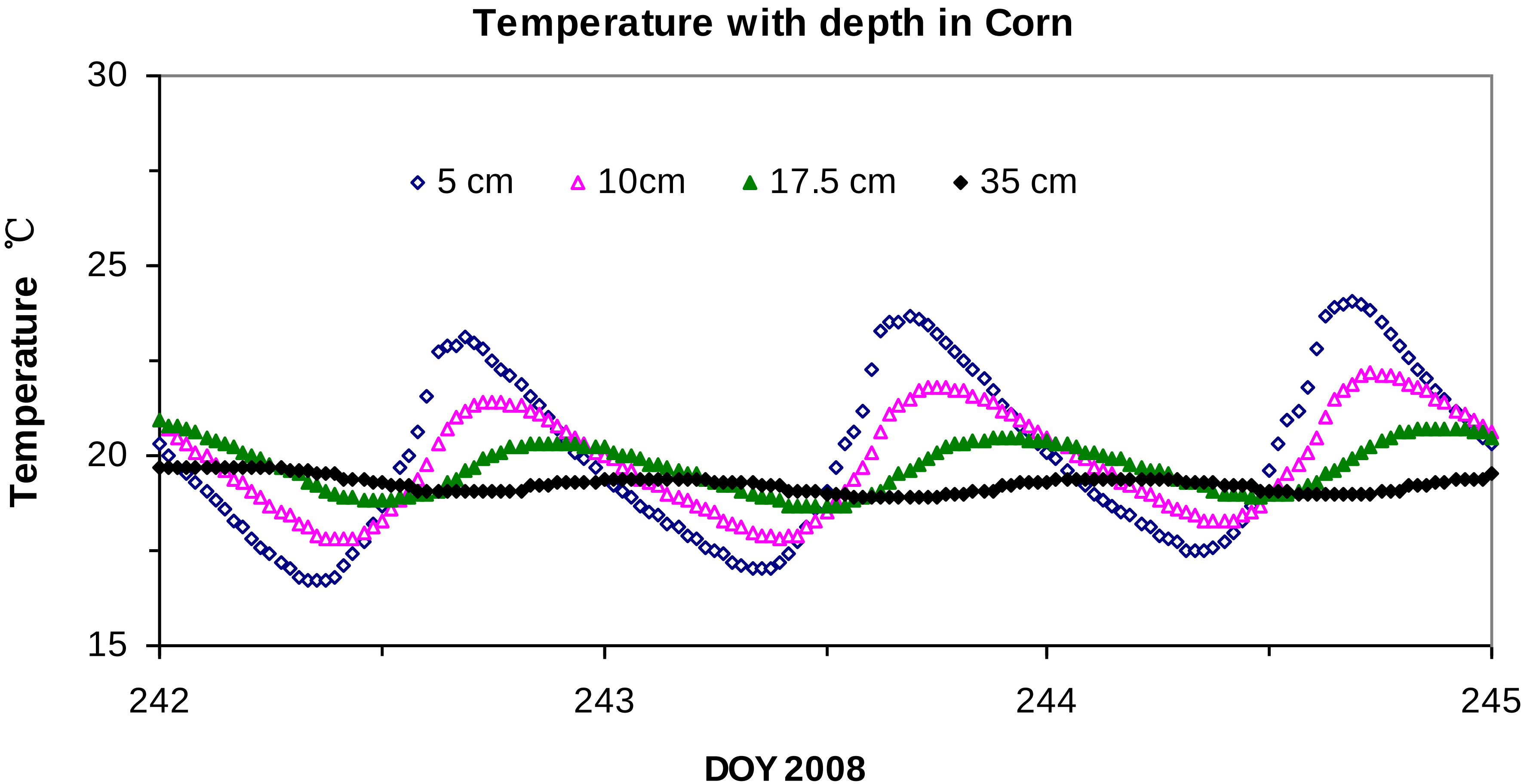
Measuring Soil Properties and Processes with Thermo-TDR Sensors

Bob Horton

Iowa State University

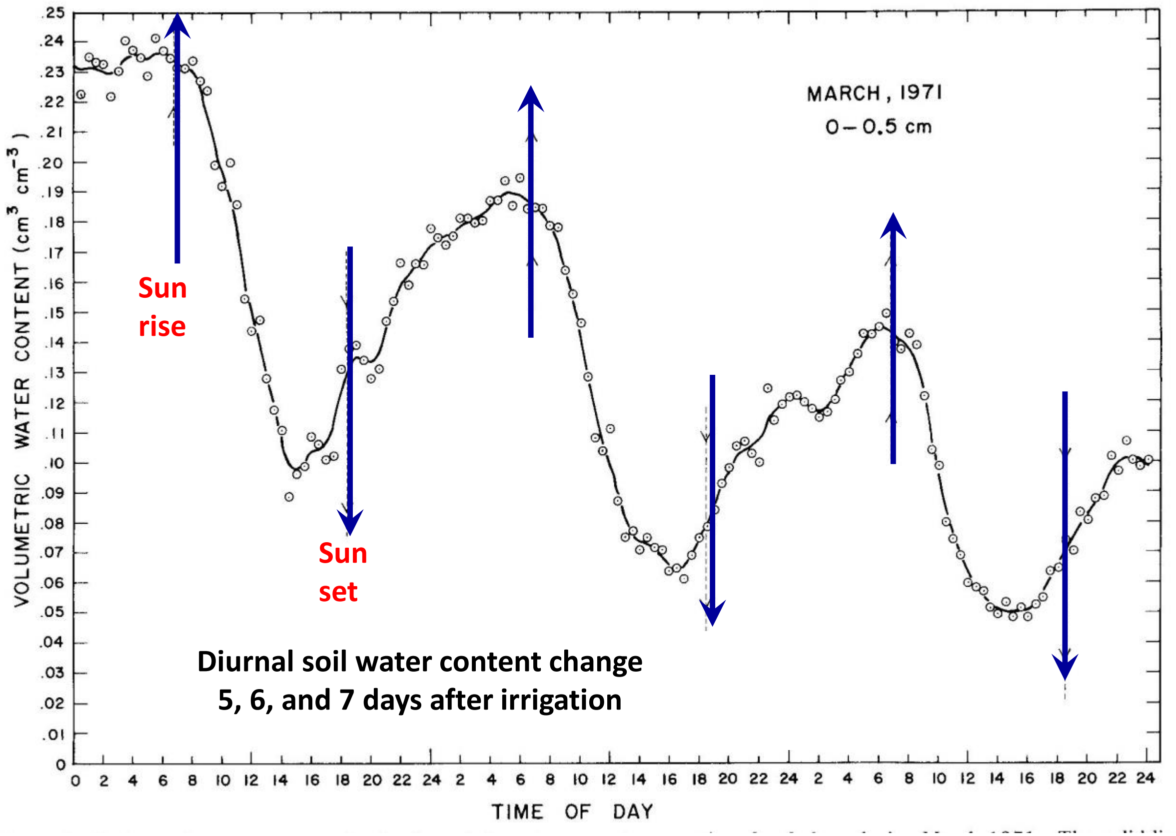
Soil heat and water dynamics

- Impact biological, chemical, and physical, processes
- Modeling coupled heat and water dynamics is difficult and requires many 'difficult to measure' parameters
- Measuring in situ coupled heat and water dynamics has improved recently



Temperature with depth in Corn
5 cm
10cm
17.5 cm
35 cm
Temperature °C
30
25
20
15
242
243
244
245
DOY 2008

Coupled heat and water movement

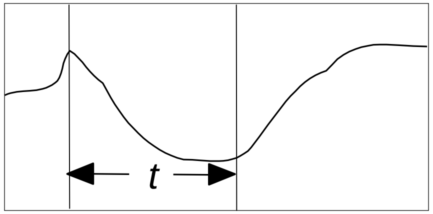


Jackson, 1973

Although models are useful, measurements are essential.

TDR: Measuring Soil Water Content

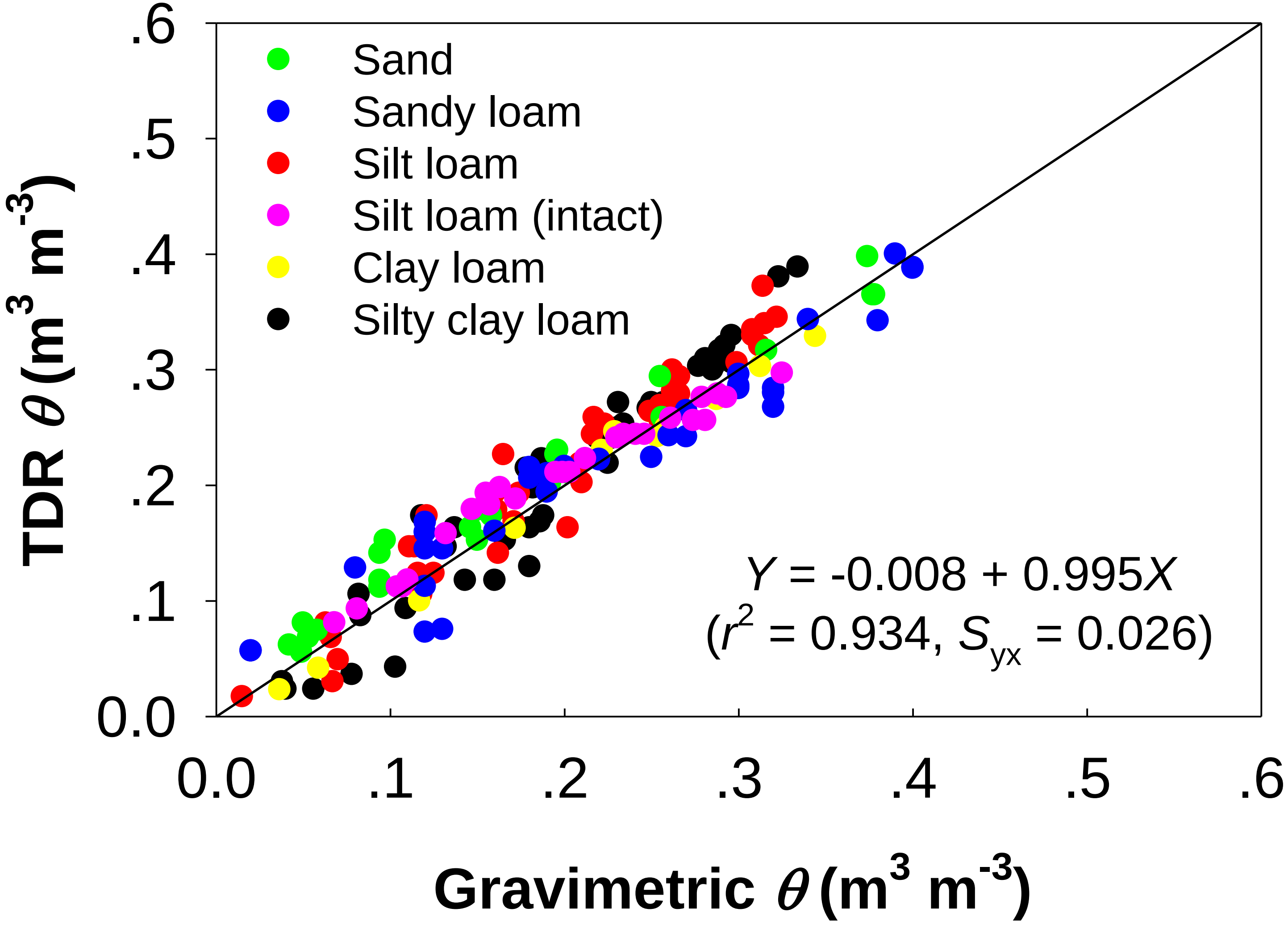
$$K_a = \left(\frac{ct}{2L}\right)^2$$



$$\theta = -5.3 \times 10^{-2} + 2.92 \times 10^{-2} K_a - 5.5 \times 10^{-4} K_a^2 + 4.3 \times 10^{-6} K_a^3$$

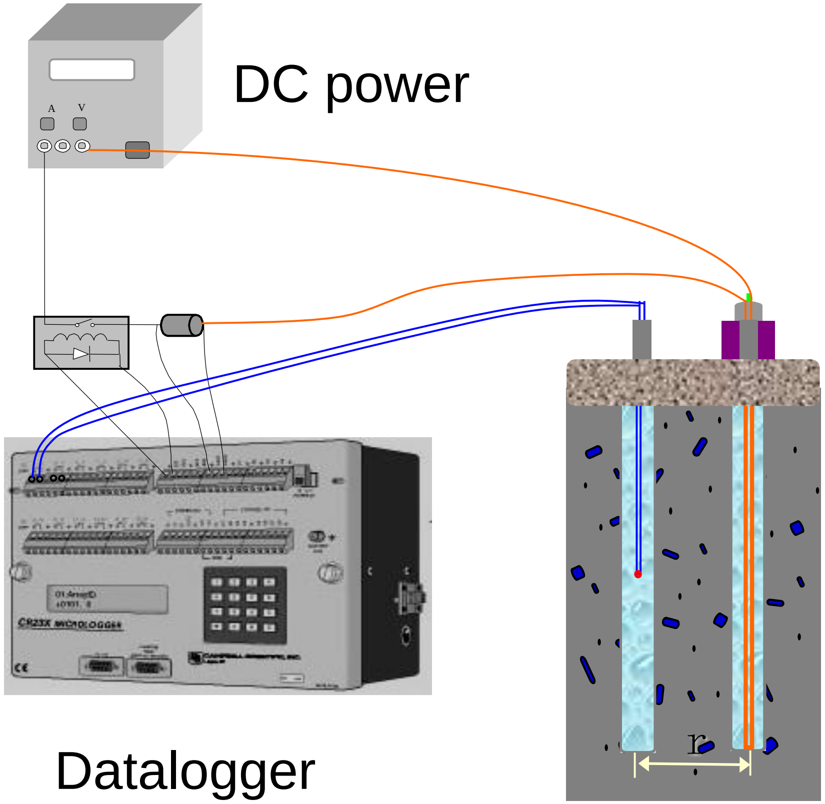
Topp et al. (1980)

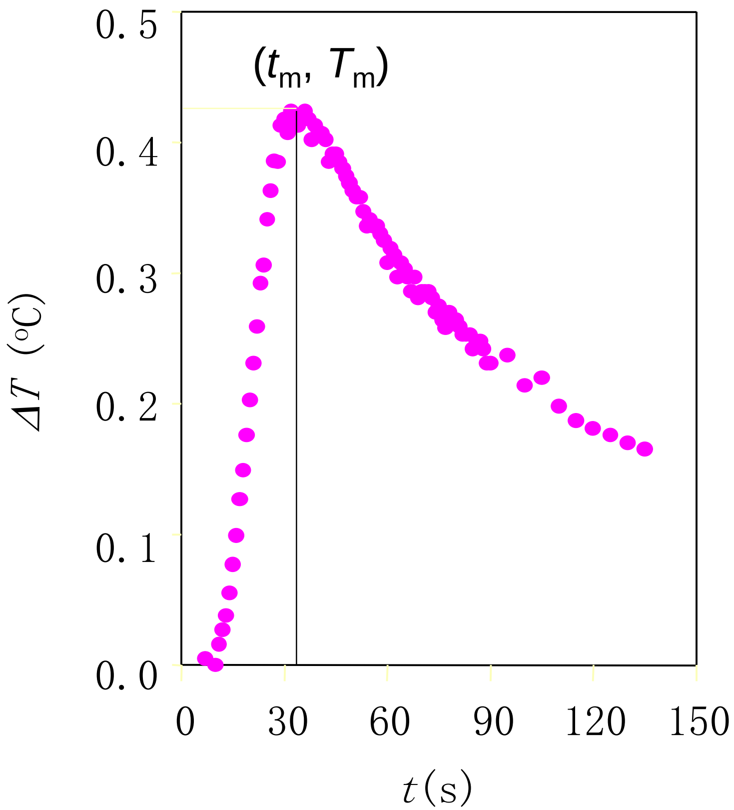
Water Content



Accuracy: 0.02-0.03 m^3 m^{-3}

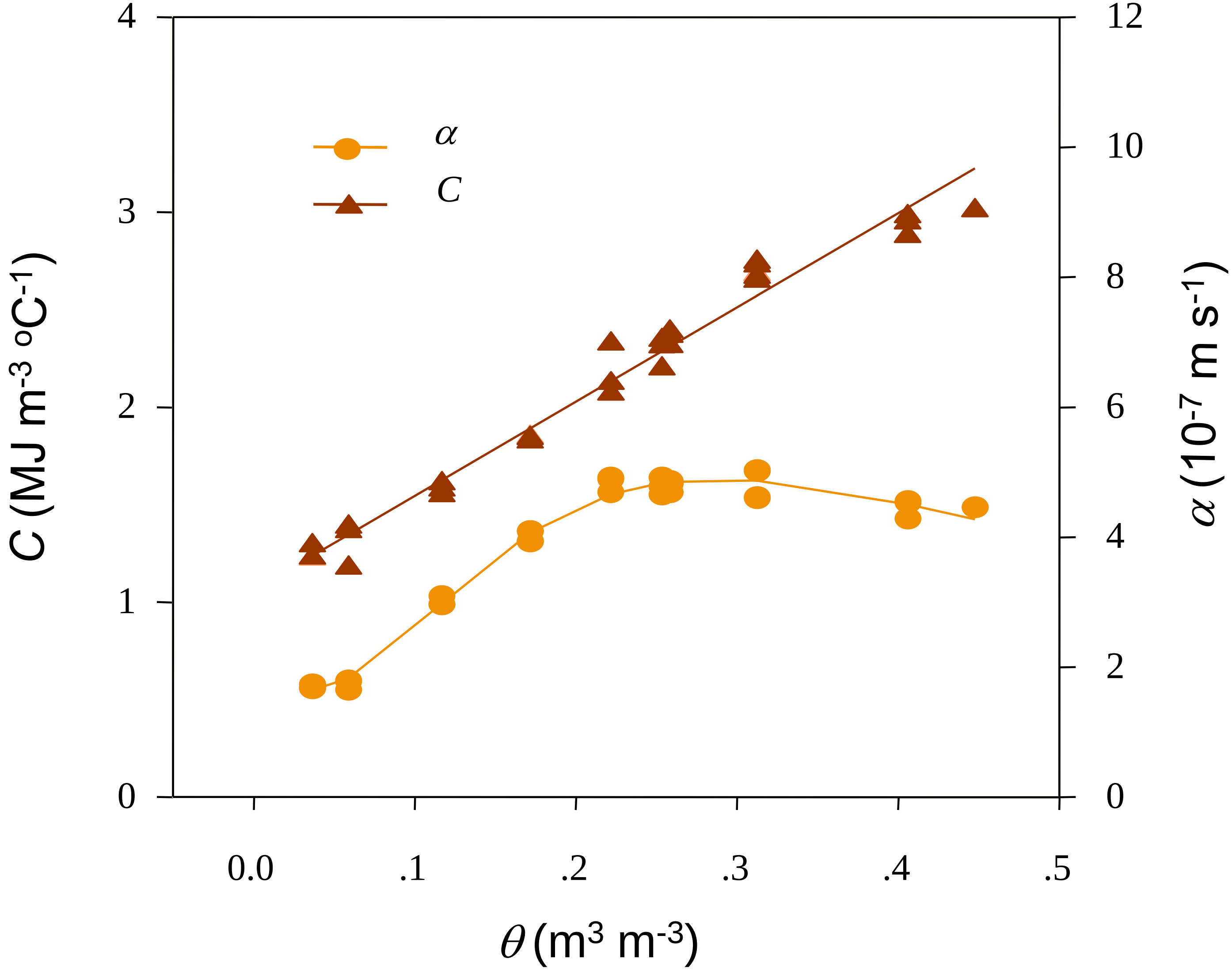
Heat Pulse Method



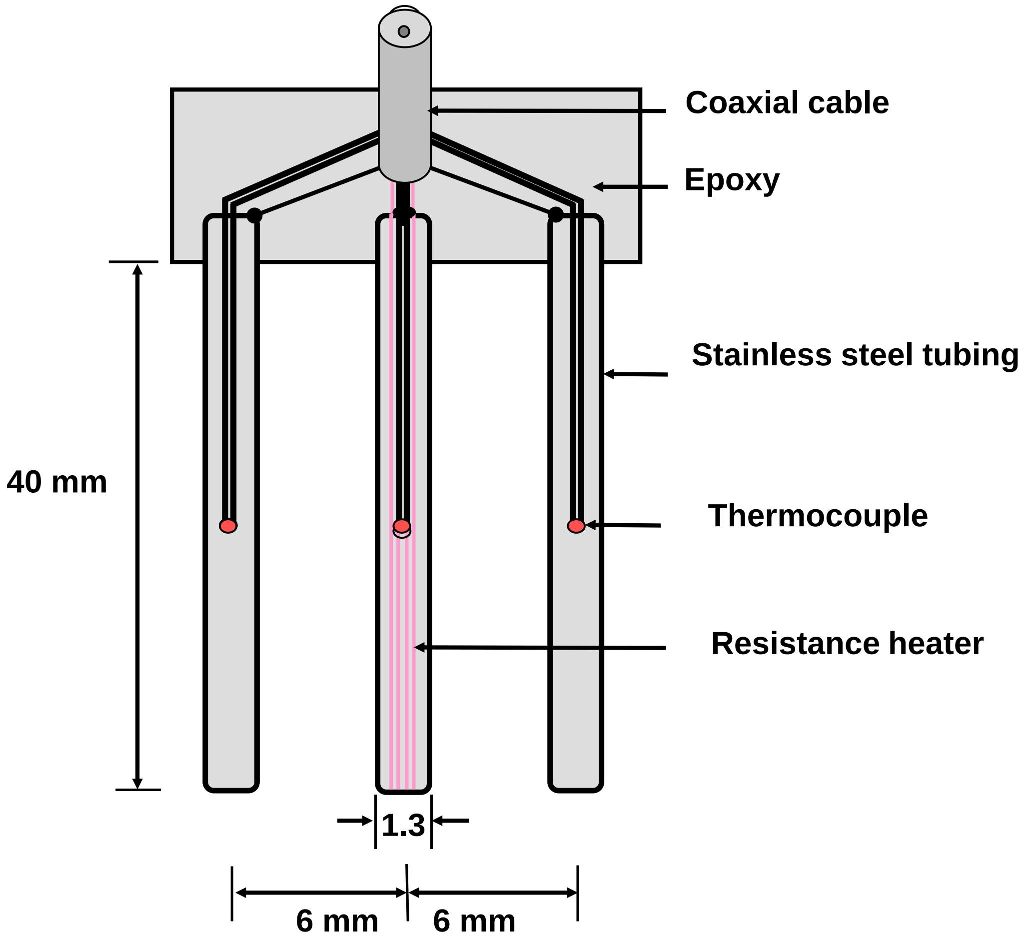


Campbell et al. (1991), Kluitenberg et al. (1993), Bristow et al. (1994)

Thermal Properties



Thermo-TDR Probe



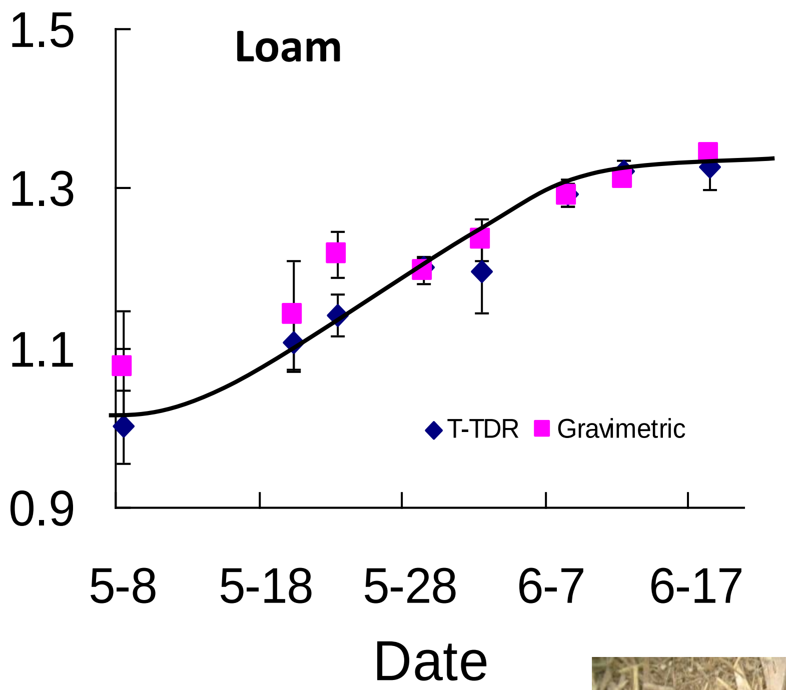
Ren, Noborio, and Horton (1999)

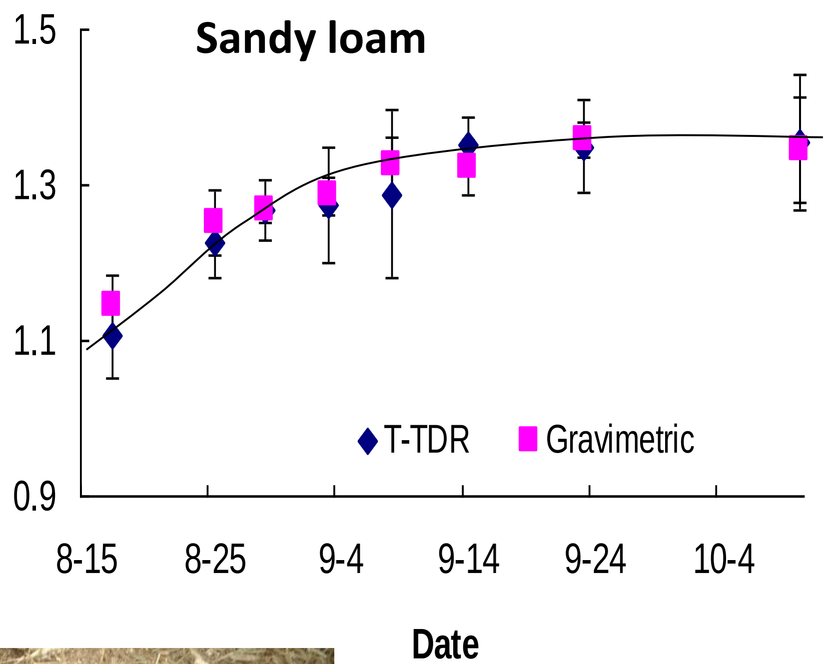
Soil Physical Parameters from Thermo-TDR

- ✓ Soil temperature and water content
- ✓ Soil thermal properties

- ✓ Bulk density (ρ_b):

Soil Bulk Density: Field Dynamics

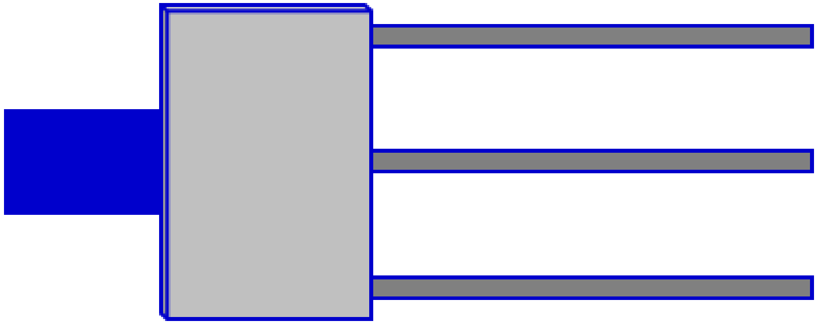




Liu, Ren, and Horton, SSSAJ, 2014

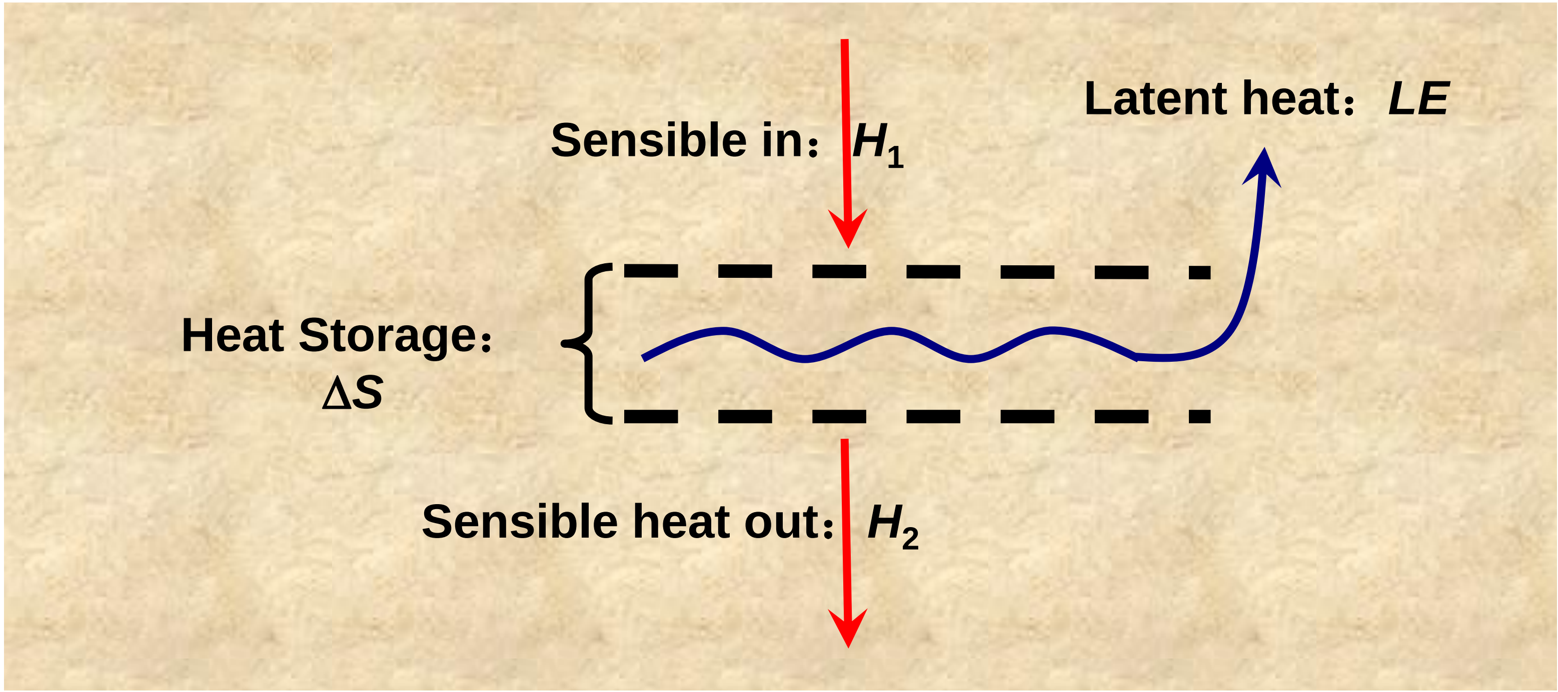
Soil Heat Flux

Gradient Method: $G = -\lambda \, (dT/dz)$



Cobos and Baker, 2003; Ochsner et al., 2006

Soil Water Evaporation from a Sensible Heat Balance

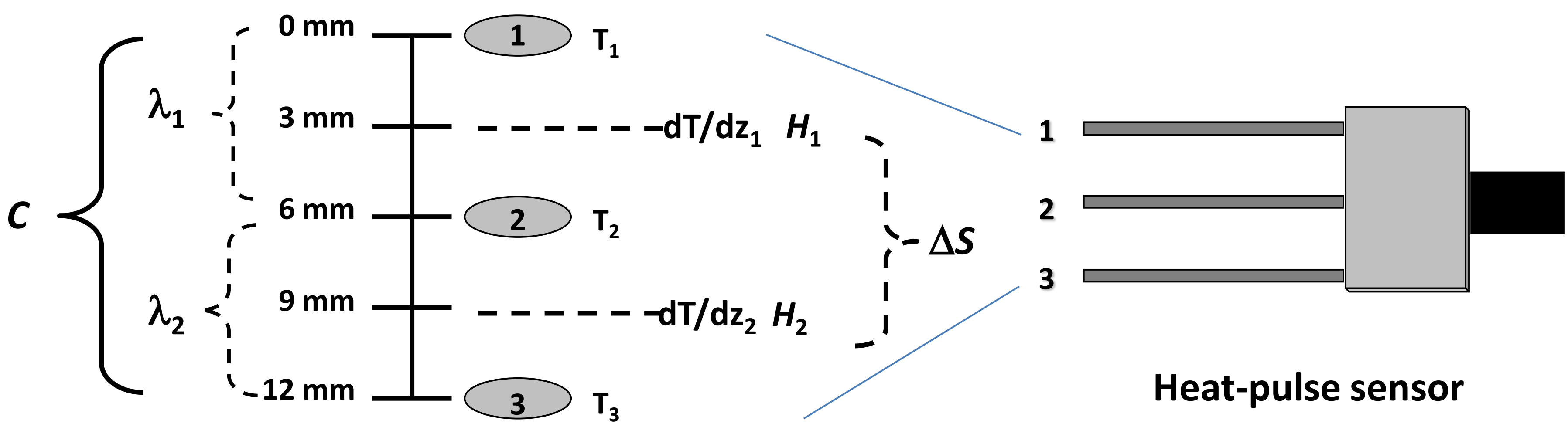


$$C\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(\lambda \frac{\partial T}{\partial z}\right) - \rho_w L \frac{\partial q_v}{\partial z}$$

$$(H_1 - H_2) - \Delta S = LE$$

Heitman, Horton, Sauer, and DeSutter (2008)

Soil Water Evaporation with Heat-Pulse Sensor

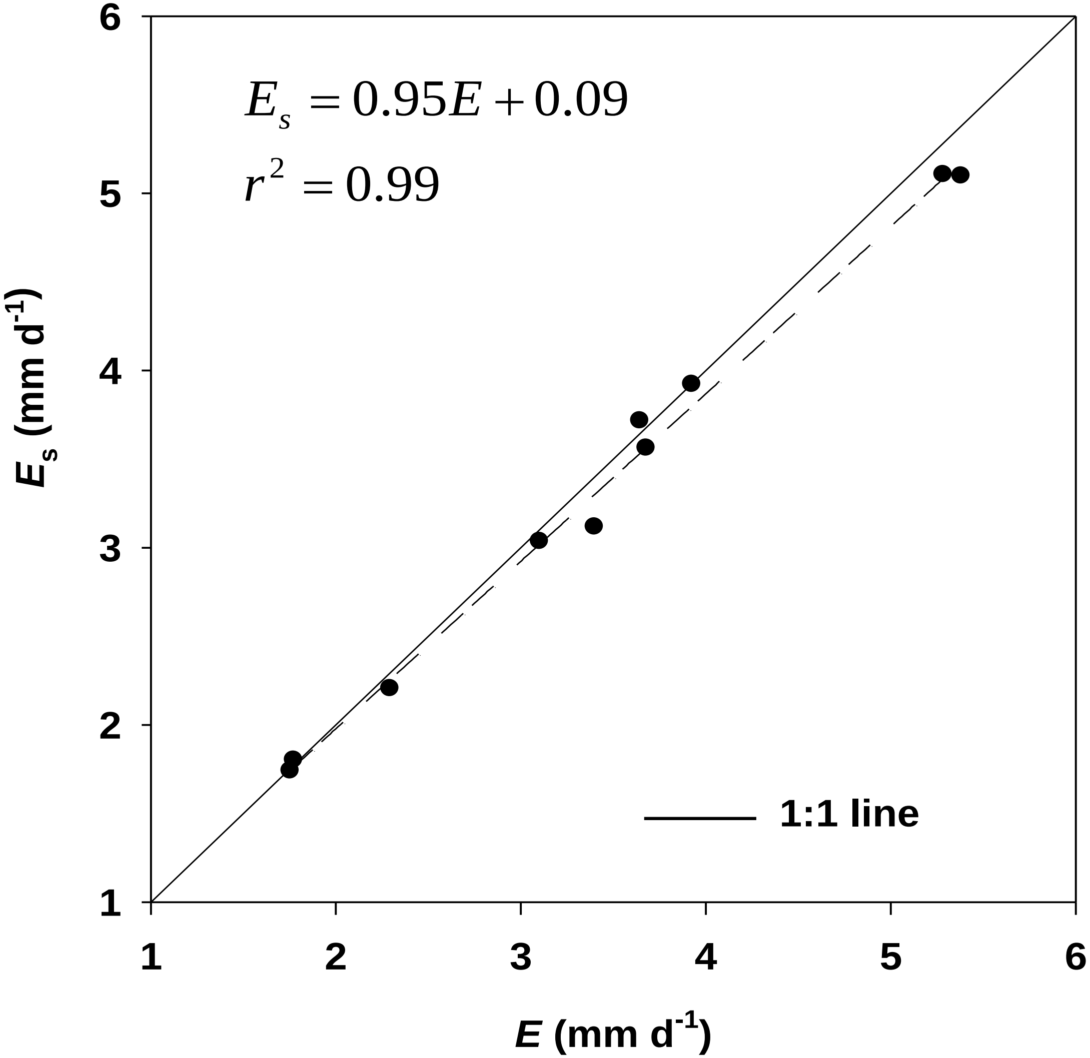


Soil heat flux: $H = -\lambda(dT/dz)$

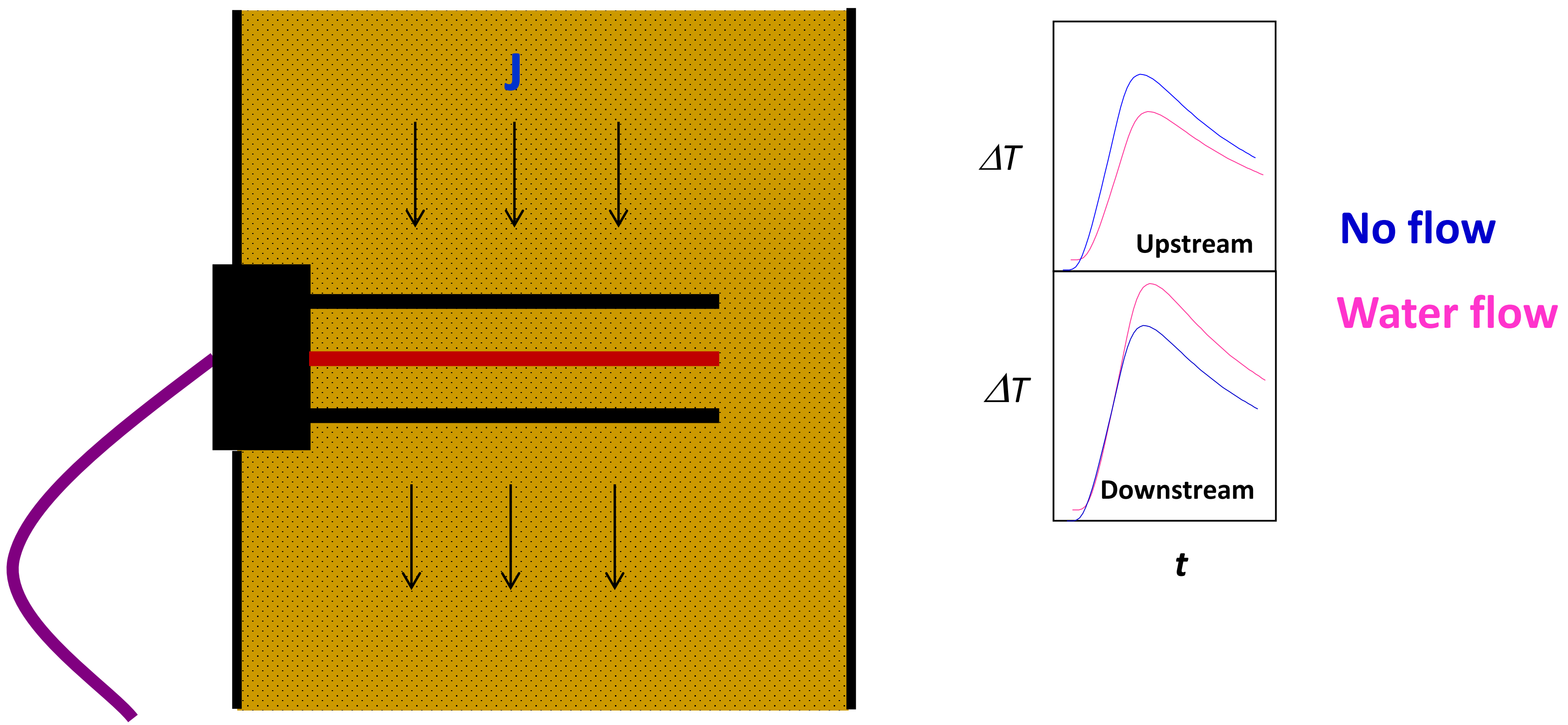
Change in soil heat storage: $\Delta S = C\,(\Delta Z)\,(dT/dt)$

$$LE = (H_1 - H_2) - \Delta S$$

Heat pulse sensor vs. weighing lysimeter



Soil Water Flow from heat pulse measurements



Ren, Kluitenberg, and Horton, SSSAJ, 2000

Water Flux Density Relates to the Ratio of T

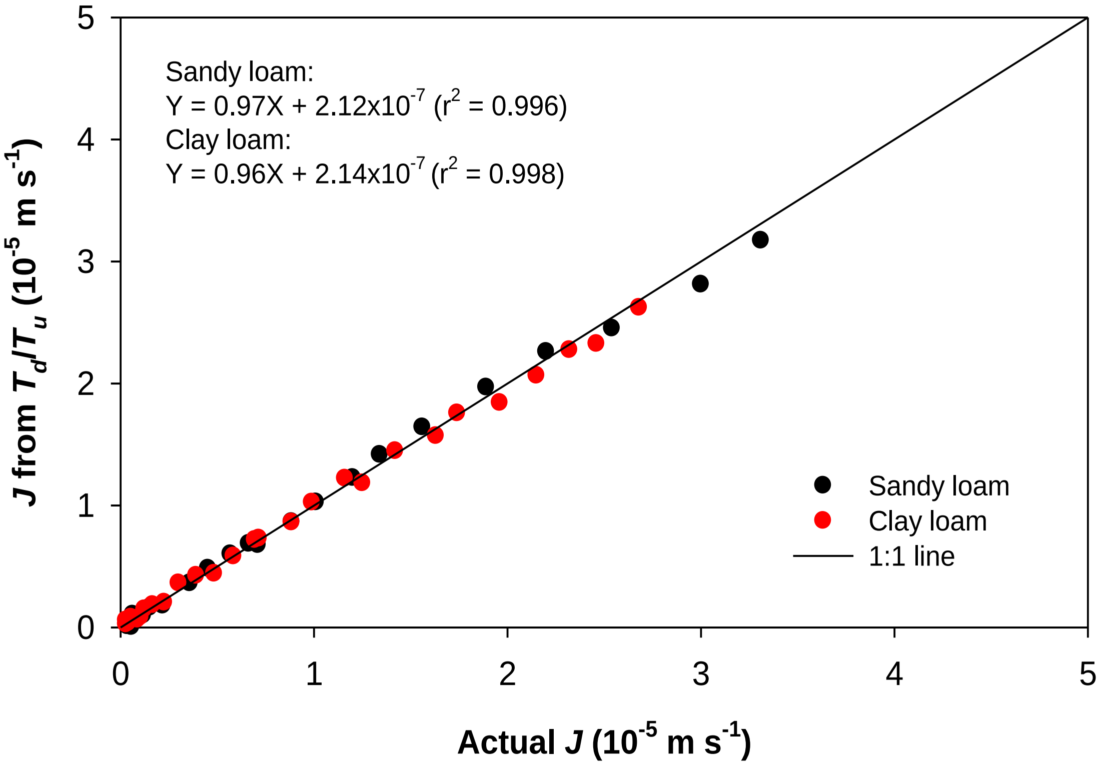
A relationship between water flux and temperature ratio is,

$$J = \frac{\lambda}{x_0 C_w} \ln\left(\frac{T_d}{T_u}\right)$$

Soil water flux density can be calculated using heat pulse measurements.

Wang, Ochsner, and Horton, WRR, 2002

Verifying Water Flux Density



Heat-pulse method is able to measure saturated water flux as low as 10^{-6} m s^{-1}.

Soil Sci. Soc. Am. J. 64: 522-560

Water Resour. Res. 38(6):1091

Soil Sci. Soc. Am. J.70: 711-717

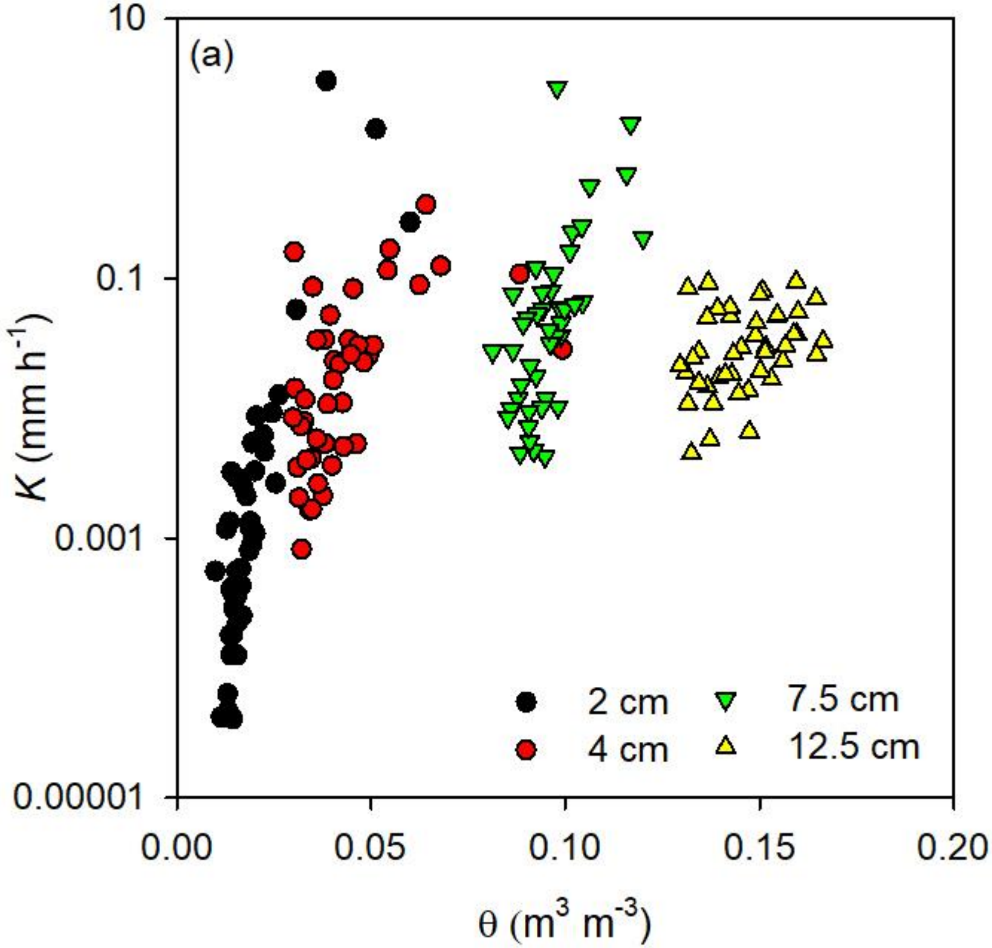
Soil Sci. Soc. Am. J.73: 1912-1920

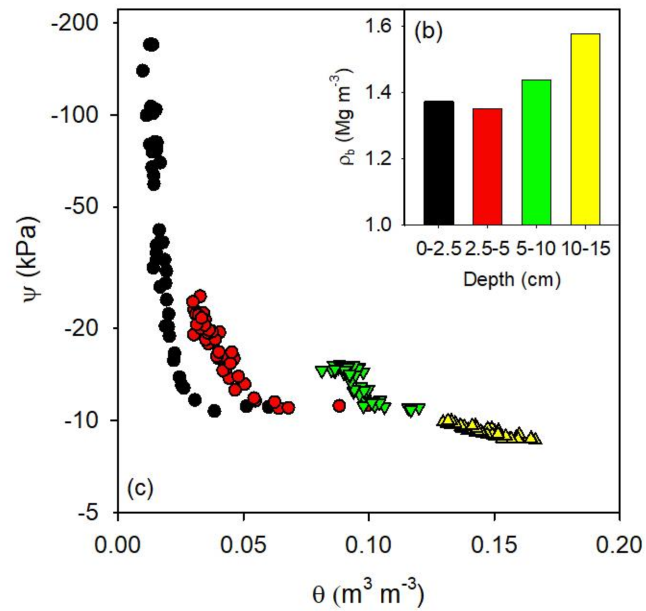
Water Resour. Res. 38(1):1006

Soil Sci. Soc. Am. J. 69:757–765

Soil Sci. Soc. Am. J. 71:53–55

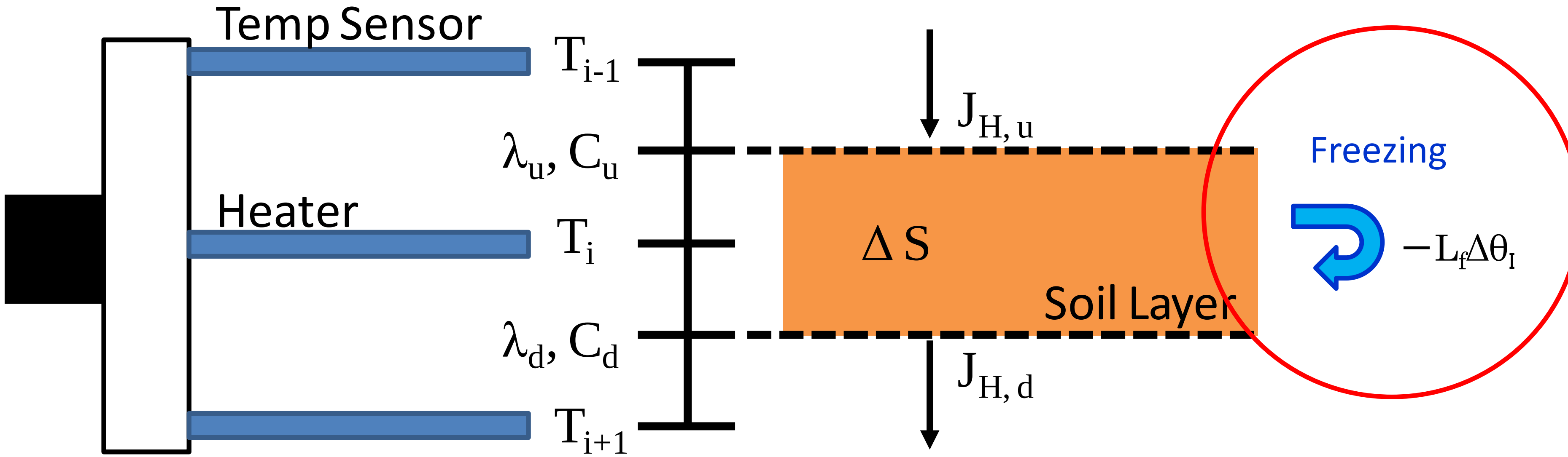
Relationship between *K* and θ





Field measured WRC varied with soil depth and bulk density.

Ice Content in Partially Frozen Soil



$$J_{H,u} = -\lambda_u \frac{T_i - T_{i-1}}{\Delta z}$$

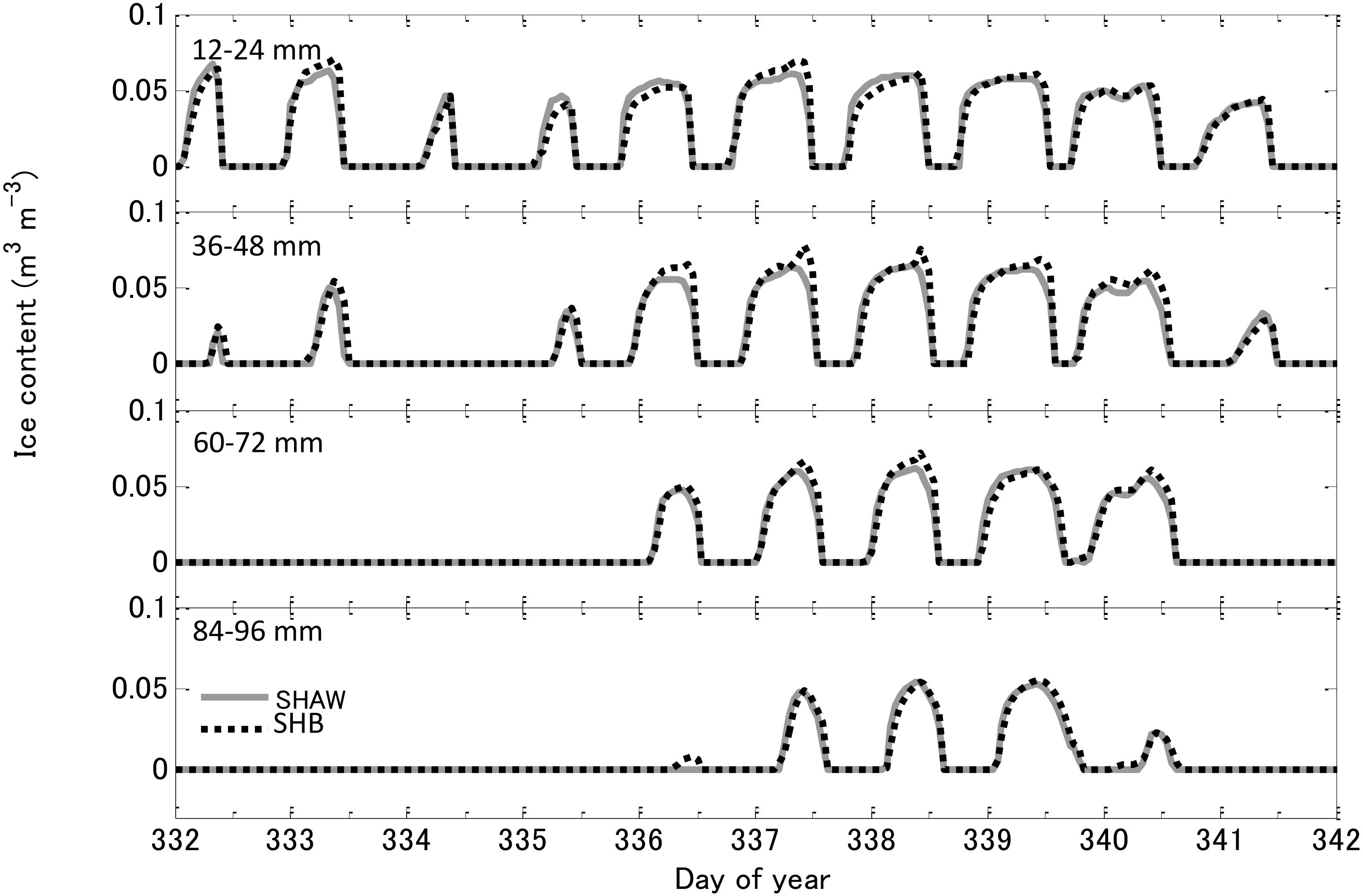
$$\Delta S = \left(\frac{C_u + C_d}{2}\right) \frac{\Delta T_i}{\Delta t} \Delta z$$

$$J_{H,d} = -\lambda_d \frac{T_{i+1} - T_i}{\Delta z}$$

$$J_{H,u} - J_{H,d} - \Delta S = -L_f \Delta\theta_I$$

$$(T_i \leq 0°C)$$

Agreement of SHB-based and SHAW-based ice content



Kojima et al., 2013

Thermo-TDR Sensor

Temperature

Water content

Bulk density

Soil heat flux

Soil water evaporation

Soil water flux

Soil ice content

Funding Sources

National Science Foundation

Army Research Office