# Towards improved TDR soil water sensing for optimizing irrigation water management

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*SSS0.10 Irrigation Challenges to Cover Social Issues in the XXI Century*

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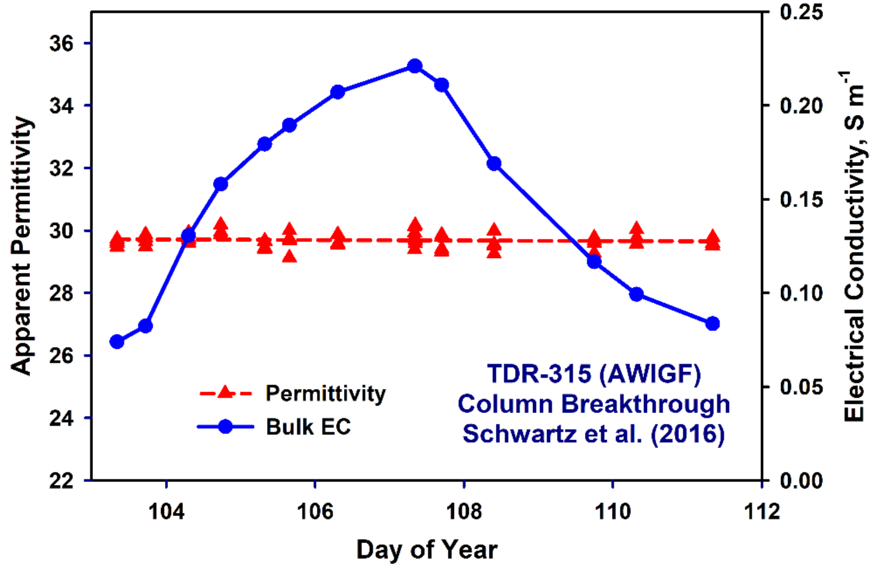
# TDR Instrumentation – Historical Perspective

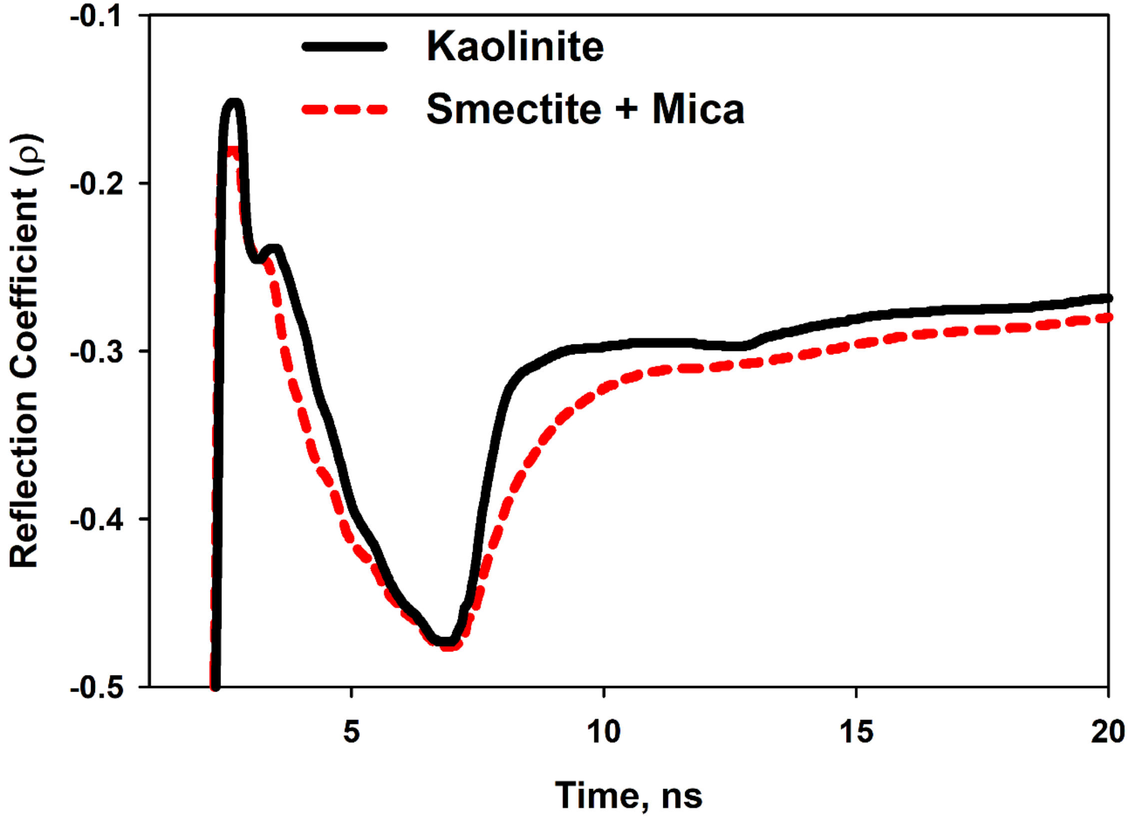
- 1990's and early 2000's: Tektronix 1502C cable tester (1.75 GHz bandwidth), CPU, 50 Ω coaxial cables, multiplexers…
  - Calibration influenced by coaxial cable length and interconnects
  - Extremely difficult to deploy in field
  - Only for scientific research


- 2016 to present: Acclima TDR-315 sensors (~1 GHz bandwidth)
  - Miniaturized TDR circuit
  - SDI-12 interface; waveforms acquired via another communication protocol
  - Solar gateway and nodes allow cloud access

# Why TDR?

- Reduced sensitivity to apparent (bulk) EC of the soil
- Measured travel time is highly linear with soil water content

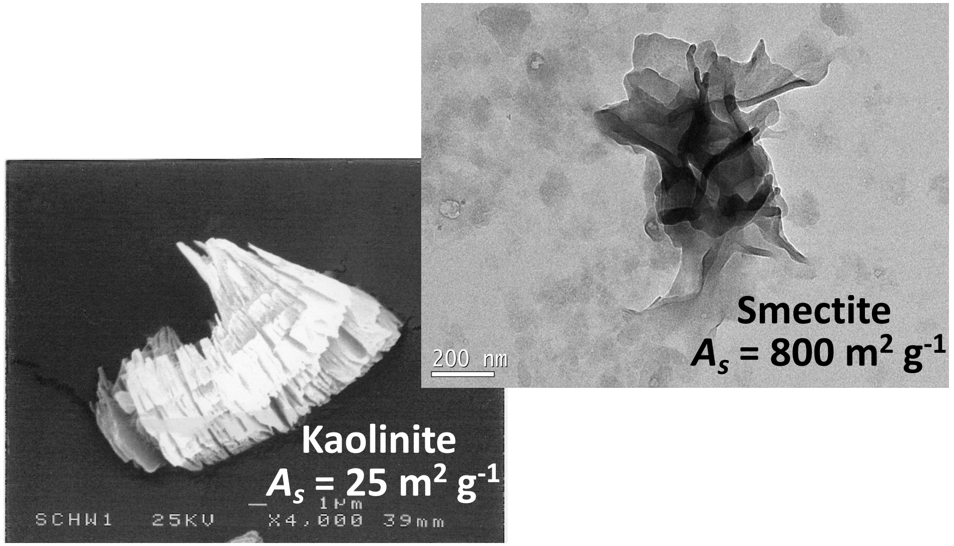


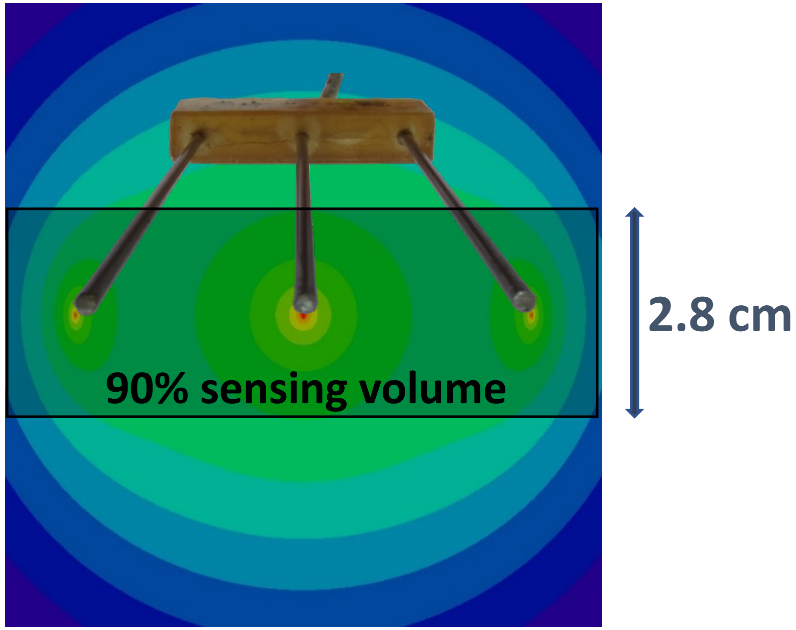

- Captured waveforms contain patterns and features that reflect soil properties

# TDR measurements – sources of imprecision/inaccuracy

- Errors 0.02 to 0.05 $m^3\ m^{-3}$ (20 – 50% management range)
- Calibrations fail to consider interaction between mineral surfaces and water (bound water relaxation):
  - Permittivity of bound water 10 – 60% of free water
  - Attenuation of high frequency components **biases graphical determination of travel time**




- Small sampling volume of probe (~300 $cm^3$)
- Sensitivity to bulk EC increases with increasing 2:1 clay content
- Temperature influences dielectric and dc losses and the amount of bound water



# Calibrations (loosely) based on theory

- Interplay between temperature and bound water (Or and Wraith, 1999) and bulk electrical conductivity (ECa) (Schwartz et al., 2009ab) – ***Complex dielectric power law mixing model***

$$\varepsilon^* = \varepsilon' - j\varepsilon'' \quad - \quad j\frac{\sigma_{dc}}{\omega\varepsilon_0}$$

⬇

$$\varepsilon^* = \left[V_{air} \cdot \varepsilon_{air}^{\alpha} + V_{min} \cdot \varepsilon_{min}^{\alpha} + V_{bw}(T) \cdot \varepsilon_{bw}^{*}(T)^{\alpha} + V_{fw}(T) \cdot \varepsilon_{fw}^{*}(T)^{\alpha}\right]^{\frac{1}{\alpha}} - j\frac{\sigma_{dc}}{\omega\varepsilon_0}$$

- *Air & Mineral permittivities are real valued*
- *Free water & bound water permittivities are complex and frequency and temperature dependent*

*Fitted Parameters:*
As – surface area of soil
α – power law exponent

**Advantages**

- Improved RMSE
- Fitted surface area closely correlated with measured surface area (r = 0.989)

**Disadvantages**

- Not a closed form calculation
- Travel time approximated from signal attenuation ≠ increases in graphically determined travel time
- Soil specific calibration is impractical for most field applications for irrigation management (large fields, spatially variable soil properties)

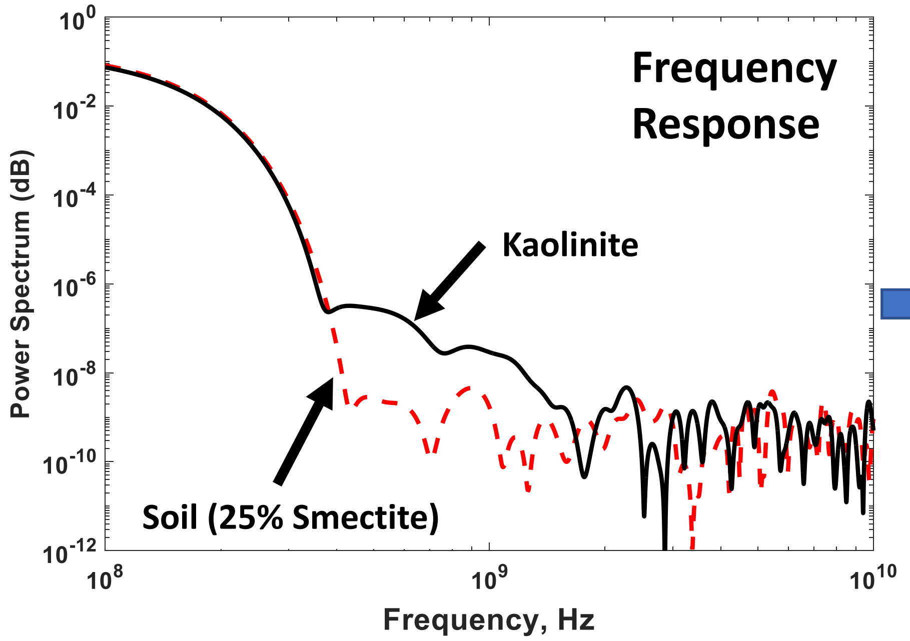
# Can we use waveform features to apply soil specific calibrations?

- Big Dirta Project / Acclima, Inc.
- Generation of waveform dataset with the TDR-315N
  - Mixtures of sand, kaolinite, high surface area soil (Pullman Bt) – range in specific surface areas
  - Saturation with < 1 dS $m^{-1}$ $CaCl_2$
  - Pressure extraction in chamber (to 100 kPa)
  - Resaturation with progressively increasing EC solutions
- Work in progress

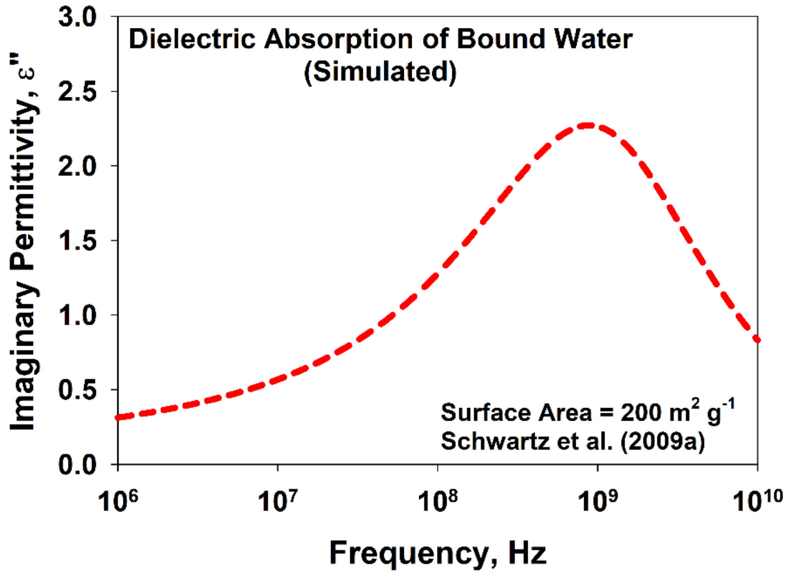
**Pressure extraction in packed container**

# Can we use waveform features to apply soil specific calibrations?

- Frequency response of soils reflect bound water associated with surfaces (amount of 2:1 clay)




**Attenuation predicted by complex permittivity model**

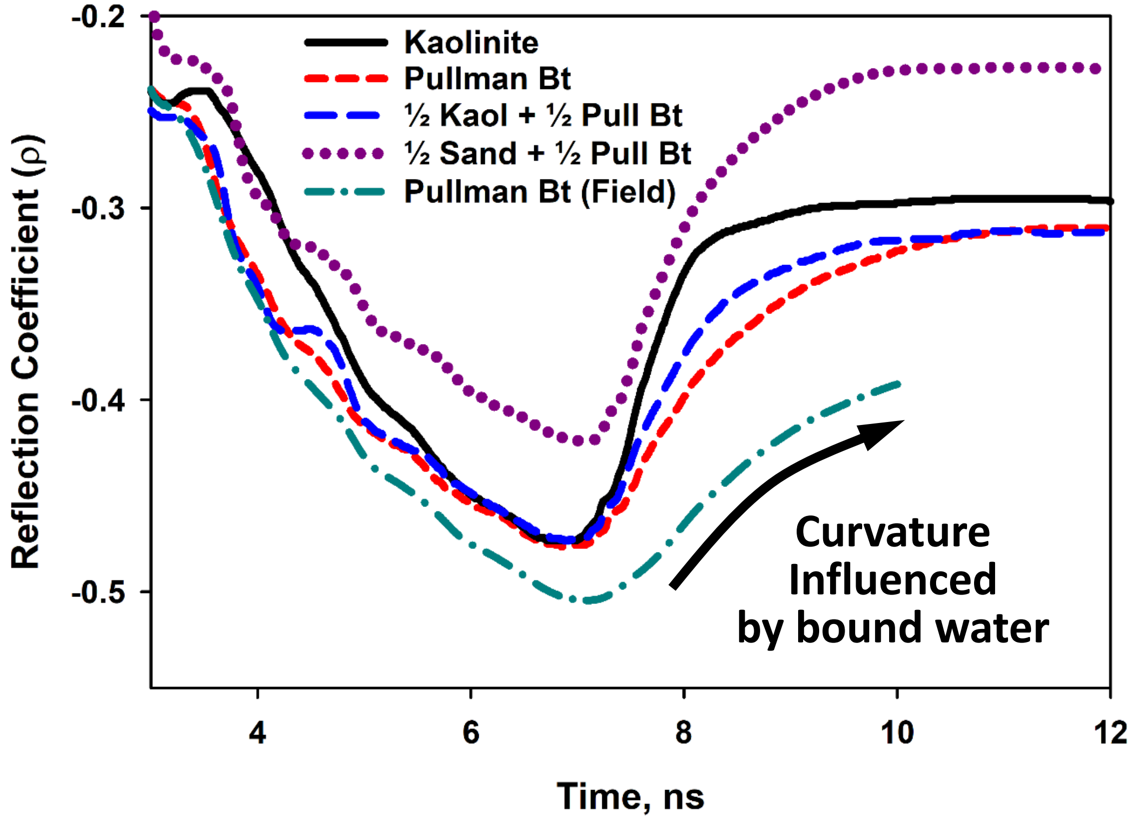


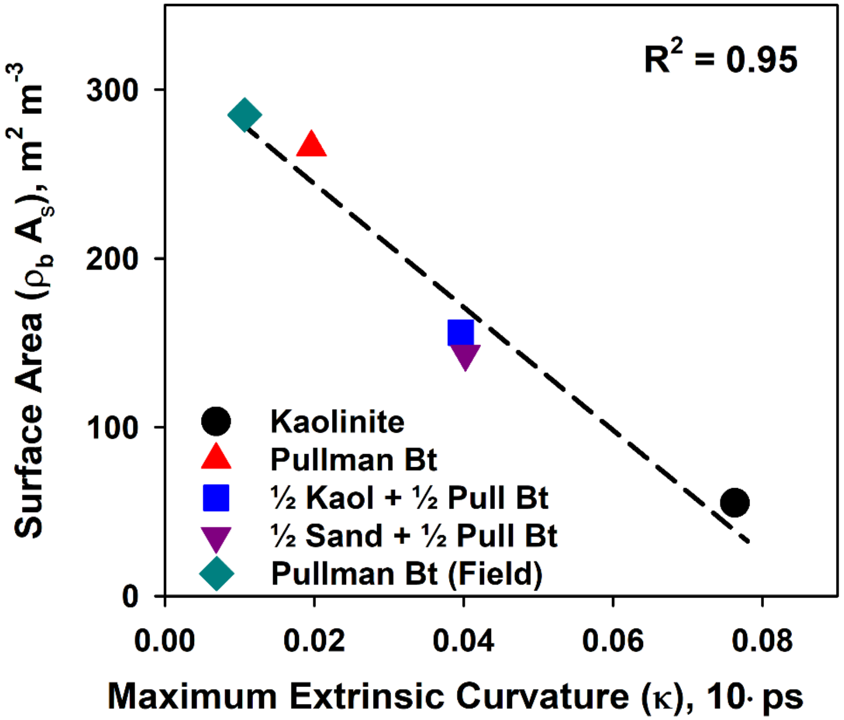

- Identify waveform features useful for soil specific calibration (machine learning approach)
- Sensors would "self-calibrate" in situ
- Collaborative work with Acclima, Inc.

# Can we use waveform features to apply soil specific calibrations?

## Waveforms with similar travel times and $EC_a$ (~1 dS $m^{-1}$)

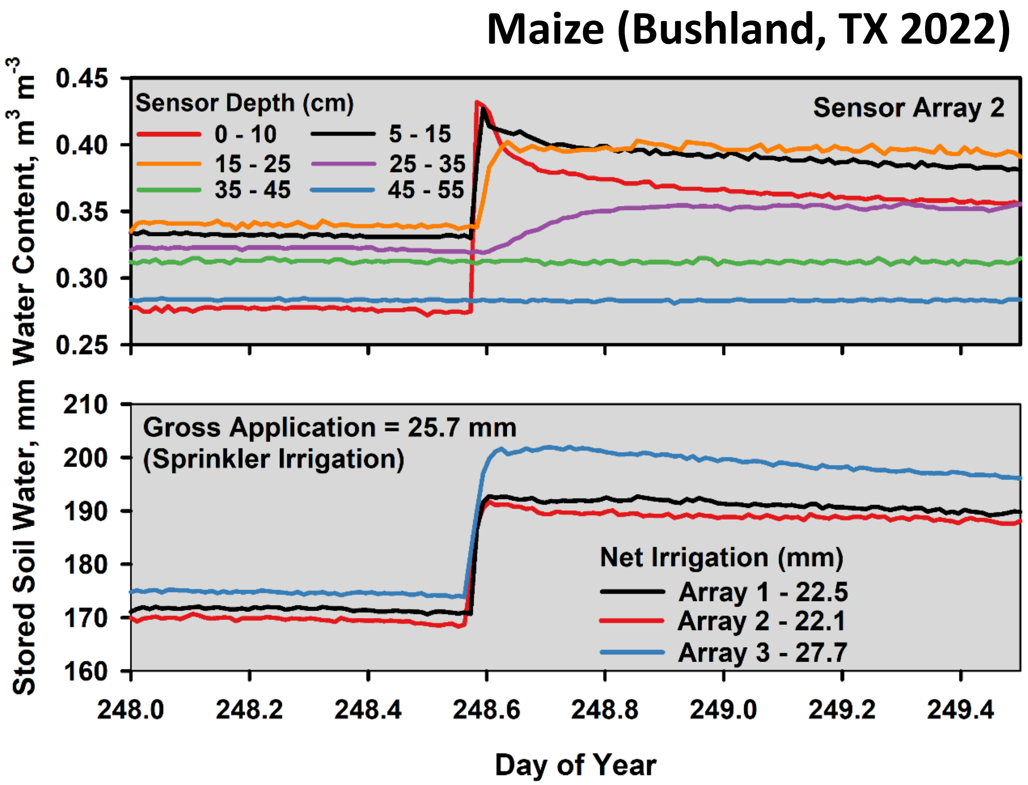
- Kaolinite - 70% clay (EPK, Edgar Minerals, FL); As = 52 $m^2$ $g^{-1}$
- Pullman Bt - 50% clay (25% smectite, 25% mica); As = 190 $m^2$ $g^{-1}$



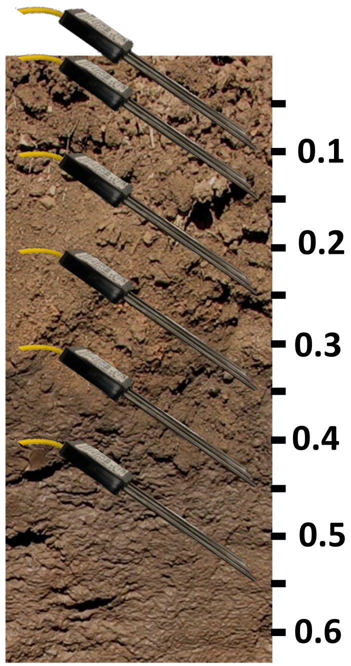



# Using TDR to quantify net irrigation and infiltration

- Large uncertainties in infiltration/runoff and irrigation application efficiency
  - Generates errors in estimated crop water use
- Use of event based method to estimate infiltration / net irrigation



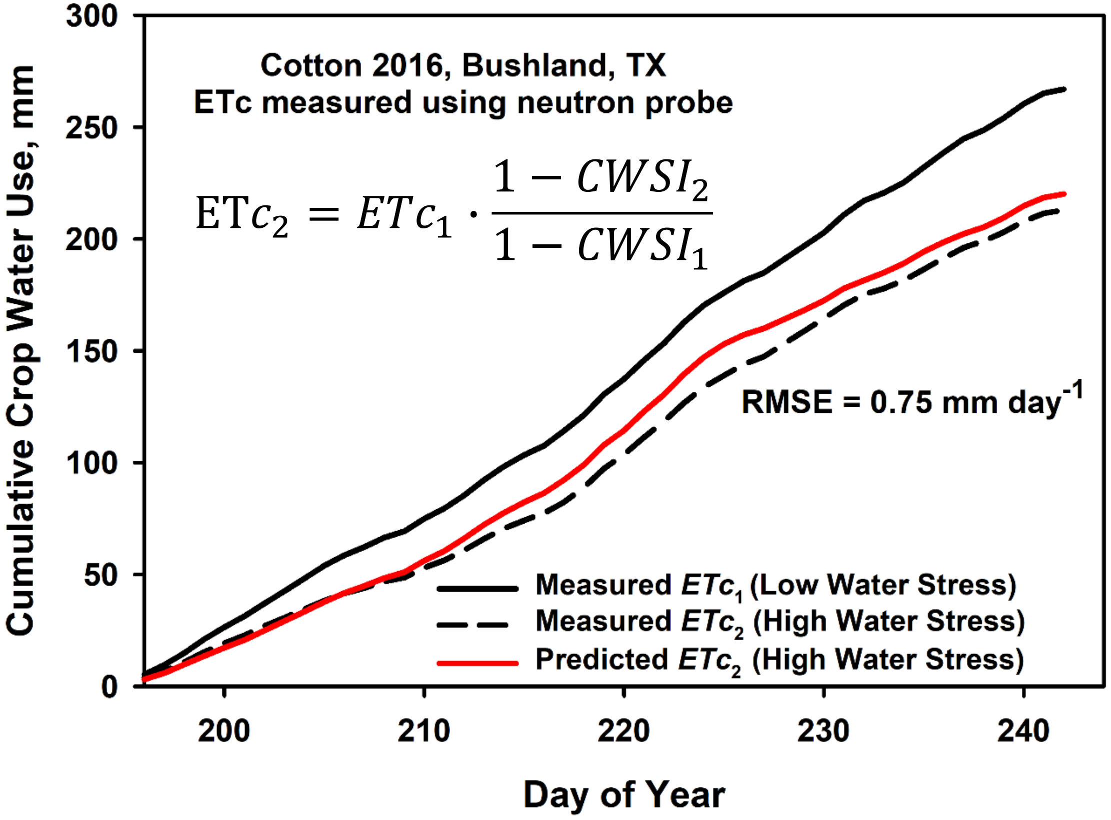

- Array of sensors near surface (detection of wetting front)




- Integration permits evaluation of the net irrigation (24 mm for 3 arrays; 93% AE)
  - Wetting front does not extend to lowest sensor
  - Negligible drainage for short time period

# IRT canopy temperatures as a proxy to scale measured crop ET

- Major limitation: Impractical & costly to deploy sufficient sensors to account for water content variability in large agricultural fields

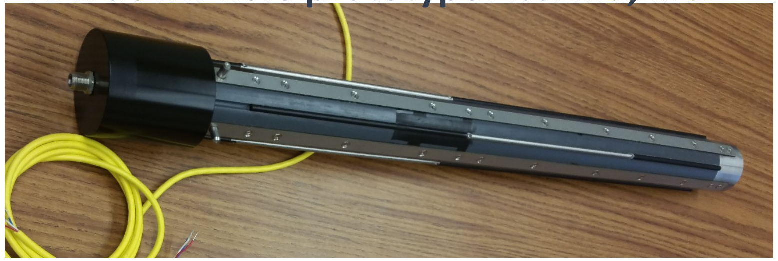



- ETc calculated using water balance and change in stored soil water with TDR
- Use of IRT crop canopy temperature to infer crop ET using the a scaled crop water stress index (CWSI)

# Challenges & Opportunities – soil water sensors for irrigation management

- **Water content measurement accuracy** is still a problem for all EM sensors in soils with significant 2:1 clays

**TDR down-hole prototype *Acclima, Inc.***



- Improvement of **downhole probes for deep soil water content sensing** (problems: air gaps in installation; reduced sensitivity)


- **Inferring water balance/crop water requirements with EM sensors** under the spatial variability imposed by surface and subsurface drip irrigation and resulting root densities
- Field variability and **upscaling measured water contents** to management zones
- Scarce water resources -> irrigating to avoid crop water stress may not result in the greatest water productivity
  - Fusion of crop models & soil water content measurements to improve **forecasting of yield and profitability** in response to irrigation

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