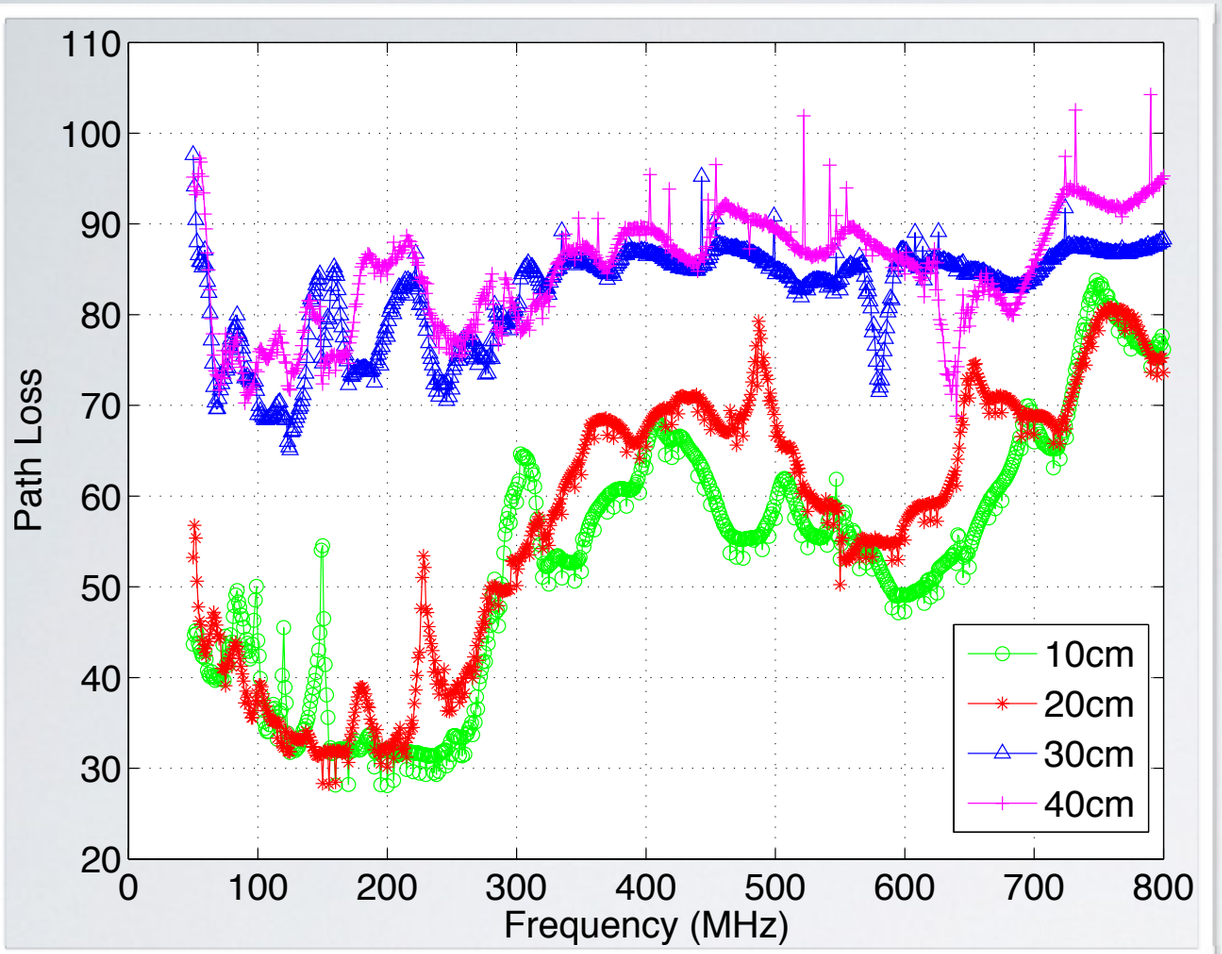


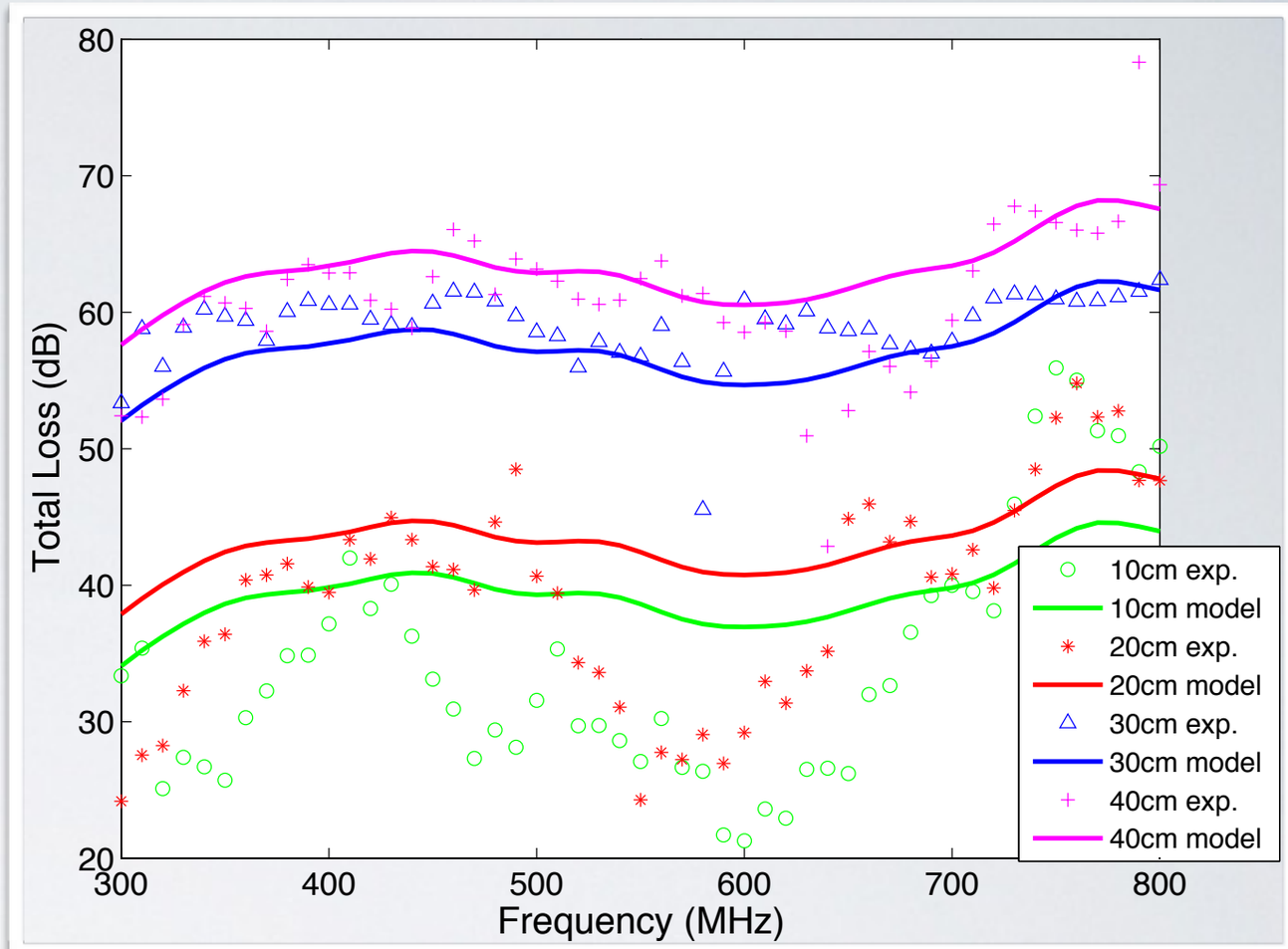
IN TIME…

Temporal characteristics of wireless underground communication channel

IN FREQUENCY…

First software-defined radio experiments for wireless underground communications in the 300-800 MHz range



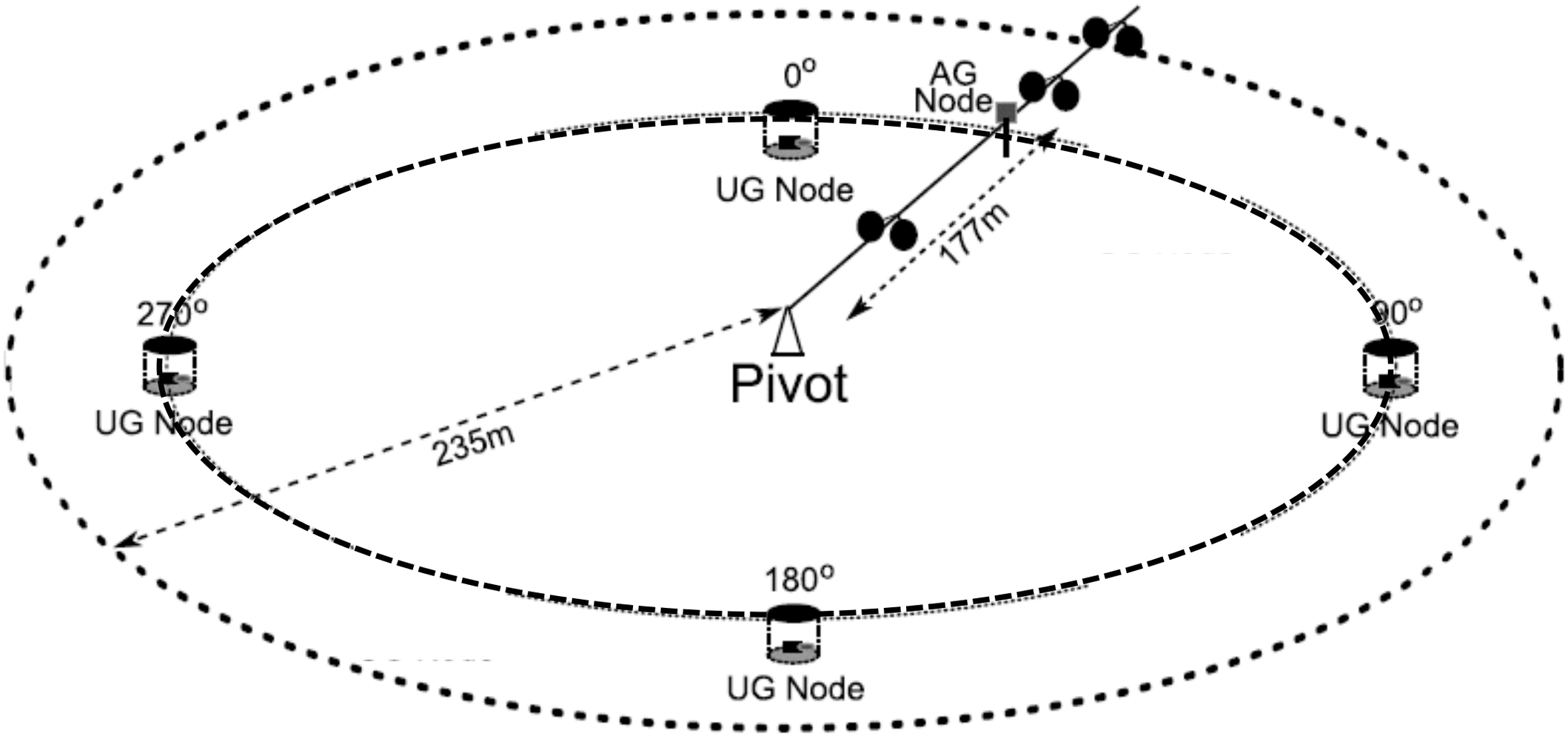


IN FREQUENCY…

Path loss experiments and modeling in 300-800 MHz

X. Dong, M. C. Vuran, and S. Irmak, "Autonomous Precision Agriculture Through Integration of Wireless Underground Sensor Networks with Center Pivot Irrigation Systems," Ad Hoc Networks Journal, vol. 11, no. 7, pp. 1975-1987, Sept. 2013.

WUSN CENTER PIVOT INTEGRATION

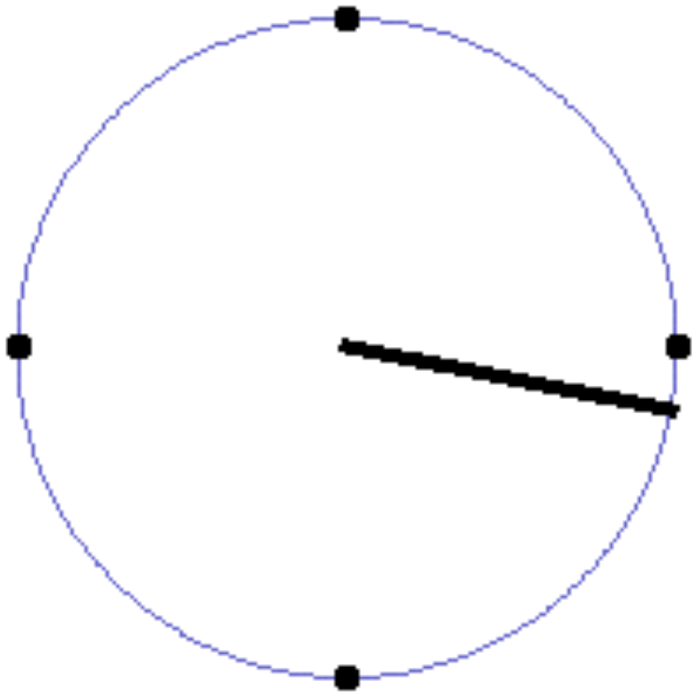


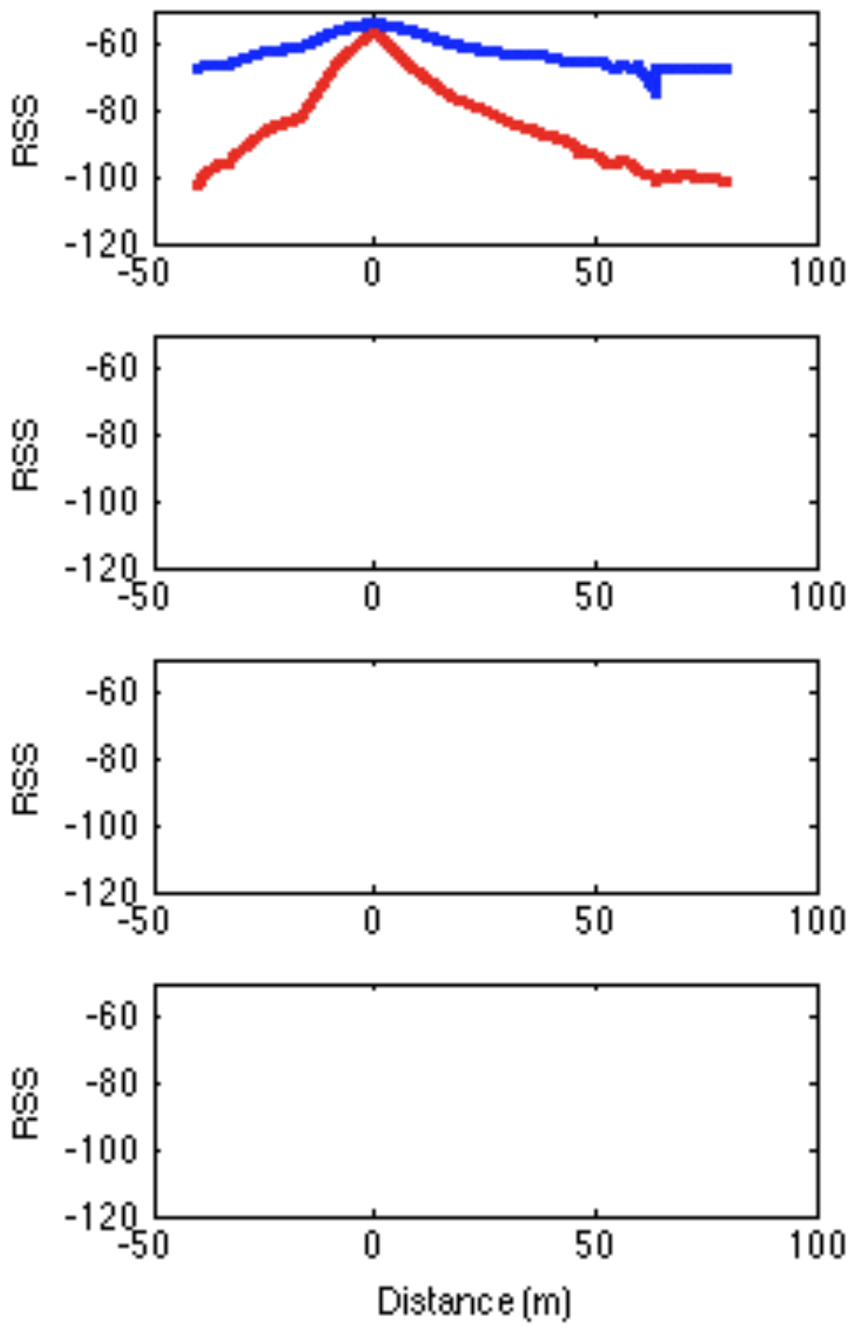
J. Tooker, X. Dong, M. C. Vuran, and S. Irmak, "Connecting Soil to the Cloud: A Wireless Underground Sensor Network Testbed," demo presentation in **IEEE SECON '12**, Seoul, Korea, June, 2012.

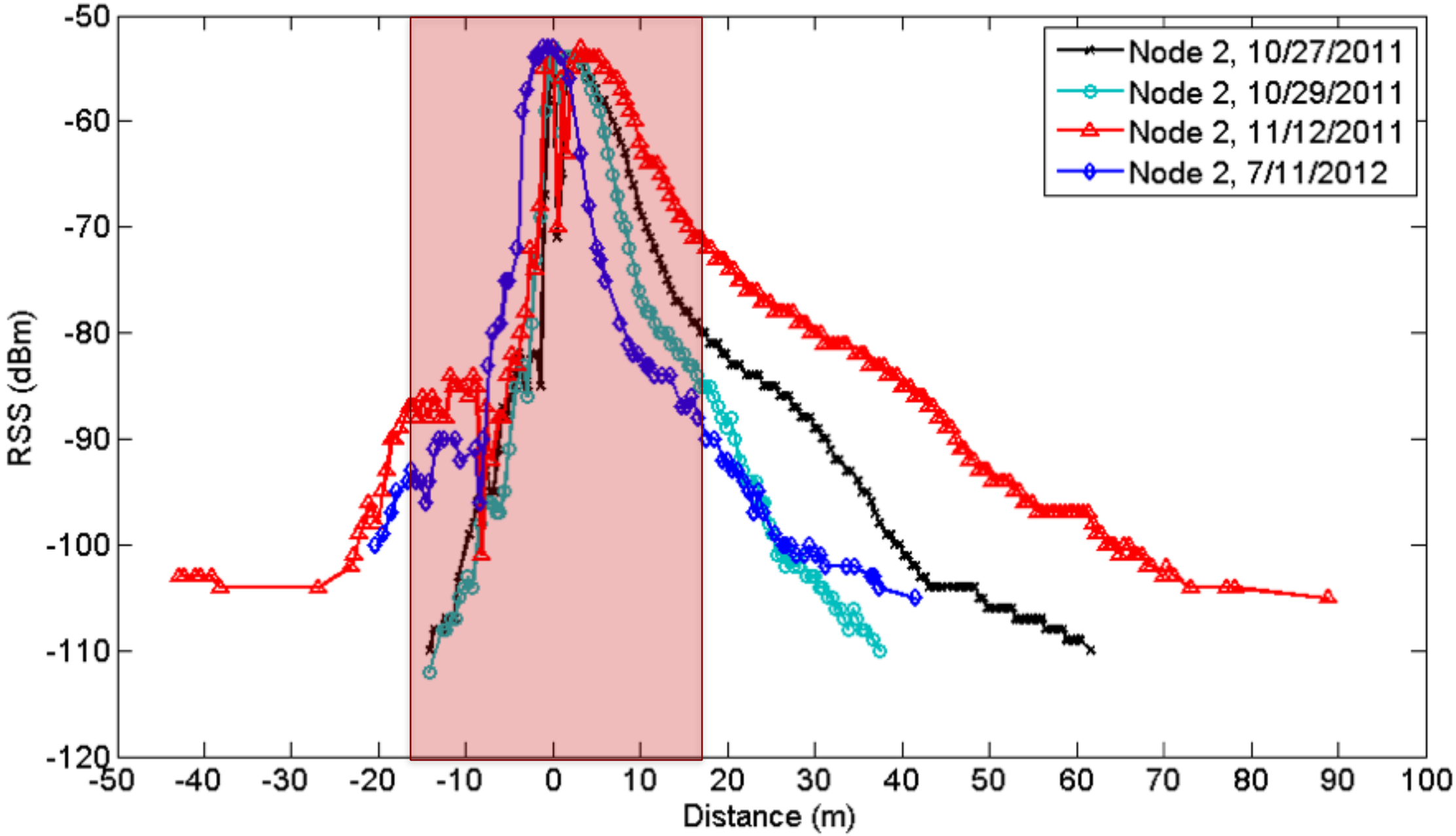
EXPERIMENT SETUP



WUSN CENTER PIVOT INTEGRATION

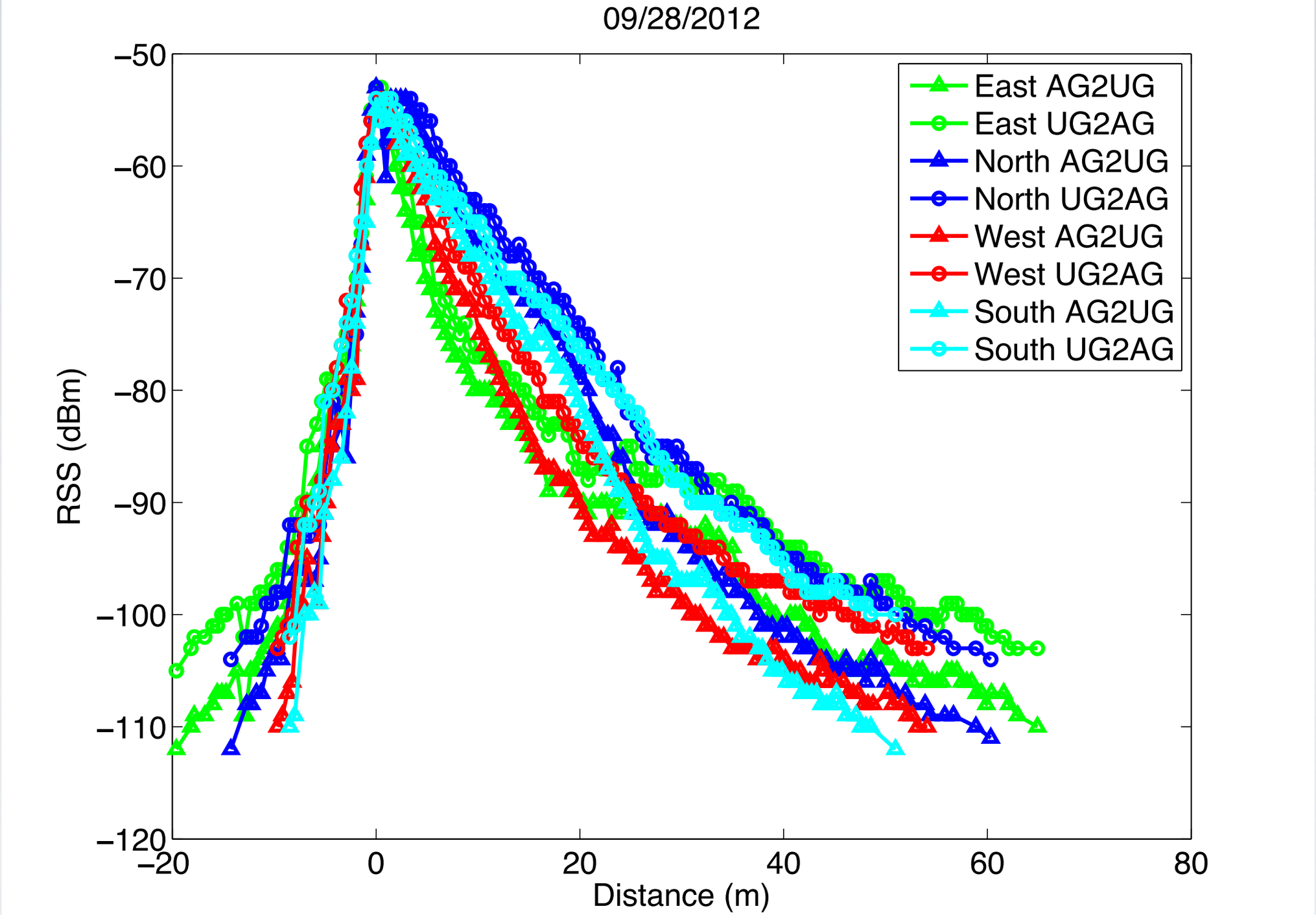



UG2AG
AG2UG
RSS
-60
-80
-100
-120
-50
0
50
100
Distance (m)

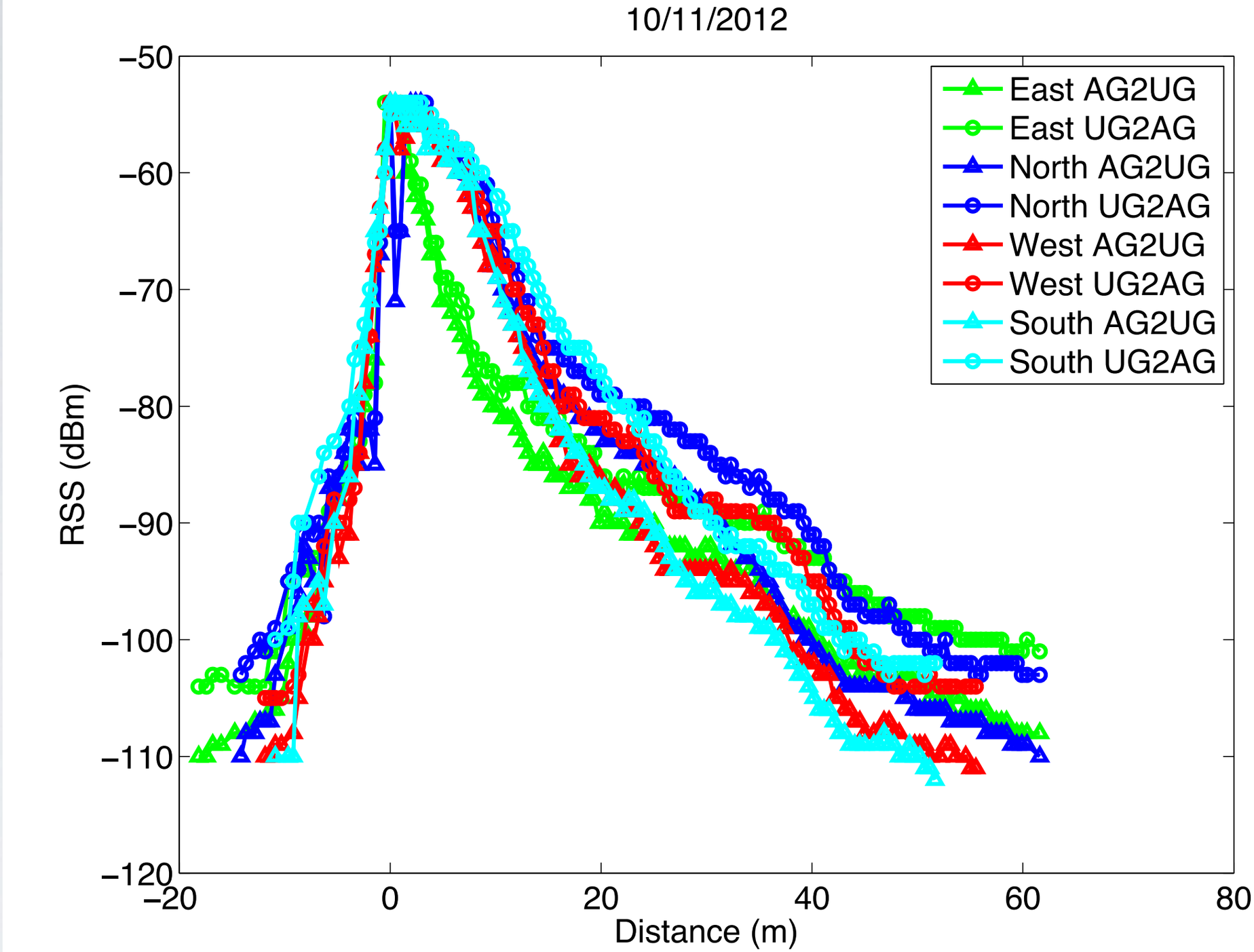


Center pivot direction

WUSN-CENTER PIVOT EXPERIMENTS ('11)



WUSN-CENTER PIVOT EXPERIMENTS ('12)



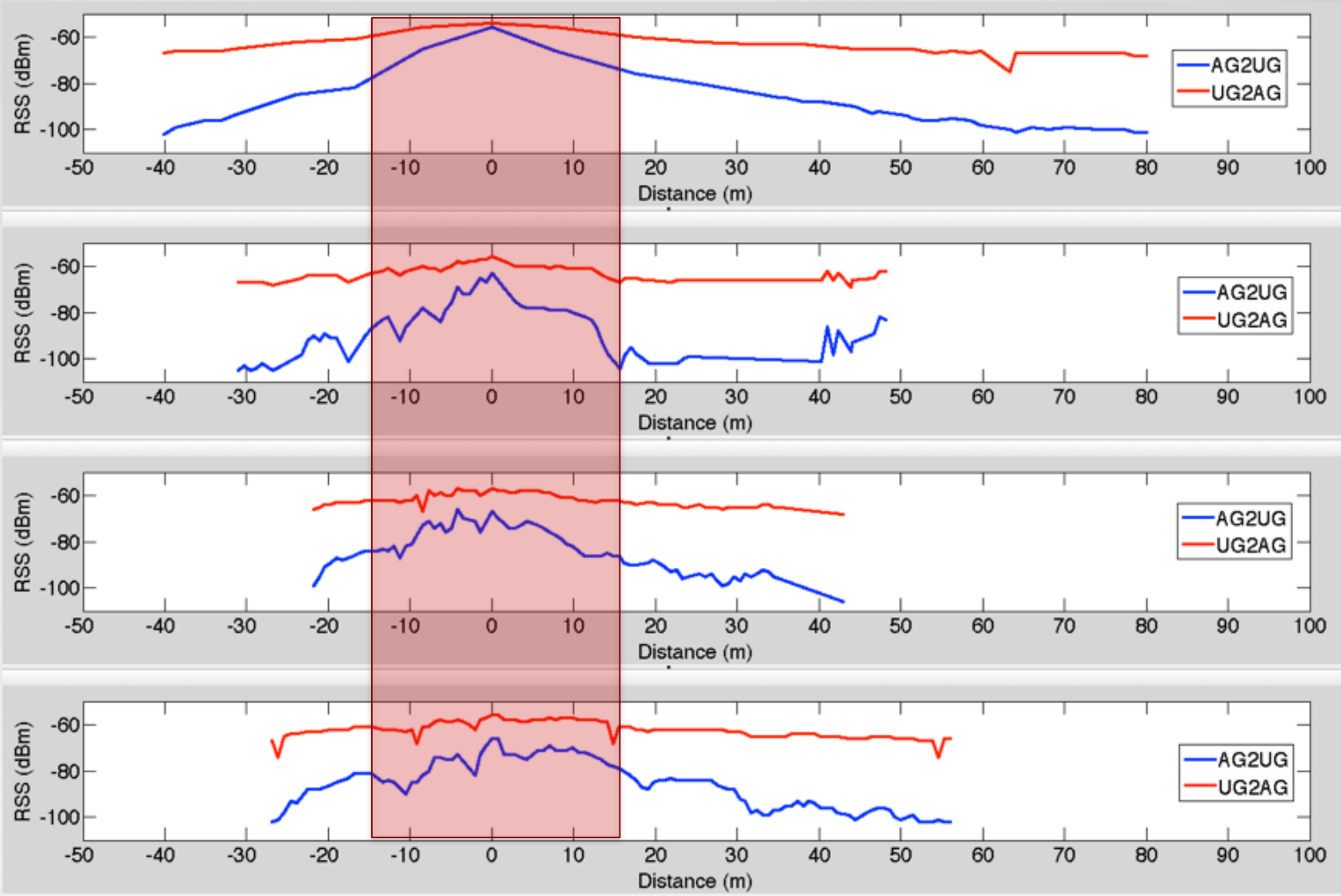
WUSN-CENTER PIVOT EXPERIMENTS ('12)

South

East

North

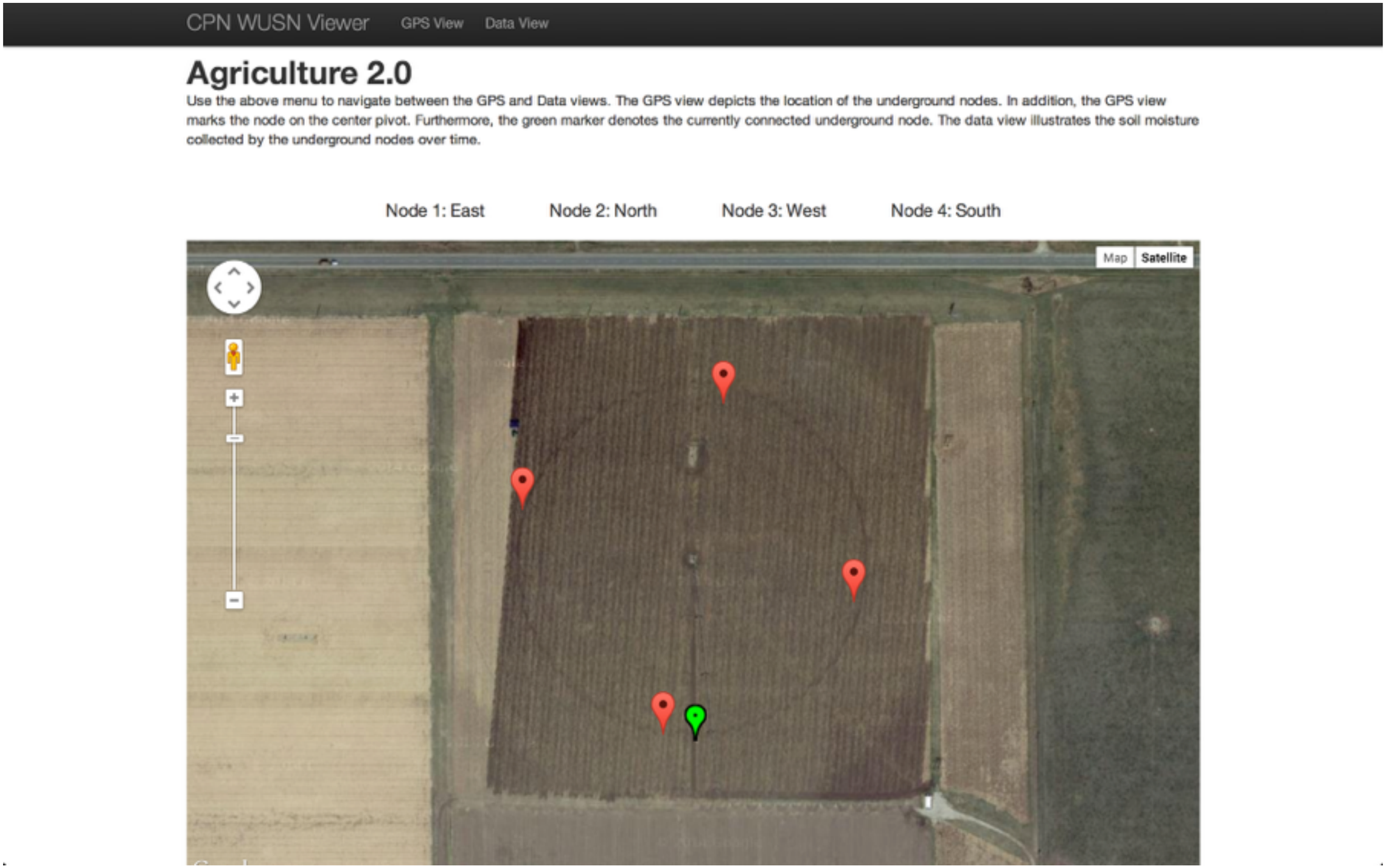
West



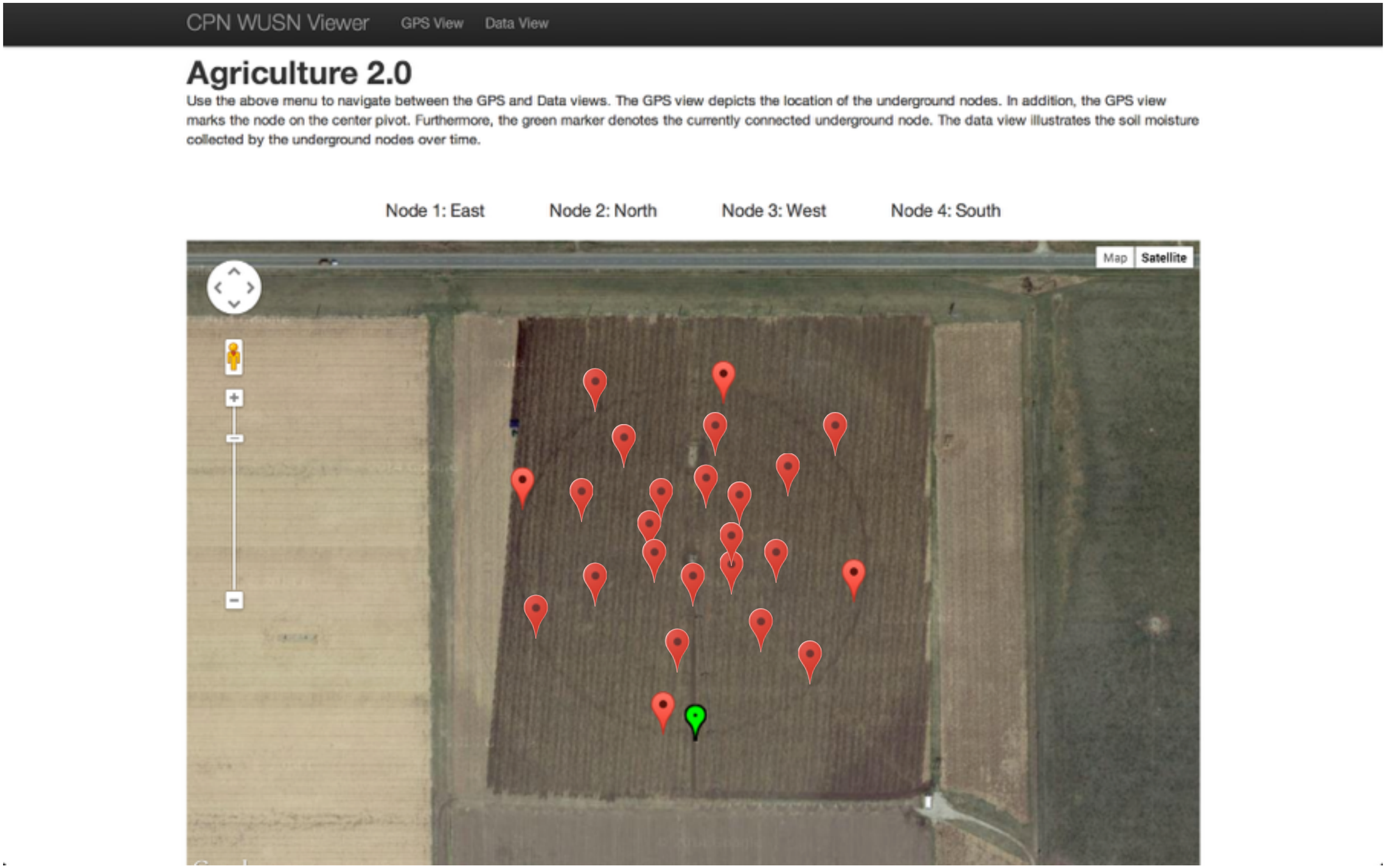
WUSN-CENTER PIVOT EXPERIMENTS ('13)

2014 DEPLOYMENTS

Web Interface



Web Interface



Smart Irrigation Management with Wireless Underground Sensors

Wise-Irr

University of Nebraska Lincoln

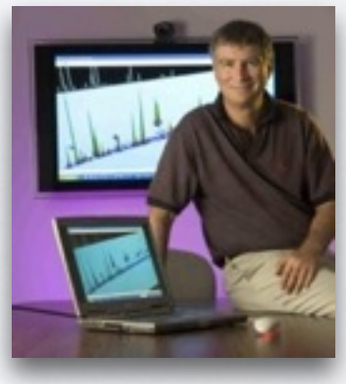
National Science Foundation
WHERE DISCOVERIES BEGIN

I-CORPS
NSF Innovation Corps

SBIR Phase I

Mehmet Can Vuran
(PI)

Xin Dong
(EL)



Stephen E. Reichenbach
(IM)

Suat Irmak
(DE)

On The Road

JOHN DEERE WATER

AquaSpy

AquaView

MONSANTO

LINDSAY CORPORATION

Intelligent Design and Innovation

VALLEY

Precision Irrigation Made Easy

AquaCheck

SOIL MOISTURE MANAGEMENT

T-L

hti PLASTICS

Upper Republican Natural Resources District

Channel

verizon wireless

Reinke

MORE RIGHT THAN RAIN

Sentek technologies

Australia

Sprint


Wise-Irr
What would you ask,
if you could talk to your soil?
Wildsense, LLC

QUESTIONS?