Estimating ET with Large Aperture Scintillometry

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Outline

- CA water use
- Existing measurement techniques
- Large Aperture Scintillometer (LAS)
- New Mexico LAS Net
- Deficit irrigation in the Imperial Valley

CA Water: Applied water use

Table 1-1 California water summary - MAF

	1998 (171% of normal)[a]		2000 (97% of normal)[a]		2001 (72% of normal)[a]	
Total supply (precipitation & imports)	336.9		194.7		145.5	
Total uses, outflows, & evaporation	331.5		200.4		159.9	
Net storage changes in state	5.5		-5.7		-14.3	
Distribution of dedicated supply (includes reuse) to various applied water uses						
Urban uses	7.8	(8%)	8.9	(11%)	8.6	(13%)
Agricultural uses	27.3	(29%)	34.2	(41%)	33.7	(52%)
Environmental water[b]	59.4	(63%)	39.4	(48%)	22.5	(35%)
Total dedicated supply	**94.5**		**82.5**		**64.8**	

maf = million acre-feet

a. Percent of normal precipitation. Water year 1998 represents a wet year; 2000, average water year; 2001, drier water year.

b. Environmental water includes instream flows, wild and scenic flows, required Delta outflow, and managed wetlands water use. Some environmental water is reused by agricultural and urban water users.

Source: DWR Water Report

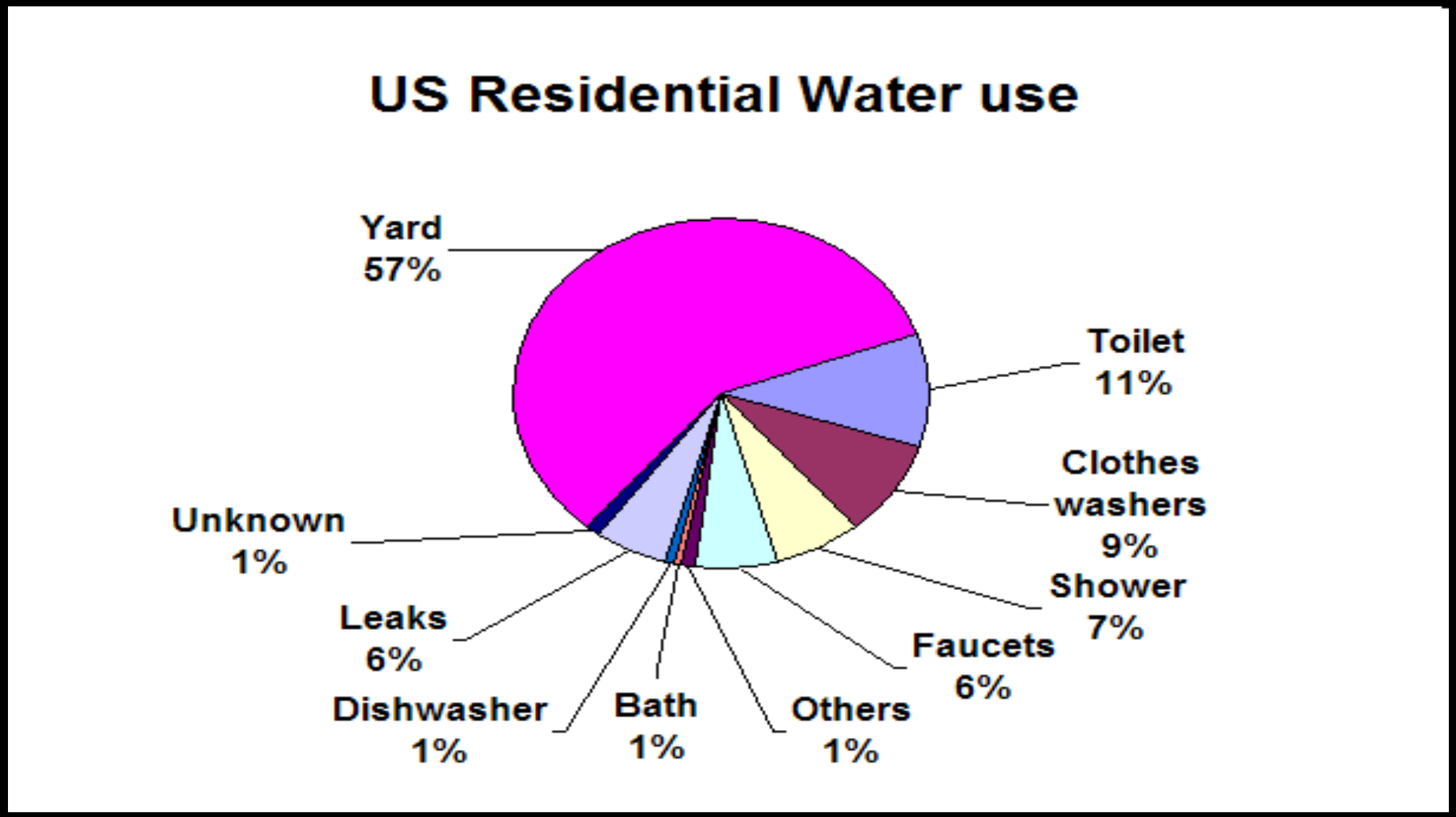
CA Water Facts: Water

Table 1-2 State of California water balance summary - MAF

Water Entering the Region – Water Leaving the Region = Storage Changes in Region

	Water Year (Percent of Normal Precipitation)		
	1998 (171%)	2000 (97%)	2001 (72%)
Water Entering the State			
Precipitation	329.6	187.7	139.2
Inflow from Oregon/Mexico	2.3	1.7	1.1
Inflow from Colorado River	5.0	5.3	5.2
Imports from Other Regions	N/A	N/A	N/A
Total	**336.9**	**194.7**	**145.5**
Water Leaving the State			
Consumptive Use of Applied Water * (Ag, M&I, Wetlands)	22.5	27.9	27.8
Outflow to Oregon/Nevada/Mexico	1.6	0.9	0.7
Exports to Other Regions	N/A	N/A	N/A
Statutory Required Outflow to Salt Sink	43.8	28.0	13.9
Additional Outflow to Salt Sink	73.0	37.1	17.7
Evaporation, Evapotranspiration of Native Vegetation, Groundwater Subsurface Outflows, Natural and Incidental Runoff, Ag Effective Precipitation & Other Outflows	190.5	106.5	99.7
Total	**331.4**	**200.4**	**159.8**
Storage Changes in State			
[+] Water added to storage			
[–] Water removed from storage			
Change in Surface Reservoir Storage	7.2	-1.3	-4.6
Change in Groundwater Storage **	-1.7	-4.4	-9.7
Total	**5.5**	**-5.7**	**-14.3**
Applied Water * (compare with Consumptive Use)	33.9	41.8	41.2

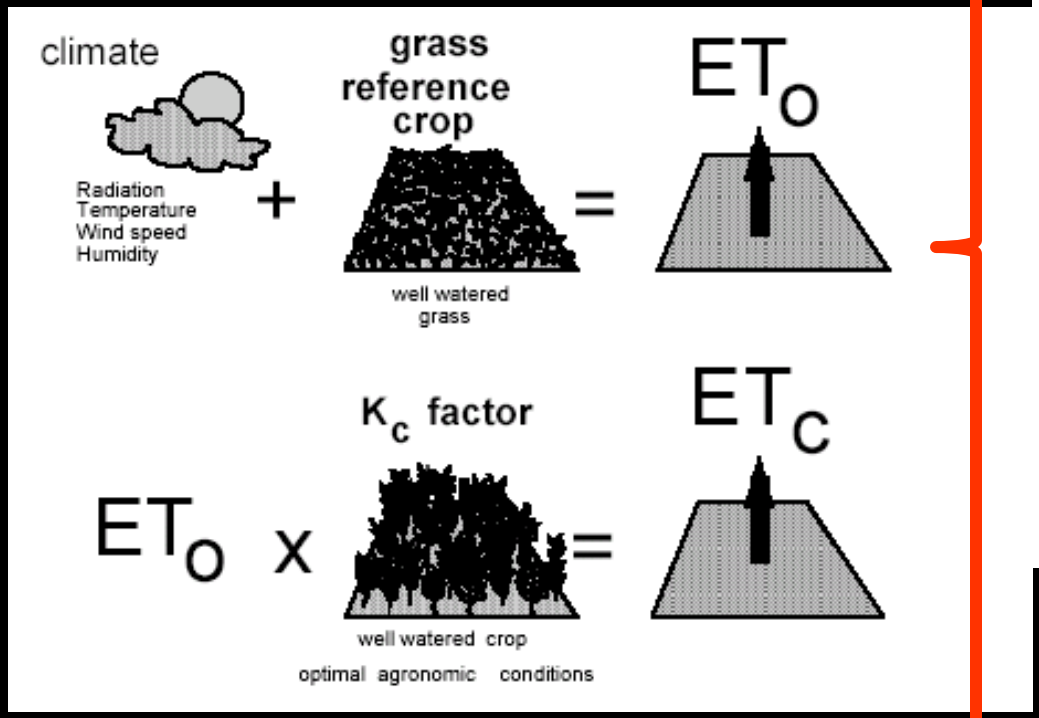
US residential water use



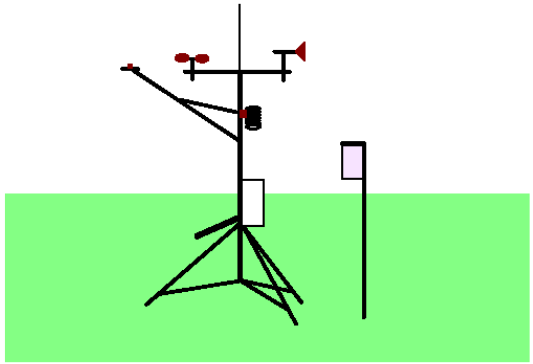
This pie chart gives the percentage of what makes up the US residential water use.

http://planetsave.com/files/2008/02/us-residential-water-use-609px.gif

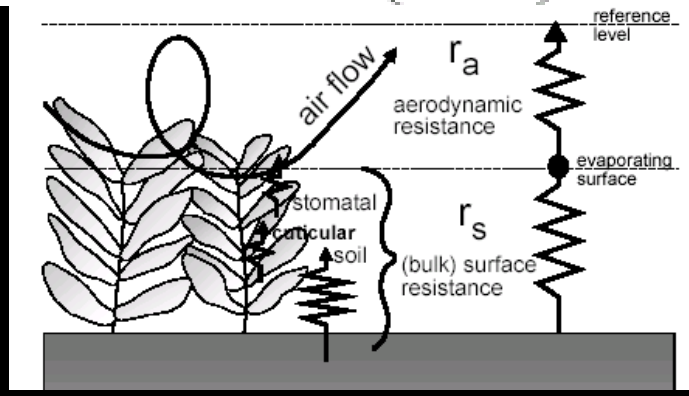
Reference ET: ET_o



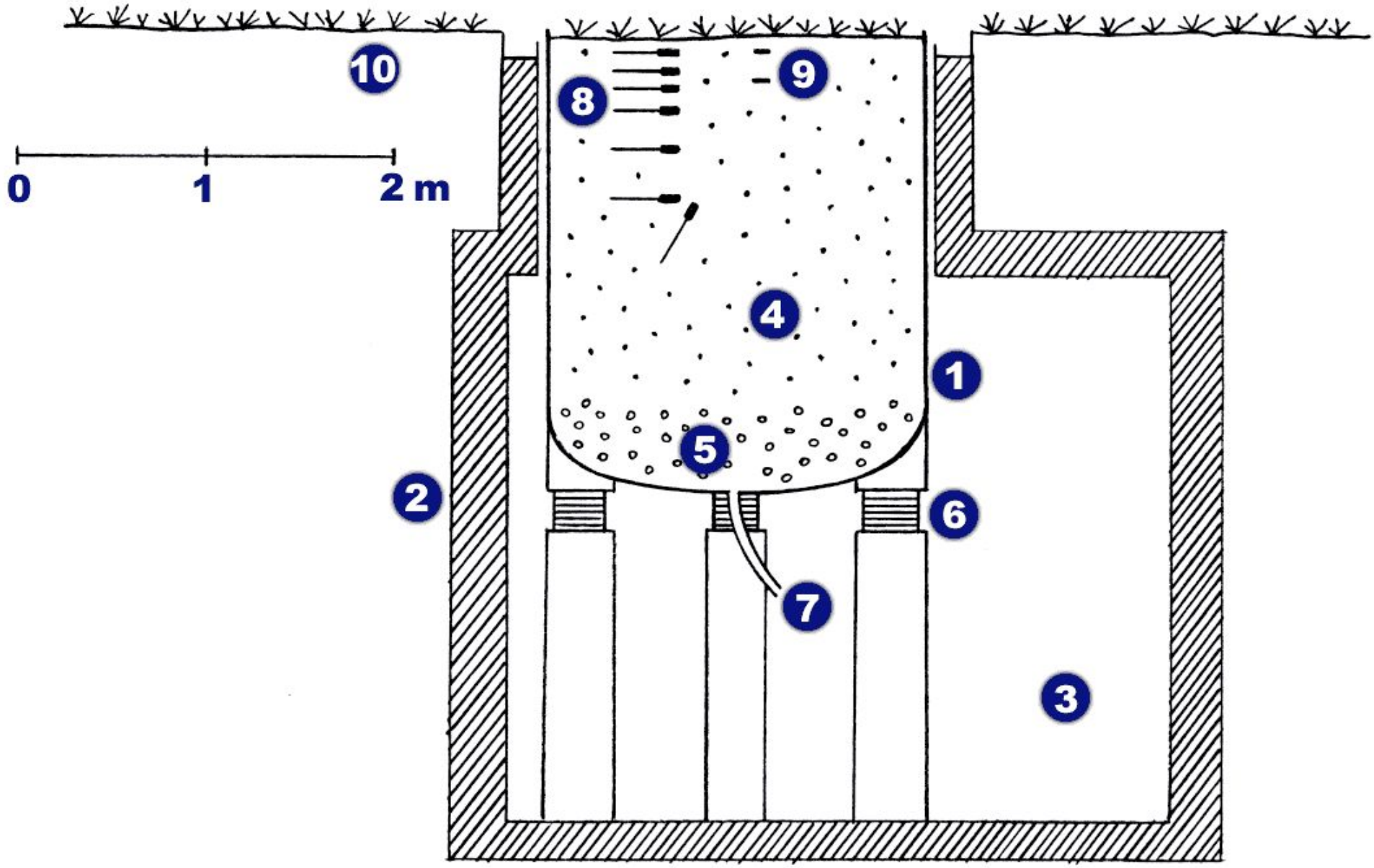
THE ASCE STANDARDIZED REFERENCE EVAPOTRANSPIRATION EQUATION



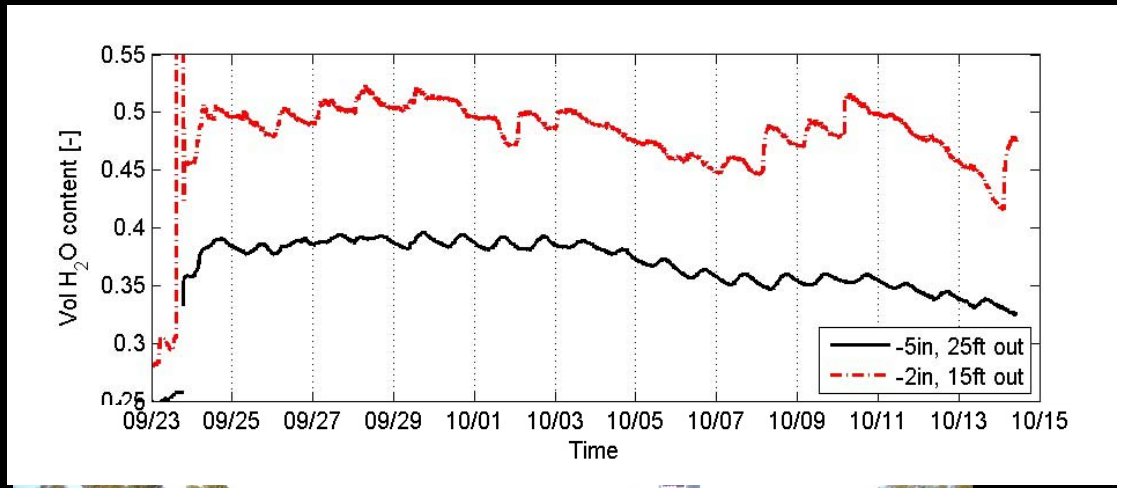
$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)}$$

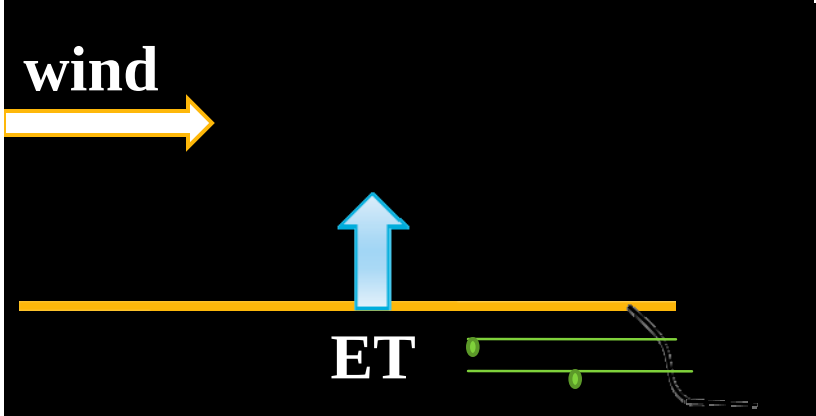


Measurements of ET:

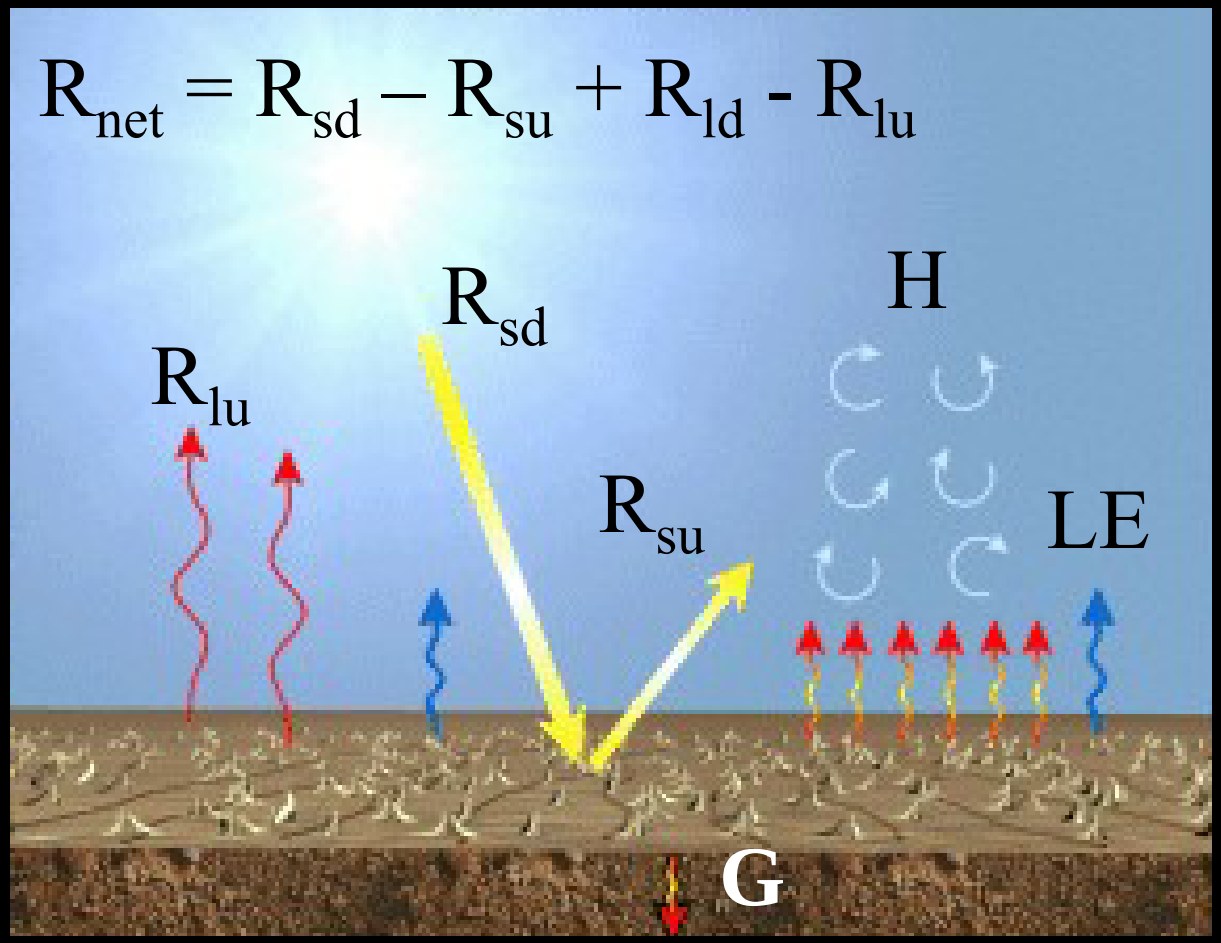


Soil Moisture





Atmospheric Measurements: The Surface Energy Balance

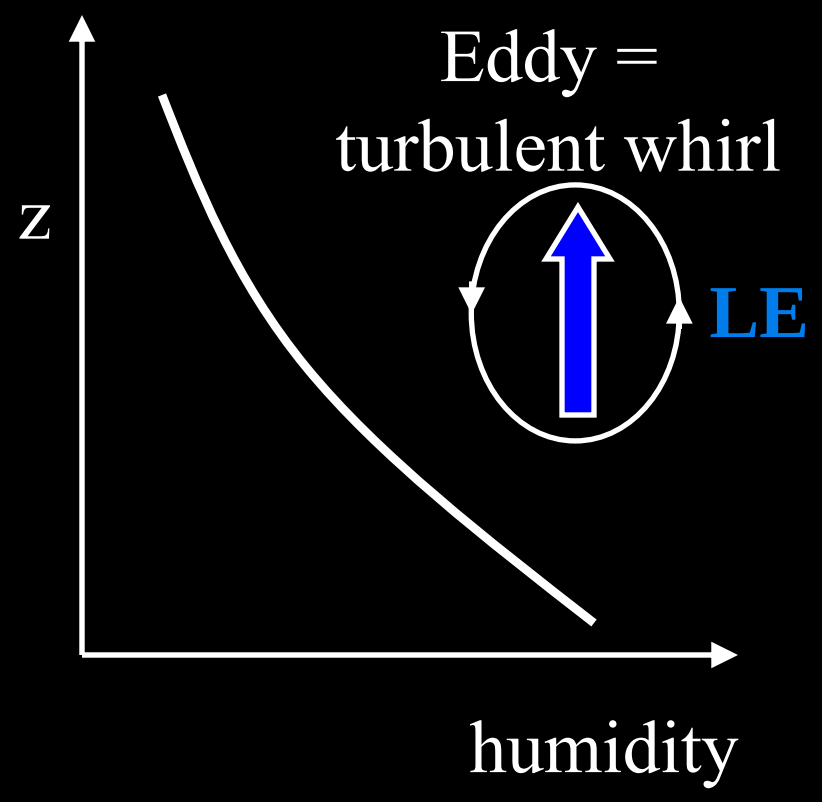


Energy balance can be used to estimate LE:

$$LE = R_{net} - G - H$$

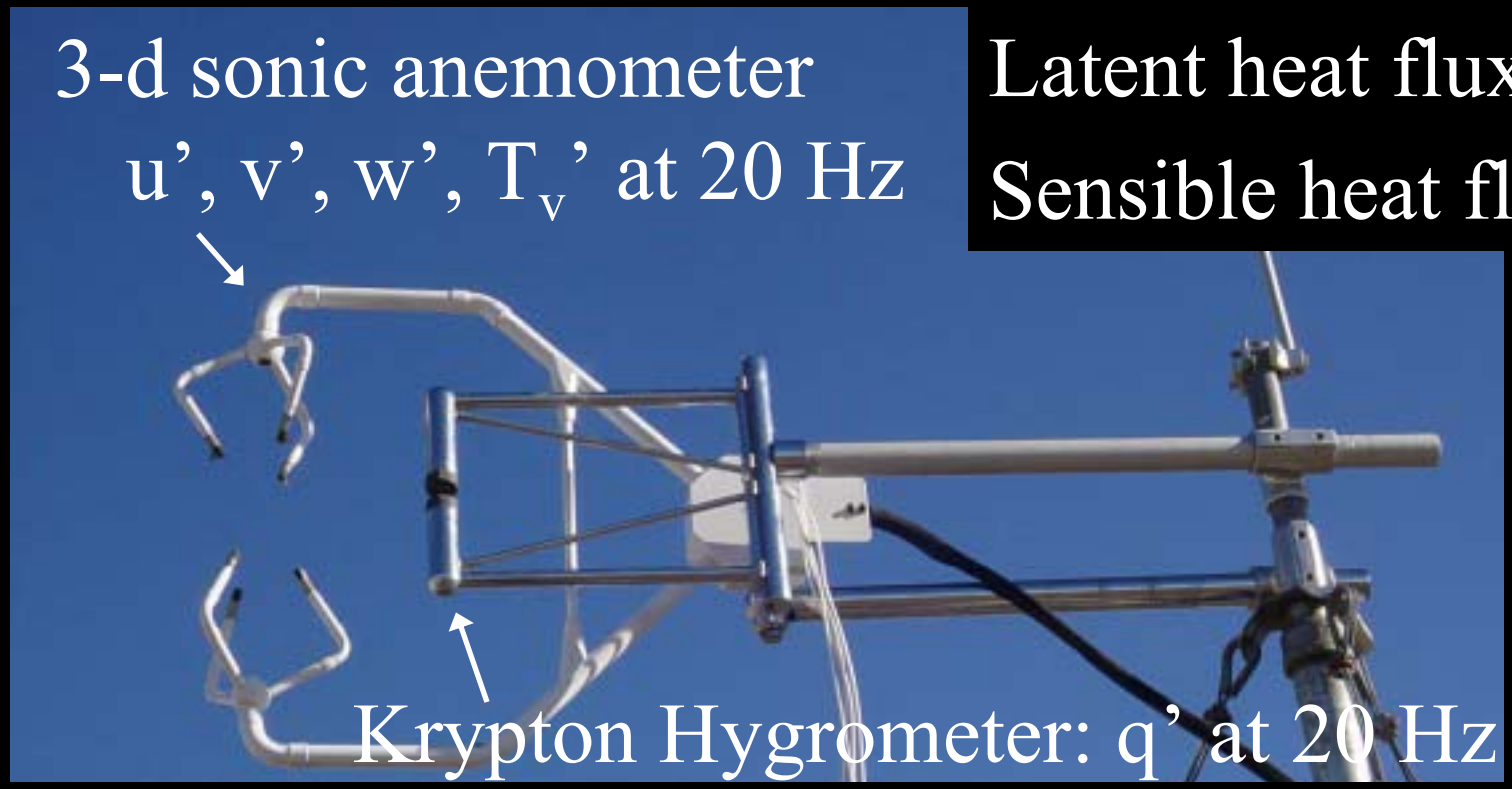
Latent Heat Flux

Day & Night



Eddy moves warm humid air up and dry air down. **Both** motions contribute to a positive (upward) flux of latent heat ("water flux").

Eddy correlation, Surface renewal



Latent heat flux w'H_2O'

Sensible heat flux w'T'

Surface renewal: measure R_{net}, G

estimate H from temperature variance

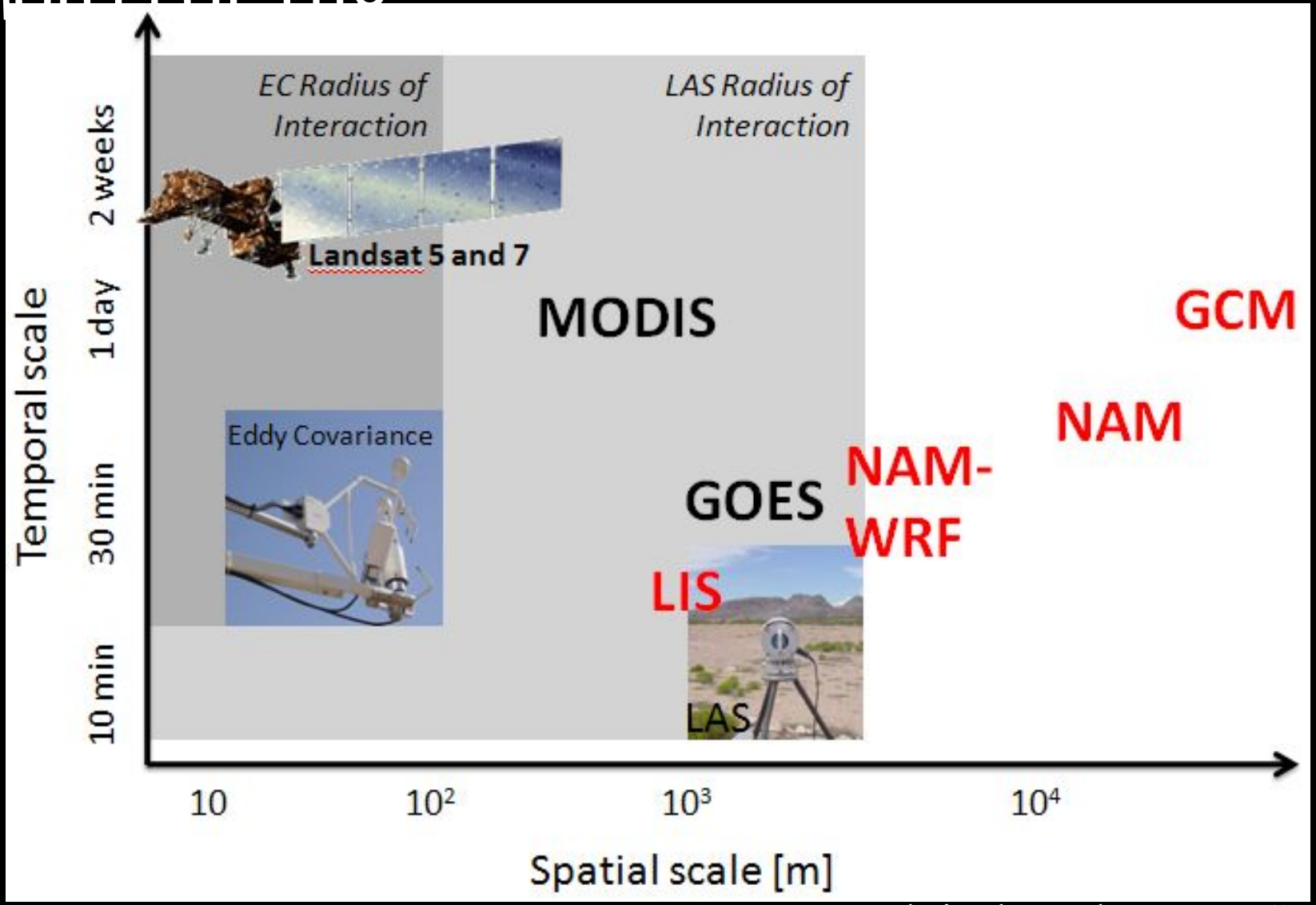
determine LE = R_{net} – G – H

Disadvantages

- Expensive (lysimeter, EC)
- In-situ (all) → conflict with operations
- Semi-empirical (reference ET, SR)
- Point measurements (all)
  - Localized
  - Not representative of field
  - Limited intercomparison to satellite remote sensing products

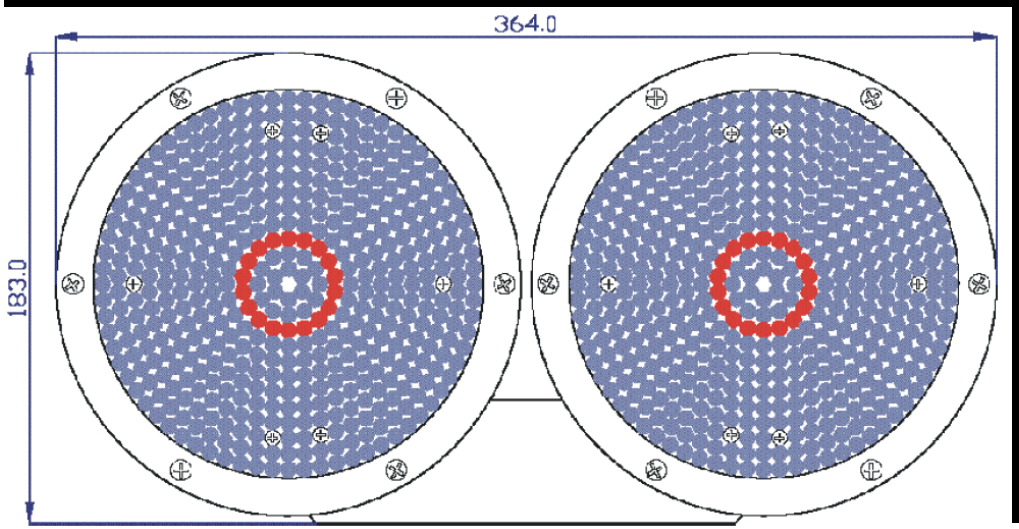
Goal: derive ET maps of CA through satellite remote sensing and ground truthing

Scales in Environmental Monitoring



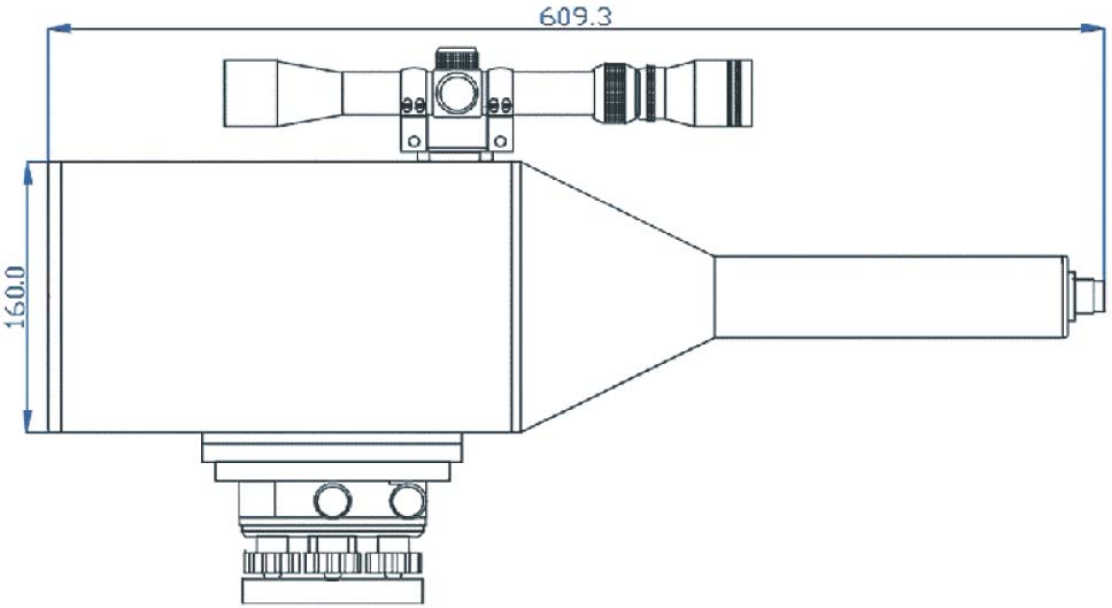
Kleissl et al., BAMS, 2009)

Transmitter and Receiver

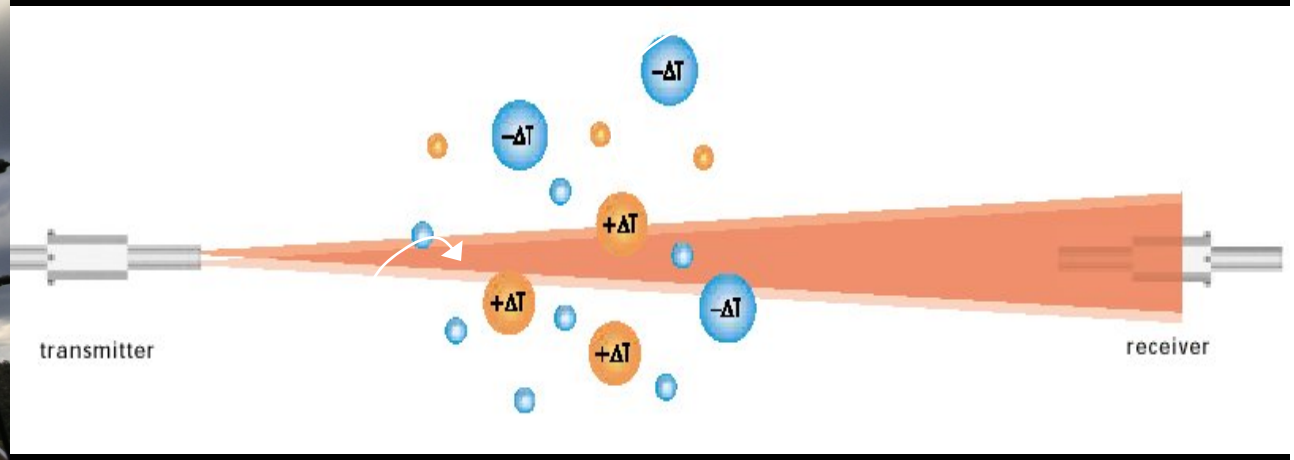


Transmitter

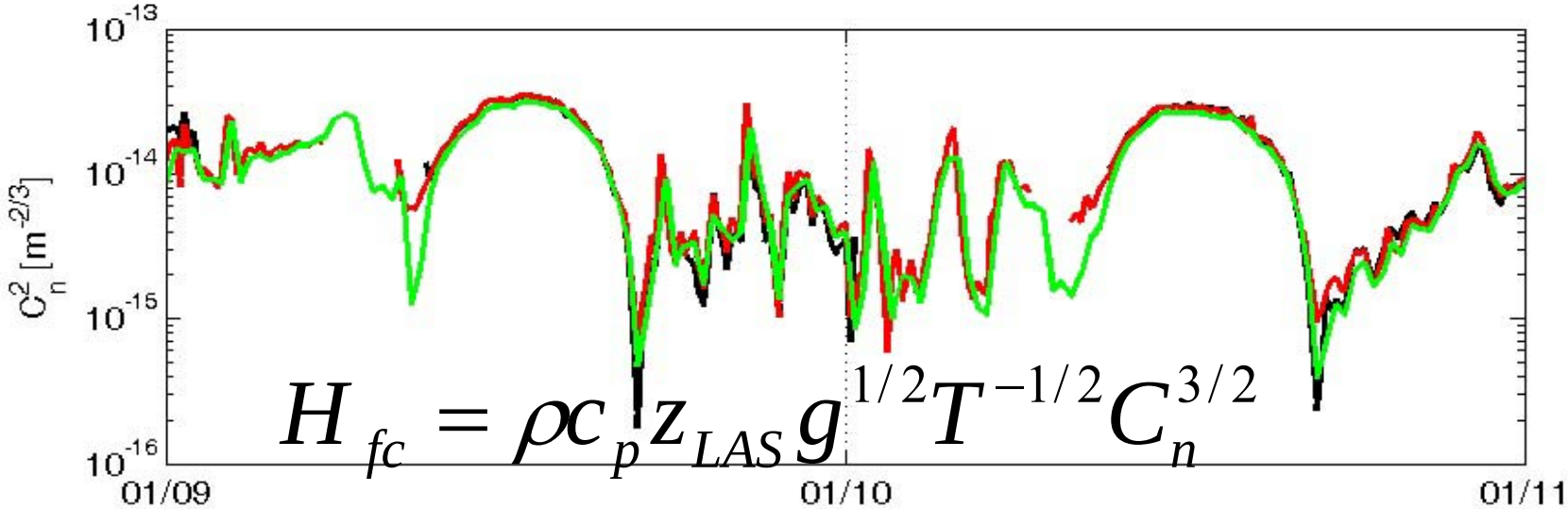
Receiver



Scintillometer Operation



Consistency of LAS measurement along the same transect



$$H_{fc} = \rho c_p z_{LAS} g^{1/2} T^{-1/2} C_n^{3/2}$$

Scintillometer Data Processing

Scintillations
T,q → n

Scintillo meter →

Small Aperture (SAS)
≤ 250 m pathlength
Inner length scale

Large Aperture (LAS)
≤ 5000 m pathlength

Structure parameter

$$\sigma_\chi^2 \rightarrow C_n^2 \rightarrow C_T^2$$

Monin-Obukhov similarity theory in the surface layer, e.g.

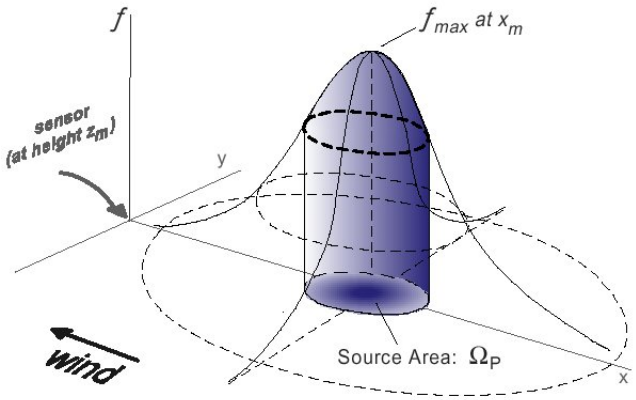
$$\frac{\partial U}{\partial z} = \frac{u_*}{z} f\left(\frac{z}{L}\right),$$

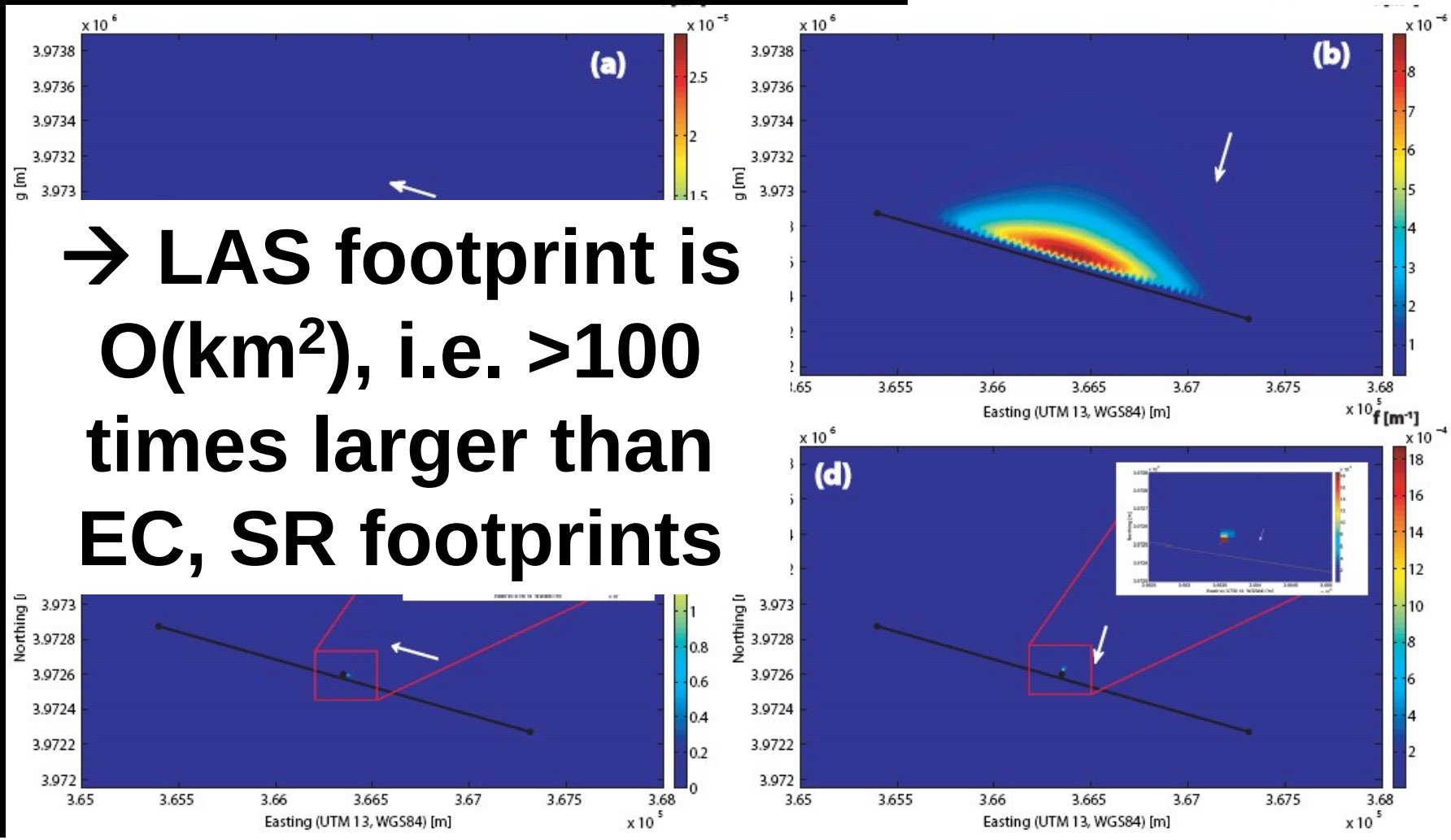
MOST
u_* →

Heat flux H

Advantage of LASs

Footprint Size



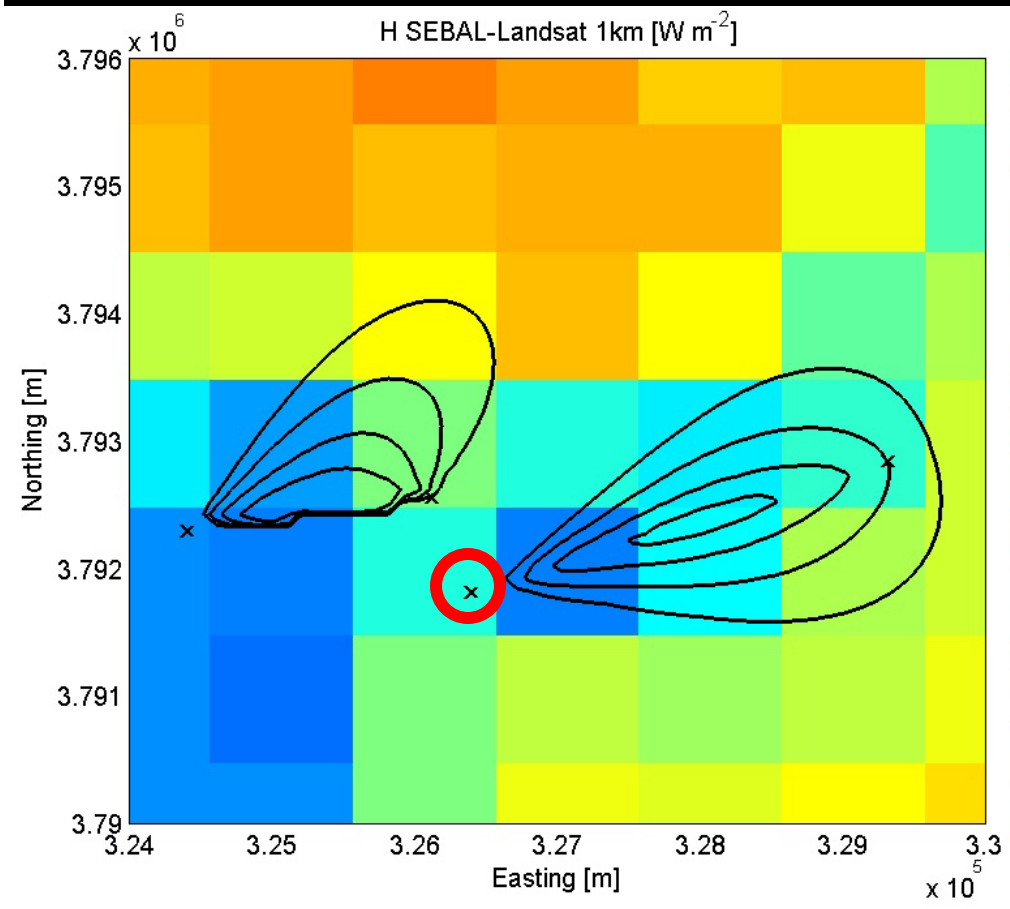


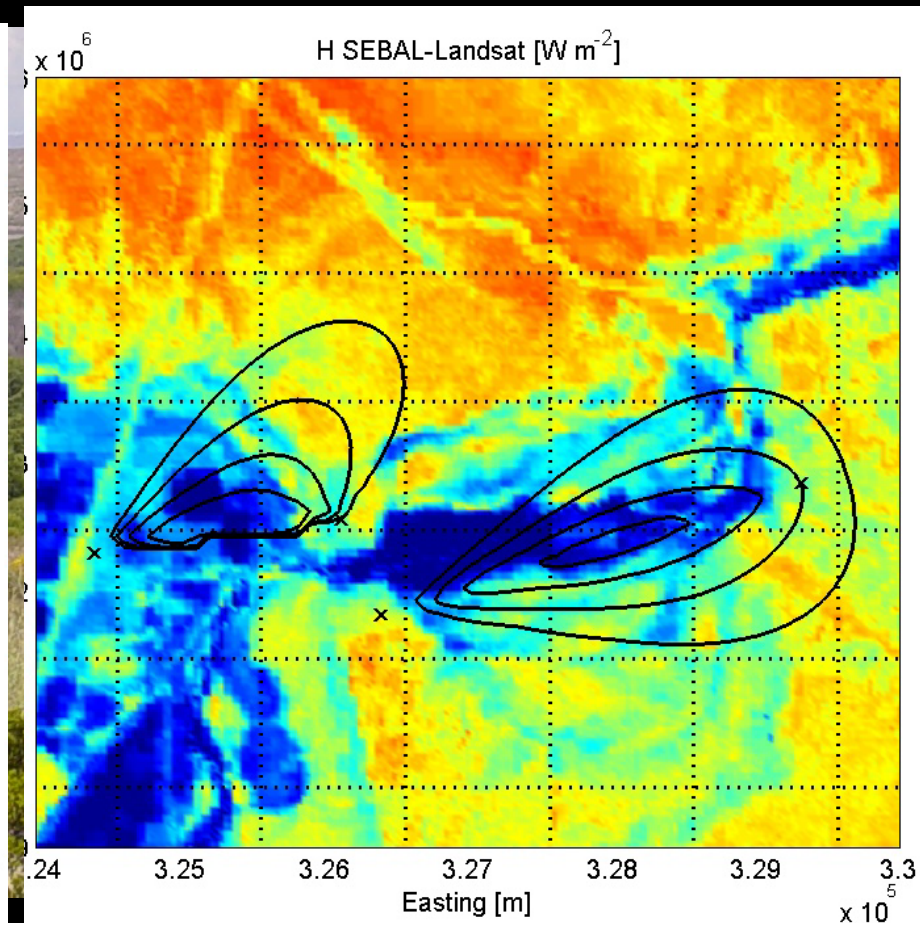
→ LAS footprint is O(km²), i.e. >100 times larger than EC, SR footprints

Ground-Truthing and Scaling for Hydrologic Remote Sensing

Wireless networks of ground-state accurate, and fine-scale data allow hydrologic variables, such as soil moisture and evapotranspiration.

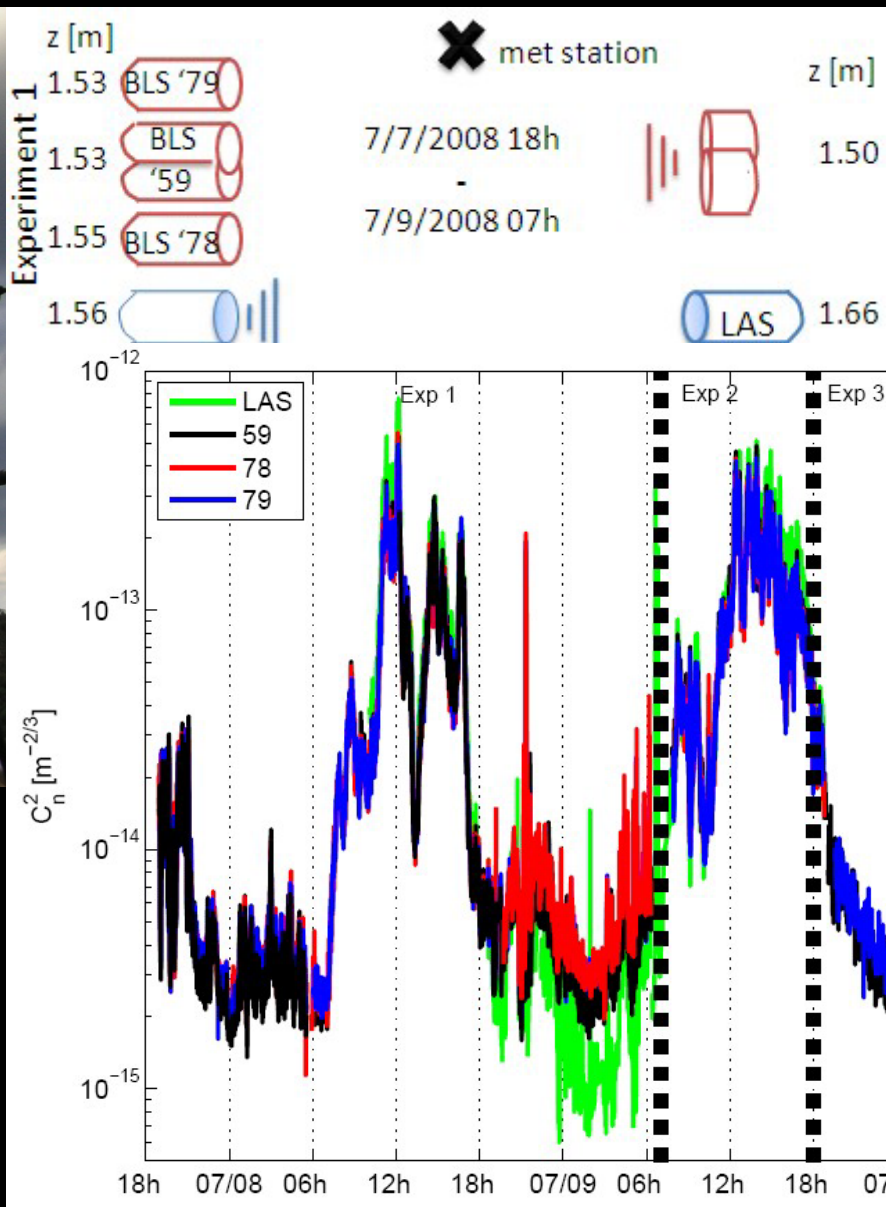
Ground measurements provide accurate, and fine-scale data allow hydrologic variables, such as soil moisture and evapotranspiration.





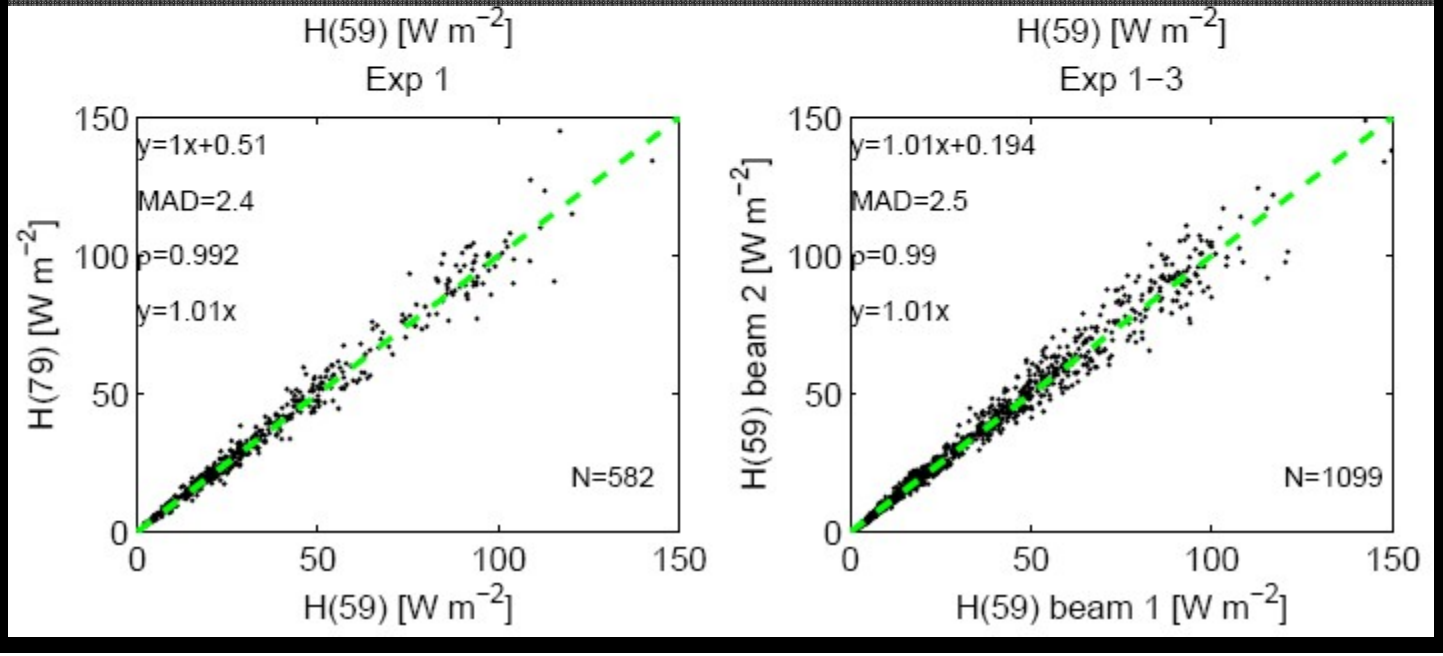
Scintillometer Intercomparison

North American Monsoon inter-manufacturer intercomparison study (Kleissl et al., BLM, 2009).
1x LAS, 2x BLS450, 1x BLS900

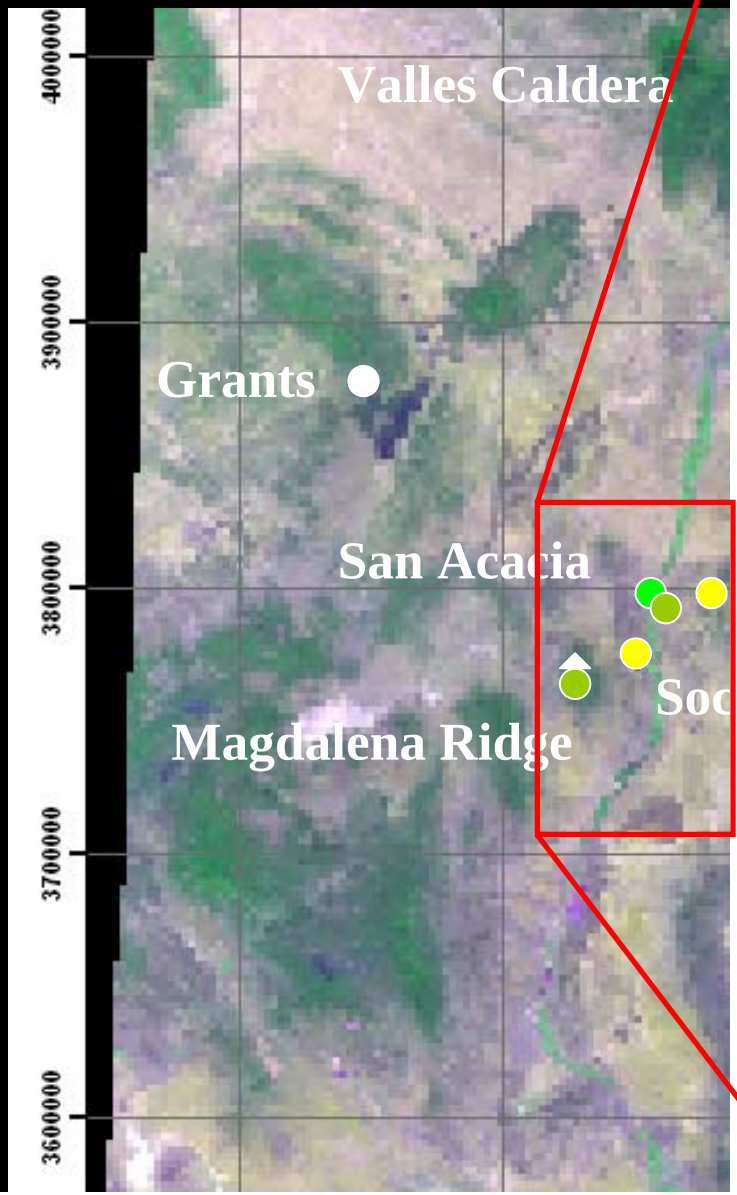


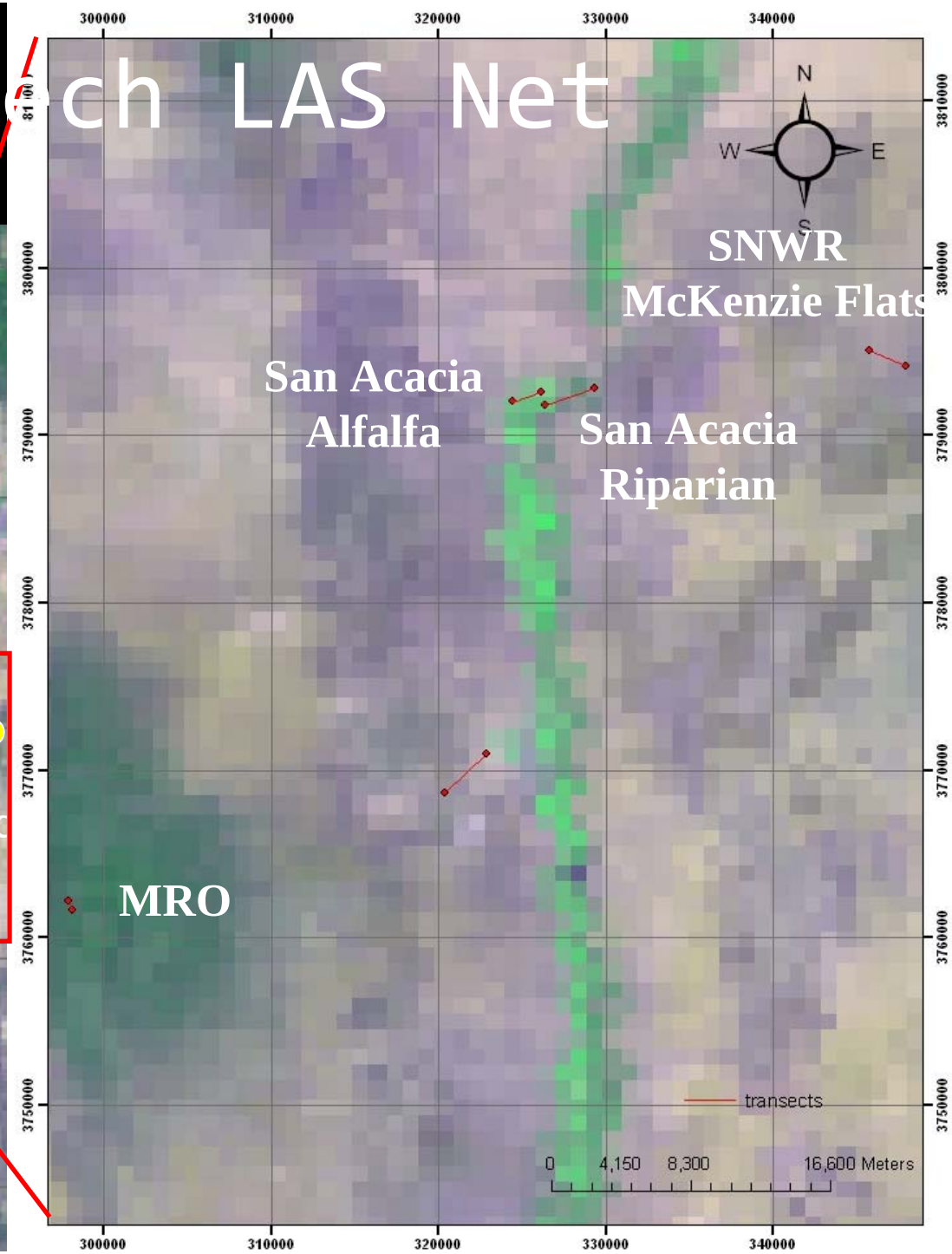
Intercomparison Results

- Extremely high correlation coefficients → robustness
- Scintec differences are statistically insignificant
- Kipp & Zonen difference of up to 21% and typically 6%

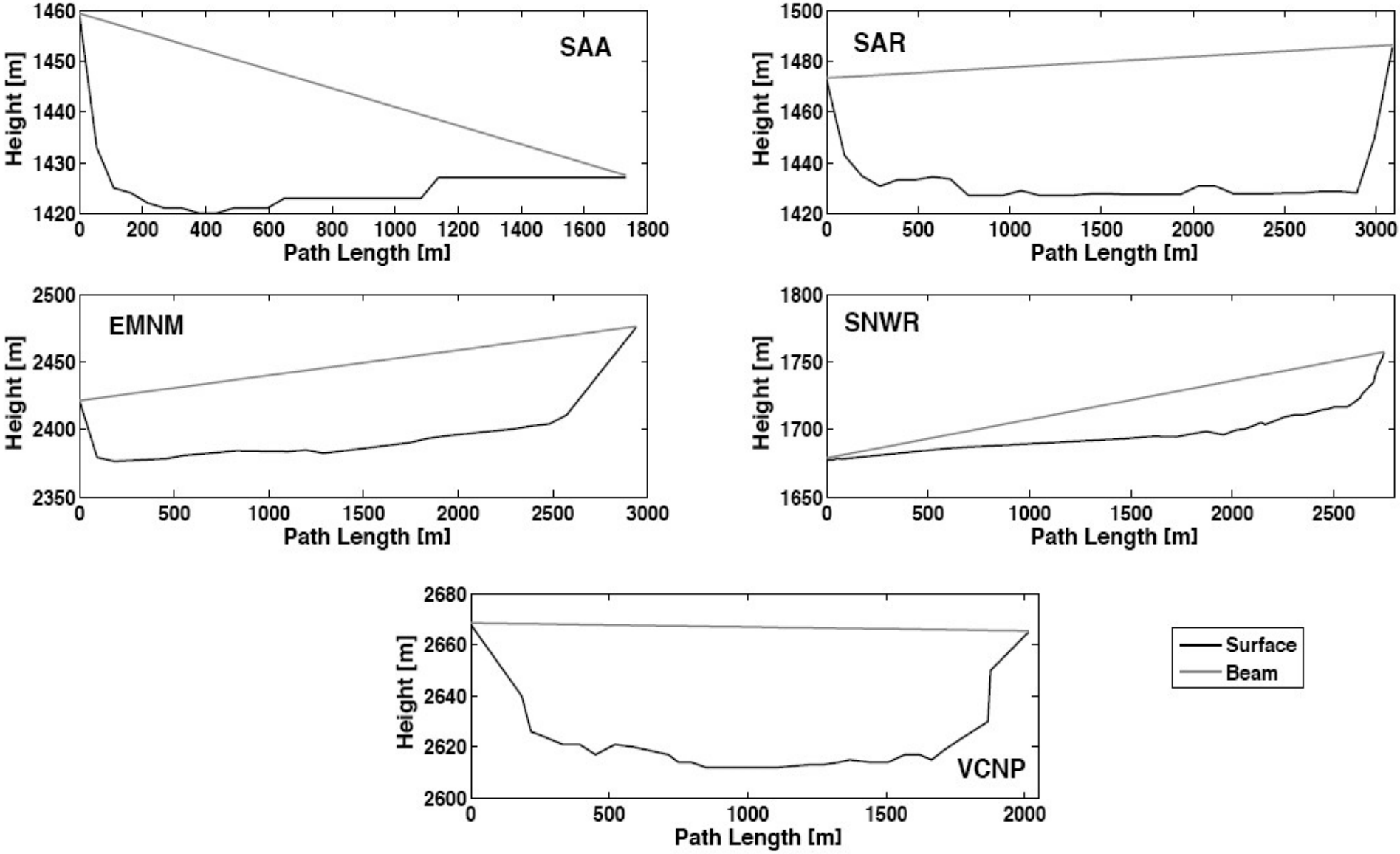


New Mexico Tech LAS Net





New Mexico Tech LAS Net



El Malpais
Basalt Outcrops

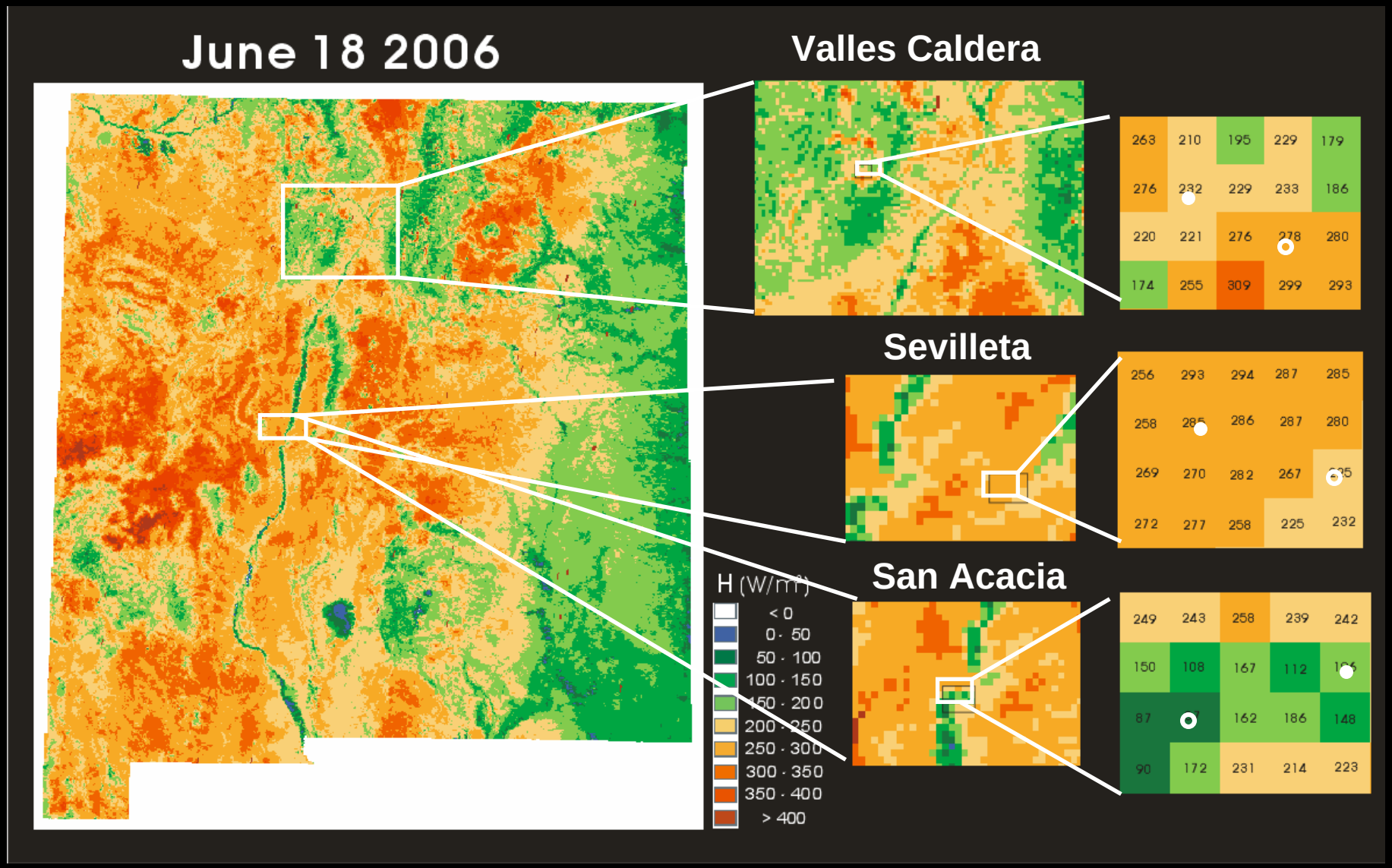
San Acacia
Riparian Area

San Acacia
Alfalfa Fields

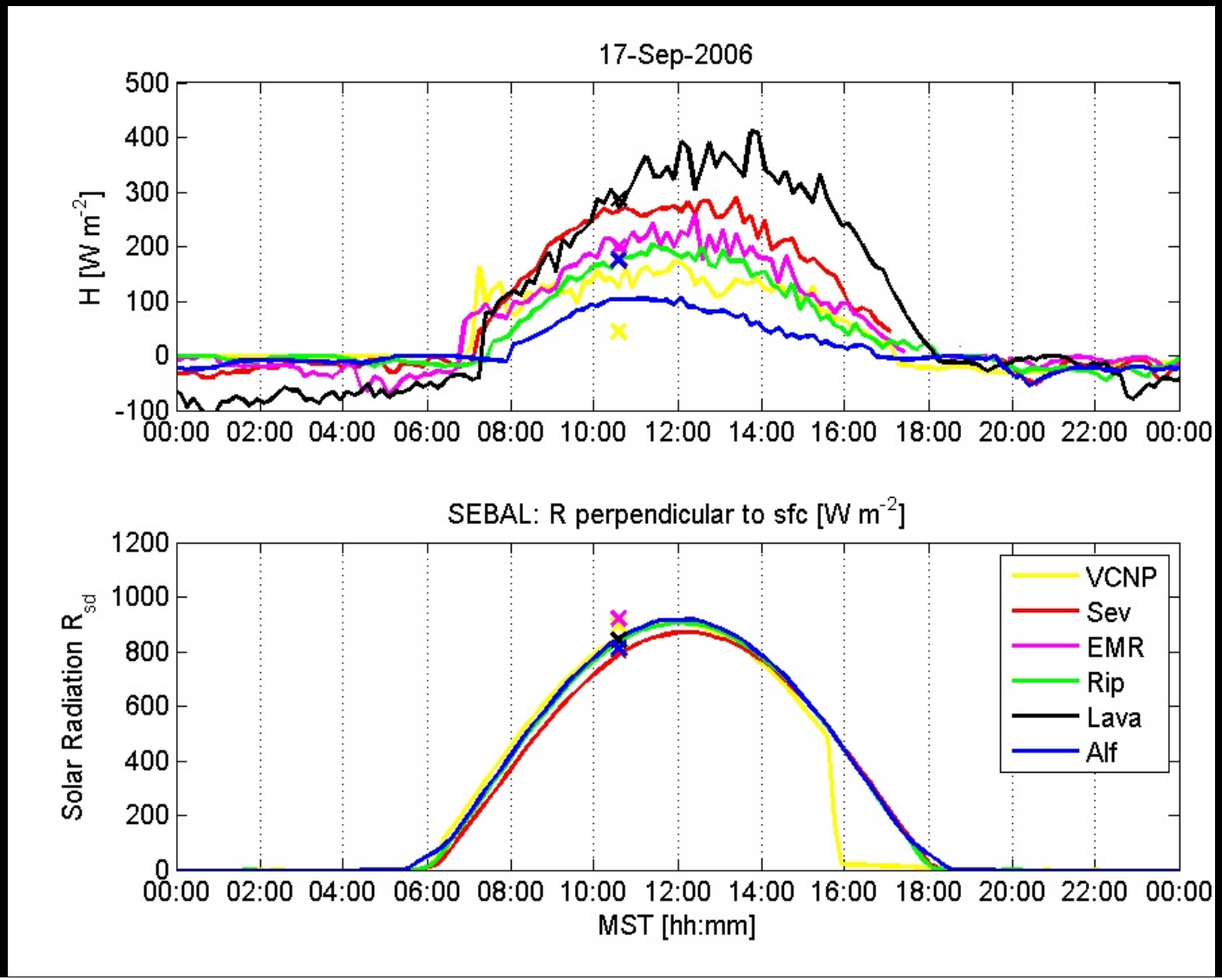
Socorro
Desert

SEBAL^{NM}-MODIS sensible heat flux maps

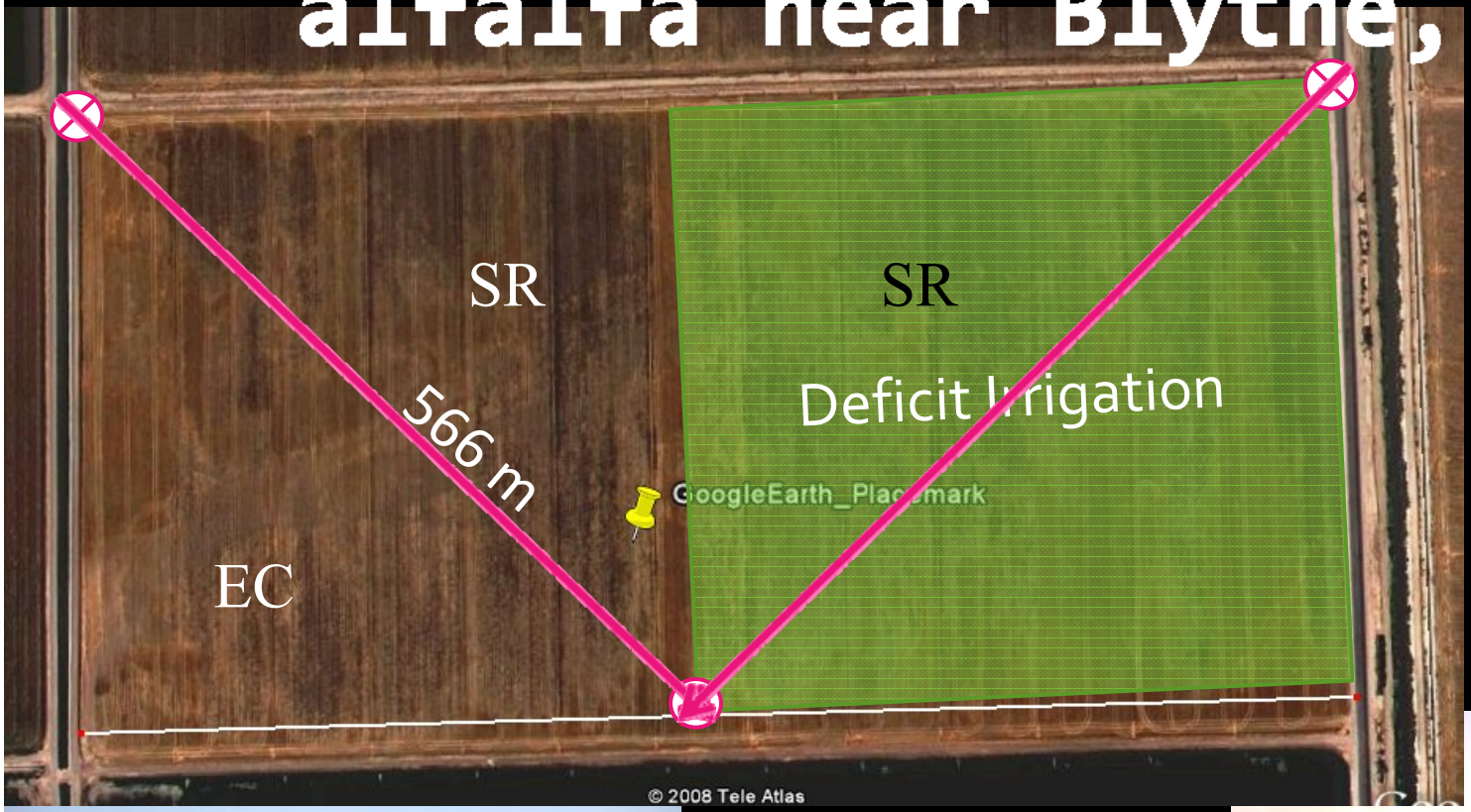
cloud-free: 6/6, 6/18, 7/16, 9/17/2006



SEBAL-LAS Intercomparison Results

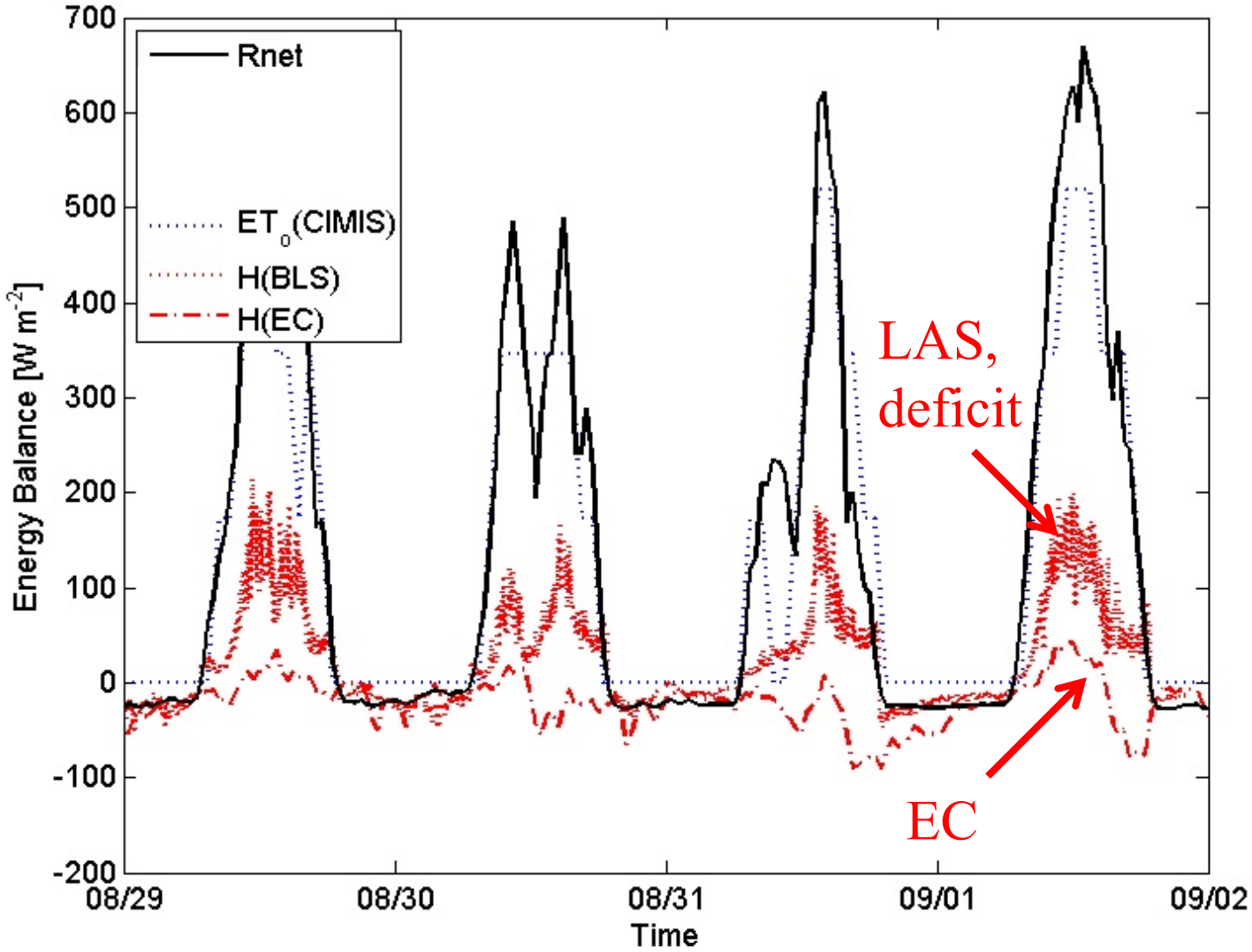


LAS over deficit irrigated alfalfa near Blythe, CA



1/2008-12/2009
Quantify water savings and yield loss

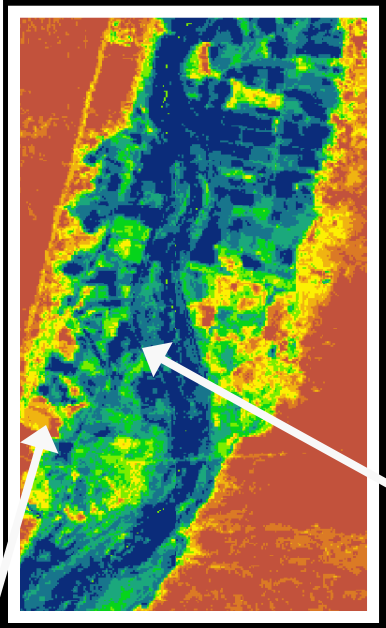
Preliminary Results

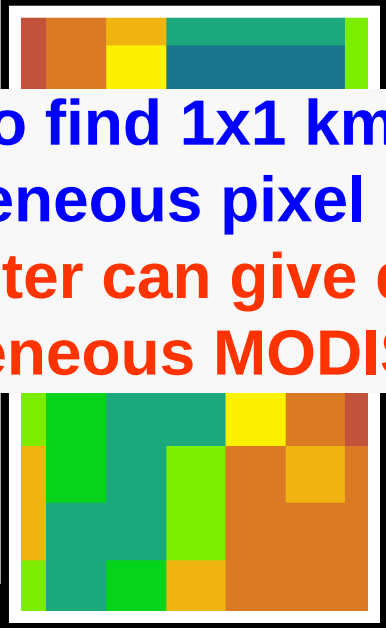


Summary

- LASs can be used to ground-truth the regional distribution of sensible heat fluxes from satellite imagery.
- Rough agreement between LAS measurement and SEBAL-MODIS sensible heat flux
- Looking for funding and remotes sensing expert to derive satellite ET maps for CA

SEBAL heat flux calibration with MODIS





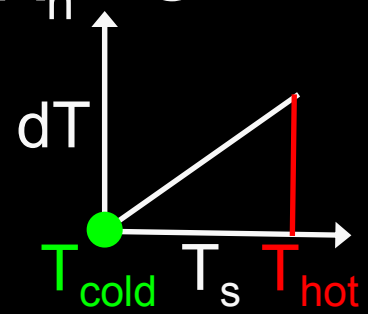
Difficult to find 1x1 km^2 homogeneous pixel

Scintillometer can give dT for heterogeneous MODIS pixel

Hot pixel: ET = 0 → H = R_n - G

cold pixel: H = 0

$$H = \rho c_p dT / r_{ah}$$



$$r_{ah} = f(u_*, z, z_o)$$

[s m^{-1}]