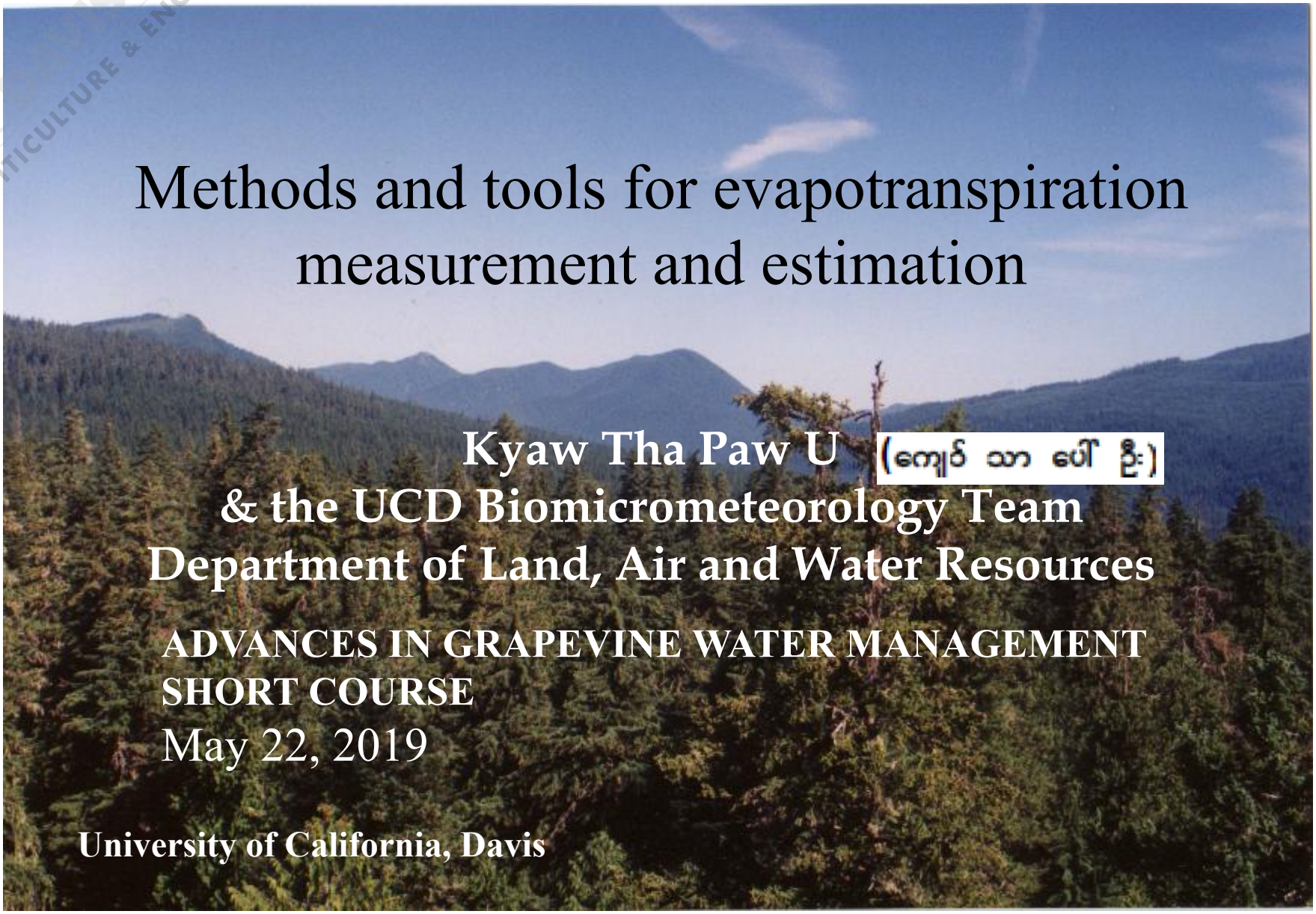


Methods and tools for evapotranspiration measurement and estimation

Kyaw Tha Paw U (ကျော်သာပေါ်ဦး)
& the UCD Biomicrometeorology Team
Department of Land, Air and Water Resources

ADVANCES IN GRAPEVINE WATER MANAGEMENT SHORT COURSE
May 22, 2019

University of California, Davis

Two Main Methods:

Mass Balance

Energy Balance linked to Mass Balance

Scales Range from Leaf to Field and Region to Globe


73F 23C 2018/06/07 16:00:06


46F 08C 2018/08/08 06:00:06


73F 23C 2018/05/10 19:00:06


68F 20C 2018/07/11 08:00:06


WINGSCAPES
DELTA-C11
07 NOV 2018 09:00 am


75F 24C 2018/10/26 10:00:06


75F 24C 2018/09/12 17:27:21


DELTA C5
17 AUG 2018 10:00 am


127F 53C 2018/07/09 18:00:06

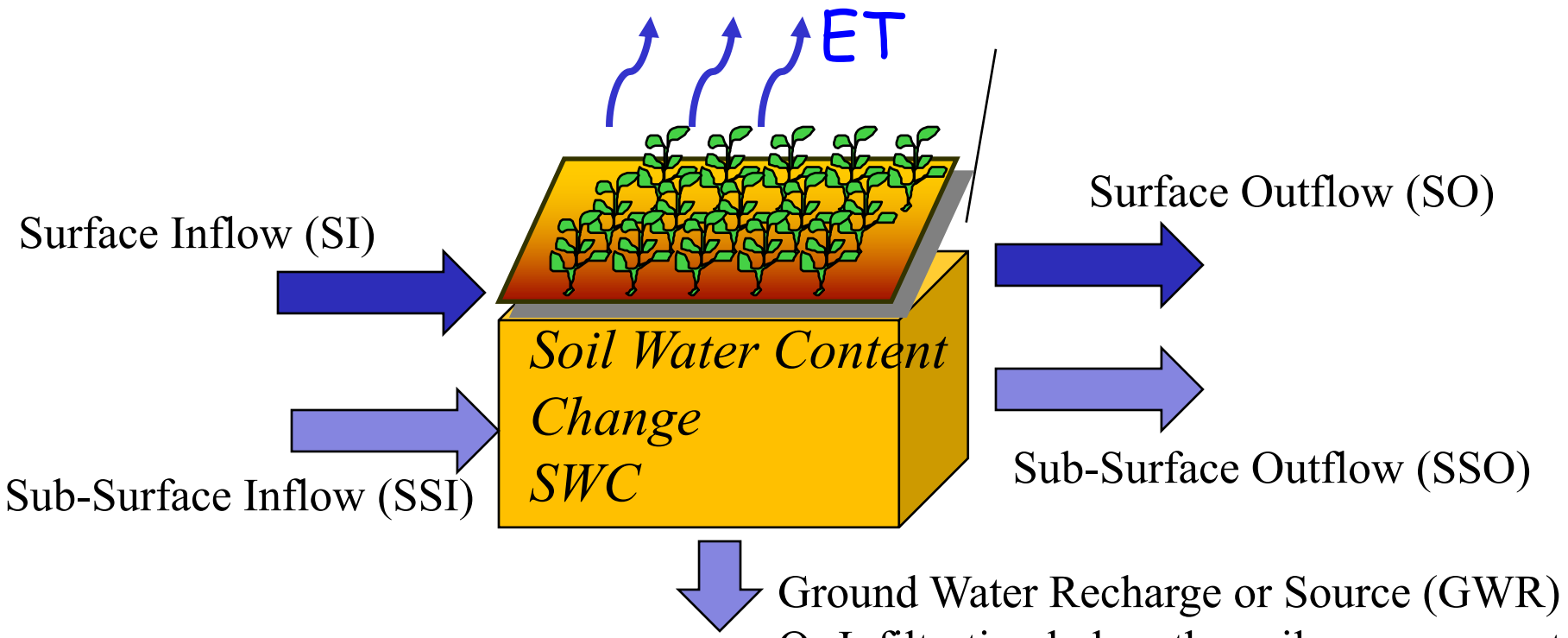

WINGSCAPES
DELTA-C11
06 NOV 2018 06:00 pm


WINGSCAPES
DELTA C5
30 AUG 2018 03:00 pm


UCDAVIS
VITICULTURE & ENOLOGY

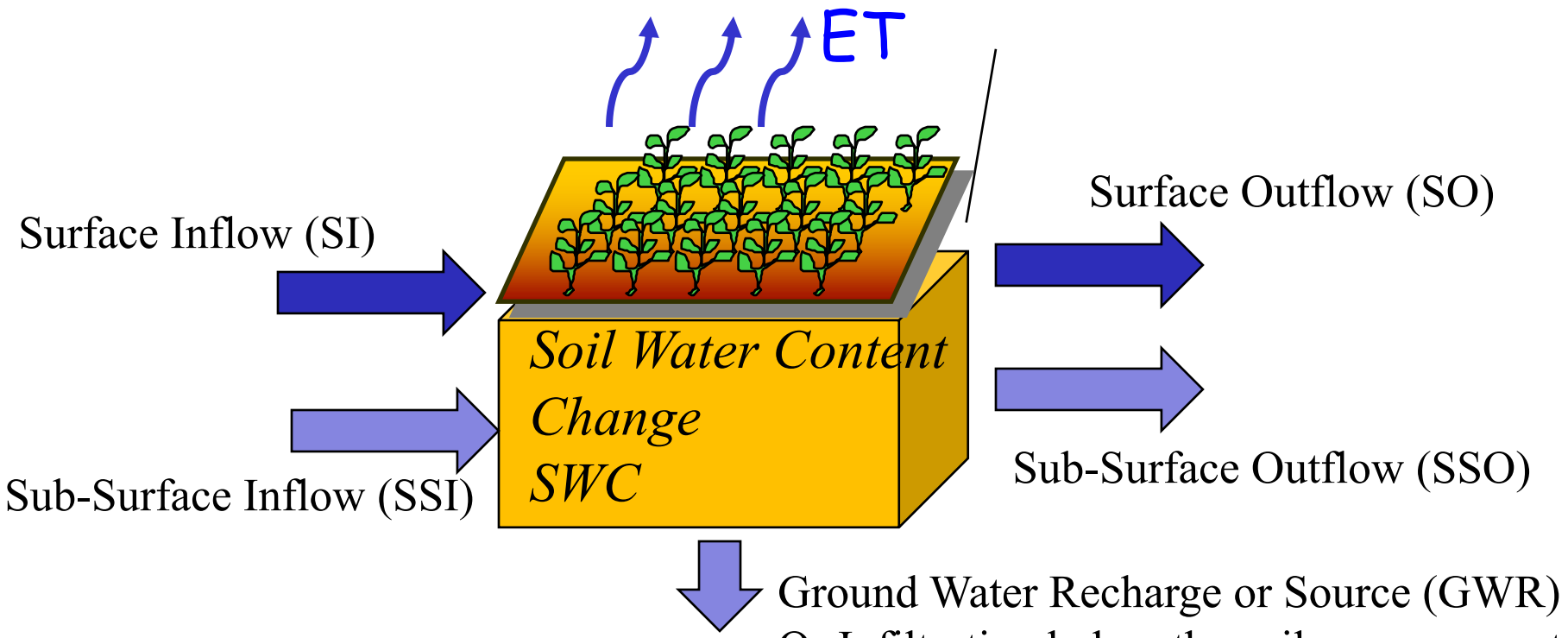
ET as a residual of the Mass Balance for Soils

$$ET = (SI - SO) + (SSI - SSO) - SWC - GWR$$



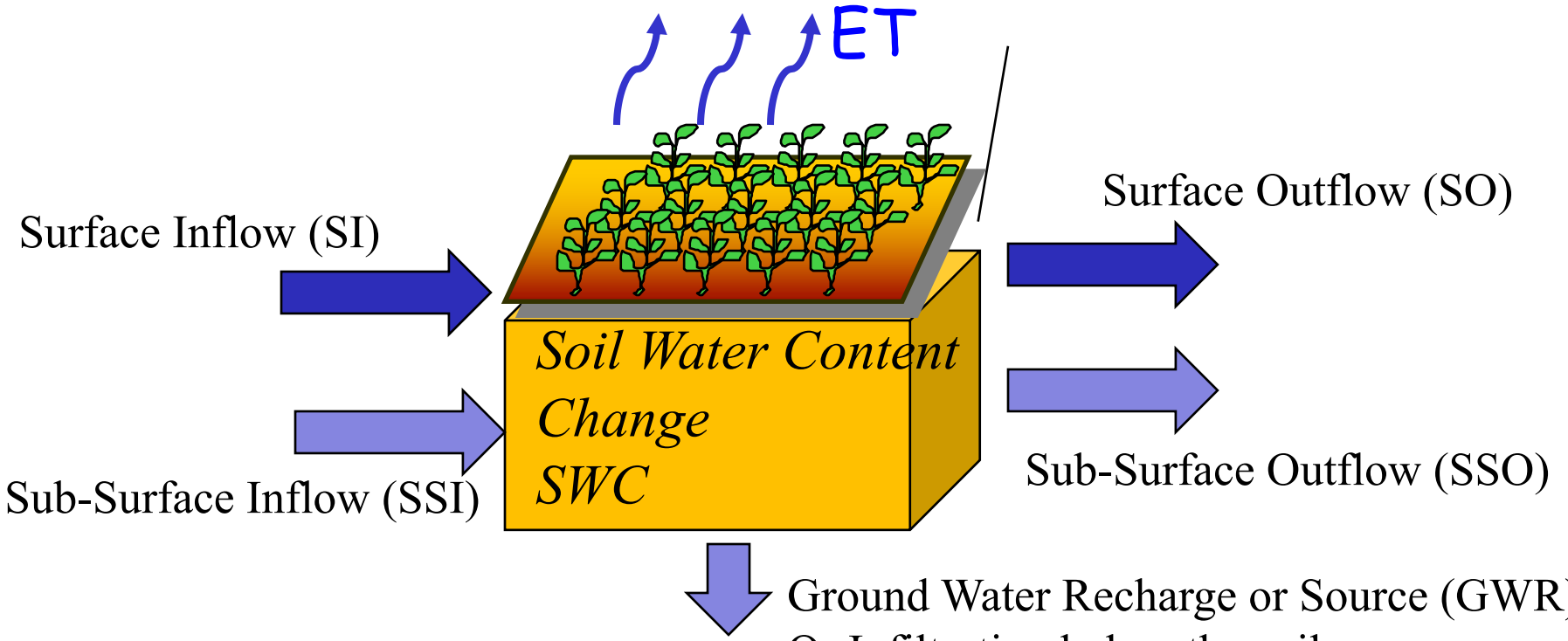
Estimation Uncertainty due to Measurement Challenges

Field Measurements--Heterogeneity of soils, Soil Sensors usually point sensors



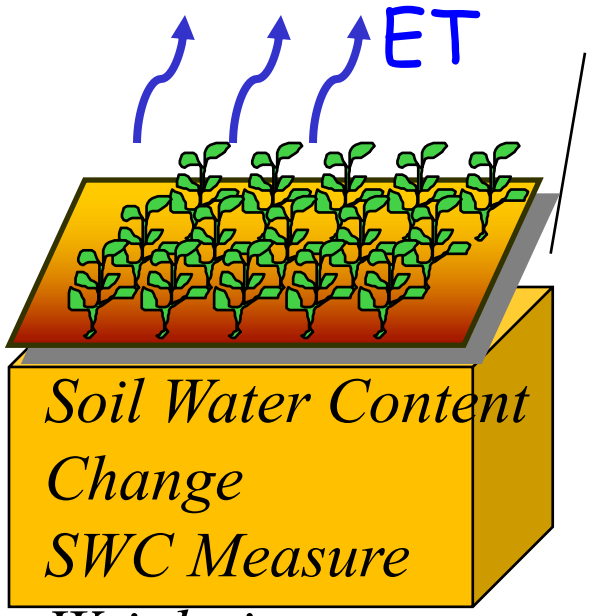
Estimation Uncertainty due to Measurement Challenges- Remote Sensing

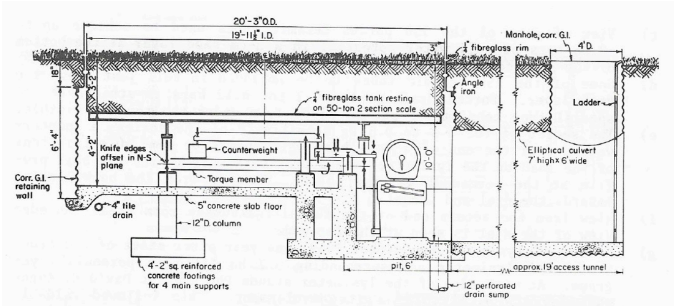
Inability of Remote Sensing to "see" deep below soil (microwave-SMAP) or distinguish between water in compartments (gravity anomaly-GRACE). Horizontal Resolution Problems



ET as a residual of the Mass Balance for Soils-- Lysimetry

ET= (SI-~~X~~O)+(SSI-~~X~~SO)-SWC-G-~~X~~R





UC Davis world's Largest Lysimeters (20 ft diameter, 3 ft depth)

Mass Budget for Plants at Different Scales

Leaf and Stem example

Chambers

Porometers, Gas Exchange Chambers

Sampling Limited in time and space; challenge for scaling to entire plant, field level

Mass Budget for Plants at Different Scales

Leaf and Stem example

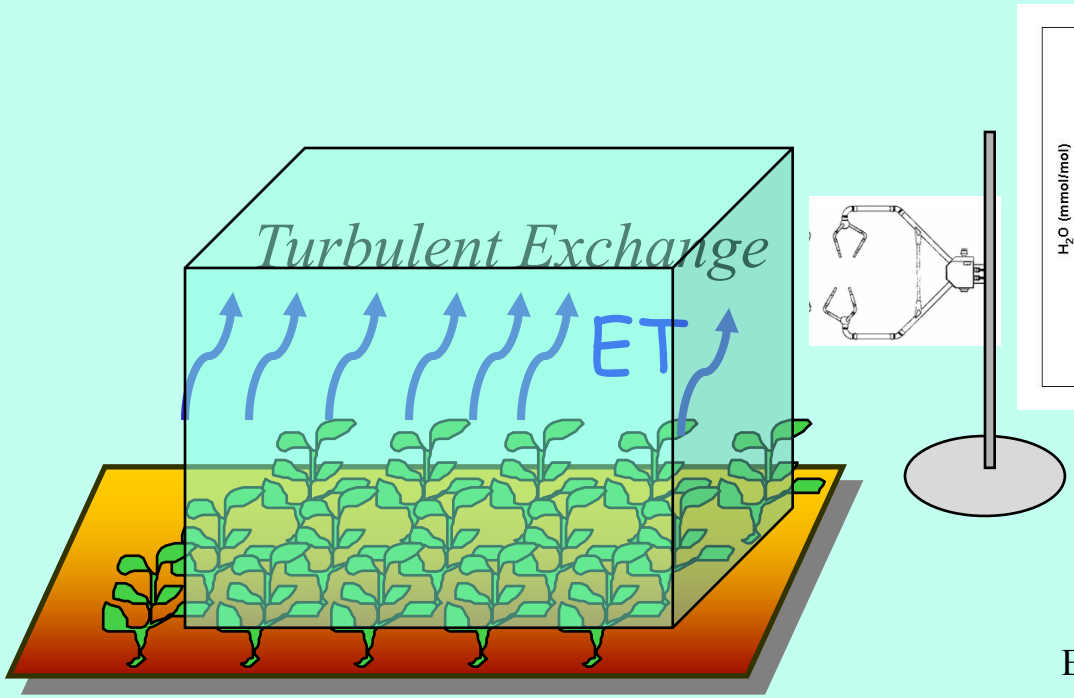
Sap Flow in trunks & stems

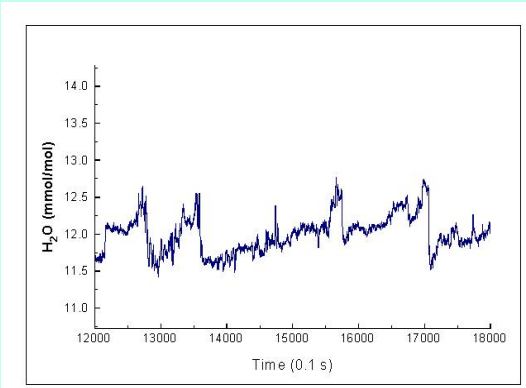
Sampling Limited in time and space; challenge for scaling to entire plant, field level

Taken from: https://www.edaphic.com.au/products/sap-flow-sensors/heat-pulse-velocity-sap-flow-sensors/

Mass Balance in Atmosphere

Vertical Turbulent Measurement of Gas Exchange using Sonic Anemometers and Gas Analyzers, 10 to 20 times a second: "Eddy Flux" or "Eddy Covariance"

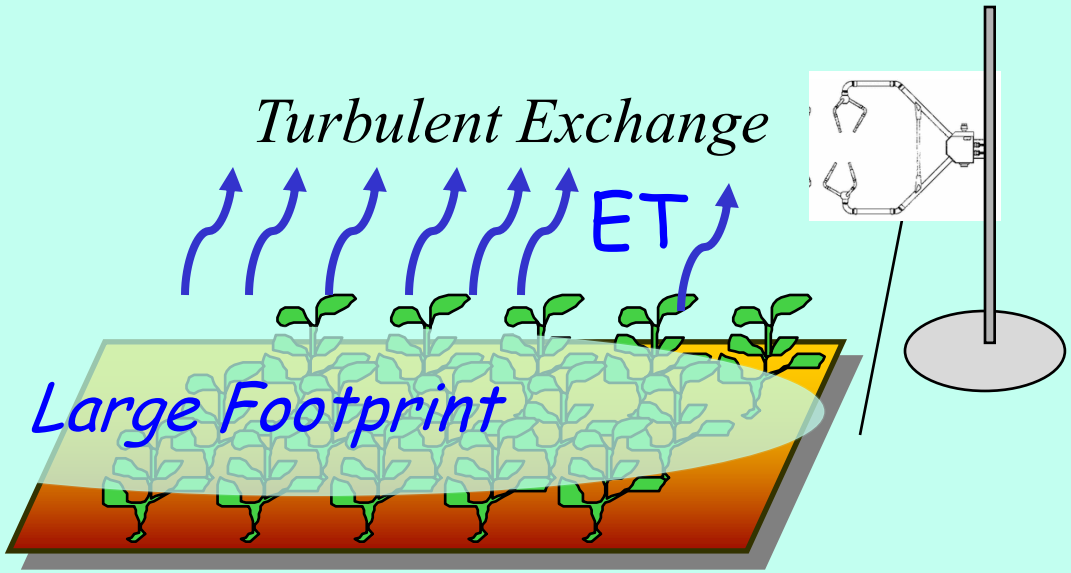




Expensive-- ~$25,000+

Mass Balance in Atmosphere

Vertical Turbulent Measurement of Gas Exchange using Sonic Anemometers and Gas Analyzers, 10 to 20 times a second: "Eddy Flux" or "Eddy Covariance"



Mass Balance in Atmosphere

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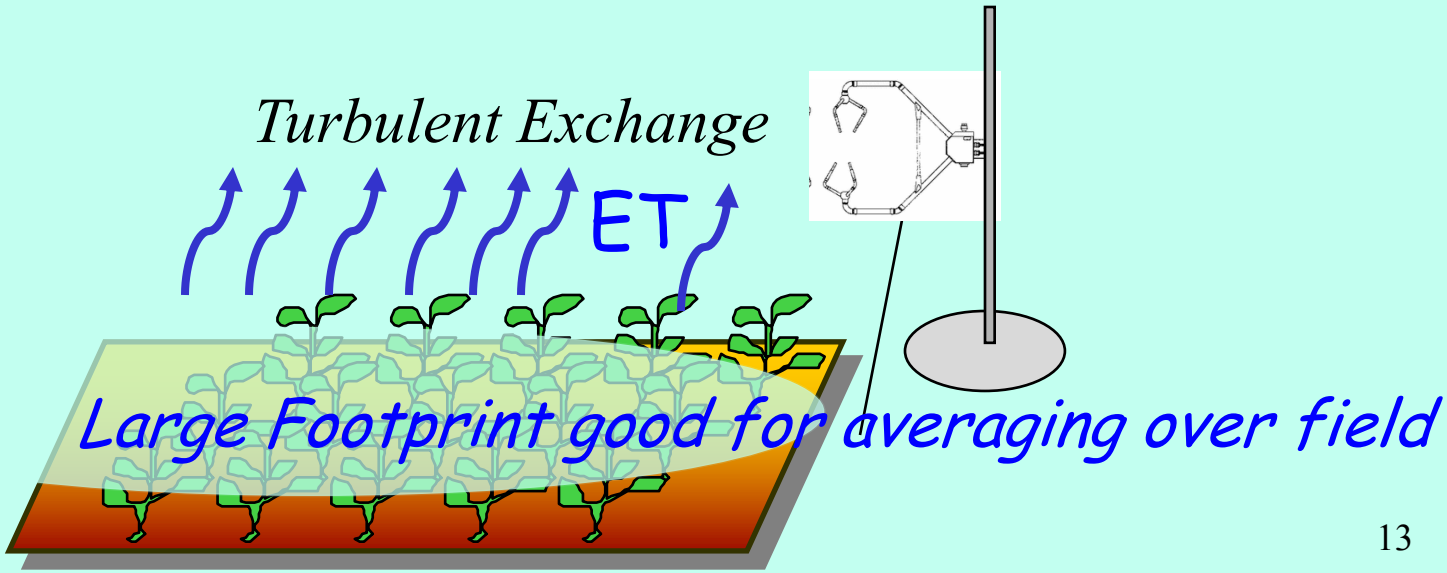
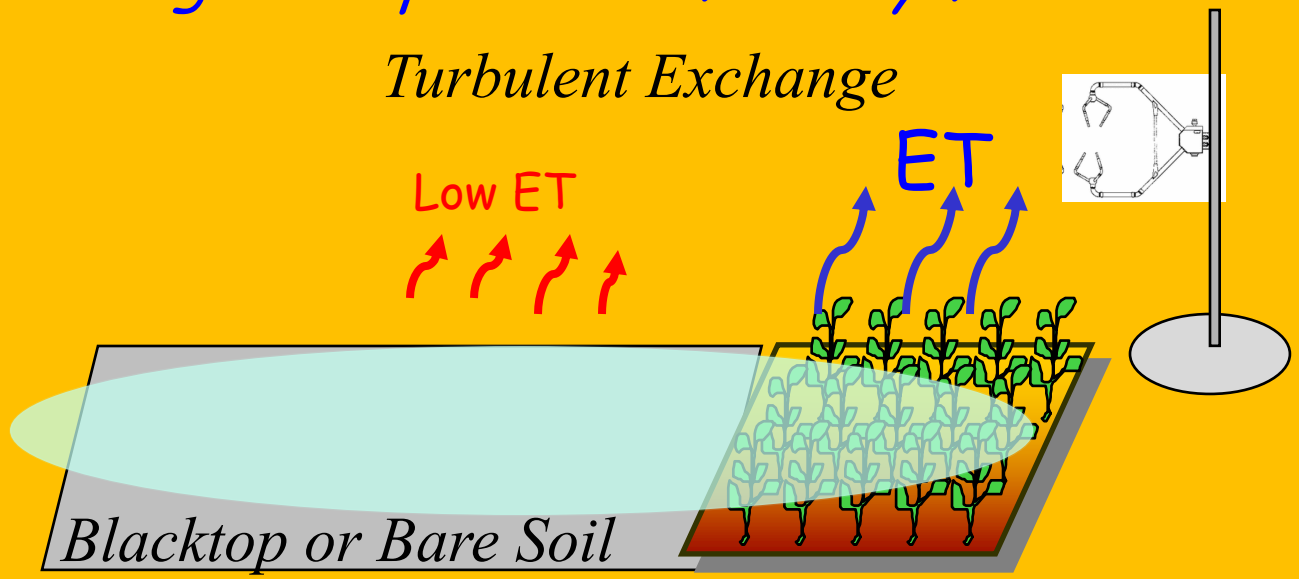


Mass Balance in Atmosphere

Vertical Turbulent Measurement of Gas Exchange using Sonic Anemometers and Gas Analyzers, 10 to 20 times a second-- "Eddy Flux" or "Eddy Covariance"

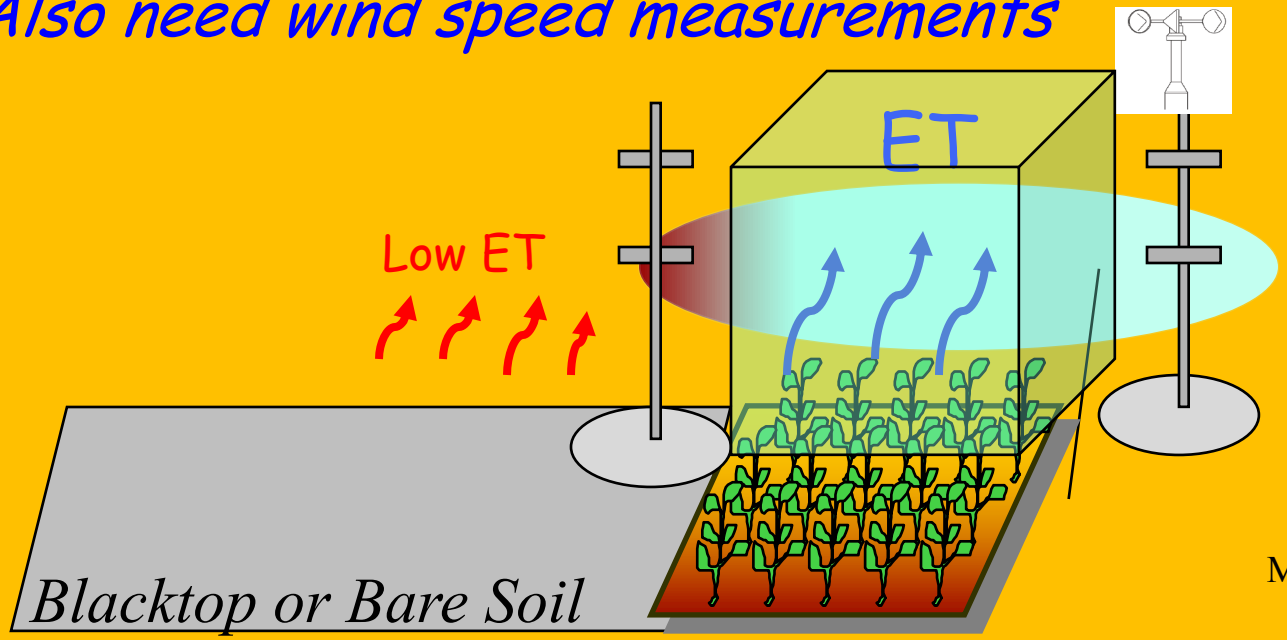
Large Footprint bad for tiny fields



Mass Balance in Atmosphere

Mass Budget Method for Small Fields, assumes little vertical exchange

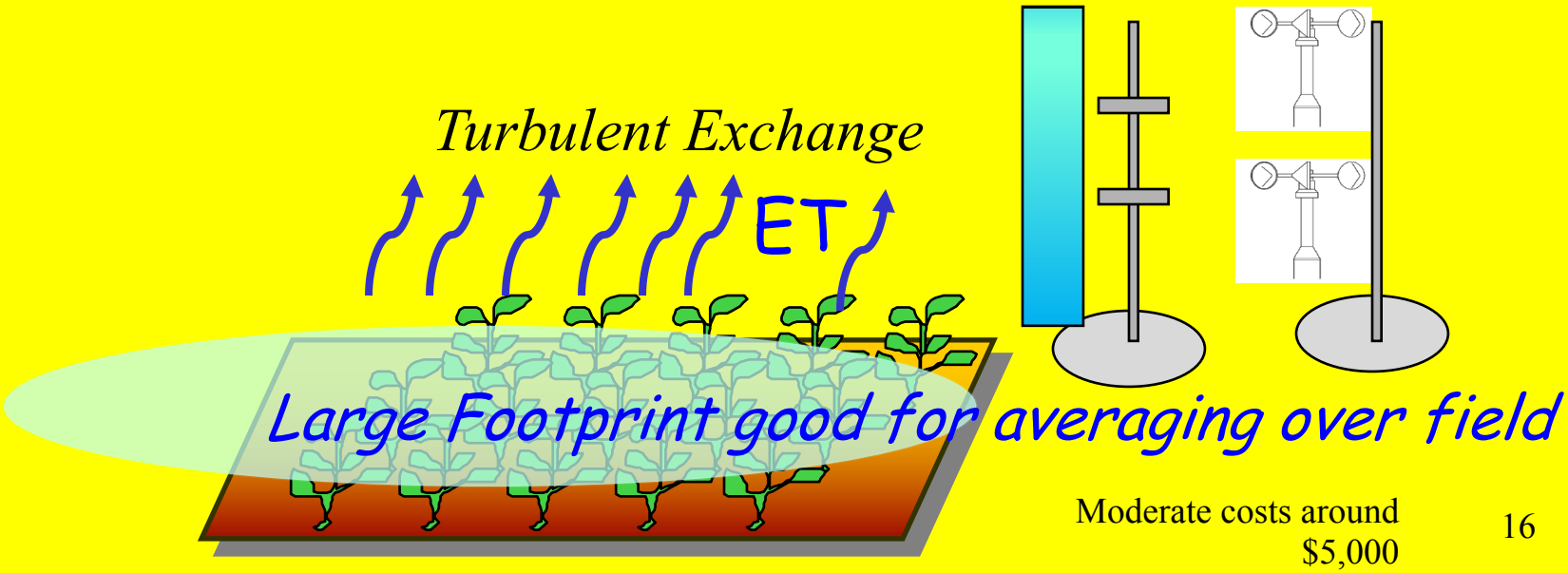
Measure Humidity upwind, downwind, look at difference
Also need wind speed measurements



Moderate costs around $4,000

Mass Balance in Atmosphere

With Large Fields other Methods also: Aerodynamic Method, need wind speeds, relative humidity and temperature at two heights; look at decrease in humidity with height; challenges in measuring decreases because they can be small



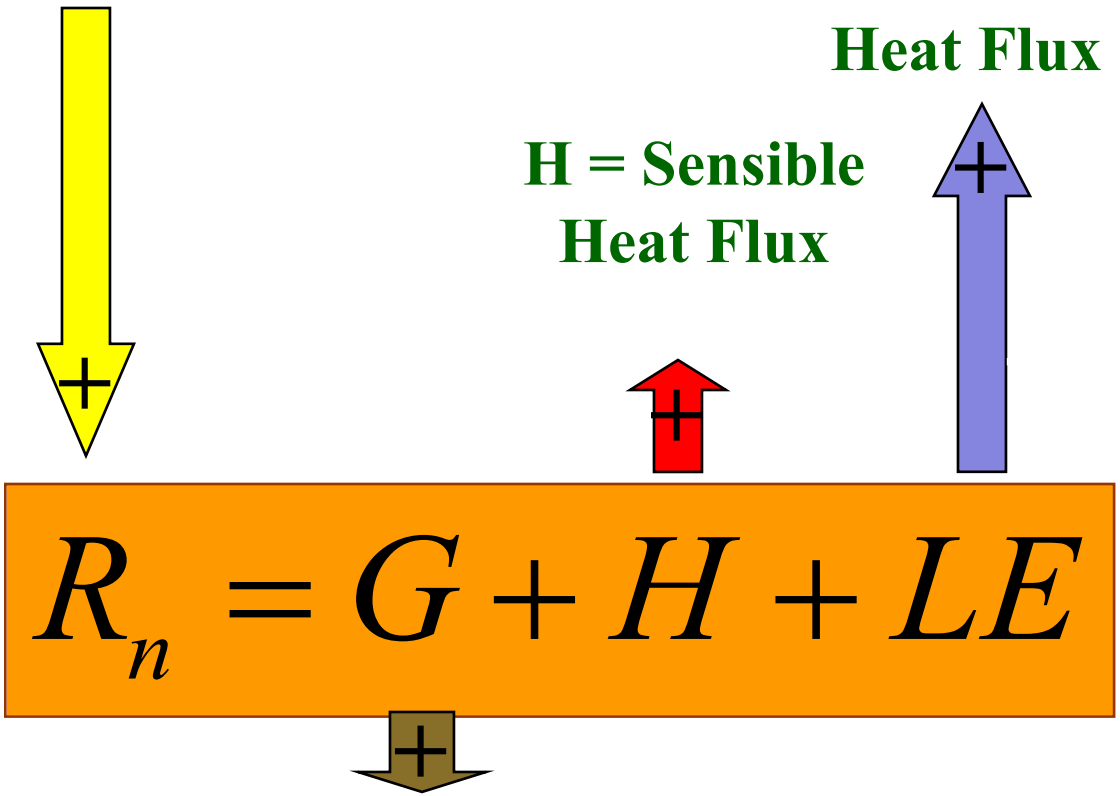
Moderate costs around $5,000

Energy Balance Methods Linked to Mass Balance

Rn = Net Radiation

LE = Latent Heat Flux

H = Sensible Heat Flux



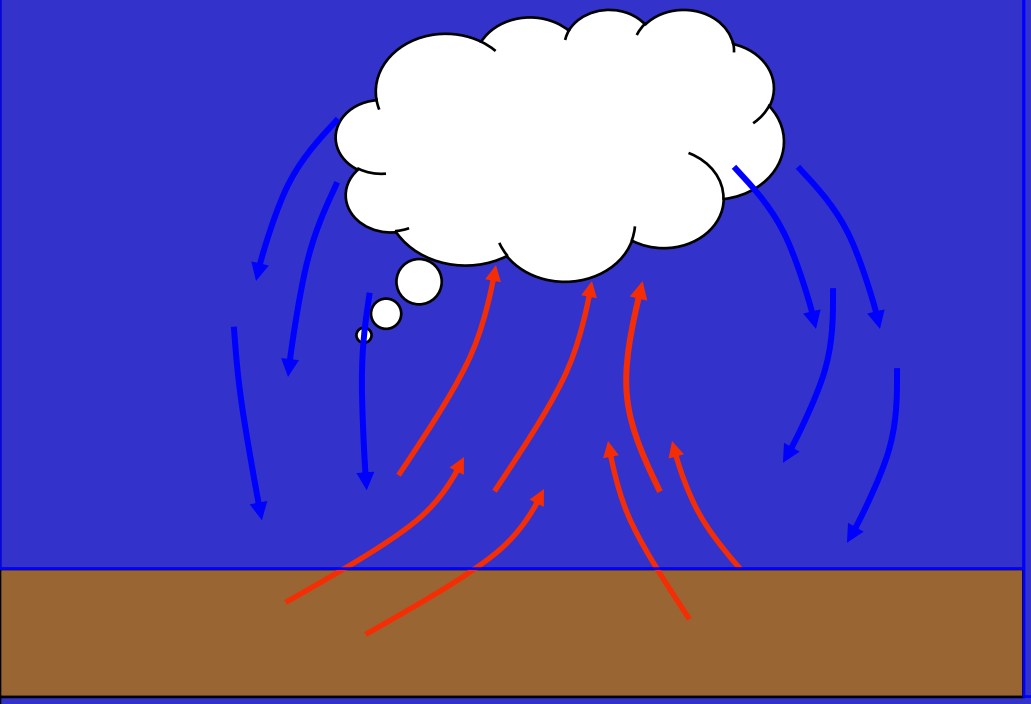
G = Ground Heat Flux

Methods of Heat Transfer

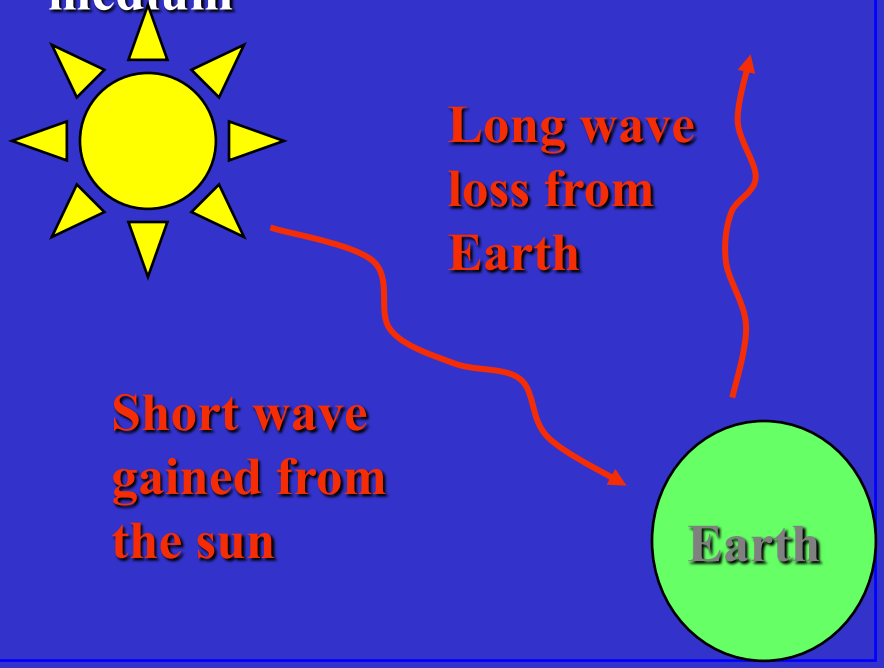
(G) Conduction- from molecule to molecule

Heat Source → Metal bar

Convection-Sensible heat (H) - by movement of heated air



Radiation (Rn) - energy passing from one object to another without a connecting medium

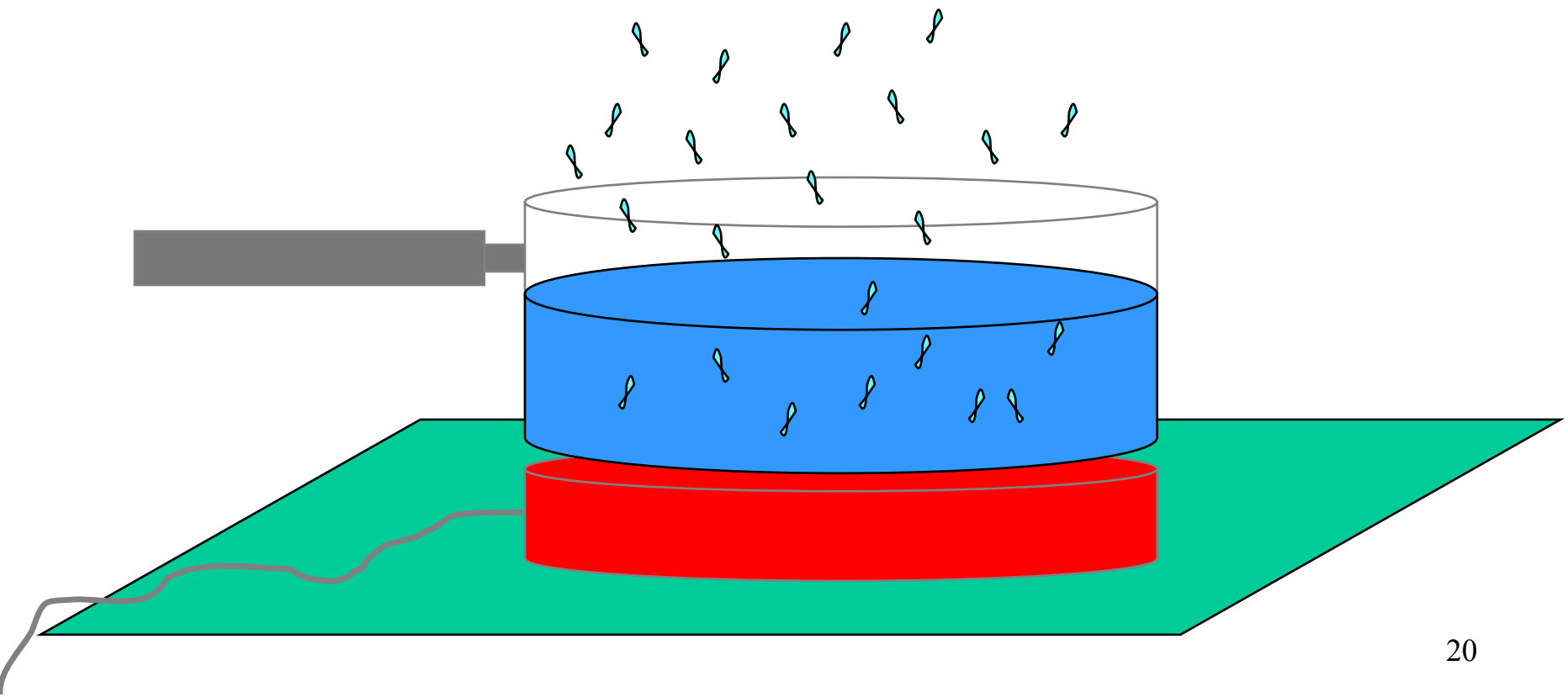


Latent Heat Flux (LE)

Energy from phase change of water resulting in water vapor release into the air, or water vapor changing into liquid or solid on surfaces +
vapor is added to the air by evaporation, takes energy and water away from surface

- vapor is subtracted from the air by condensation/sublimation-deposition, adds energy to surface which now has moisture on it

Latent Energy is needed to break hydrogen bonds



Latent Heat Flux Density

$$LE = L \times E$$

$$J\ m^{-2}\ s^{-1} = J\ kg^{-1} \times kg\ m^{-2} s^{-1}$$

$$L \approx 2.45 \times 10^{6}\ J\ kg^{-1} \approx 2.45\ MJ\ kg^{-1}$$

Evapotranspiration from LE:

$$ET = LE/L$$

This is the link between mass balance and energy balance

Radiation (Rn)

Electromagnetic radiation – a form of energy derived from oscillating magnetic and electrostatic fields that is capable of transmission through empty space.

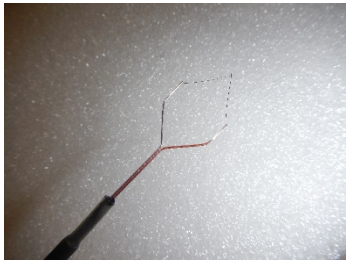
Can be measured with Net Radiometers

Sensible Heat Flux (H)

Movement of air (usually turbulent) from one location to another transfers heat

Can be measured by Eddy-Flux

or Surface Renewal

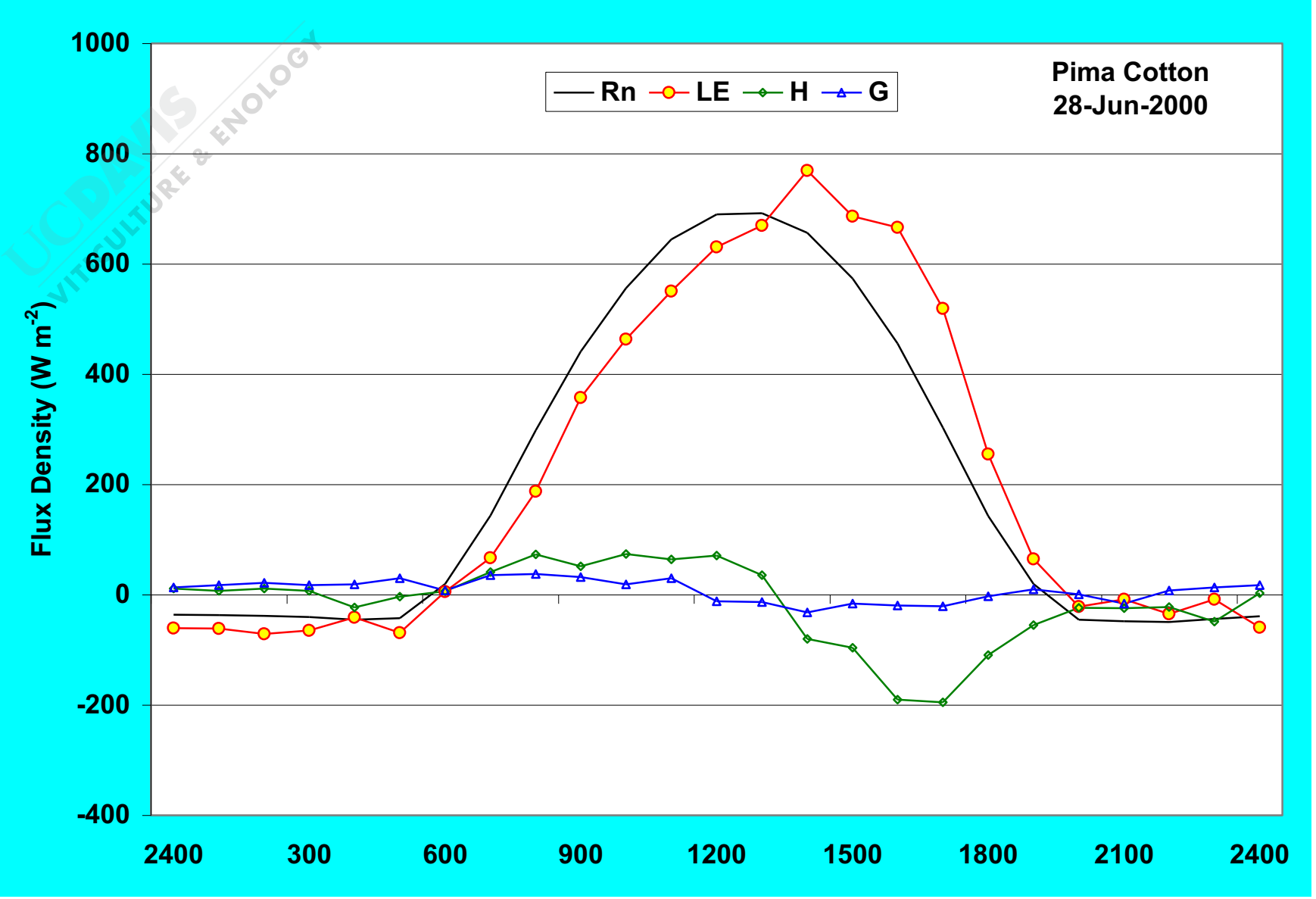


or Aerodynamic Methods

Conduction (G)

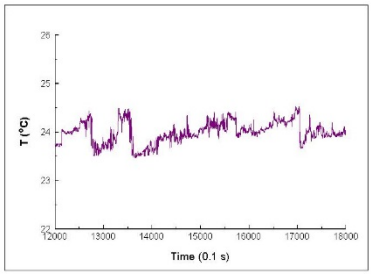
Movement of heat from surface, then through a solid in response to a temperature gradient-- Storage of Energy in soil and biomass.

Can be Measured with Soil Heat Flux Plates and soil temperature sensors


Rn
LE
H
G
Pima Cotton
28-Jun-2000
Flux Density (W m-2)
1000
800
600
400
200
0
-200
-400
2400
300
600
900
1200
1500
1800
2100
2400

Energy Balance Methods Linked to Mass Balance– Energy Budget Residual

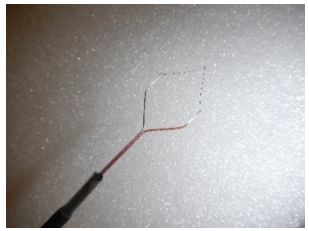
Rn = Net Radiation



Eddy Flux~$10,000

H = Sensible Heat Flux

$$LE = R_n - G - H$$



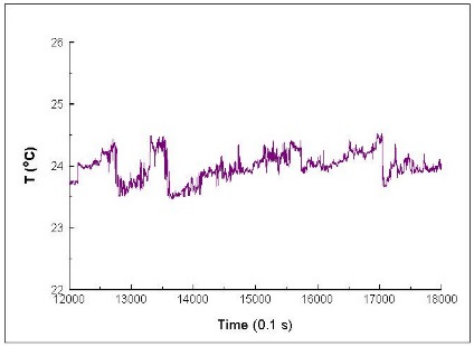
G = Ground Heat Flux or ~0 over day

Surface Renewal $5,000-$7,000

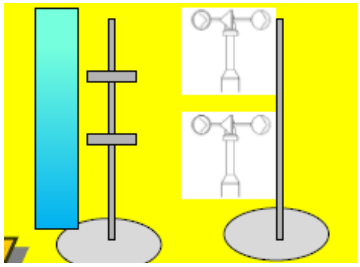
Energy Balance Methods Linked to Mass Balance– Energy Budget Residual Sensible Heat Measurement and Estimation

$$LE = R_n - G - H$$

H = Sensible Heat Flux



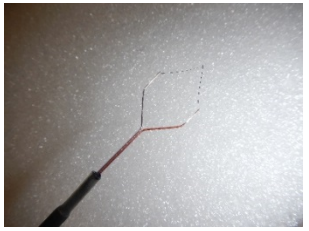
Aerodynamic Method ~$5,000

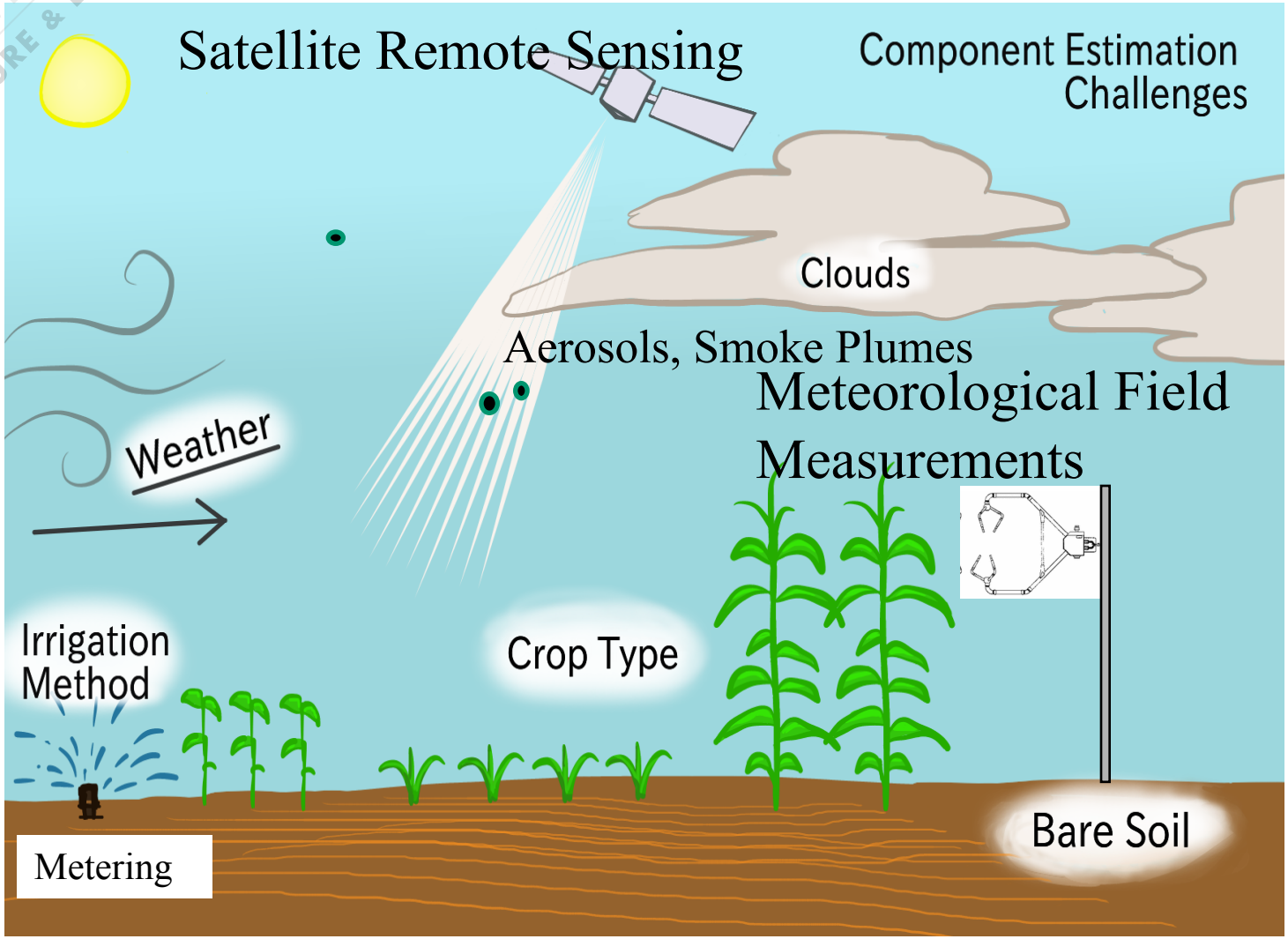


Eddy Flux~$10,000

Infrared Thermometers, wind speed, air temperature~$6,000-$8,000

Surface Renewal $5,000-$7,000





Modified from A Comparative Study for Estimating Crop Evapotranspiration in the Sacramento-San Joaquin Valley; Medellin-Azuara, Paw U et al.; https://ucdavis.app.box.com/s/yp99952rfp4xd0po6pm7ftc6k6owc30o

Energy Balance Methods Linked to Mass Balance– Energy Budget Residual

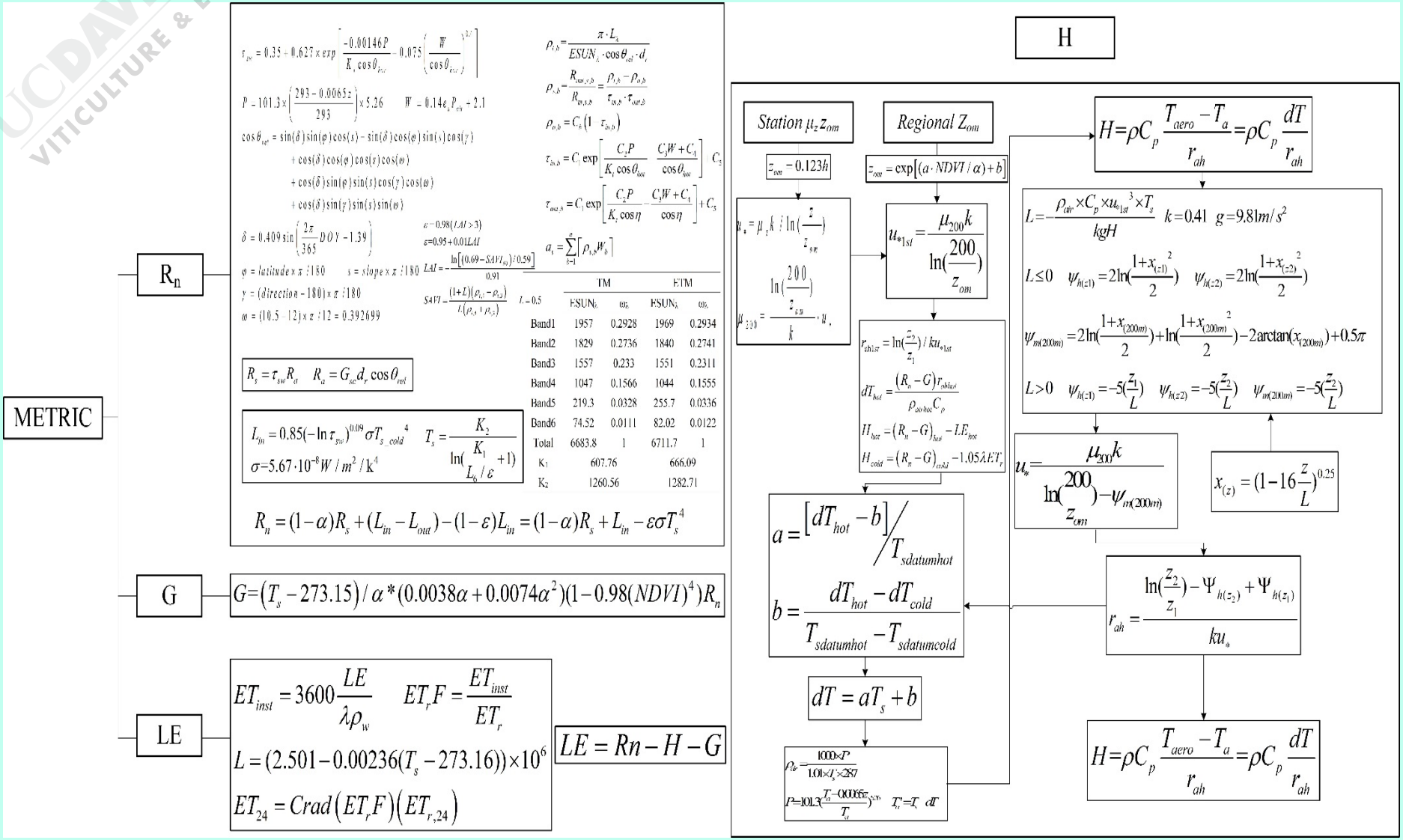
Rn = Net Radiation Estimated from Satellite data

H = Sensible Heat Flux Estimated from Remotely Sensed Surface Temperature

$$LE = R_n - G - H$$

G = Ground Heat Flux Estimated from Rn or ~ 0 over a day

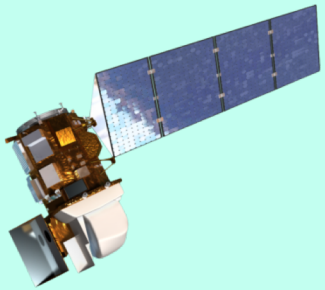
Satellite Modeling Methods: Example of one Model (METRIC)



From Tao Zhang, visiting graduate student at UCD Biomicrometeorologial Team

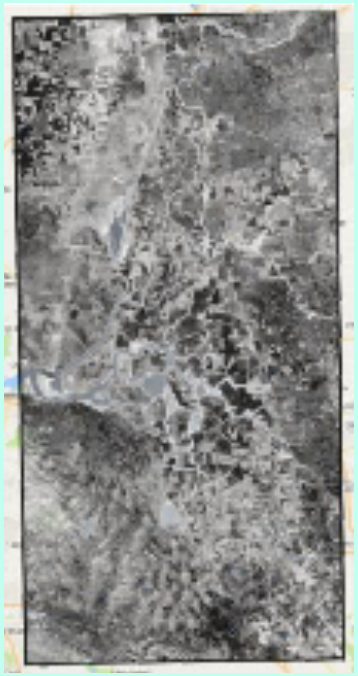
Modeling Consumptive Water Use

Satellite Remote Sensing



Advantages

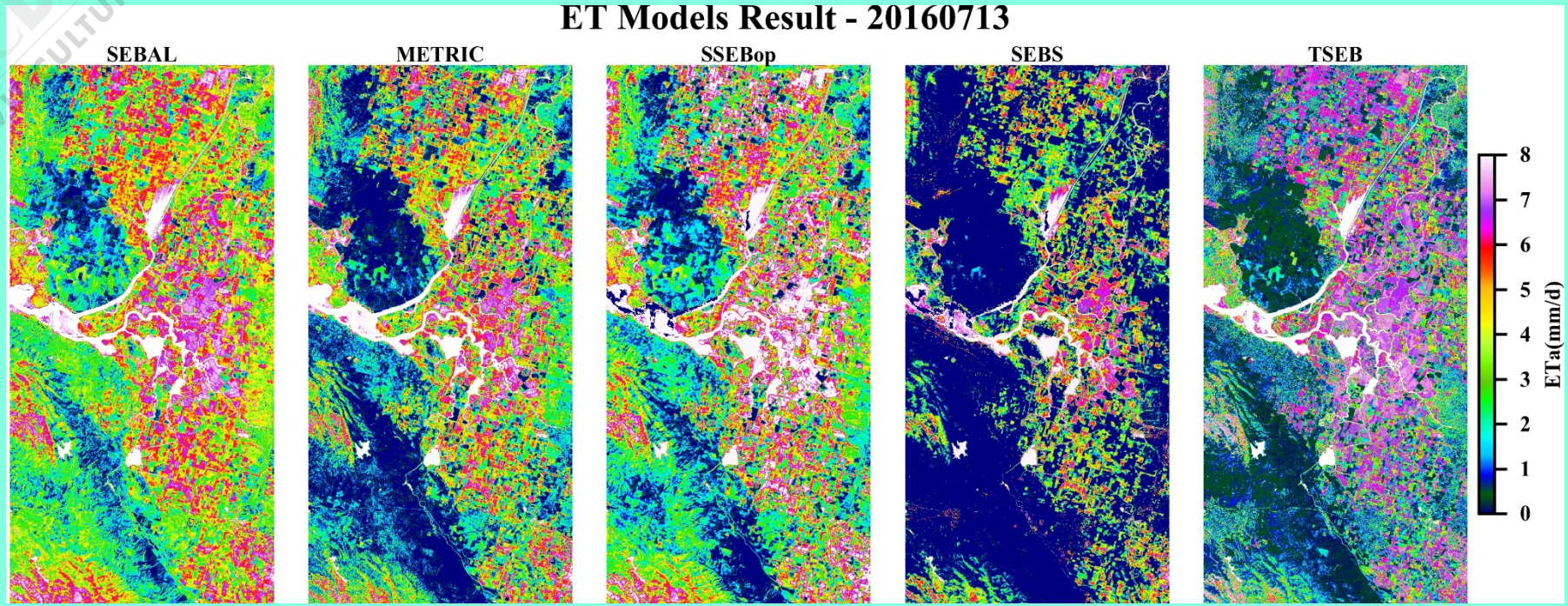
- Complete spatial coverage, covers large areas
- Less expensive than many field measurements (for large areas such as the entire state of California)
- Some Savings because much of the launching and operation infrastructure already paid for by US Federal Gov't and other sources.



Disadvantages

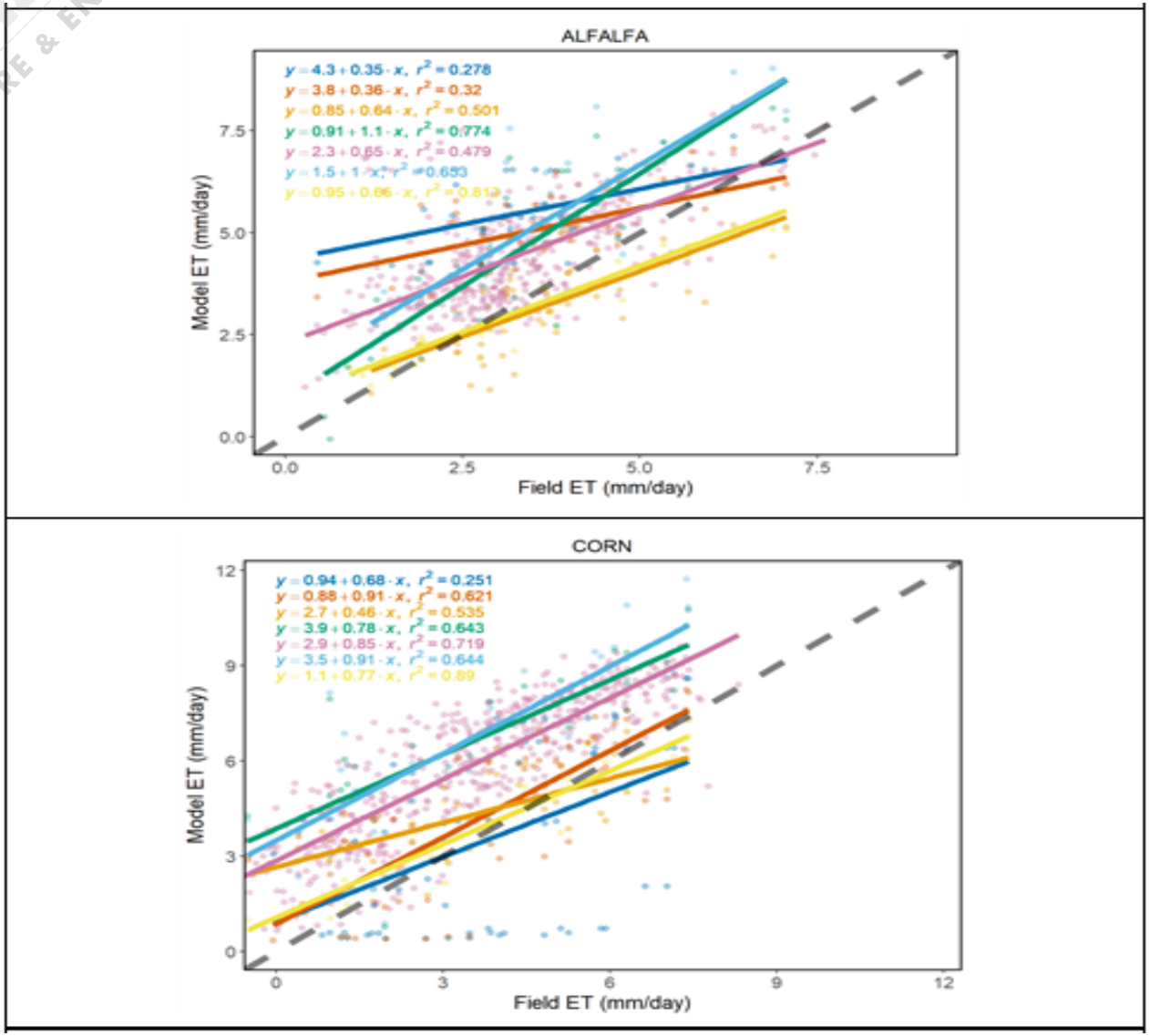
- Satellite overpasses only about every 8 days to two weeks –between 11 am and noon; ET must be interpolated in between, each field seen for around 1/70th of a second (for the individual field scale)
- Can only measure radiation emitted or reflected by surfaces after passing through the atmosphere: visible, near infrared, and thermal infrared, so ET must be inferred from these radiation snapshots using models

Comparisons of Remote Sensing Models



Significant differences between different Remote Sensing Models

Application to a Delta July 13, 2016, from Tao Zhang



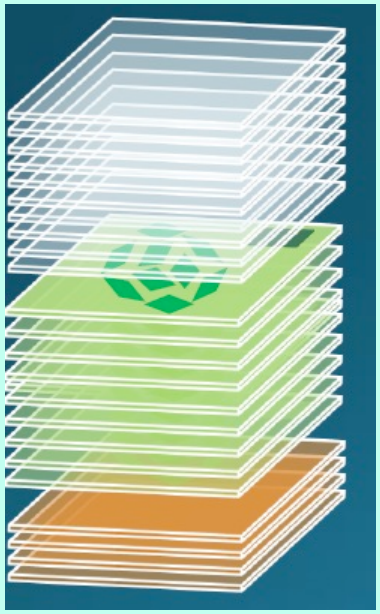
ET from Models vs Field Measurements

Dashed Black Line = 1:1 agreement

Modified from A Comparative Study for Estimating Crop Evapotranspiration in the Sacramento-San Joaquin Valley; Medellin-Azuara, Paw U et al.; https://ucdavis.app.box.com/s/yp99952rfp4xd0po6pm7ftc6k6owc30o

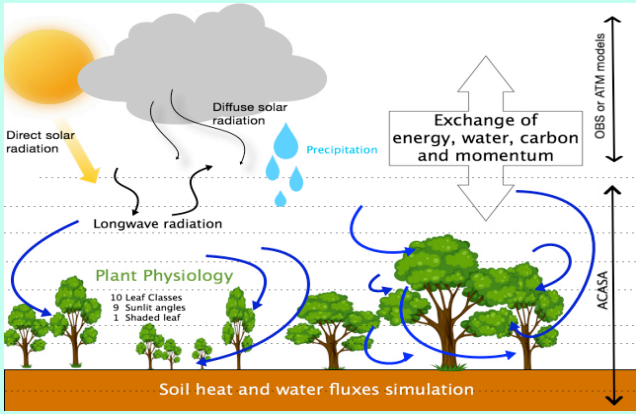
Modeling Consumptive Water Use

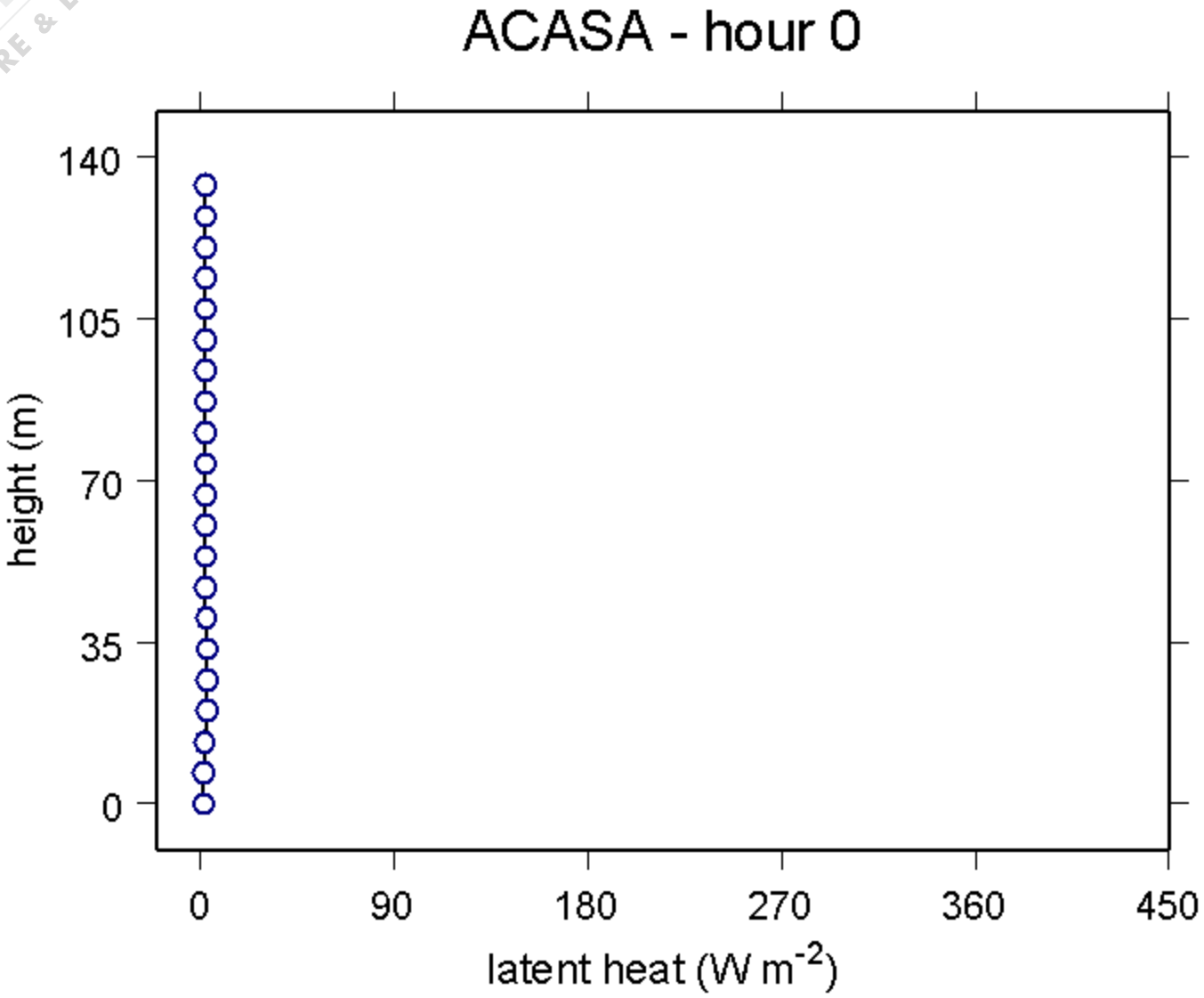
Land Surface Biomicrometeorological Models and Regional Scale Weather Models

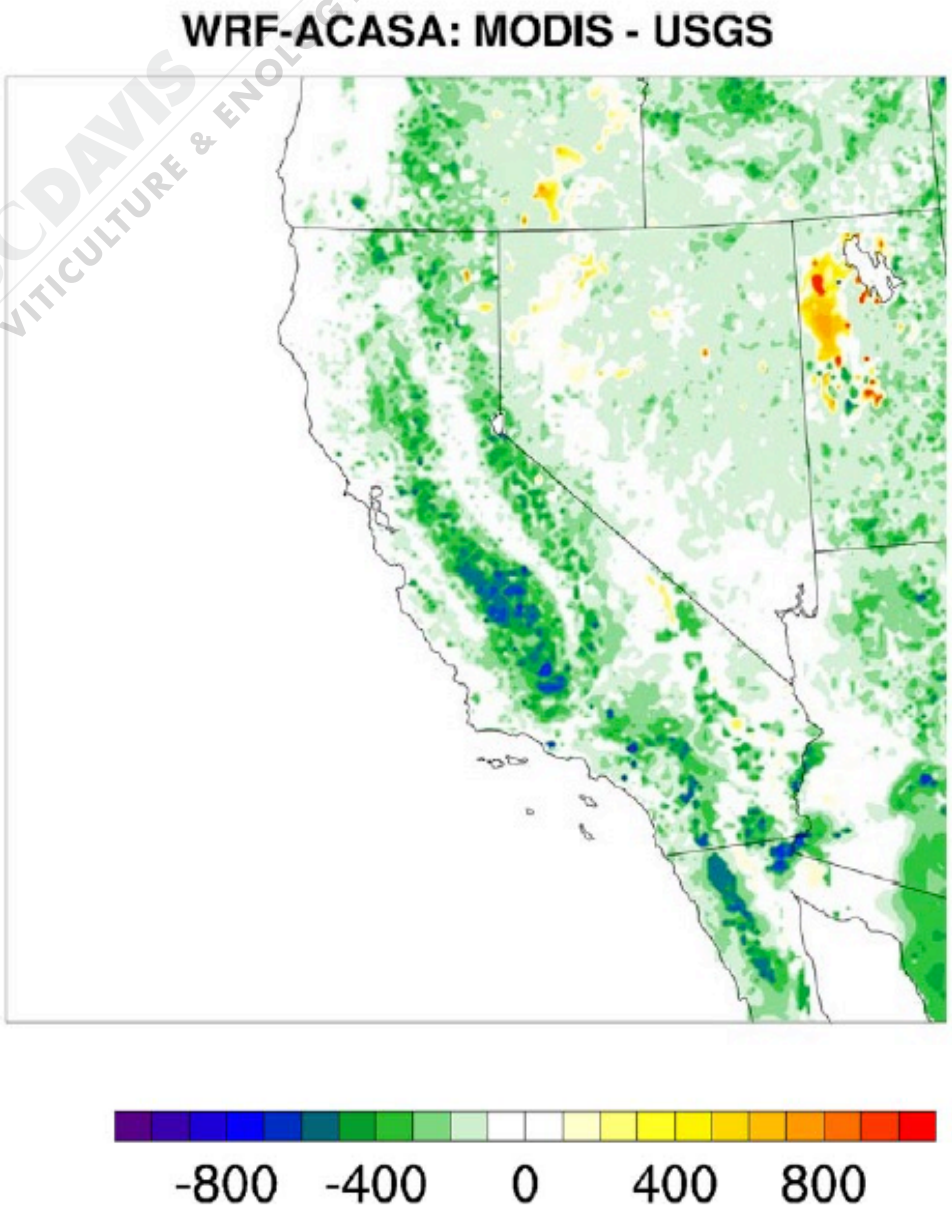


Use for Climate Extremes, Variability, Climate Change Analysis

- Process-based includes soil physics, plant physiology, turbulent transfer, regional scale interactions, cloud formation, precipitation
- Example here is Weather Research & Forecasting Model (WRF) and the UC Davis Advanced Canopy Atmosphere Soil Algorithm (ACASA)
- Can link carbon balance to water use of plant systems, including agricultural fields and wildlands







Regional ET using WRF-ACASA

mm/yr

Taken from Xu et al. 2017 Agricult. Forest Meteorol. 247:79

Take Away Points

- Field Measurements to characterize small and large fields possible, costs range from ~ $5,000 to $30,000+. Field size important.
- Technological advances could decrease costs for field measurements and drone based sensors
- Satellite or Pseudo-Satellite Remote Sensing important for Regional and State scale ET estimates, but still much room for improvements and have increased uncertainty for application for different agricultural methods and to wildlands and urban areas
- New Satellite technologies could improve models' utility
- Field measurements needed to continue calibrating Remote Sensing especially in the context of California's diversity of commodities, wild lands and microclimates & individual fields
- Advanced surface layer models linked to regional scale models can be developed to understand evapotranspiration and its effects on weather (WRF-ACASA)

Acknowledgments

Delta Growers and Land Owners, State Water Resources Control Board, California Department of Water Resources, Delta Stewardship Council, Metropolitan Water District; Michael George and John Collins; Western Regional Center (WESTGEC) of the National Institute for Global Environmental Change (NIGEC) through the U.S. Department of Energy (Cooperative Agreement No. DE-FC03-90ER61010)

For their help with numerous fieldwork tasks: Jean-Jacques Lambert, Yongzong Lu, Tracy Zhou, David Quinones, Sean Freiberg, David Edgar, Clayton Kleppinger, Andrew Loberg, Jacob Feuerstien, Tao Zhang, and Shicheng Yan

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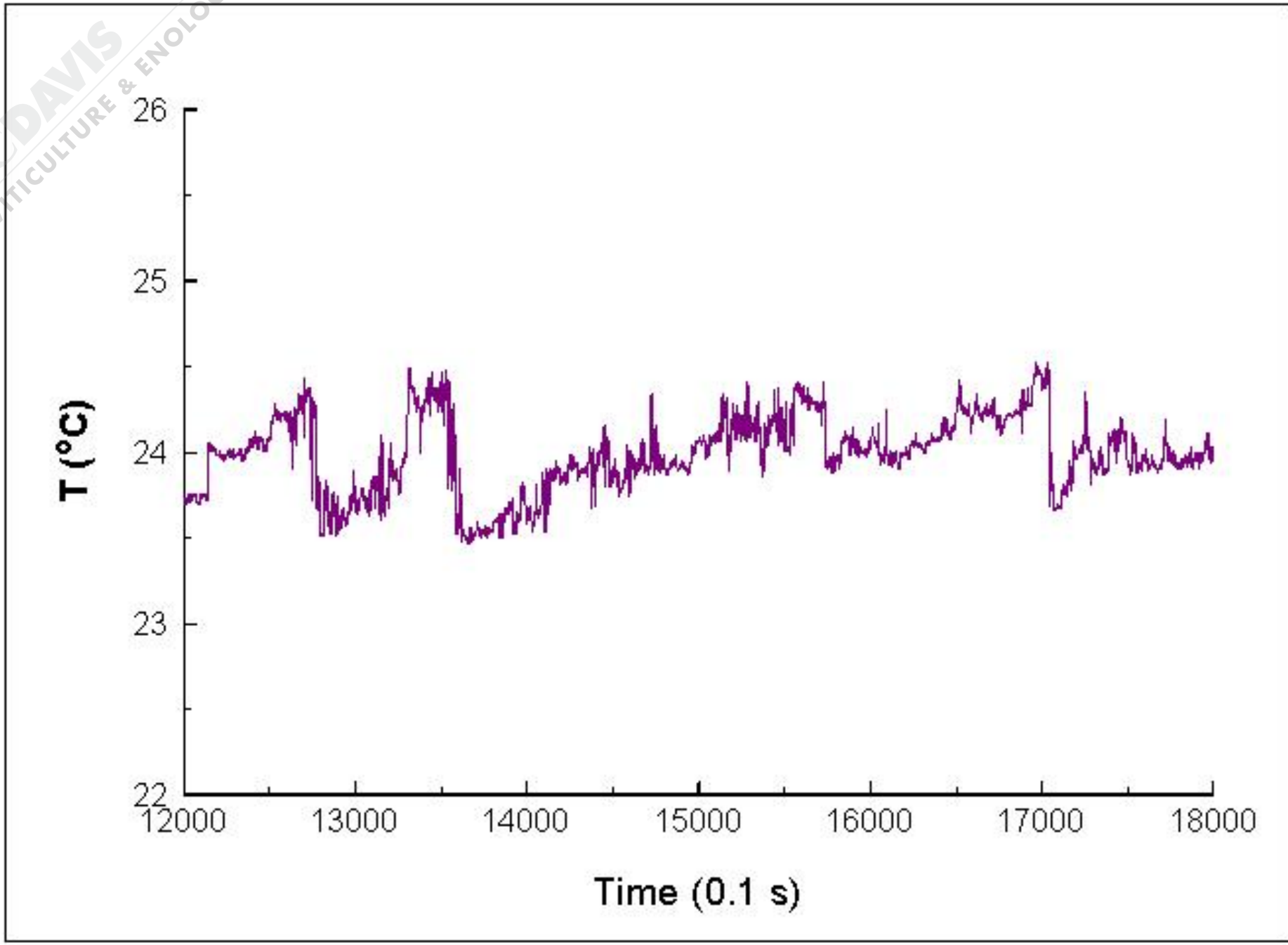
For their assistance with transportation to the field: UCD Fleet Services

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY
STATE WATER RESOURCES CONTROL BOARD

DELTA STEWARDSHIP COUNCIL

Eddy Covariance Sensors Bonus Slide 1

Bonus Slide 2



Bonus Slide 3

Footprint Analysis

- **What does your sensor "see"**
- **Conservative Rule--100 horizontal units for 1 unit height**
- **Daytime, convective--more like 5:1**
- **Nightime, stable--more like 100 or 500:1**