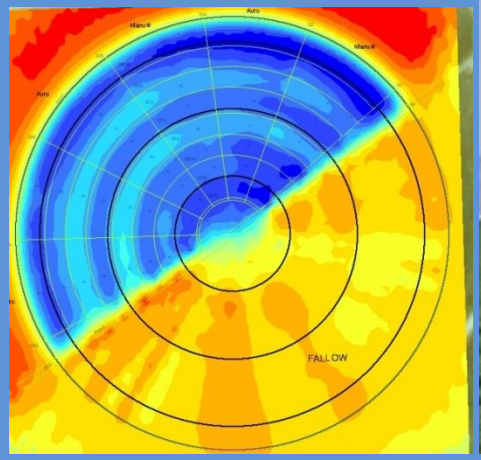
Center Pivot Mounted Infrared Sensors: Retrieval of ET and Interface with Satellite Systems



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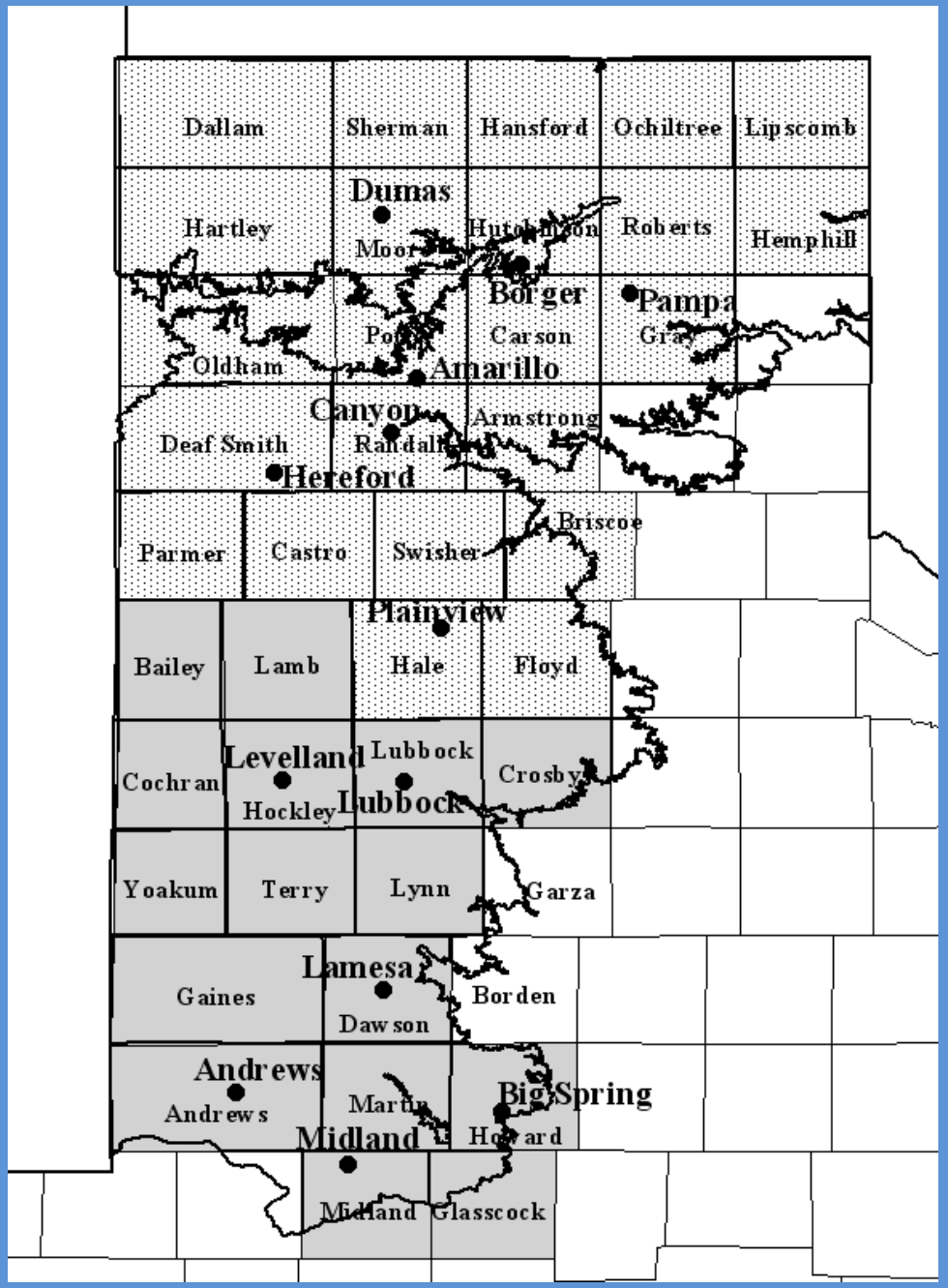
Irrigation in the Texas High Plains

- ~2 million ha irrigated
- >90% water usage is for irrigation
- 80% Center Pivot
- 15% Gravity
- 5% Microirrigation (SDI)

Irrigation in US

- >50% Center Pivot

(TWDB, 2012; FRIS, 2013; local groundwater district data)



Center pivot equipped with

- **Variable rate irrigation (VRI) system**
- **Wireless infrared thermometers**

Wireless infrared thermometers and mesh network developed at ARS Bushland (O'Shaughnessy et al.) Commercialized by CRADA with Dynamax, Inc., Houston, TX

GPS guided moving irrigation system as a platform for plant sensors

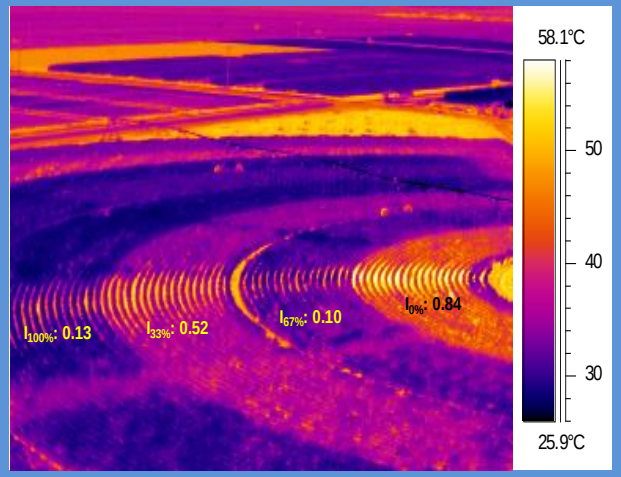
Moving network of plant sensors

- 802.15.4 IEEE communication standard
- ZigBee stack
- Mesh networking
- Central data collection and management
- Remote communication and data access

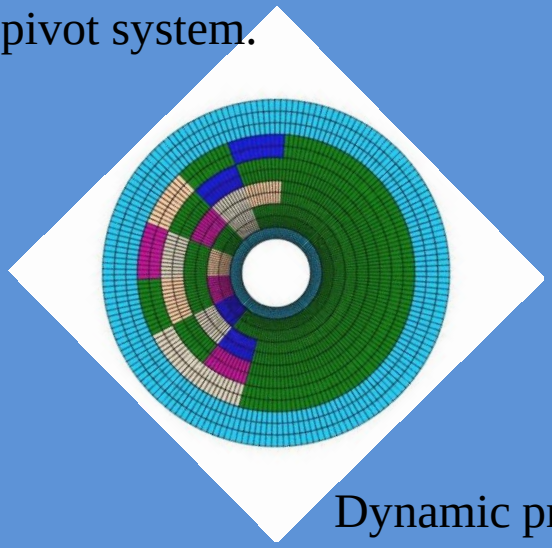
Stationary network of plant sensors

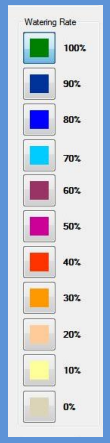
Site-specific Irrigation Management with a Supervisory Control and Data Acquisition (SCADA) System

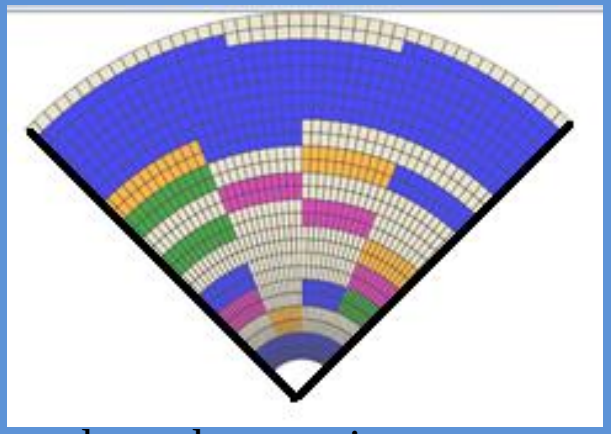
A wireless network of infrared thermometers is mounted on a variable rate irrigation center pivot system.



The SCADA system quantifies the stress level of the crop using canopy temperature and weather data.



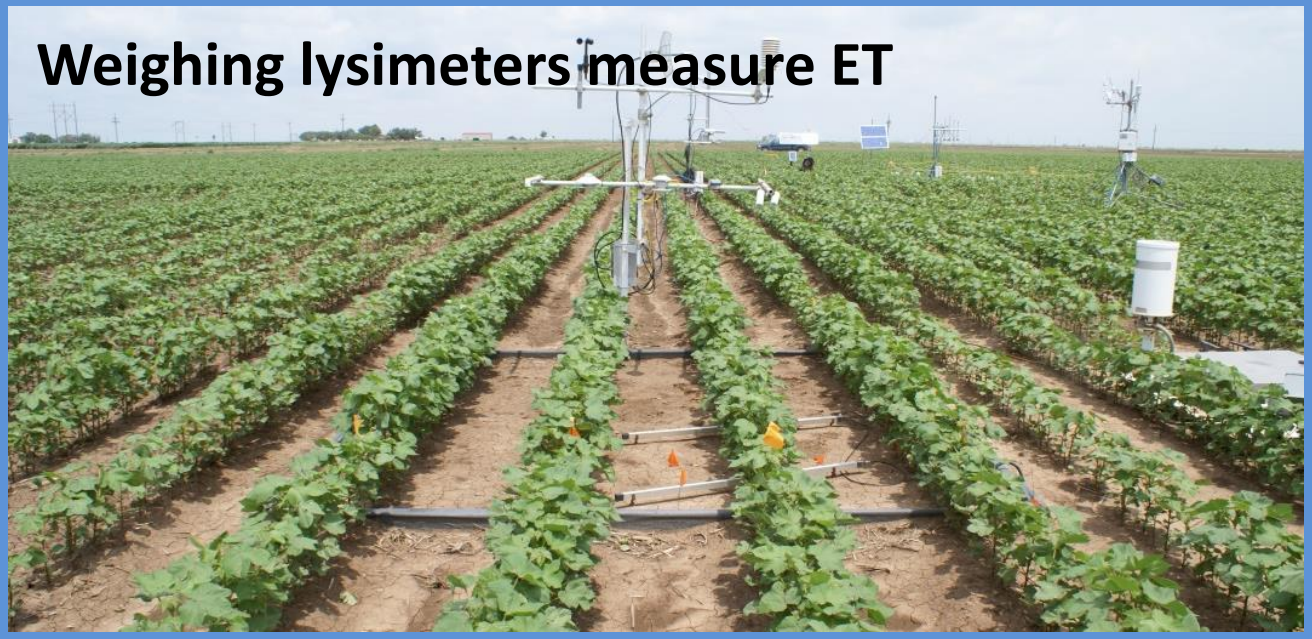


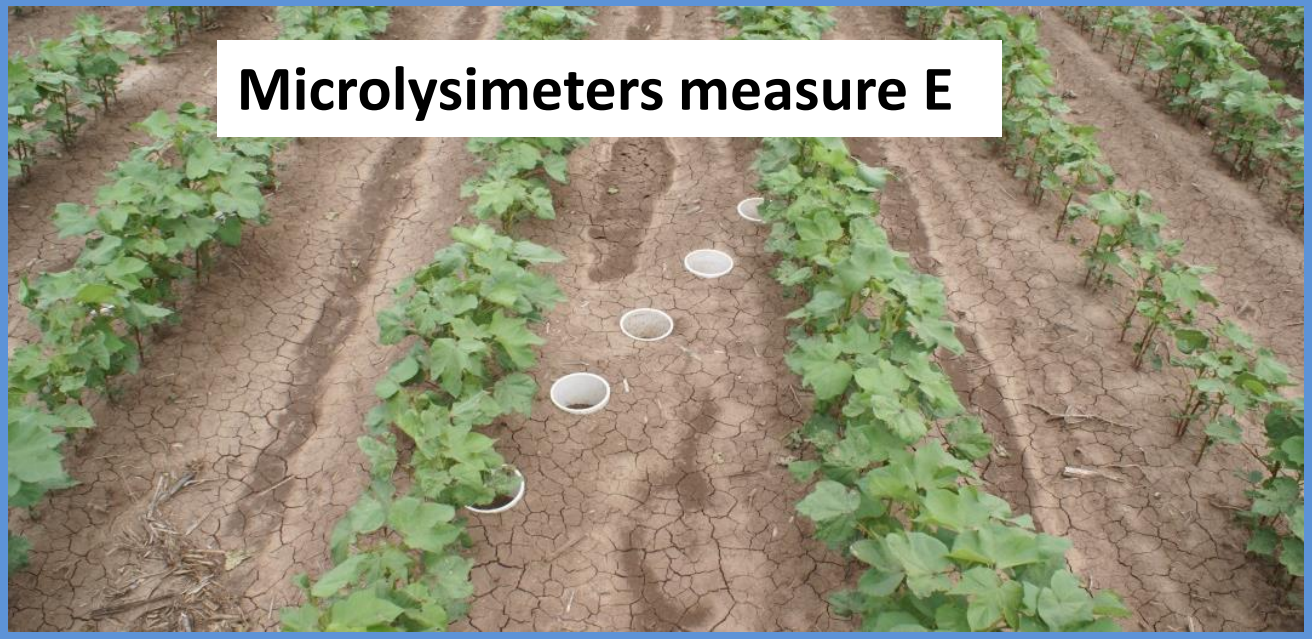


Dynamic prescription maps are built throughout the growing season to manage irrigation using stress index thresholds.

Some aspects of the Two-Source Energy Balance (TSEB) Model

- Norman et al. (1995); Kustas and Norman (1999)
- A few recent refinements at ARS Bushland
  - Replaced clumping index with geometric view factors (Colaizzi et al., 2010; 2012a; 2012b; 2012c)
  - Replaced Priestley-Taylor with Penman-Monteith for initializing transpiration (Colaizzi et al., 2012d; 2014)
  - New soil heat flux model that partitions sunlit and shaded soil surface (Colaizzi et al., 2015a; 2015b)
  - Additional details appropriate for circular crop rows (i.e., center pivots) at 1 to 5 m scales (Colaizzi et al., 2015c)

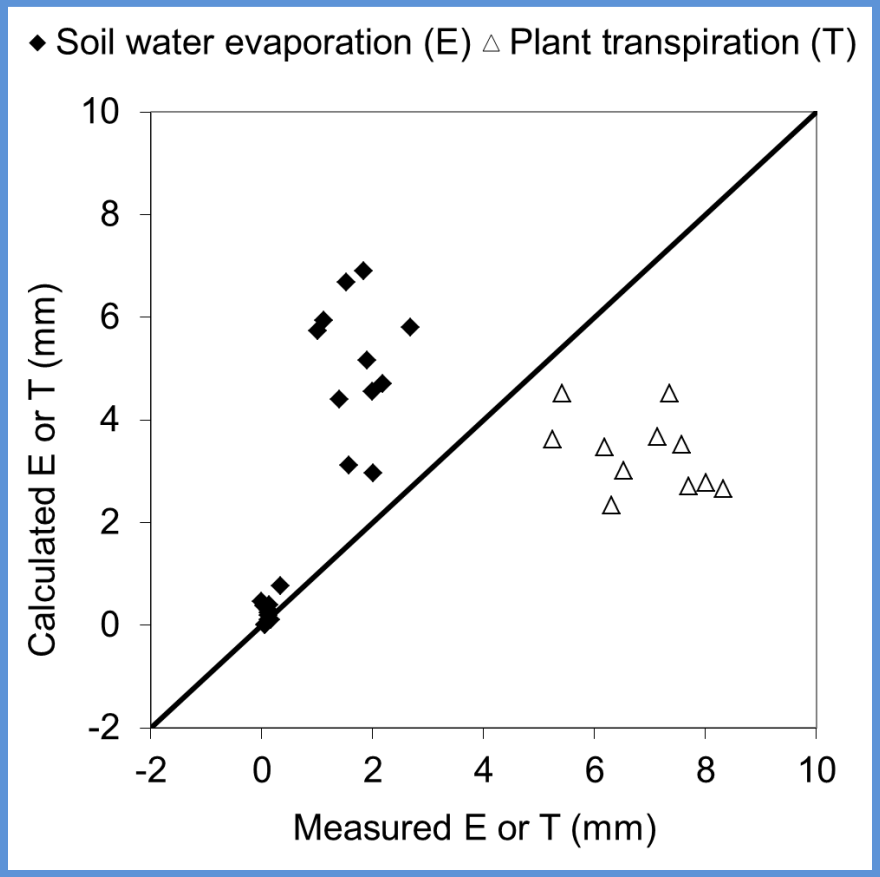

Weighing lysimeters measure ET


Microlysimeters measure E

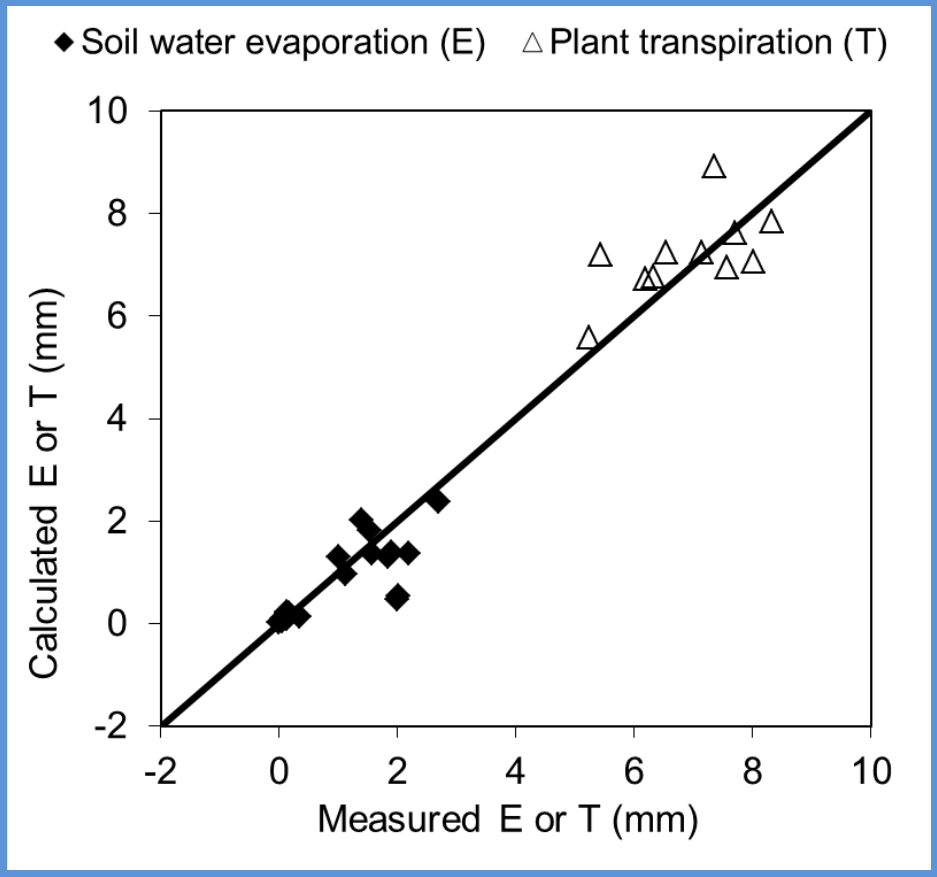

Sap flow gauges measure T

Replacing Priestley-Taylor with Penman-Monteith for T_{ini} improved *E* & *T* partitioning

Priestley-Taylor Version

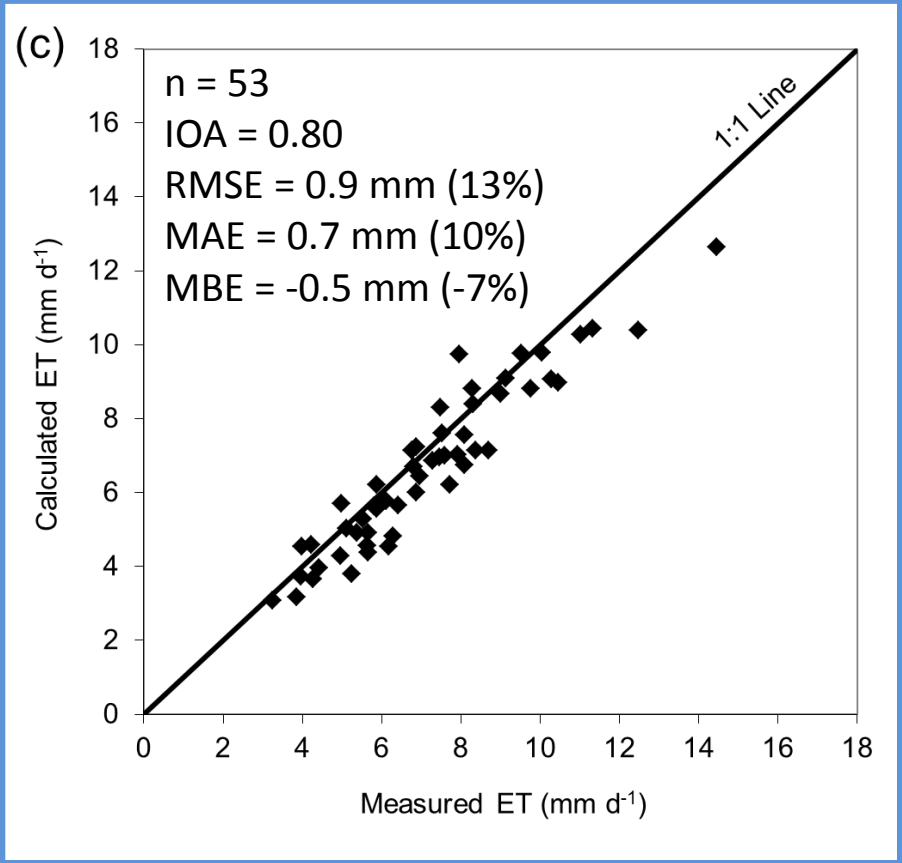


Penman-Monteith Version

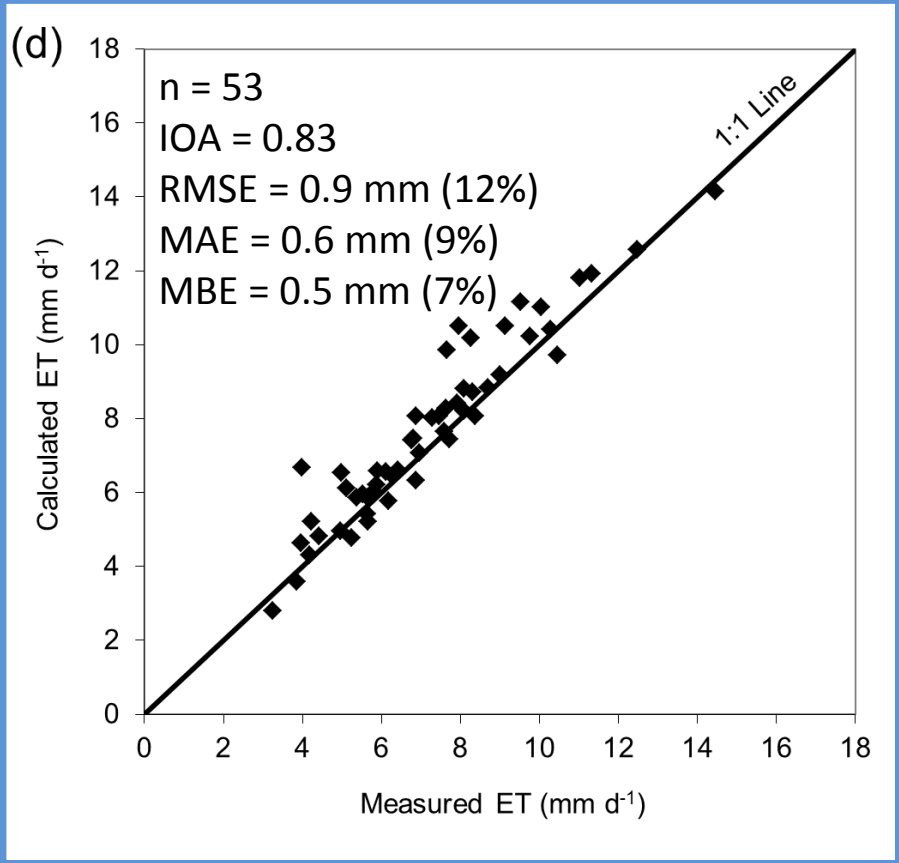


However, PT vs. PM did not result in much difference of daily ET

Priestley-Taylor Version



Penman-Monteith Version



Test TSEB Model (Bushland version) for Center Pivots

Ground truth ET:

Soil water balance ($ET = I + P + RO + DP + LF + \Delta S$)

- I is metered
- P measured by tipping bucket
- RO controlled by furrow dikes, irrigation scheduling
- DP controlled by irrigation scheduling
- LF controlled by large plots

Test TSEB Model (Bushland version) for Center Pivots

Ground truth ET:

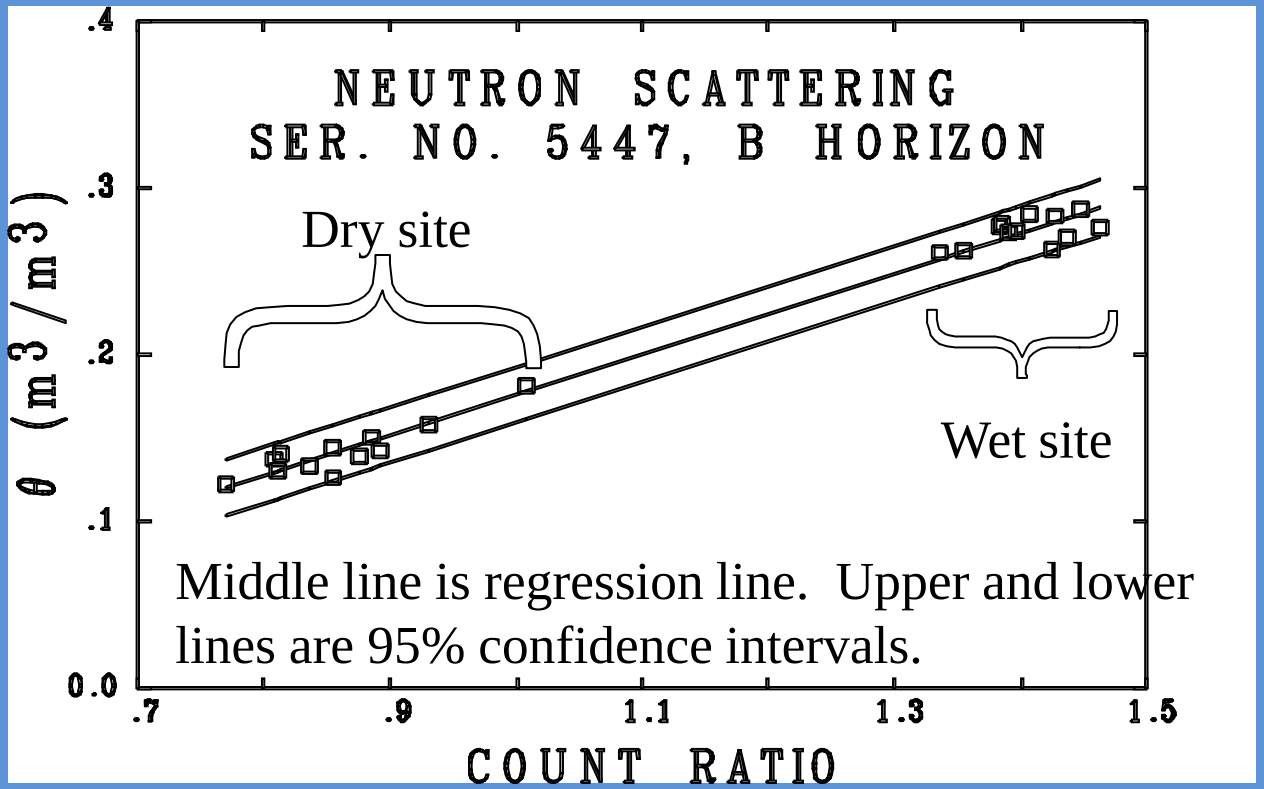
Soil water balance ($ET = I + P + RO + DP + LF + \Delta S$)

- ΔS measured by field-calibrated neutron probe
  - Depth control stand (Evett et al., 2003)
  - Calibration RMSE < 0.01 $m^3\ m^{-3}$, including 10-cm depth!
  - Measurement intervals limited to weekly or biweekly
  - No separate E or T measurements yet (but there will be)

Importance of depth control stand and good calibration for soil water balance using the neutron probe

Depth control stand (Evett et al., 2003)

Calibration of Pullman clay loam soil, Bushland, TX (Evett et al., 1995)



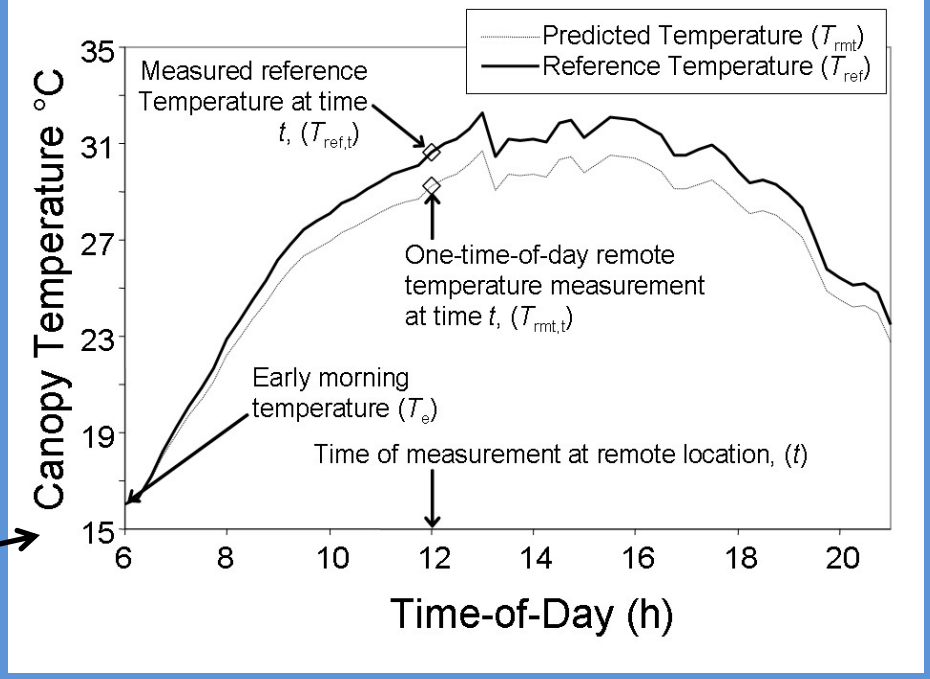
Test TSEB Model (Bushland version) for Center Pivots

TSEB ET:

- Moving arrays of wireless IRTs aboard center pivots

- A few stationary IRTs to model one-time-of-day IRT measurements to 24 h (Peters and Evett, 2004)

$$T_{RMT} = T_E + \frac{(T_{RMT,t} - T_E)(T_{REF} - T_E)}{(T_{REF,t} - T_E)}$$

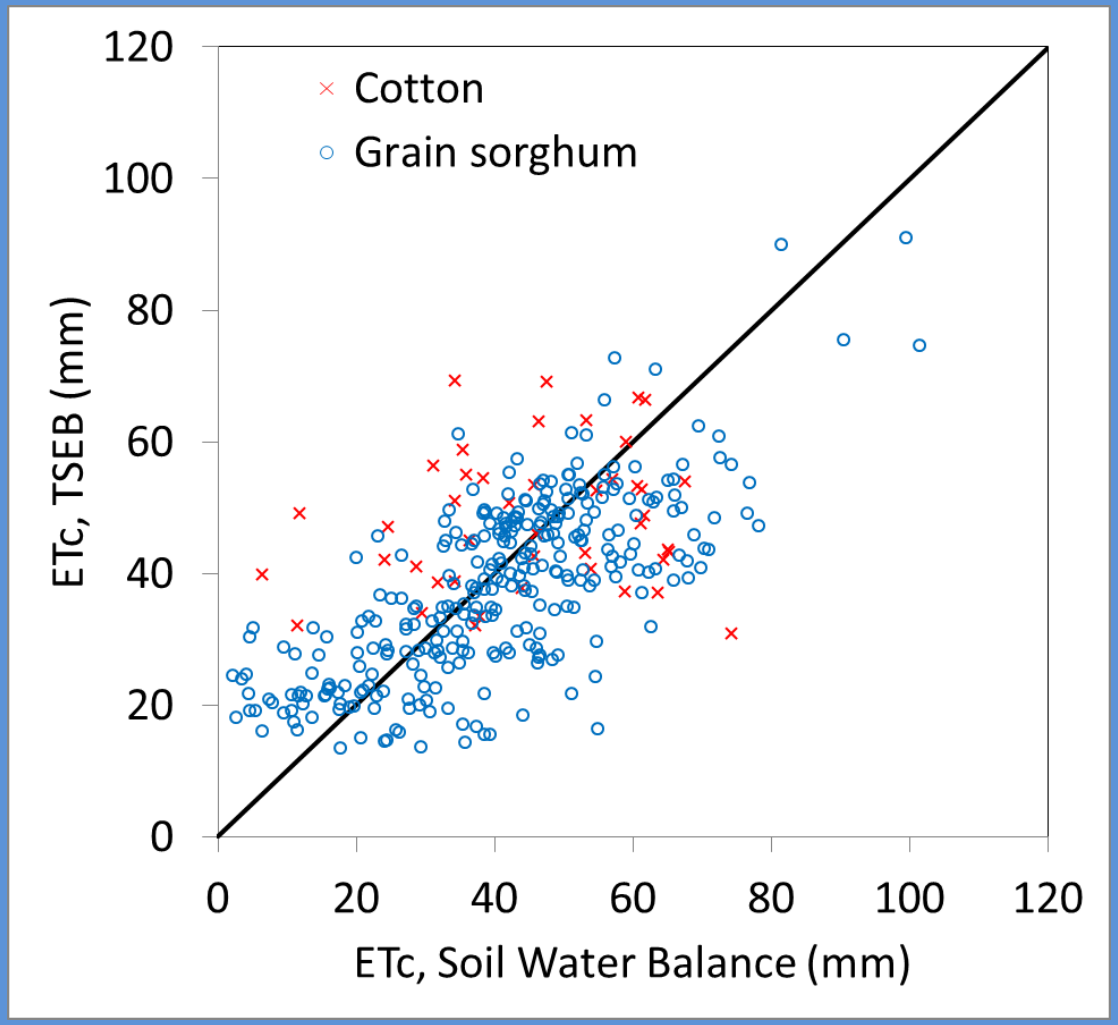


Test TSEB Model (Bushland version) for Center Pivots

n = 353
IOA = 0.59
RMSE = 13.3 mm (32%)
MAE = 10.3 mm (25%)
MBE = -2.1 mm (-5%)

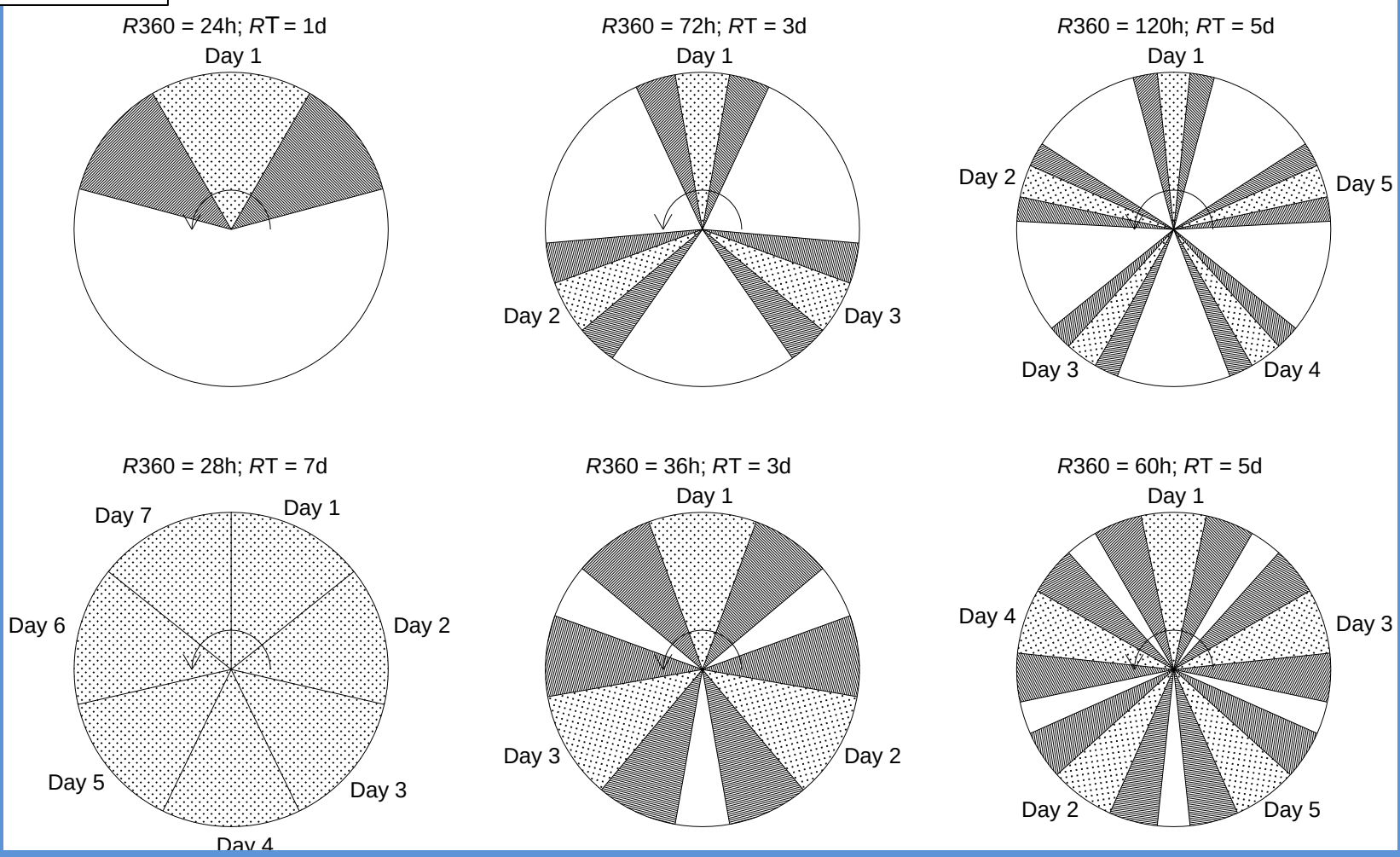
Greater discrepancies compared with lysimeters:

- Less frequent ground truth (biweekly)
- Rainfall uncertainty
- Plant w_c, h_c, LAI uncertainty
- Moving IRT vibration



Repeat Frequency and Field Coverage of Center Pivots

$$F_{CP} = W_0 \frac{R_t}{R_{360}}$$



Summary

- Wireless IRTs aboard center pivots can provide thermal measurements suitable to map ET
- Spatial resolutions are sub- to several meters
- Repeat frequency and field coverage depend on pivot speed, but satellites are still needed to supplement
- Micrometeorological data are required that meet reference ET quality standards
- TSEB (ARS Bushland version) recommended
- WOAT and separate E & T measurements forthcoming