Evaluation of a digital TDR for determination of permittivity and bulk electrical conductivity

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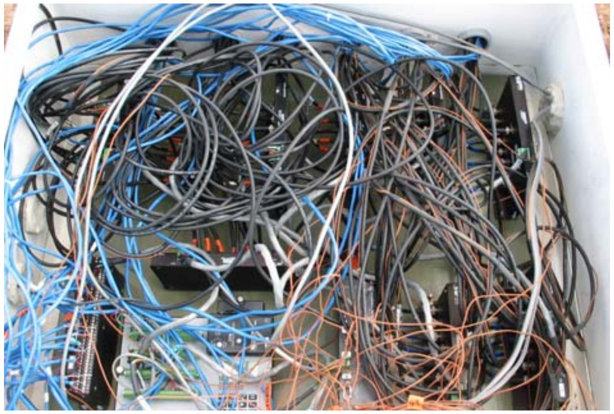
Time Domain Reflectometry



- Signal attenuation in coaxial cable, probe handle, mux's, logistics managing cables
- Can partly correct for attenuation but difficult and not always satisfactory (Schwartz et al., 2009; 2013)
- Acclima, Inc. released a new TDR probe that circumvents problem of maintaining high frequency signal over long distances (5–15 m)

Acclima TDR-315[1]

- All electronics required for waveform acquisition are embedded in probe handle; SDI-12 communication
- Series of step pulses launched down a 0.15 m transmission line
  - Digitized amplitude obtained with voltage comparator at given time offset
  - Time offset is increased (i.e. by 20 ps) and the amplitude is evaluated again
  - Entire waveform can be acquired in about a 2 minutes (400 amplitudes at sampling intervals of 20 ps).

Acclima TDR-315

- Operationally waveforms are not acquired; firmware in memory chip acquires pertinent waveform features:
  - Waveform generated at coarse time increments
  - Window identified containing the reflection at end of transmission line
  - This portion of waveform sampled at higher time resolution for determination of travel time
  - Apparent permittivity, bulk EC, water content, time offset, and other waveform features transmitted to data logger via SDI12 communications

Objectives

- Calibrate TDR-315[1] using waveforms in air & water and in solutions of $CaCl_2$
- Soil water content calibration of Pullman clay loam
  - TDR-315 using firmware estimates Ka & BEC
  - TDR-315 using acquired waveforms
  - Conventional TDR with 0.15 m probes
- Present results for a column displacement experiment (TDR & TDR-315)
  - Vary bulk EC independent of water content & porosity

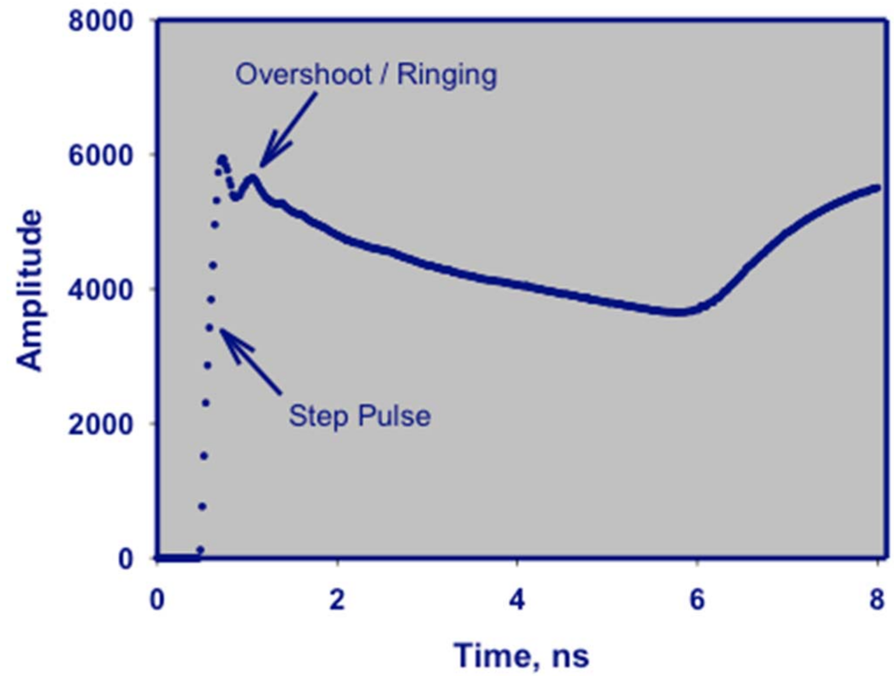
[1]Prototype sensors with identical electronics as sensors currently sold by Acclima but with a preliminary version of the firmware.

TDR-315 waveform acquisition

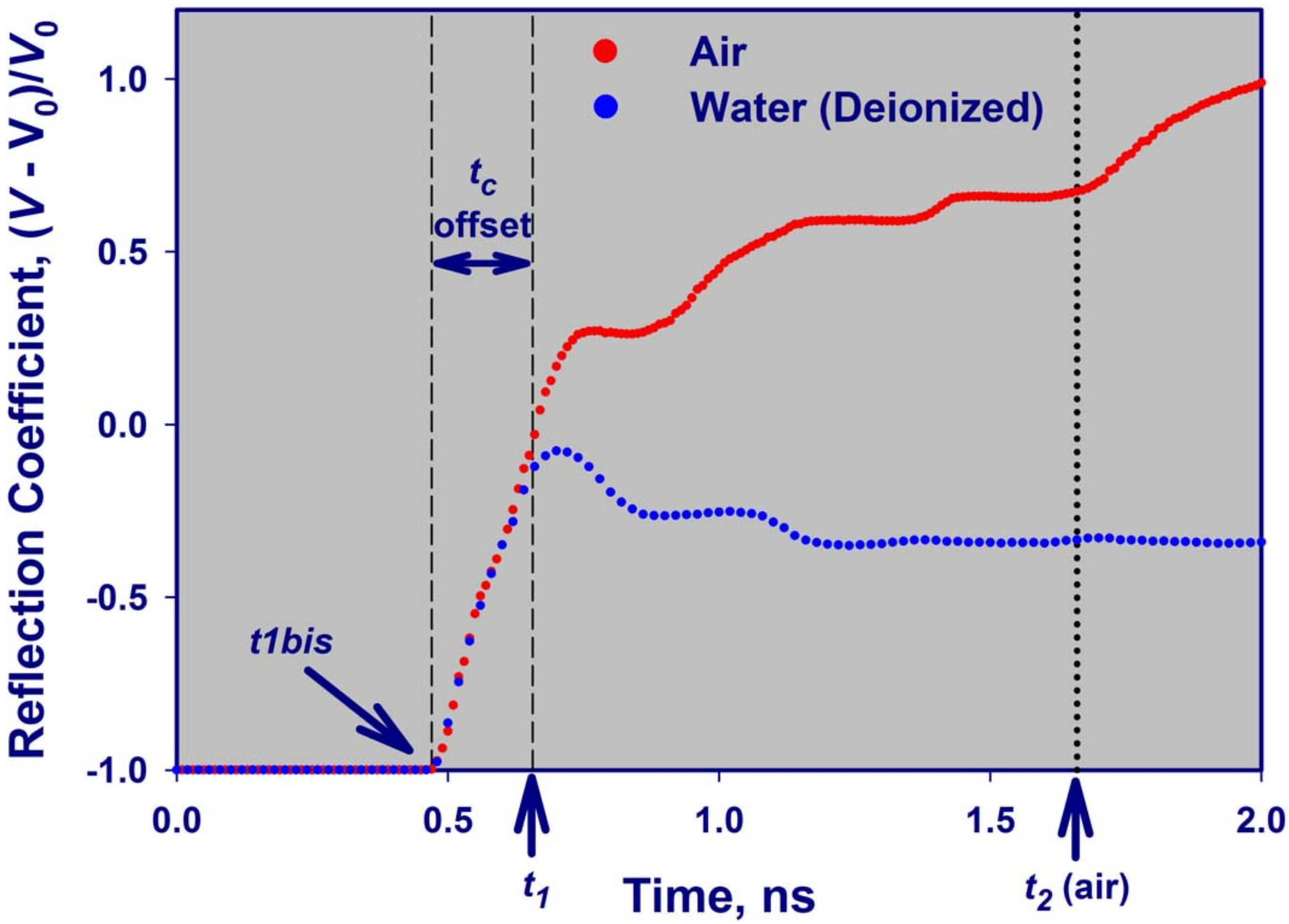
- Waveforms acquired 20 ps increments
- Amplitudes converted to reflection coefficients

$$\rho = \frac{V - V_0}{V_0} \qquad where \qquad V_0 = \frac{V_{20\,ps}}{2} \quad in\,air$$

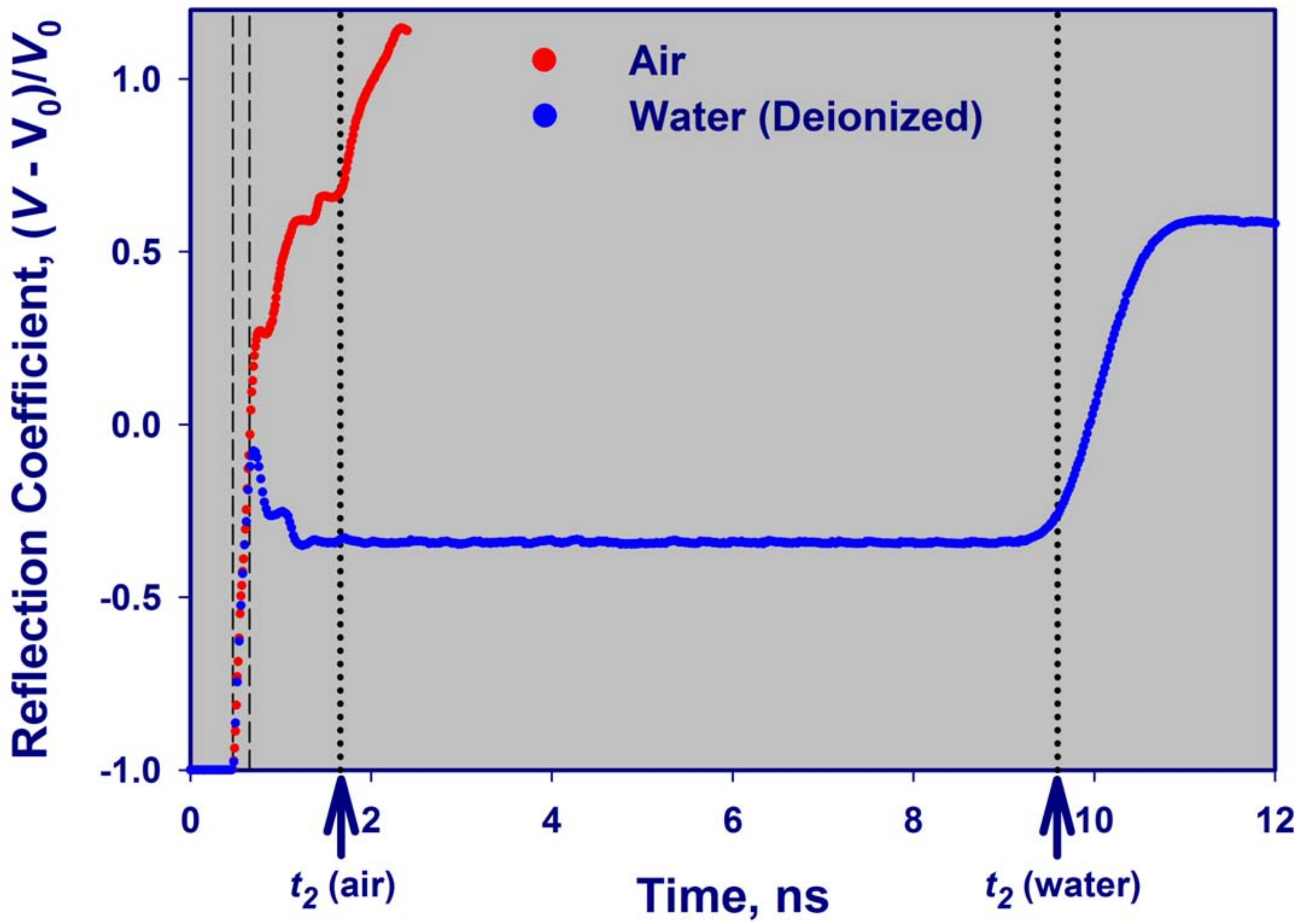
- Calculation of travel time using AWIGF (Schwartz et al., 2014)
- Calculation of Bulk EC using reflection coefficient at ~20 ns



TDR-315 air – water calibration (using AWIGF)

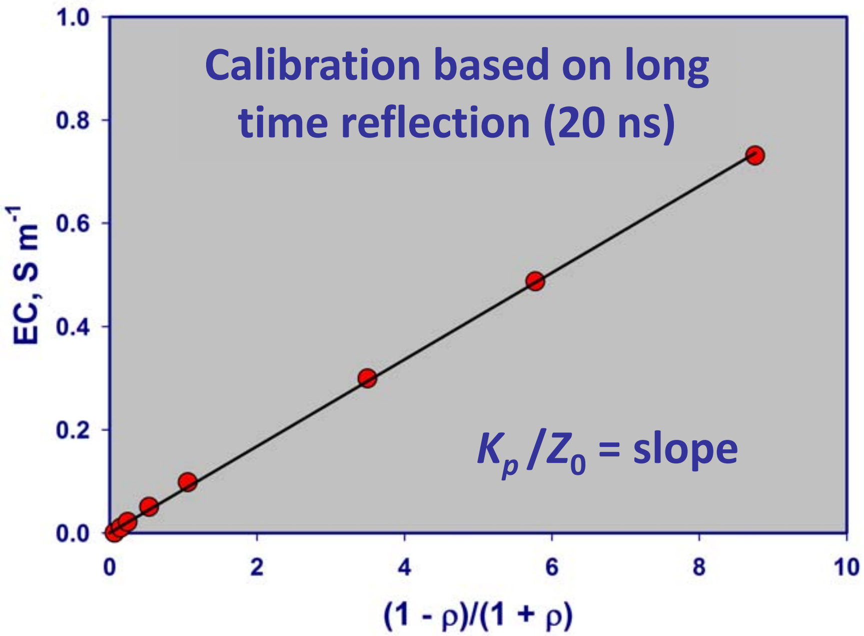


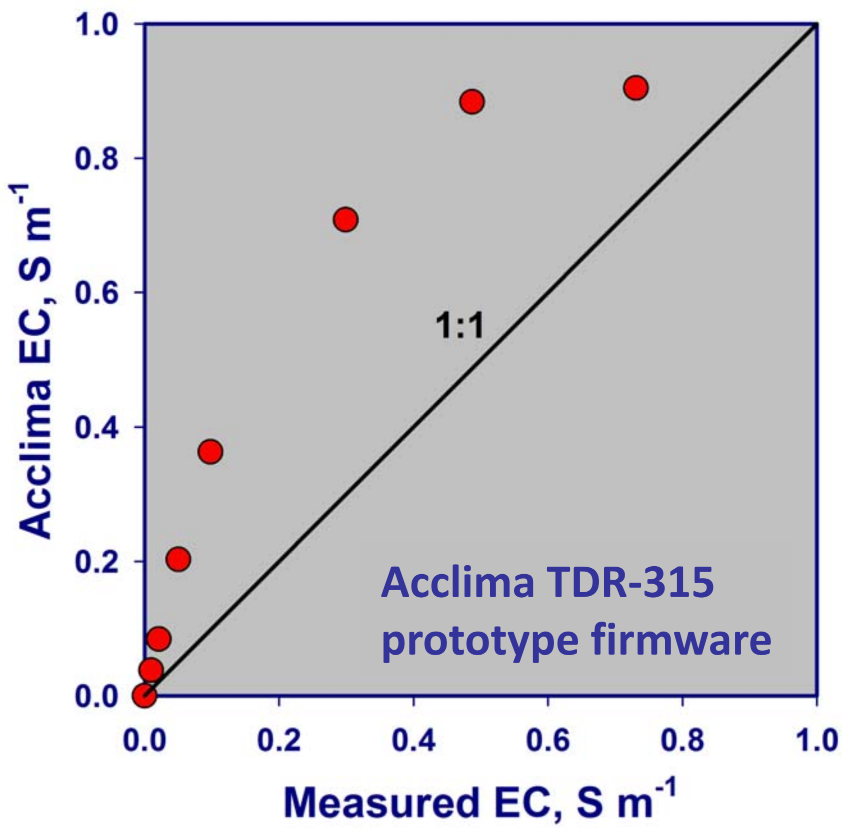
TDR-315 air – water calibration (using AWIGF)



TDR-315 – EC calibration in $CaCl_2$ solutions

Giese and Tiemann (1975)
thin-section approach





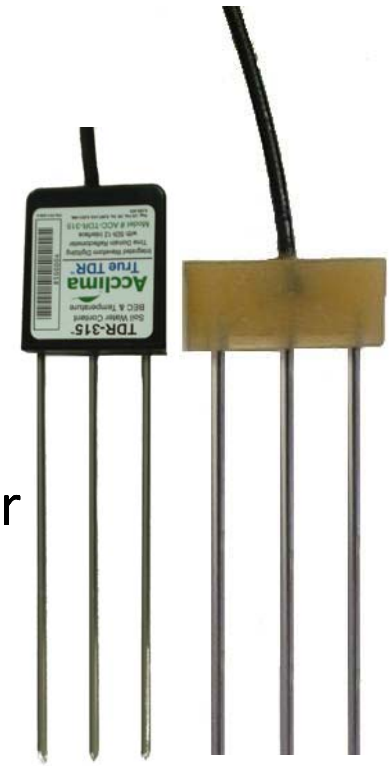
TDR-315 calibration results

	Electrical			
Probe	Length	t_c (offset)	V_0	K_p/Z_0
	m	ns	-	S m^{-1}
1	0.1495	0.186	6064	0.0840
2	0.1493	0.226	5980	0.0923
3	0.1496	0.205	5901	0.0917
4	0.1493	0.150	5754	0.0815
5	0.1489	0.202	5453	0.0978
6	0.1493	0.204	5965	0.0918

***** K_p/Z_0 of TDR (0.15 m) averaged 0.0926 S m^{-1}**

Pullman soil water calibration details

- Six TDR-315 probes
  - Acquired waveforms analyzed with AWIGF (Schwartz et al., 2014) for travel time & K_a
  - Firmware estimates of K_a

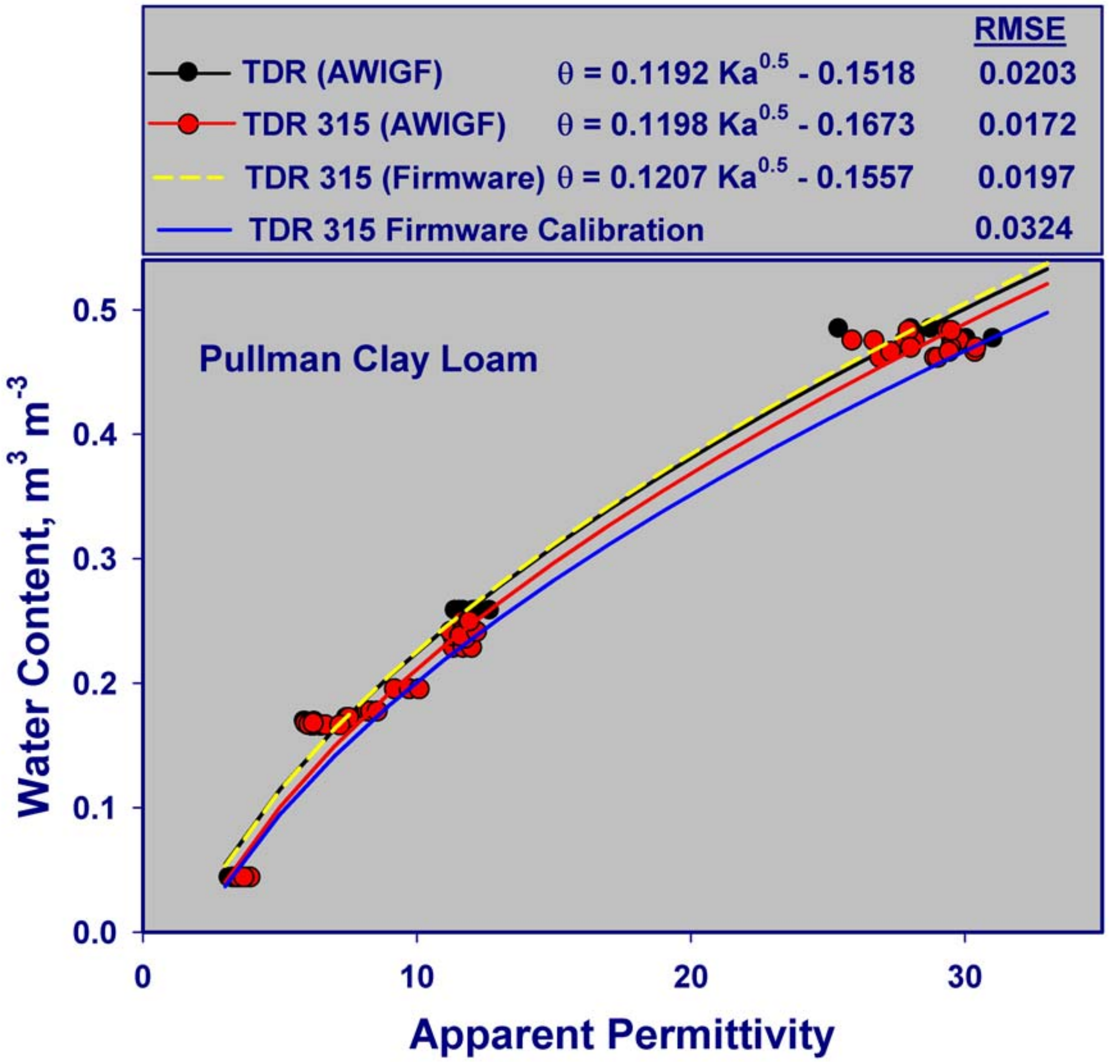


- Two TDR probes (0.15 m length)
  - 8.5 m cable with 1502C Tektronix cable tester
  - Probe calibration identical to TDR-315
  - Acquired waveforms analyzed with AWIGF

- Repacked soil in 10.2 cm diameter columns
  - 4 water contents (air dry to near saturation)
  - 3 temperatures: 6, 20, & 40^{o} Celsius

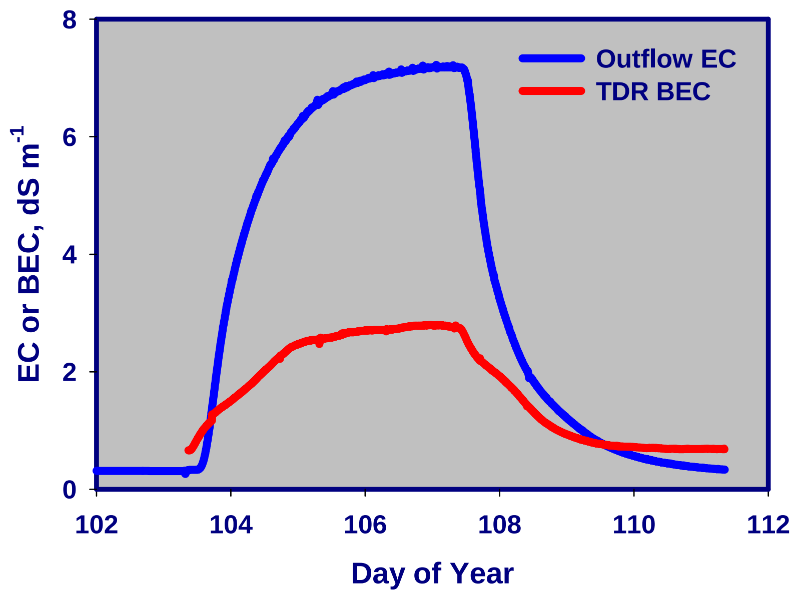
Pullman soil water calibration results

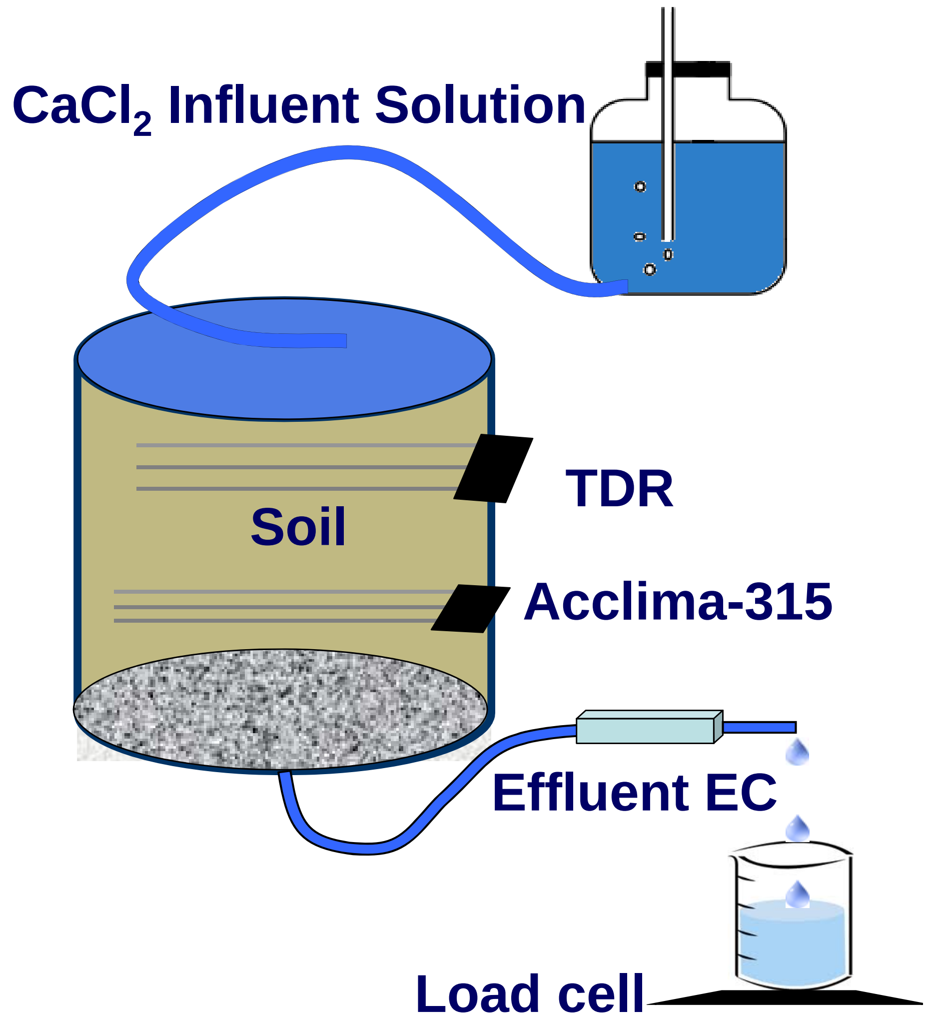
- Close agreement of permittivity (K_a) estimated by TDR, TDR-315 waveforms, TDR-315 firmware
- RMSE = 0.017 to 0.020 $m^3\ m^{-3}$
- RMSE = 0.032 $m^3\ m^{-3}$ for water content estimated by firmware



Column displacement experiment

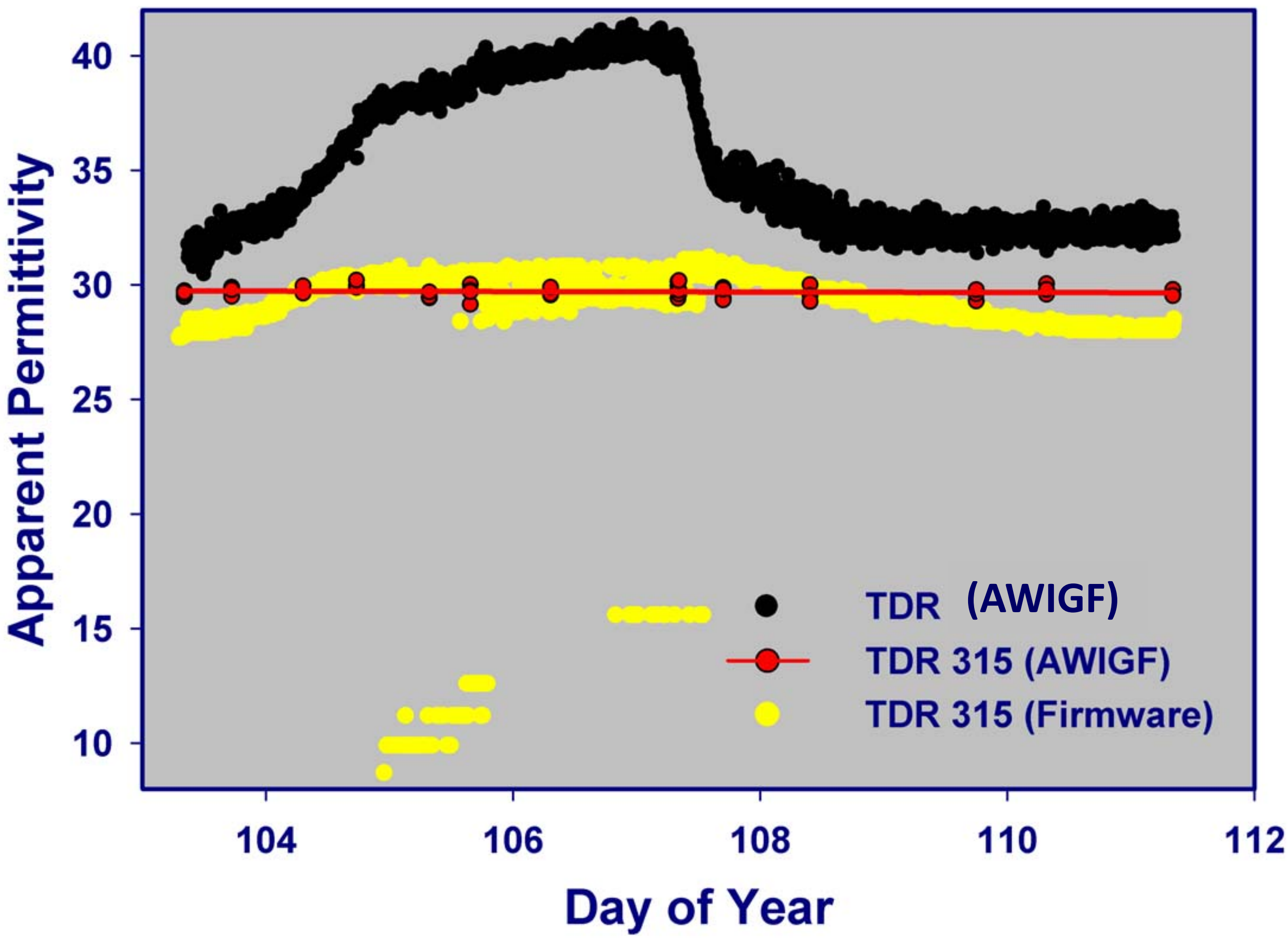
- Establish flow and equilibrium with influent solutions
  - 0.25 dS m^{-1} $CaCl_2$
  - 7.2 dS m^{-1} $CaCl_2$
  - 0.25 dS m^{-1} $CaCl_2$
- Monitor permittivity & BEC during breakthrough of solutions





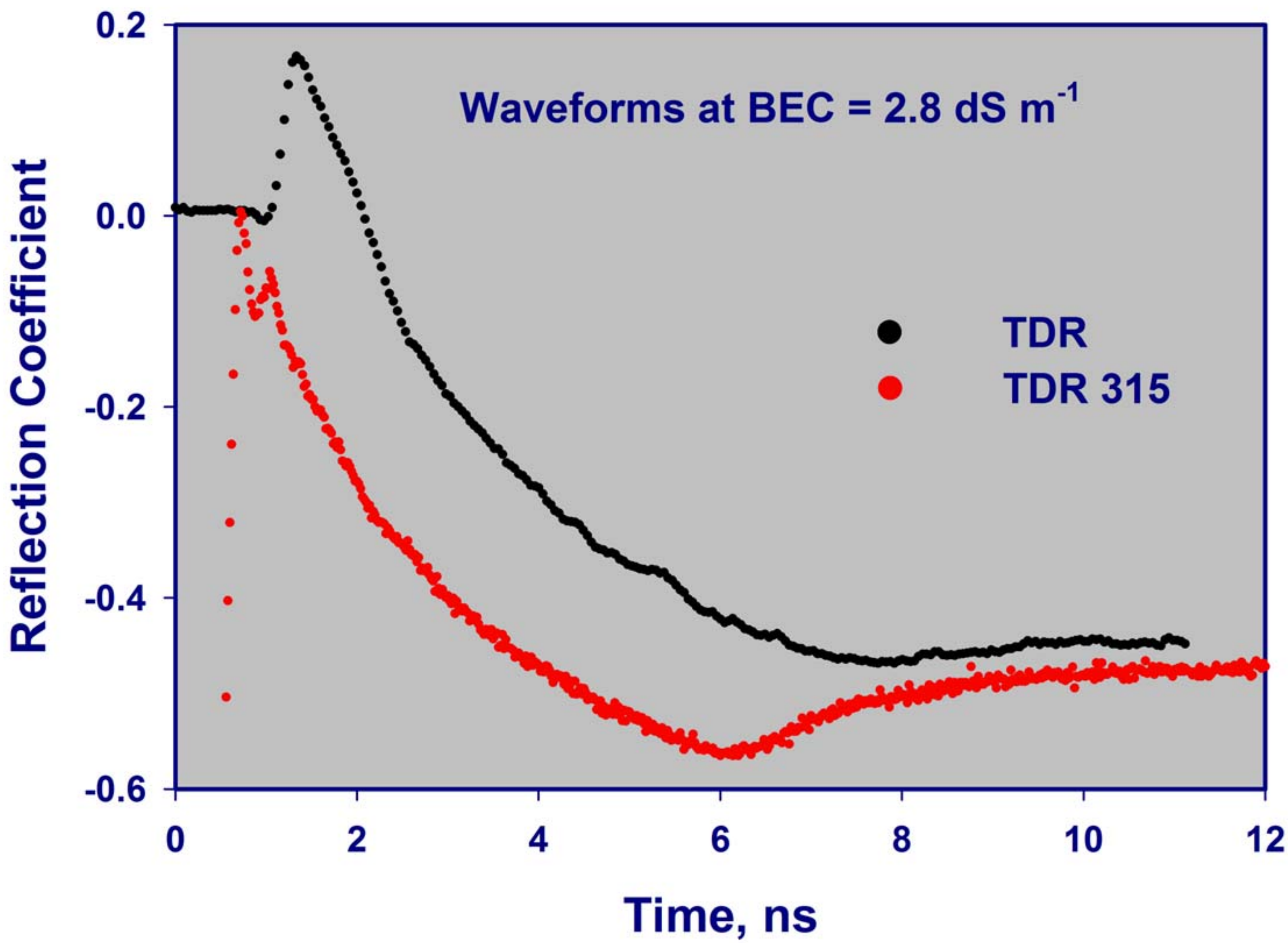
Column Displacement – Apparent Permittivity

Water content NOT changing

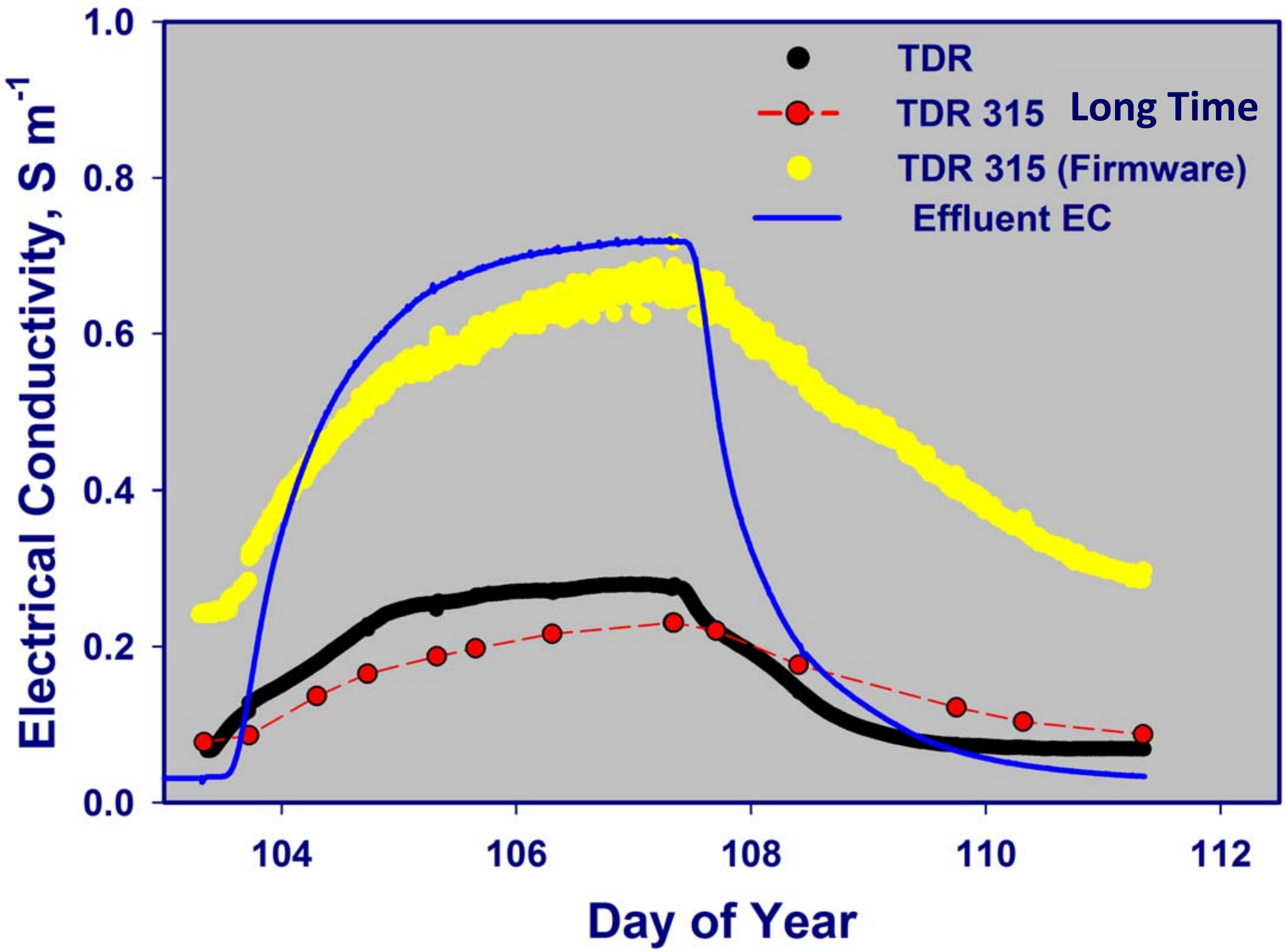


Column Displacement – Apparent Permittivity

Distinct reflection required to accurately measure travel time



Column Displacement – Bulk EC



Summary

- Response is essentially identical to conventional TDR
- Significantly less attenuation than conventional TDR
  - Greater proportion of high frequency portion of signal retained
  - Suitable for higher BEC (stable K_a up to 2.8 dS m^{-1})
- Giese and Tiemann (1975) approach for Bulk EC determination gives highly linear response
  - Probe constant K_p / Z_0 similar to TDR
- Algorithms used in firmware of prototype sensors (algorithms have been modified for sensors currently sold by Acclima)
  - Bulk EC algorithm not yet developed for these prototype sensors.
  - Apparent Permittivity: Stable estimate of travel time (and K_a). Better estimates of permittivity may be obtained by sampling waveforms at a higher time resolution when bulk EC is large (> 2 dS m^{-1})

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References

Giese, K., and R. Tiemann. 1975. Determination of the complex permittivity from thin-sample time domain reflectometry improved analysis of the step waveform. Adv. Mol. Relax. Processes 7:45-59.

Schwartz, R.C., J.J. Casanova, J.M. Bell, and S.R. Evett, S.R. 2014. A reevaluation of TDR propagation time determination in soils. Vadose Zone J. 2014.

[1]The use of trade, firm, or corporation names in this article is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the United States Department of Agriculture or the Agricultural Research Service of any product or service to the exclusion of others that may be suitable.