Observing Wisconsin Central Sands water budget components under high groundwater demand and a changing climate

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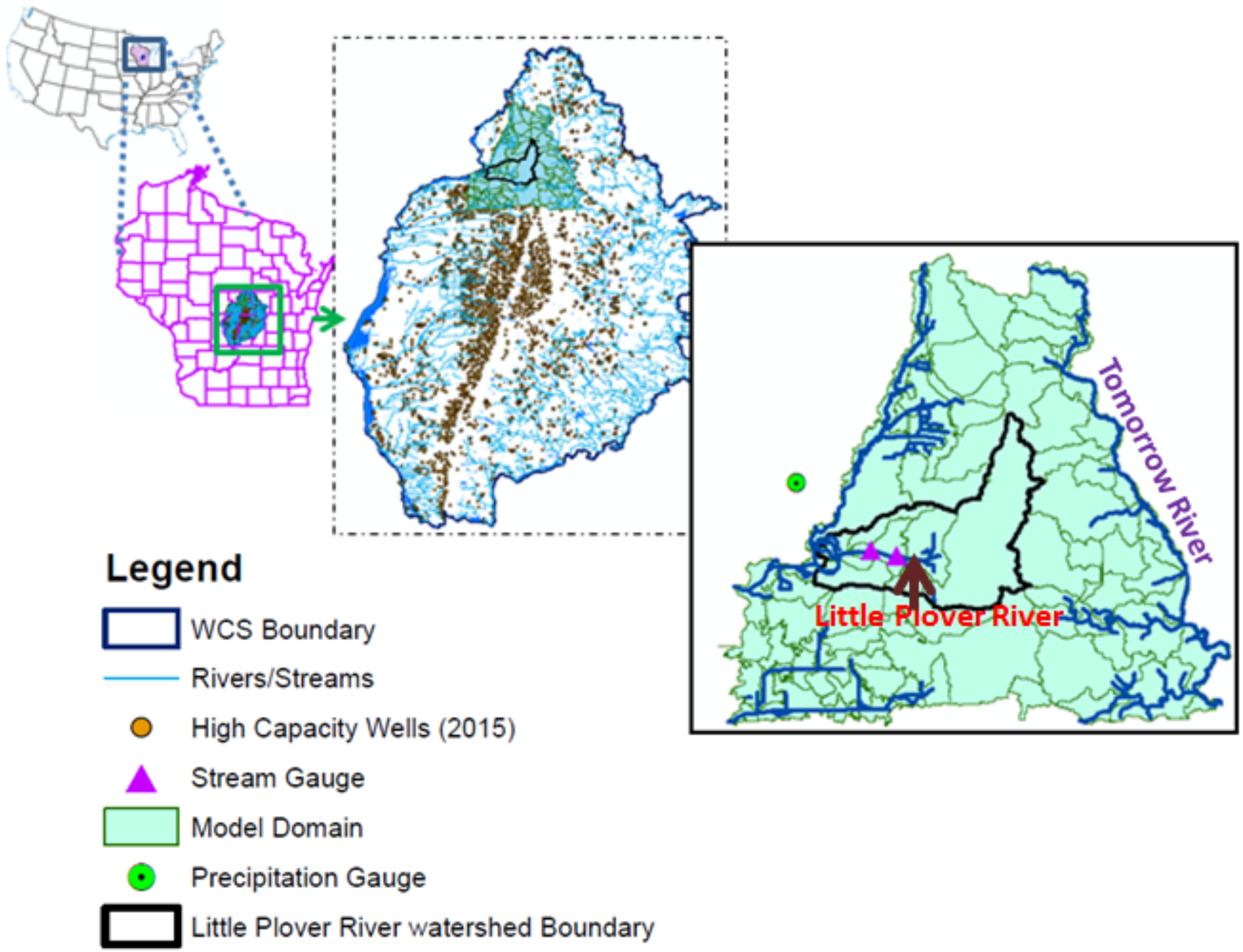
CPEP, Jan 30th 2018

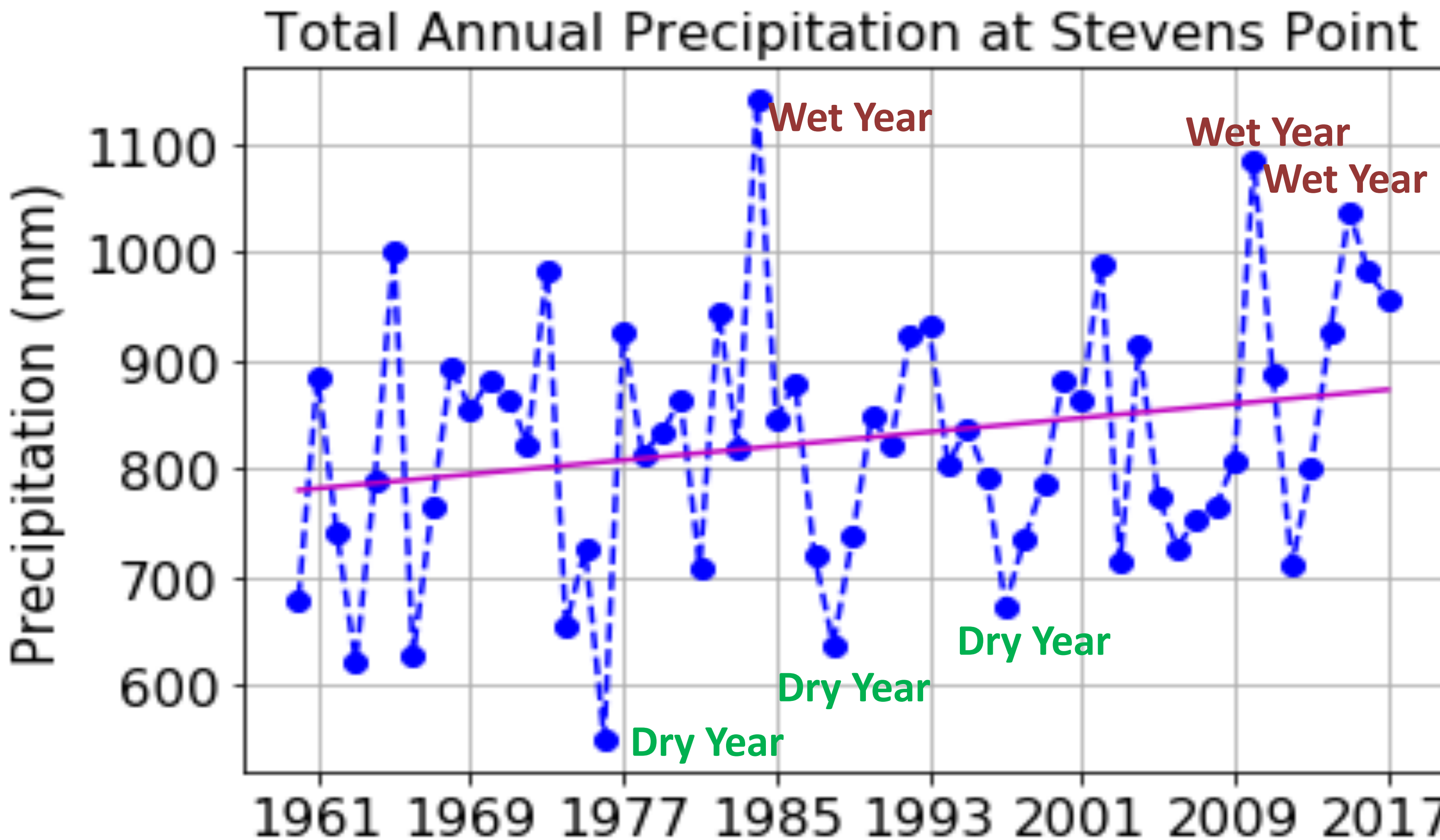
Outline

- Background
- Purpose/Objective
- Approach
- Results/Discussion
- Conclusion
- Future Research/Big Picture (Prof. Desai)

Background

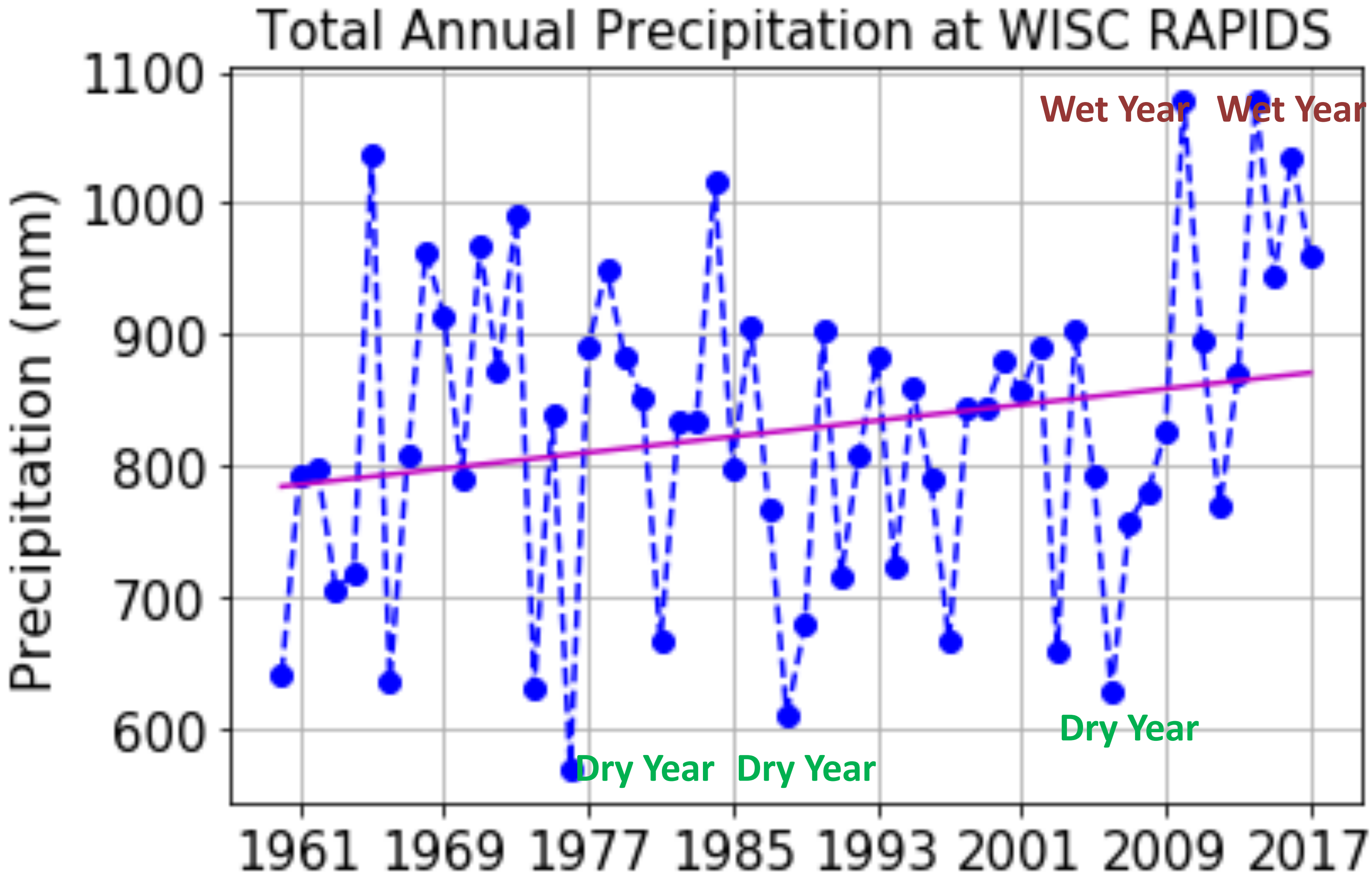

Tomorrow River
Little Plover River
Legend
WCS Boundary
Rivers/Streams
High Capacity Wells (2015)
Stream Gauge
Model Domain
Precipitation Gauge
Little Plover River watershed Boundary

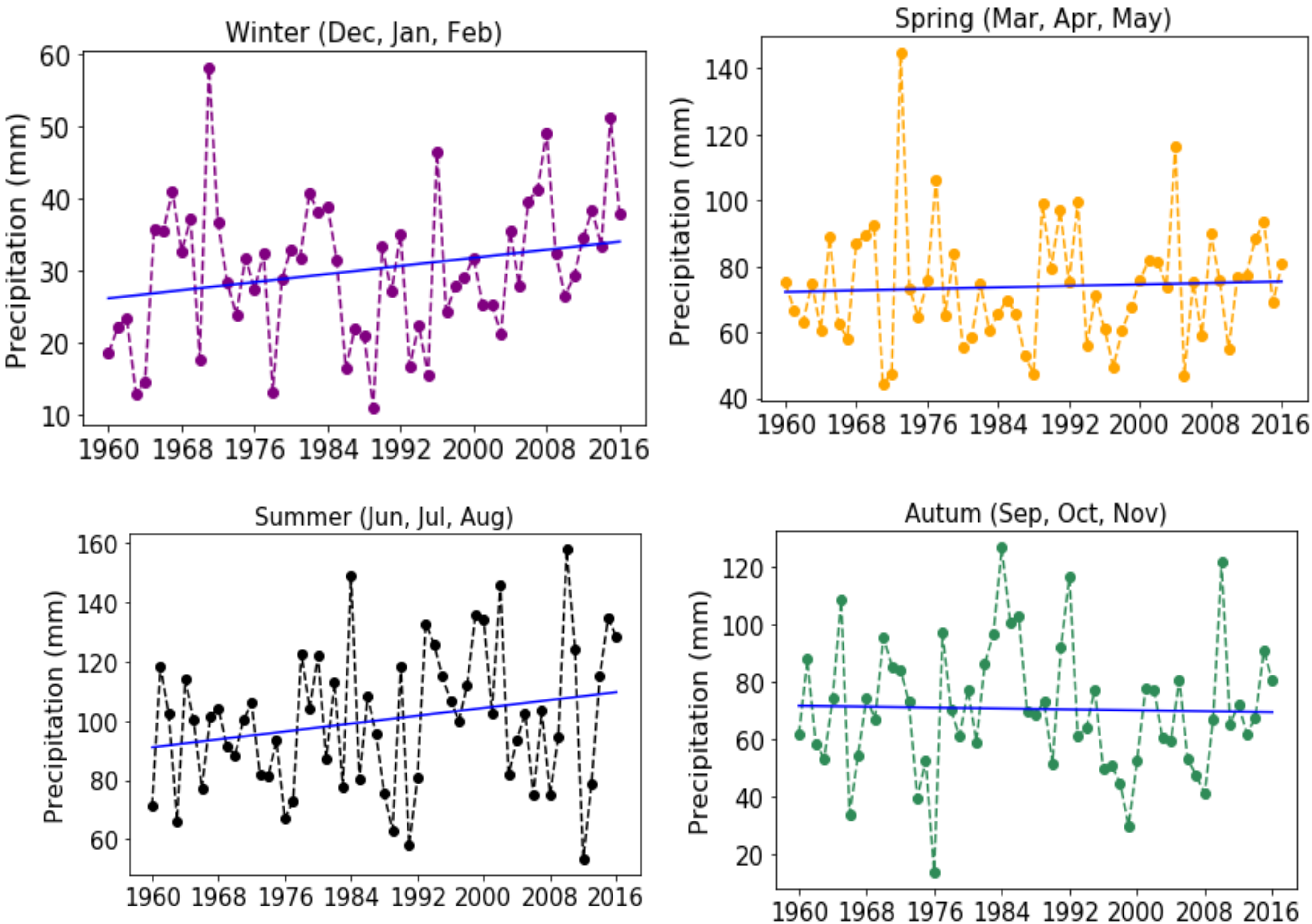

NOTICE
TREATED LAKE
ADVISE
CATCH & RELEASE
Long Lake
No Wake
NO LITTERING
PREVENT THE SPREAD OF
INVASIVE SPECIES
IT'S THE LAW
Before launching and before leaving
INSPECT
REMOVE
DRAIN
NEVER MOVE
STOP AQUATIC HITCHHIKERS!

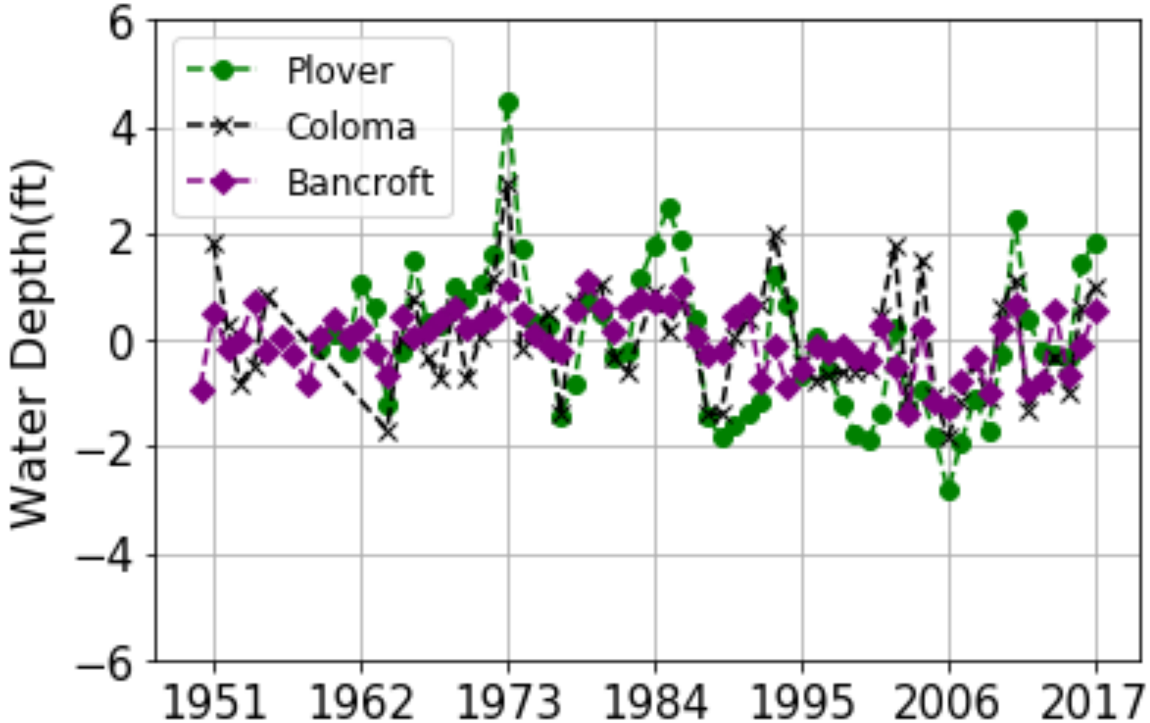


Wet Years
2014
2015
2016
2017

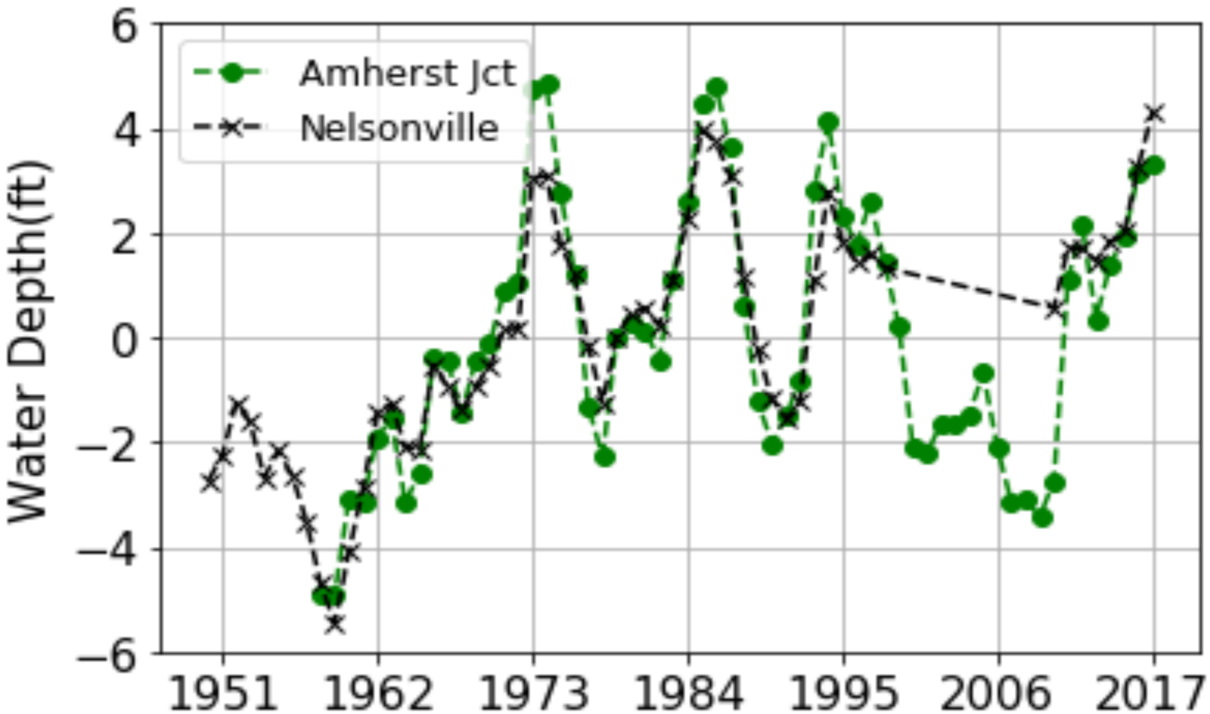
Dry Years
1988
1997
2003
2012


Total Annual Precipitation at WISC RAPIDS
Precipitation (mm)
1100
1000
900
800
700
600
1961
1969
1977
1985
1993
2001
2009
2017
Wet Year
Wet Year
Dry Year
Dry Year
Dry Year


Winter (Dec, Jan, Feb)
Spring (Mar, Apr, May)
Summer (Jun, Jul, Aug)
Autum (Sep, Oct, Nov)
Precipitation (mm)
1960 1968 1976 1984 1992 2000 2008 2016



High Capacity Wells

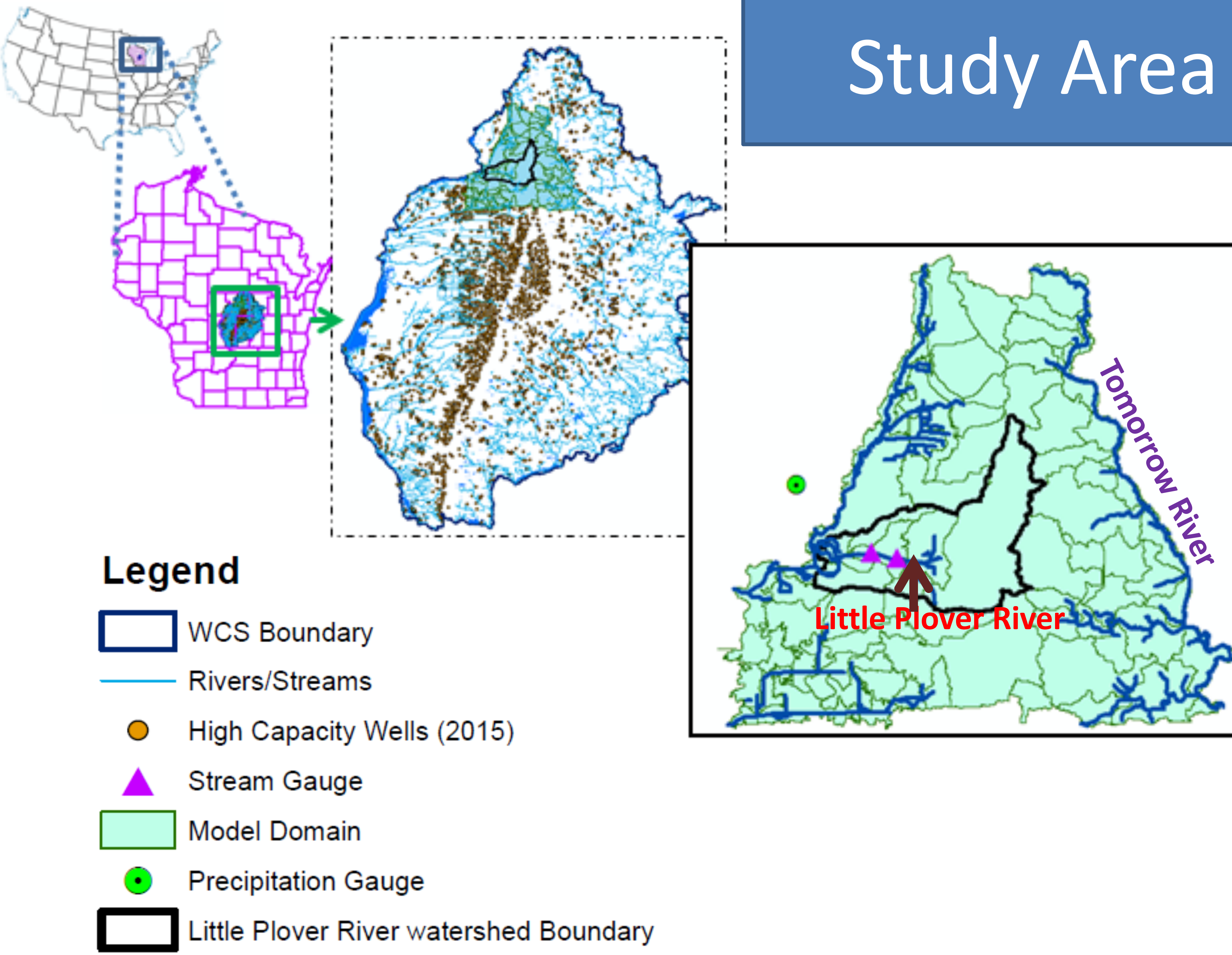


Low Capacity Wells


Little Plover River


War Over water in a Land of Plenty

Study Area


Tomorrow River
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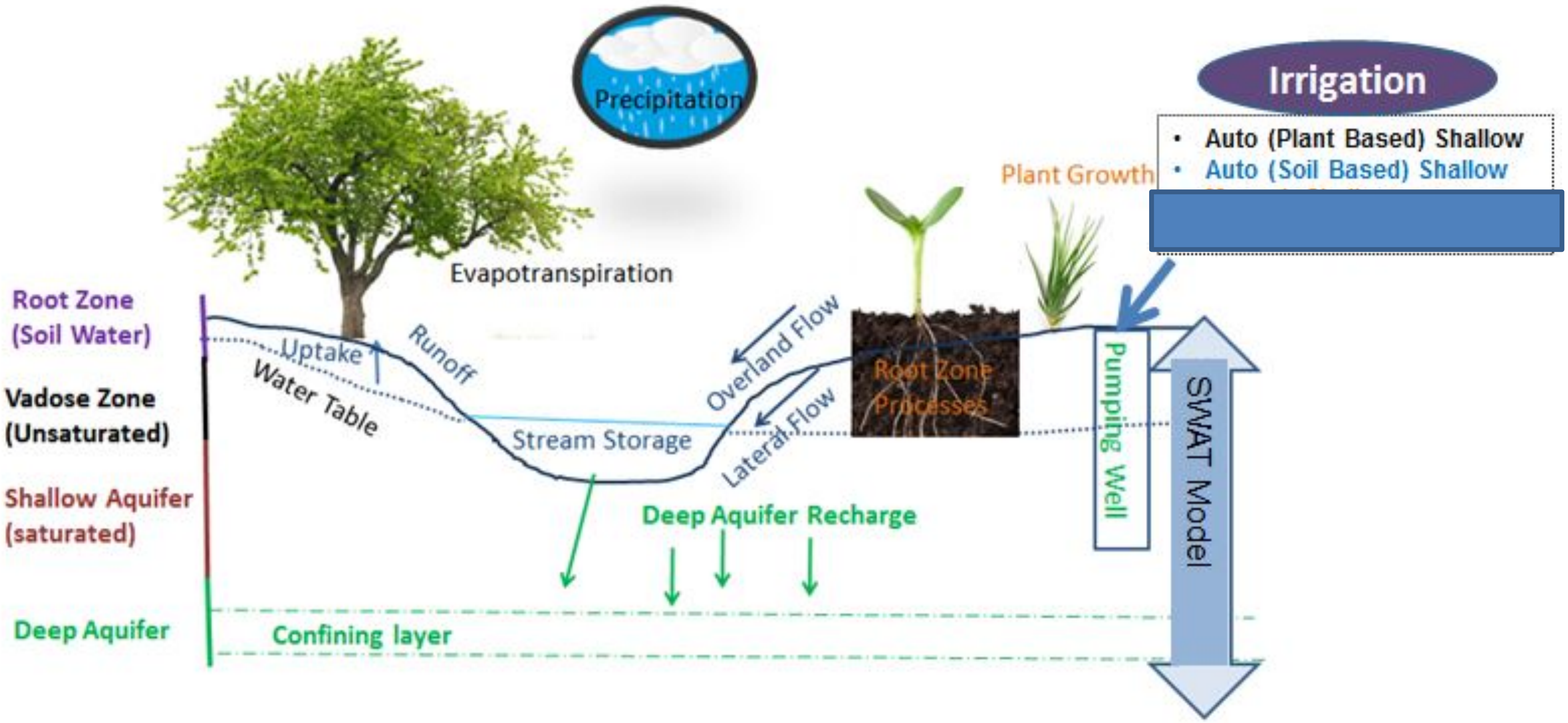
Legend
WCS Boundary
Rivers/Streams
High Capacity Wells (2015)
Stream Gauge
Model Domain
Precipitation Gauge
Little Plover River watershed Boundary

Purpose/Objectives

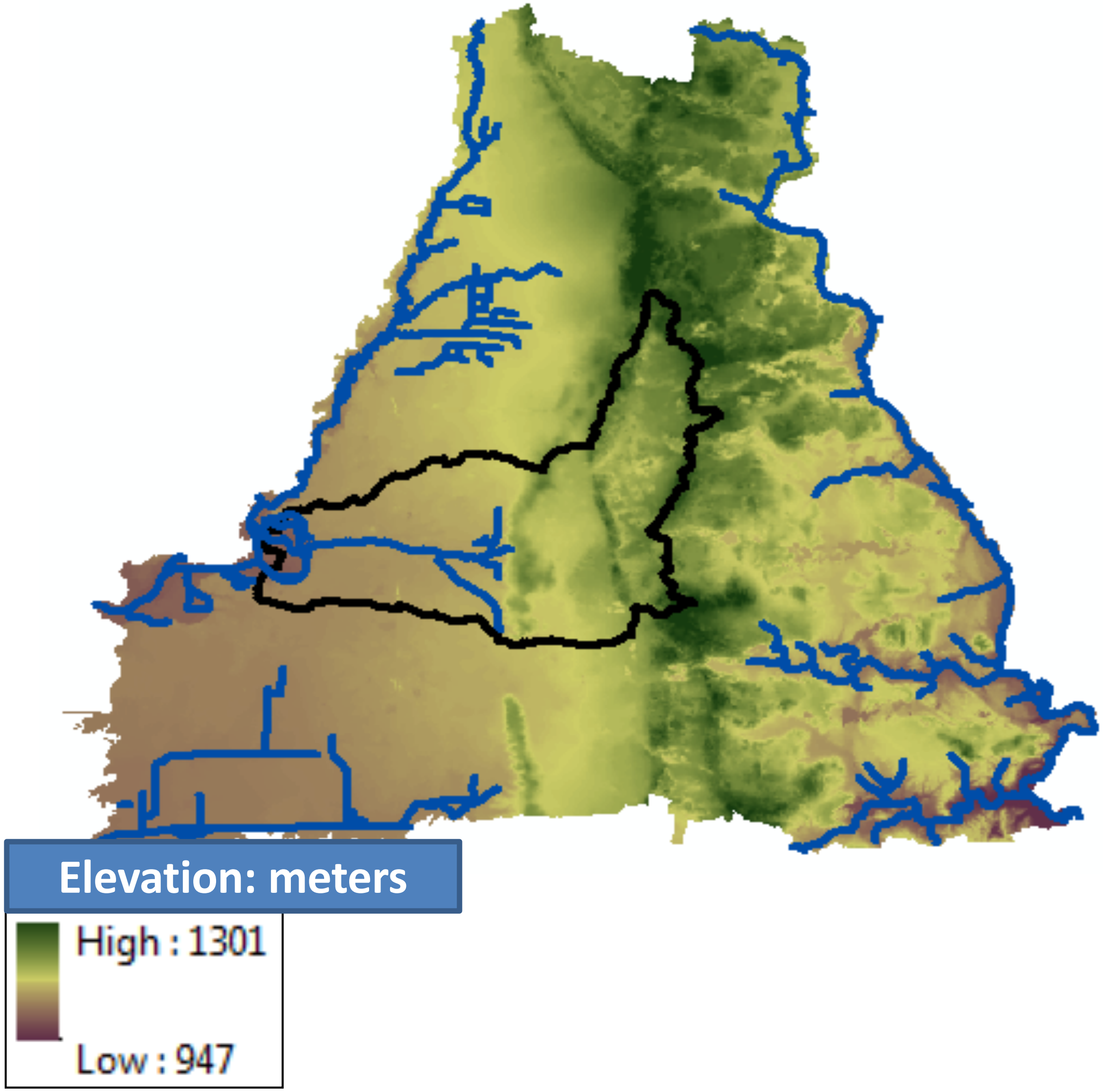
- Efficacy of hydrologic Models to adequately simulate irrigation practices

- Water budget based on crop types

Conceptual Framework for Hydrologic Model

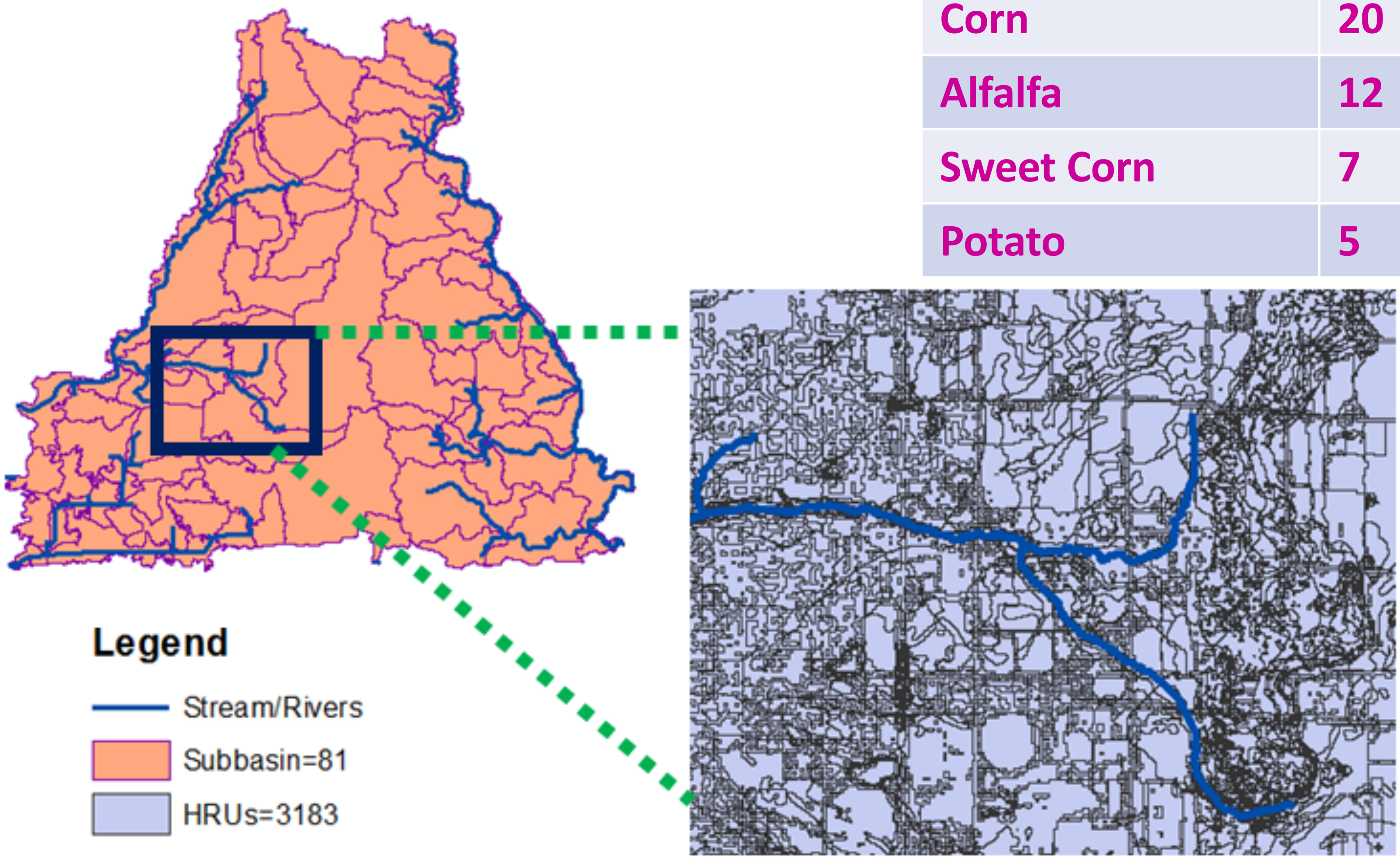


Watershed Delineation



Hydrologic Response Units (HRUs)

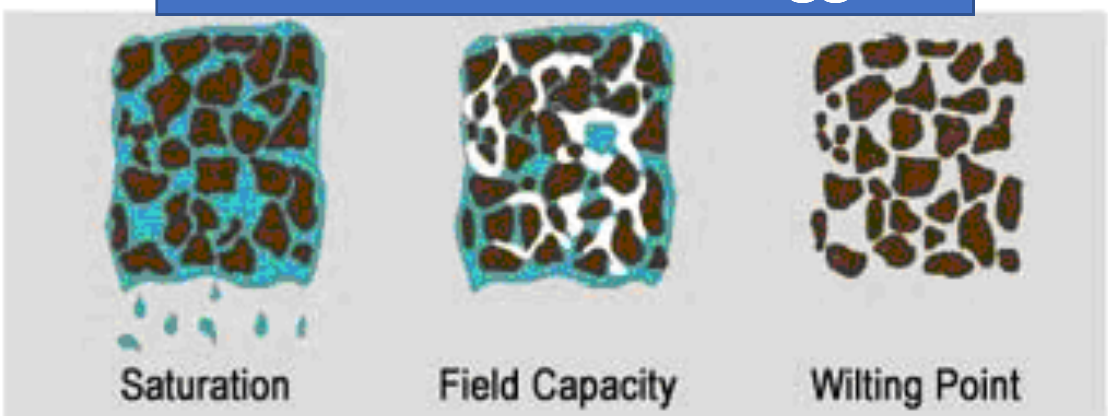
Landuse	Percentage
Deciduous Forest	32
Corn	20
Alfalfa	12
Sweet Corn	7
Potato	5



Triggers for Auto-irrigation function

Plant water demand trigger

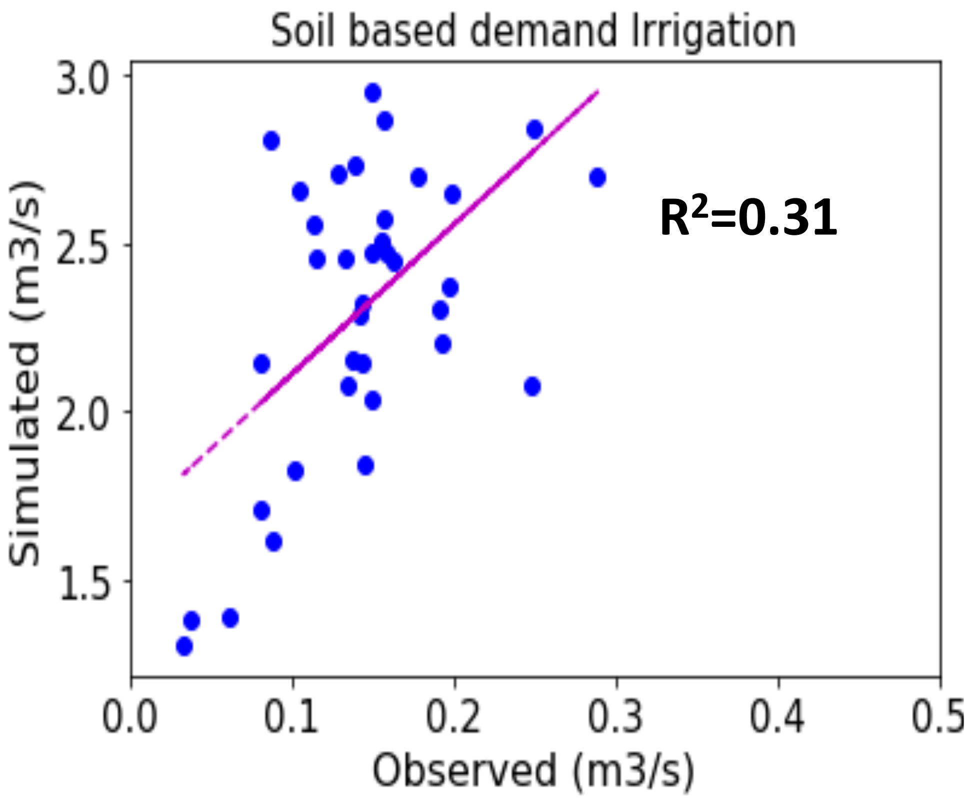
Soil water demand trigger

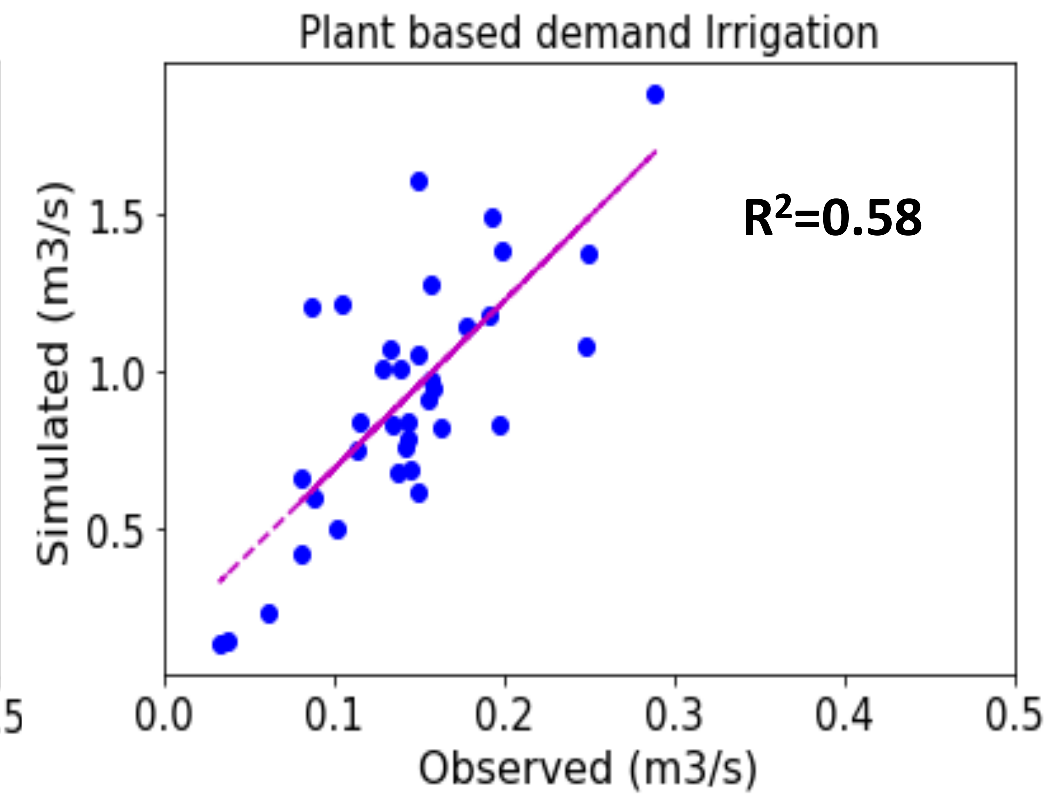


Results

Average Monthly Streamflow (m^3/s)

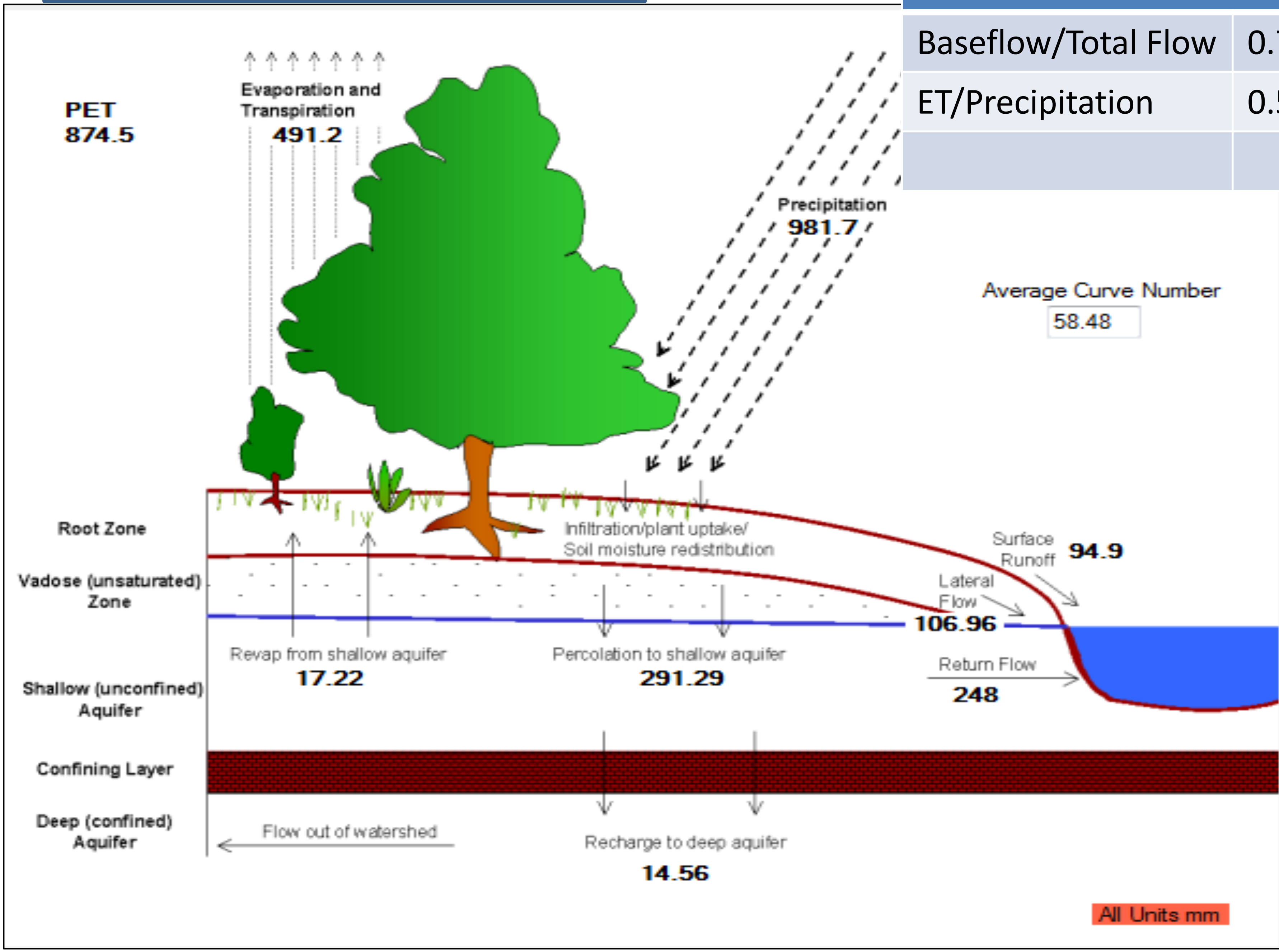
Calibration: 2014-2015
Validation: 2016

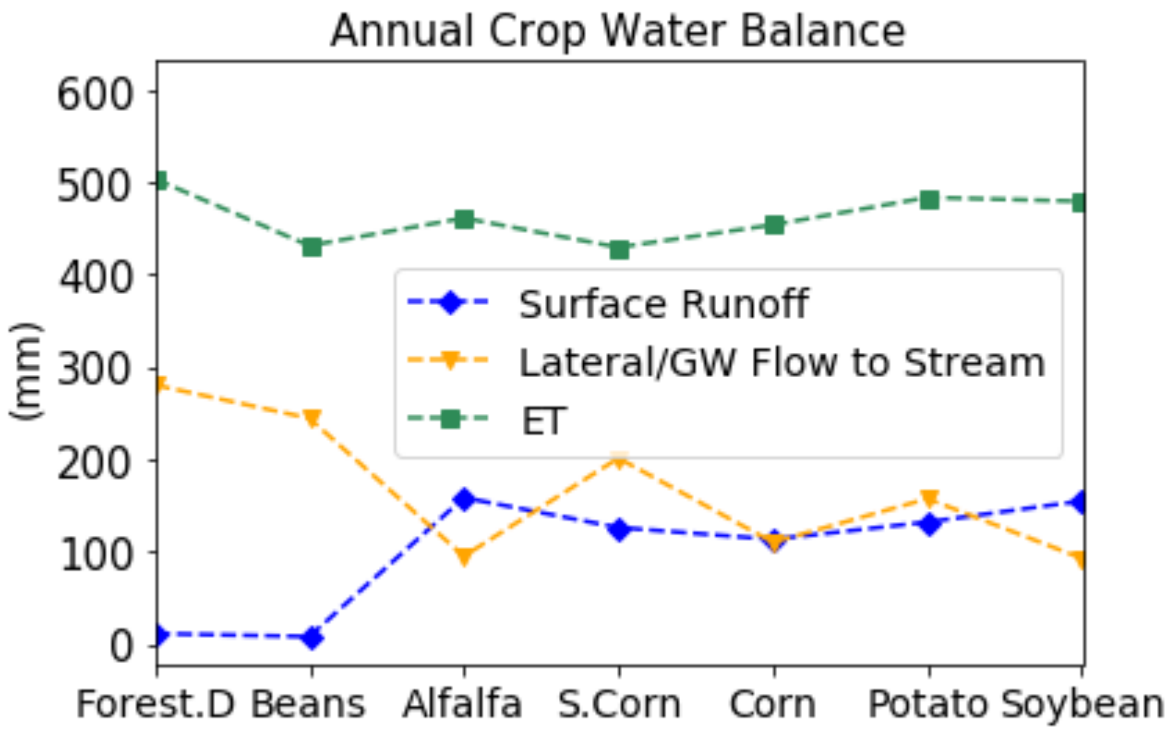


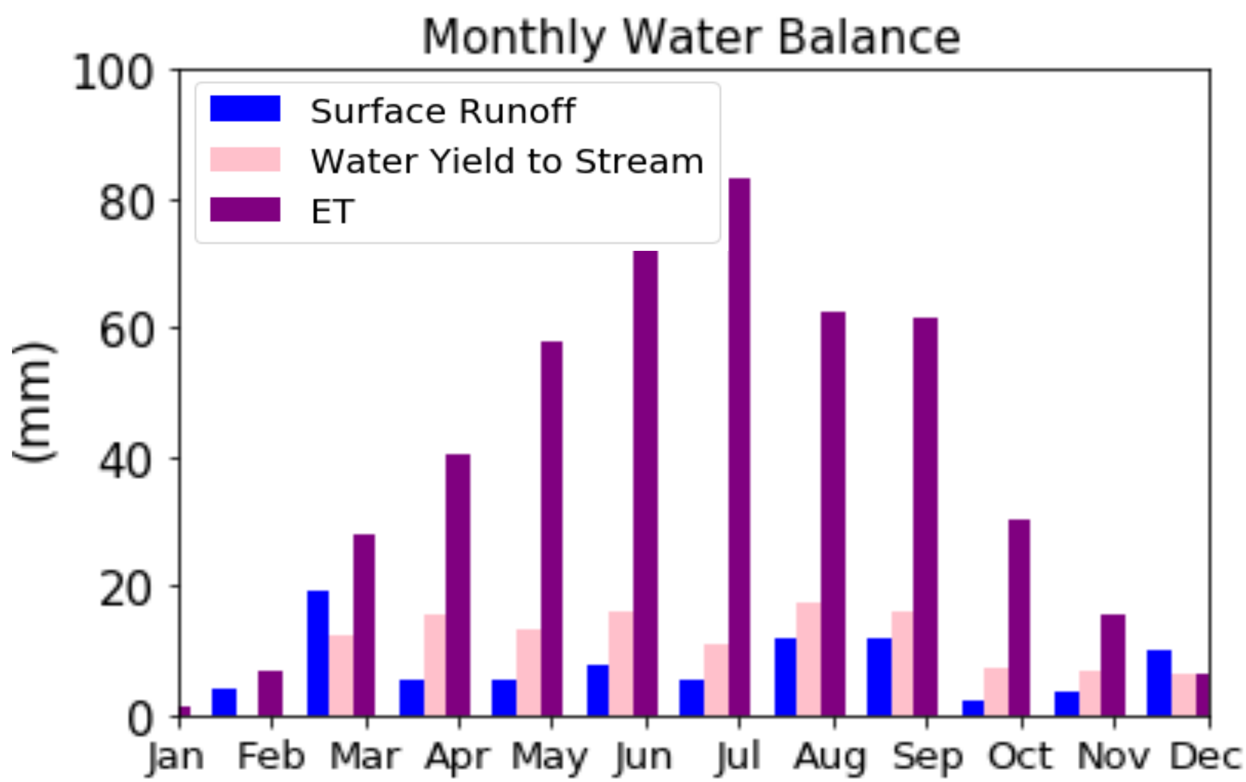


Annual Average water Budget

Water balance Ratio	
Baseflow/Total Flow	0.79
ET/Precipitation	0.5




Annual Crop Water Balance
(mm)
600
500
400
300
200
100
0
Surface Runoff
Lateral/GW Flow to Stream
ET
Forest.D
Beans
Alfalfa
S.Corn
Corn
Potato
Soybean

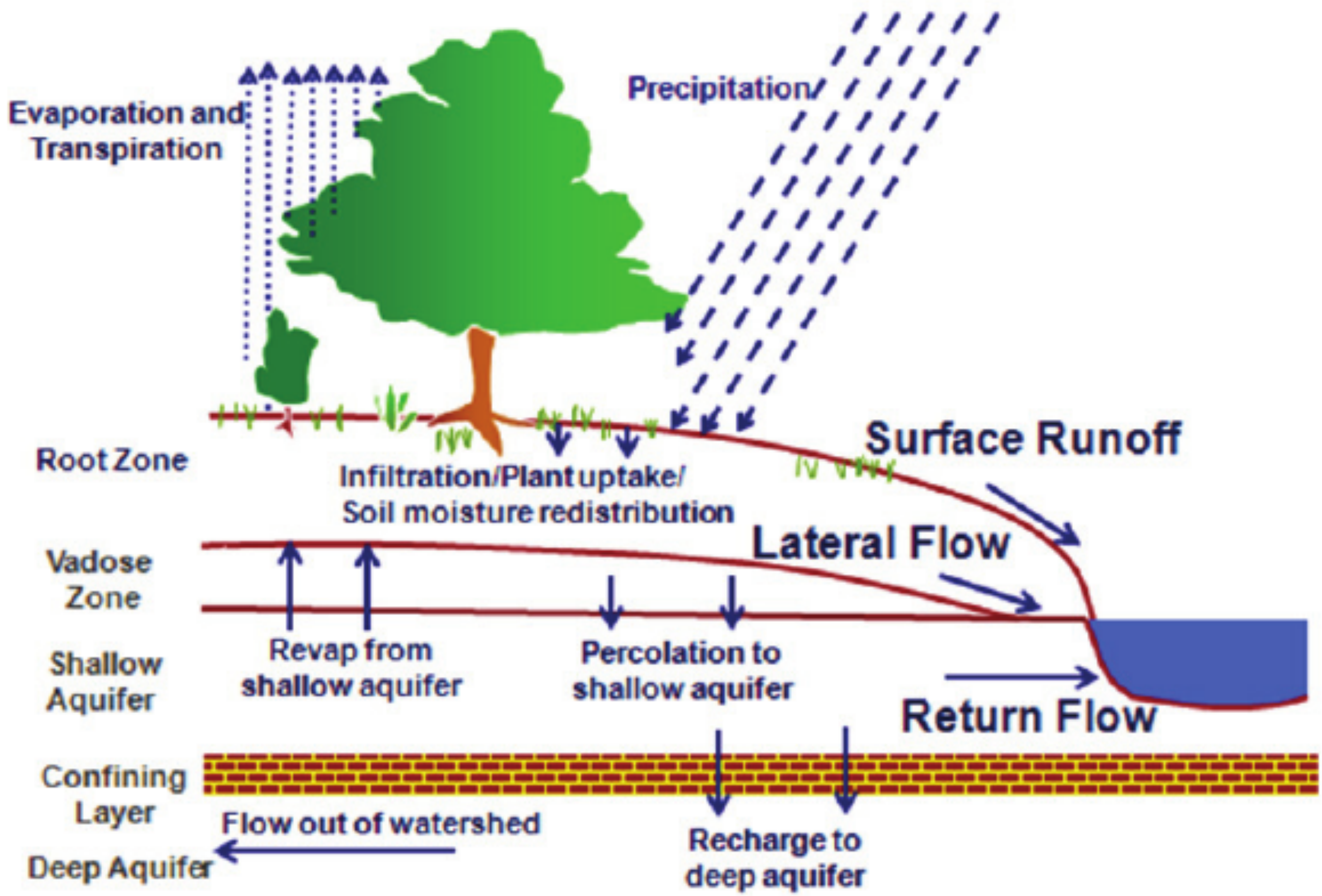

Monthly Water Balance
(mm)
100
80
60
40
20
0
Surface Runoff
Water Yield to Stream
ET
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Sensitivity Analysis

Parameter	Unit	Description
SHALLST	mm H20	Initial depth of water in shallow aquifer
GWQMN	mm H20	Threshold Depth of water in shallow aquifer require for return flow
RCHRG_DP	Coefficient	Deep Aquifer Percolation
GW_Delay	Days	GW delay time (Lag time water takes to reach to aquifer)
SOL_K	mm hr^{-1}	Saturated Hydraulic conductivity

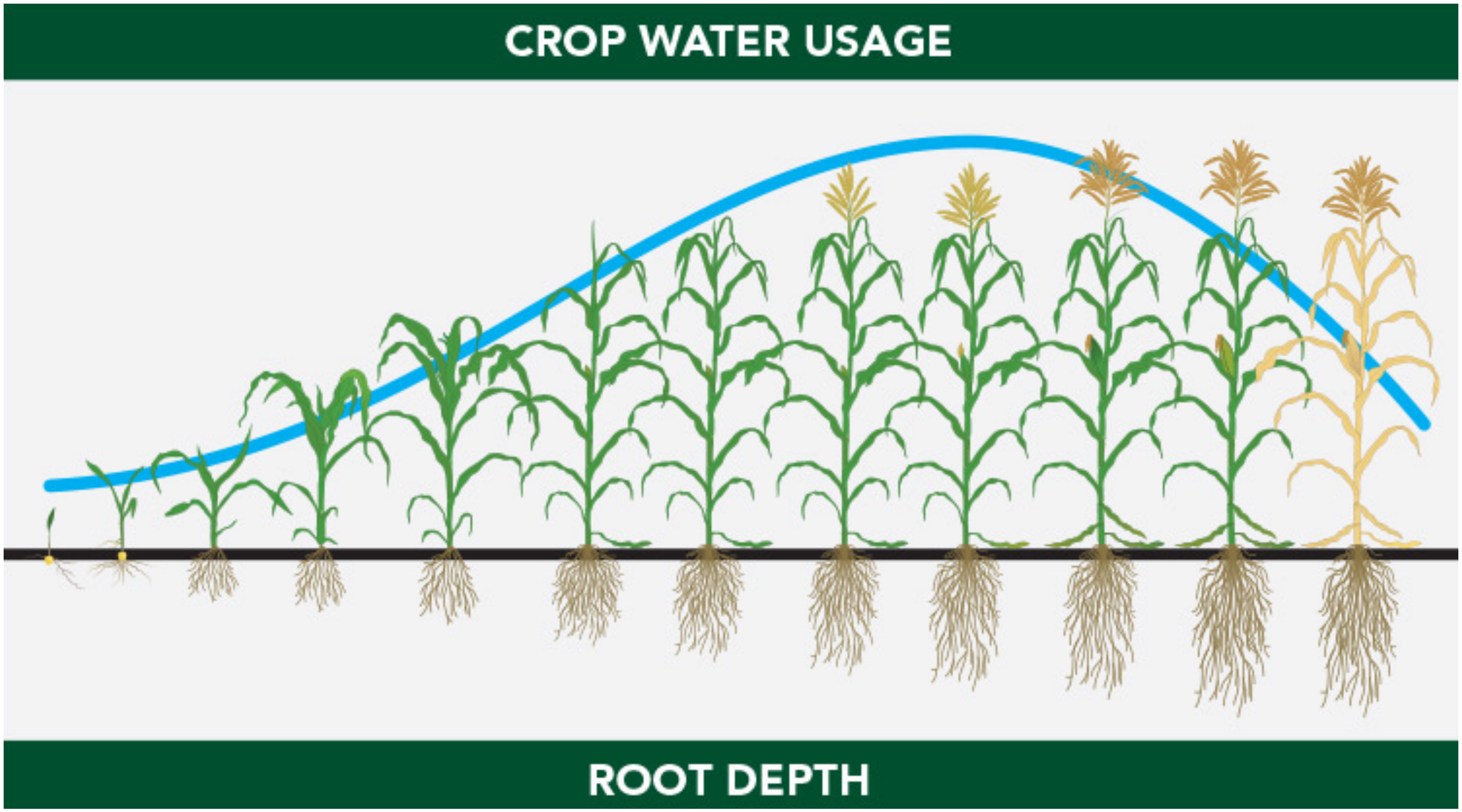
Conclusion

- Auto irrigation function return excess irrigation water to the source rather than accounting for water balance

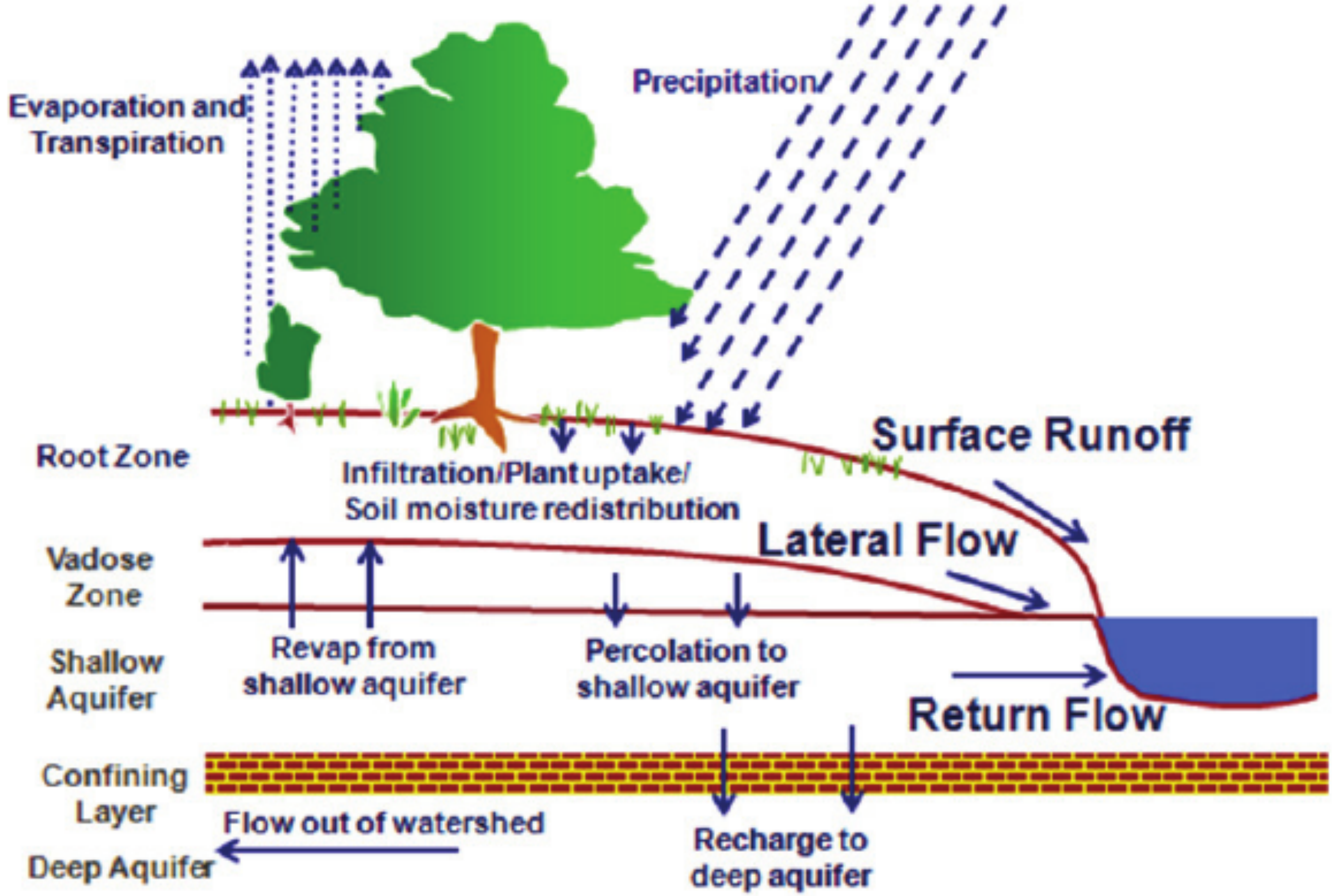


Evaporation and Transpiration
Precipitation
Root Zone
Infiltration/Plant uptake/
Soil moisture redistribution
Surface Runoff
Lateral Flow
Vadose Zone
Shallow Aquifer
Revap from shallow aquifer
Percolation to shallow aquifer
Return Flow
Confining Layer
Flow out of watershed
Deep Aquifer
Recharge to deep aquifer

❖ **Crop growth stage specific Irrigation demands**



Is streamflow enough to calibrate a hydrologic model in intensively irrigated watershed/farms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Lateral Flow
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Shallow Aquifer
Revap from shallow aquifer
Percolation to shallow aquifer
Return Flow
Confining Layer
Flow out of watershed
Deep Aquifer
Recharge to deep aquifer

Field Measurement

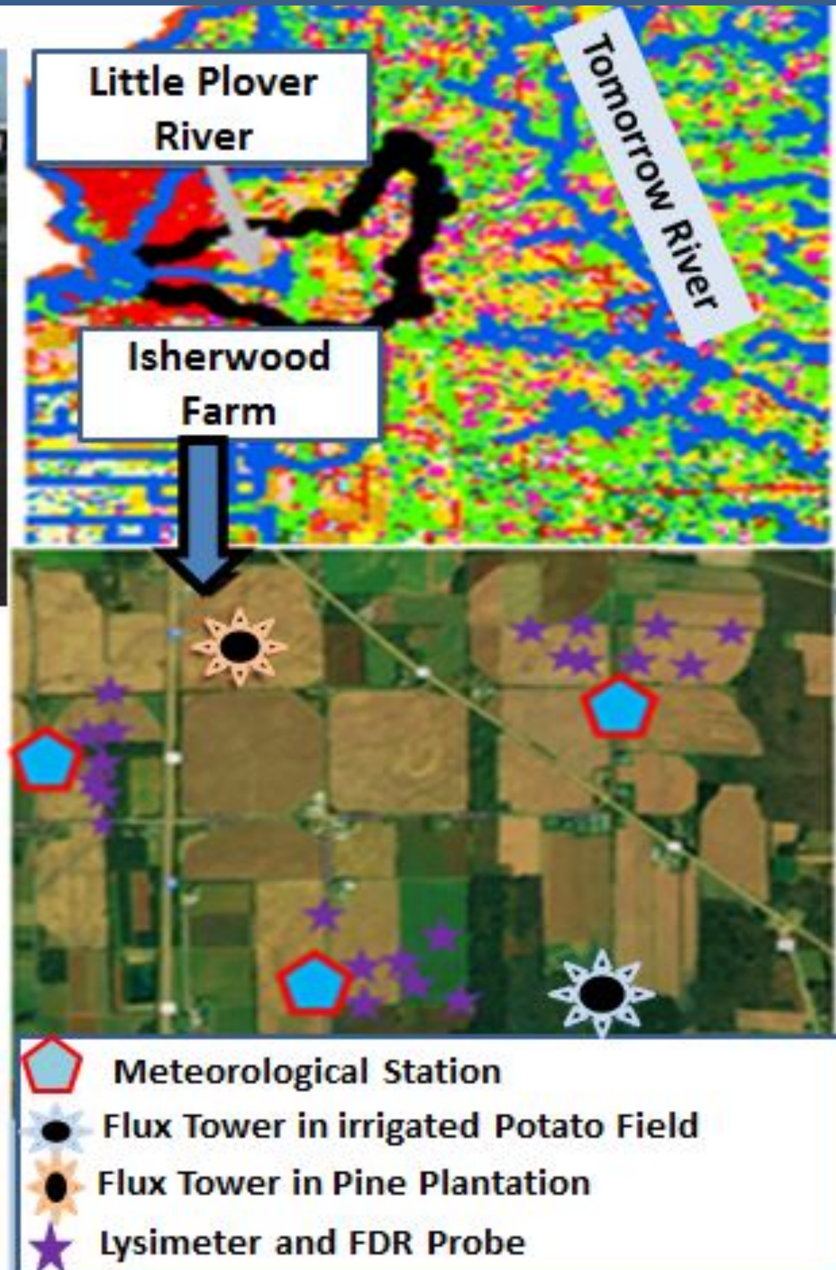
- ❑Daily Evapotranspiration (ET)
- ❑Leaf Area Index (LAI)
- ❑Crop yield
- ❑Sub-Daily Climate Data
- ❑Detailed Management Records (Crop Rotation)

Field Work: Evapotranspiration and recharge measurement

Coupling with Ground water Model for Recharge

Irrigation Demand uncertainty in Model

Optimization of Hydrologic model



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- Eawag. Anderson, M. C., Allen, R. G., Morse, A., and Kustas, W. P. 2012. Use of Landsat thermal imagery in monitoring evapotranspiration and managing water resources. Remote Sensing of Environment, 122: 50-65.
- Kraft, G. J., D. J. Mechenich, K. Clancy, and J. Haucke. 2010. Groundwater pumping effects on groundwater levels, lake levels, and streamflows in the Wisconsin Central Sands. Report to the Wisconsin Department of Natural Resources. Center for Watershed Science and Education. College of Natural Resources, University of Wisconsin-Stevens Point and UW-Extension.
- Nocco, M.A., Kraft, G.J., Loheide, S.P. II, Kucharik, C.J. 2017. Drivers of potential recharge from irrigated agroecosystems in the Wisconsin Central Sands. Vadose Zone Journal. doi: 10.2136/vzj2017.01.0008

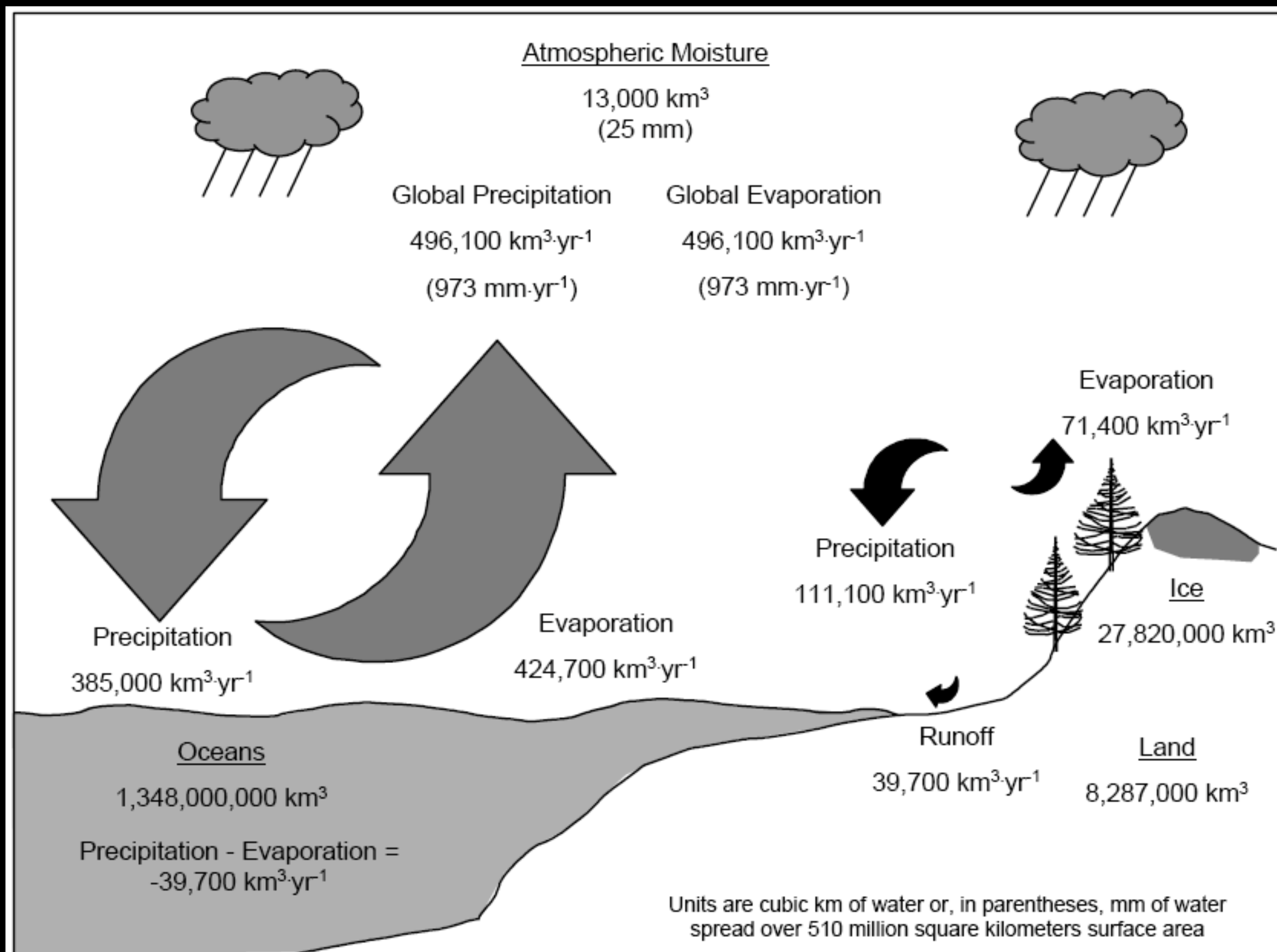
Acknowledgment

UW CCR Climate, People, Environment Program (CPEP) Seed Grant, UW AOS Ned P Smith Professorship of Climatology, NSF DBI-1457897

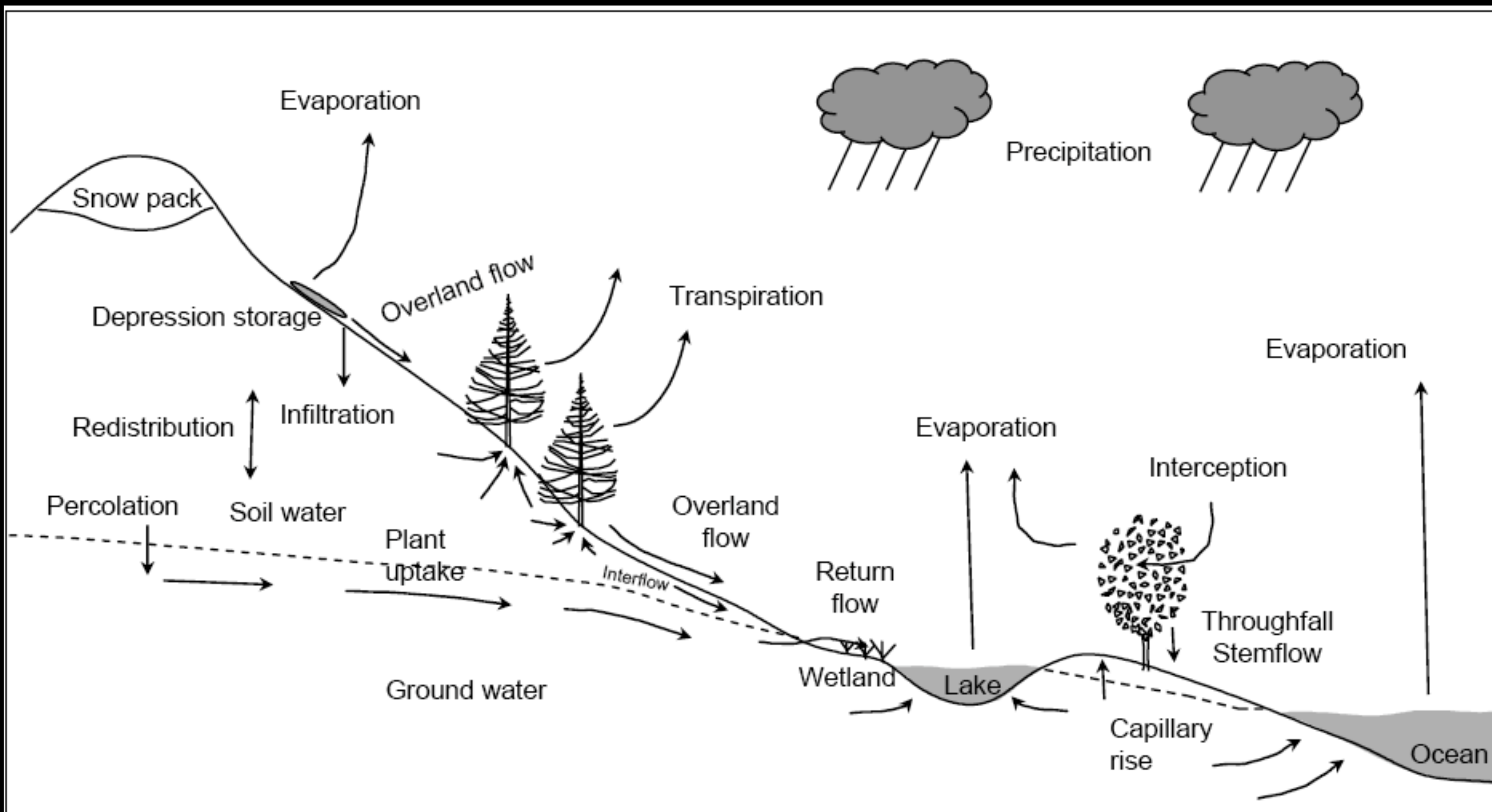
Dr. Desai
Dr. Nocco
Desai Lab members


Moving Forward...

Hydrology: Global scale, all about the ocean



But: Regionally, terrestrial evapotranspiration (ET) is a key component to the water cycle, for example, in the Central Sands



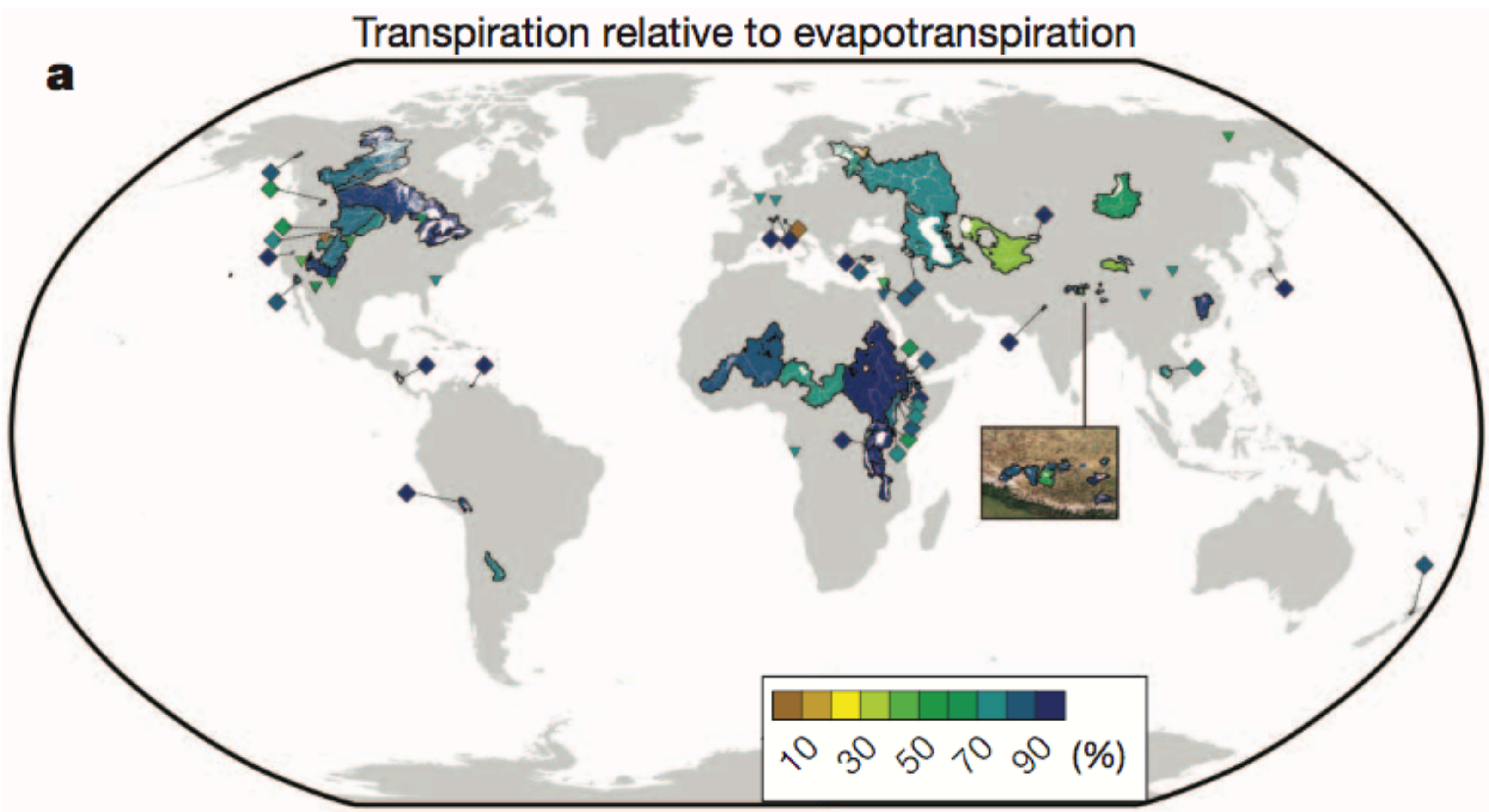
Chapin, 2011, Principles of Terrestrial Ecosystem Ecology

LETTER

doi:10.1038/nature11983

Terrestrial water fluxes dominated by transpiration

Scott Jasechko[1], Zachary D. Sharp[1], John J. Gibson[2,3], S. Jean Birks[2,4], Yi Yi[2,3] & Peter J. Fawcett[1]

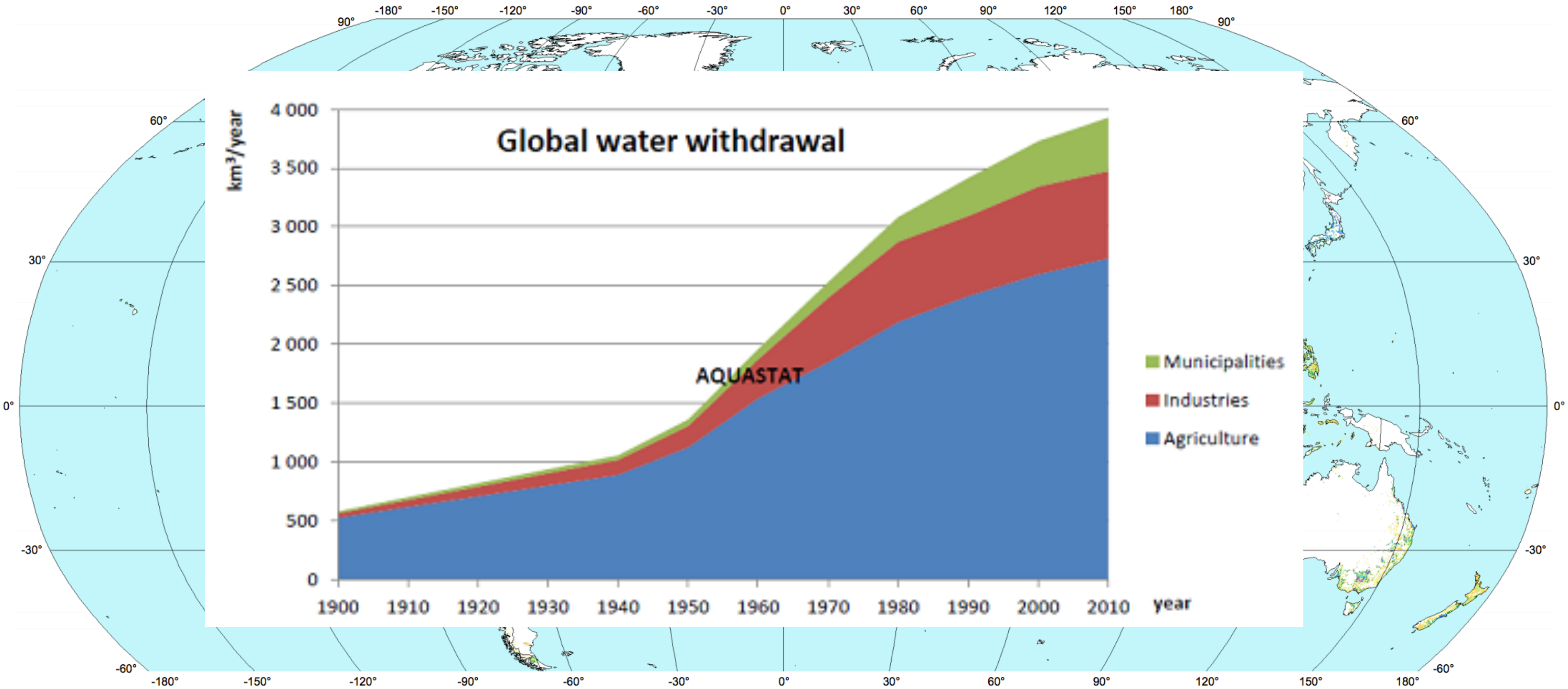


The big question

How does
a changing climate and
water use decisions
influence
groundwater and plant water use
in agricultural regions?

The digital global map of irrigation areas

October 2013



Area equipped for irrigation in percentage of land area

- 0
- < 0.1
- 0.1 - 1
- 1 - 5
- 5 - 10
- 10 - 20
- 20 - 35
- 35 - 50
- 50 - 75
- 75 - 100

The map shows area equipped for irrigation in percentage of cell area.
For the majority of countries the base year of statistics is in the period 2000 - 2008.

Projection: Robinson
Resolution: 5 arc-minutes

http://www.fao.org/nr/water/aquastat/irrigationmap/index.stm

Stefan Siebert, Verena Henrich (Institute of Crop Science and Resource Conservation, University of Bonn, Germany) and
Karen Frenken, Jacob Burke (Land and Water Division, Food and Agriculture Organization of the United Nations, Rome, Italy)

universitätbonn

nature climate change
LETTERS
PUBLISHED ONLINE: 5 SEPTEMBER 2016 | DOI: 10.1038/NCLIMAT

The increasing importance of atmospheric demand for ecosystem water and carbon fluxes

Kimberly A. Novick[1]*, Darren L. Ficklin[2], Paul C. Stoy[3],
A. Christopher Oishi[6], Shirley A. Papuga[7], Peter D. Bla
Russell L. Scott[11], Lixin Wang[12] and Richard P. Phillips[13]

Plant responses to increasing CO_2 reduce estimates of climate impacts on drought severity

Abigail L. S. Swann[a,b,1], Forrest M. Hoffman[c,d], Charles D. Koven[e], and James T. Randerson[f]

Geophysical Research Letters

RESEARCH LETTER
10.1002/2017GL072759

Key Points:
- Base flow is consistently declining along the Australian east coast

CO_2-vegetation feedbacks and other climate changes implicated in reducing base flow

Ralph Trancoso[1,2], Joshua R. Larsen[1,3], Tim R. McVicar[4,5], Stuart R. Phinn[1] and Clive A. McAlpine[1]

nature plants
PUBLISHED: 5

Intensifying drought eliminates the expected benefits of elevated carbon dioxide for soybean

Sharon B. Gray[1†], Orla Dermody[1], Stephanie P. Klein[1†], Anna M. Locke[1†], Justin M. McGrath[1], Rachel
E. Paul[1], David M. Ro
A. Ainsworth[1,2], Carl

Warm spring reduced carbon cycle impact of the 2012 US summer drought

Sebastian Wolf[a,b,1], Trevor F. Keenan[c,2], Joshua B. Fisher[d], Dennis D. Baldocchi[a], Ankur R. Desai[e], Andrew D. Richardson[f], Russell L. Scott[g], Beverly E. Law[h], Marcy E. Litvak[i], Nathaniel A. Brunsell[j], Wouter Peters[k,l], and Ingrid T. van der Laan-Luijkx[k]

Global Change Biology (2016), doi: 10.1111/gcb.13428

Relationships between individual-tree mortality and water-balance variables indicate positive trends in water stress-induced tree mortality across North America

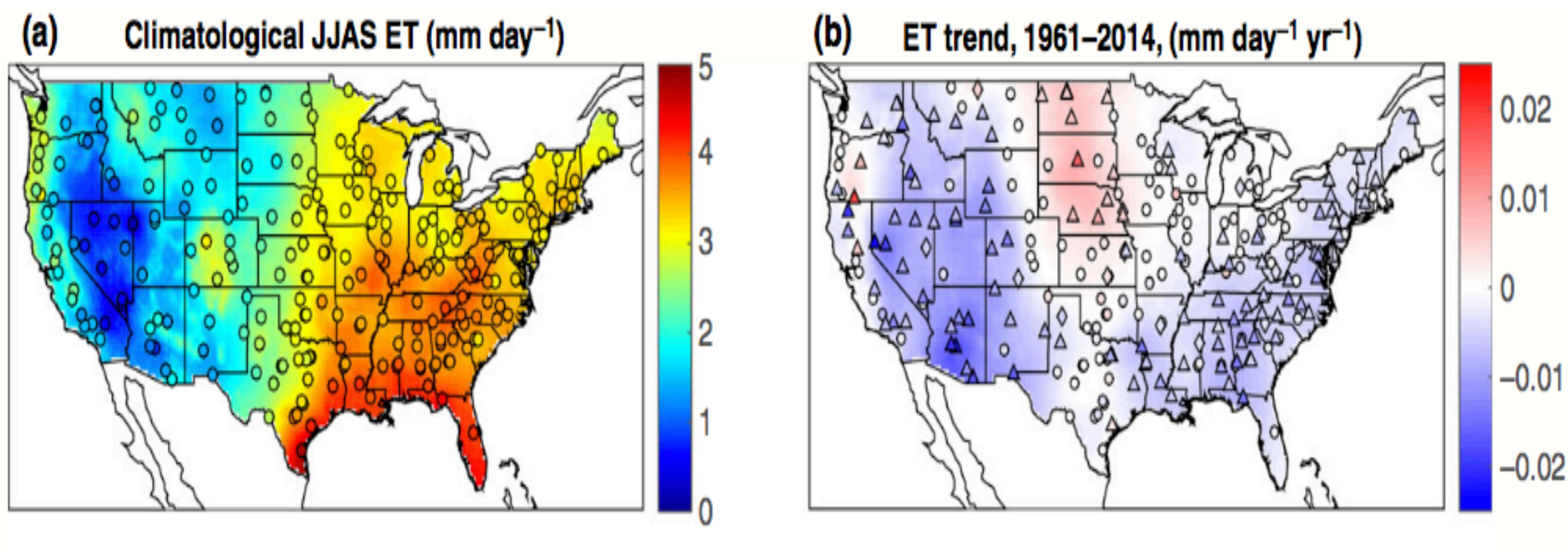
RNER A. KURZ[2] and NICHOLAS C. COOPS[1]

Global Change Biology (2017) 23, 1140–1151, doi: 10.1111/gcb.13439

Stomatal response to humidity and CO_2 implicated in recent decline in US evaporation

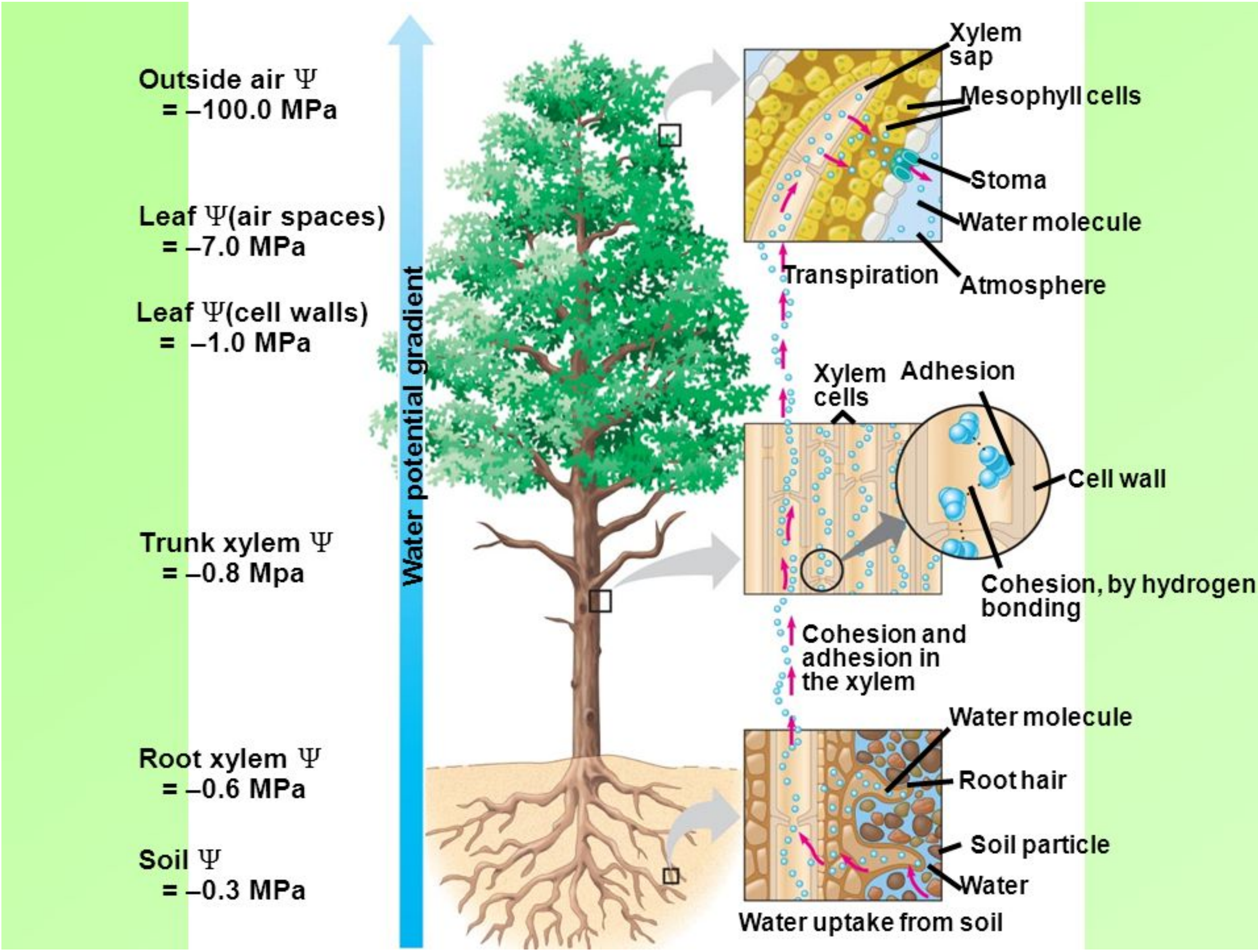
ANGELA J. RIGDEN and GUIDO D. SALVUCCI
Department of Earth and Environment, Boston University, 675 Commonwealth Ave., Boston, MA 02215, USA

Recent trends in U.S. evapotranspiration show a range of trends, driven by changes in surface



Rigden and Salvucci, 2017

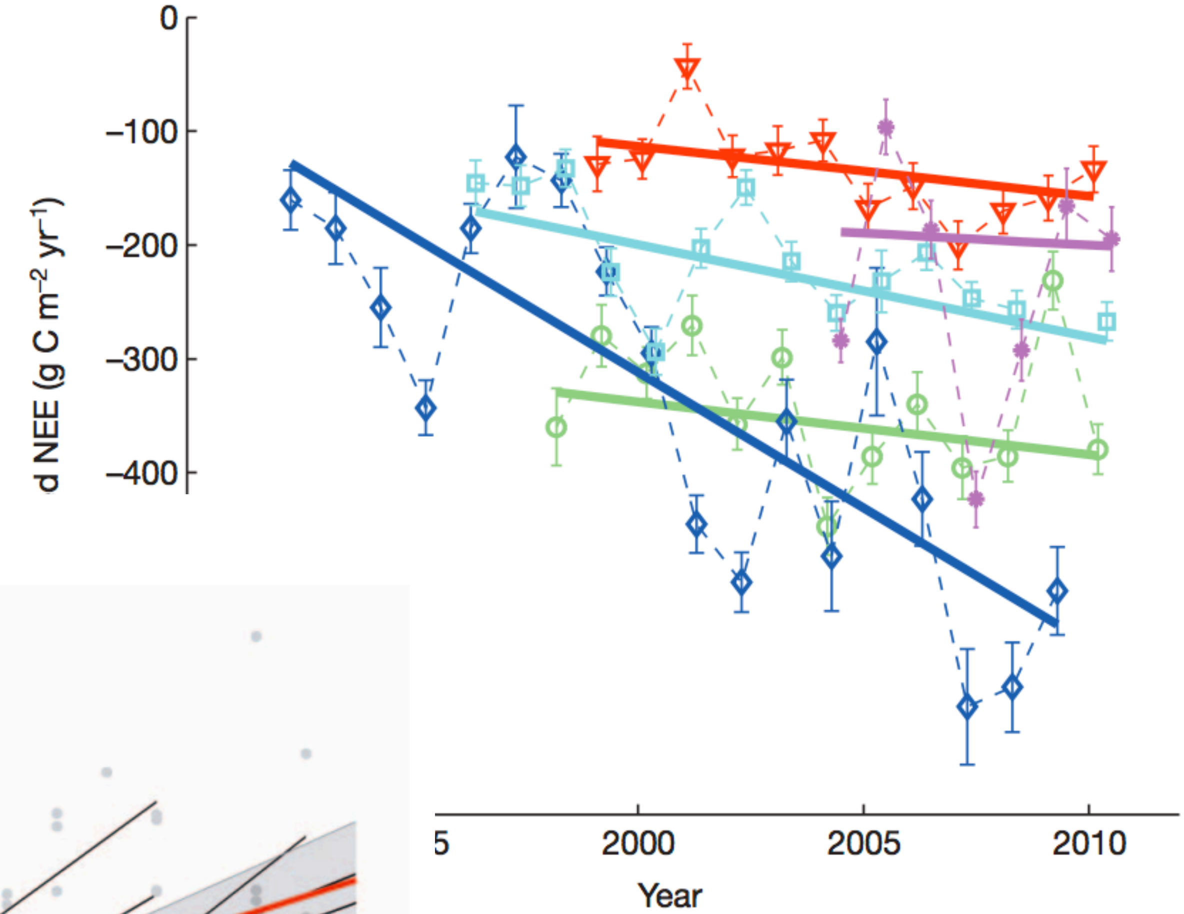
Plant transpiration ~60% of global terrestrial water flux (Wei et al., 2017)!

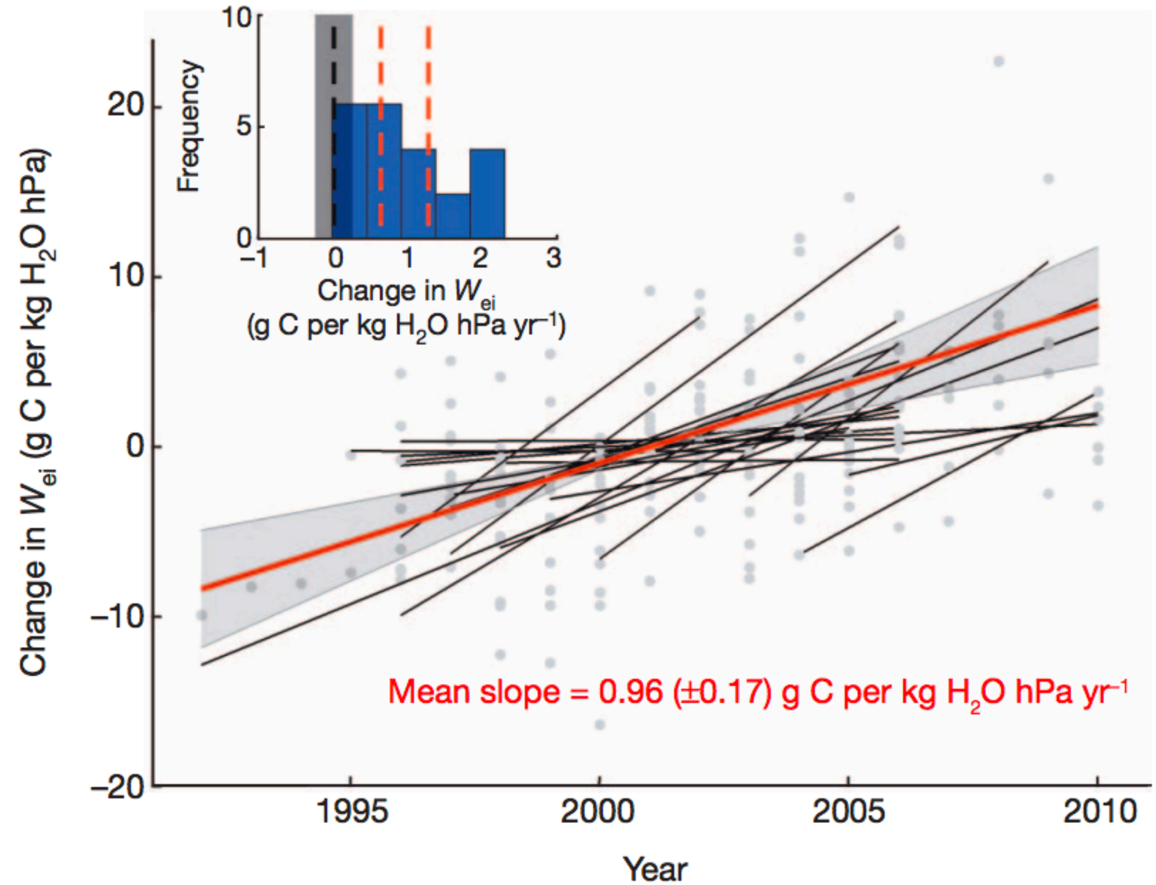


https://www.emaze.com/@AWQQLQIL/Transpiration

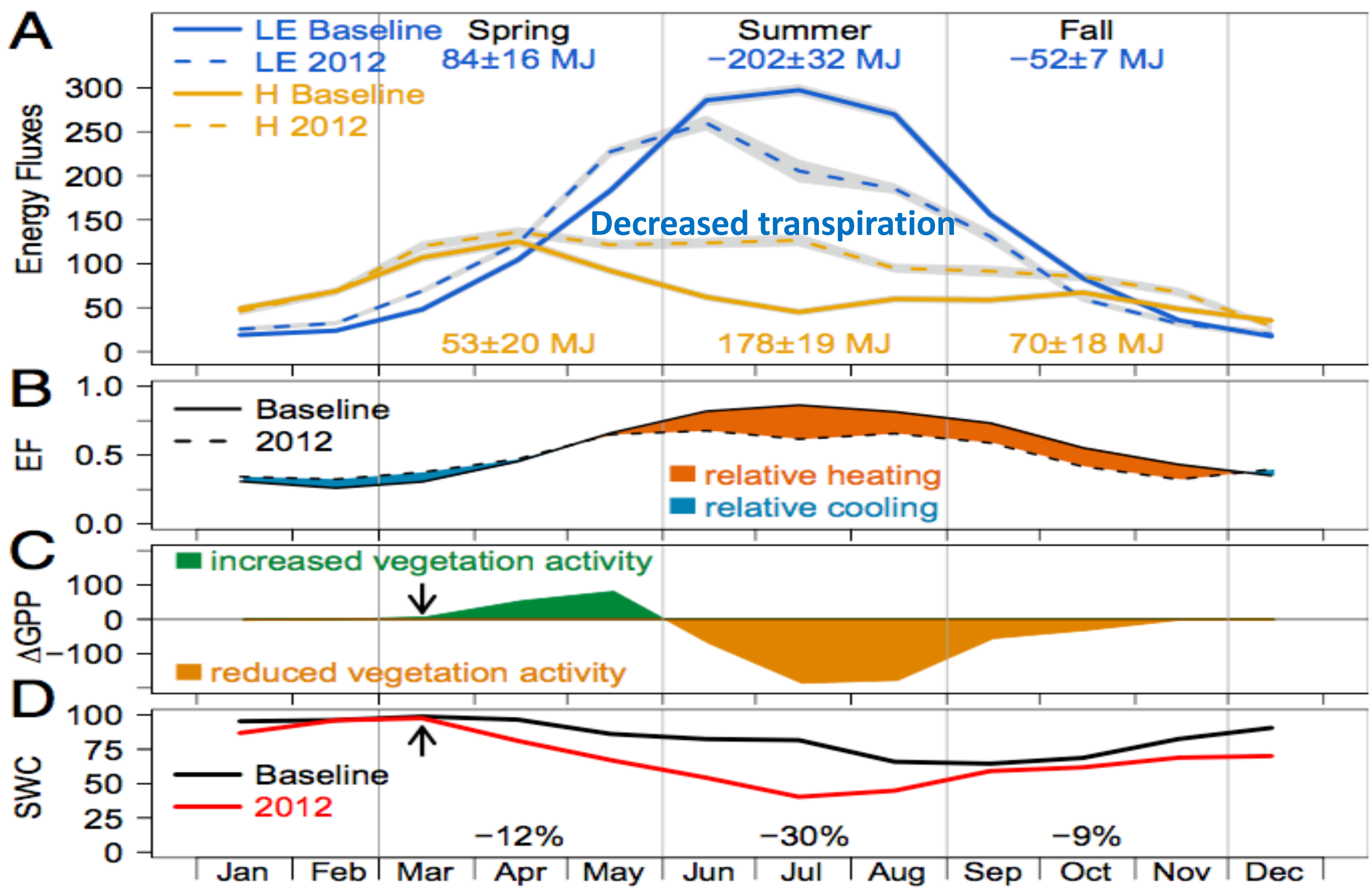
Some evidence shows decreasing transpiration rates

- Higher CO_2 means less need to keep stomata open
  - Evidence: *Increasing water use efficiency*
- Increased atmospheric demand for moisture in warmer climates leads to stomatal closure
  - Evidence: *Higher vapor pressure deficit*
- Longer growing seasons lead to earlier depletion of plant available water
  - Evidence: *Soil moisture deficiency in summer*

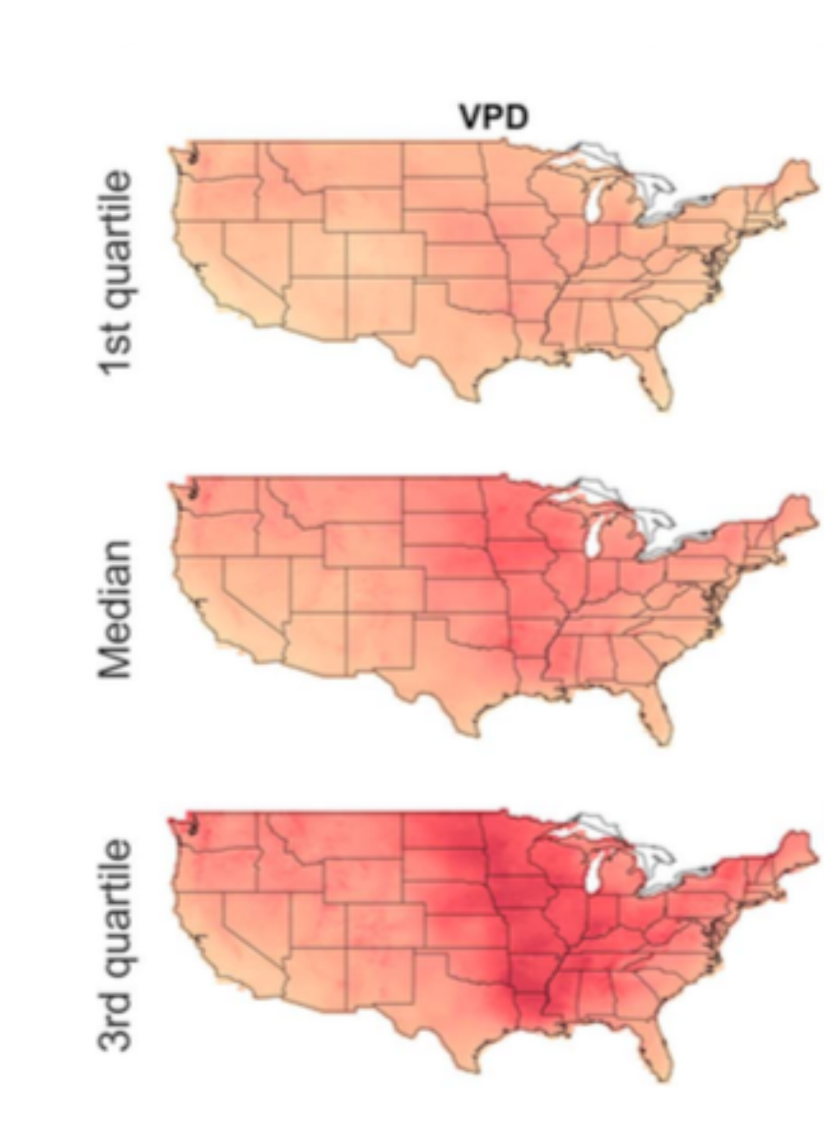




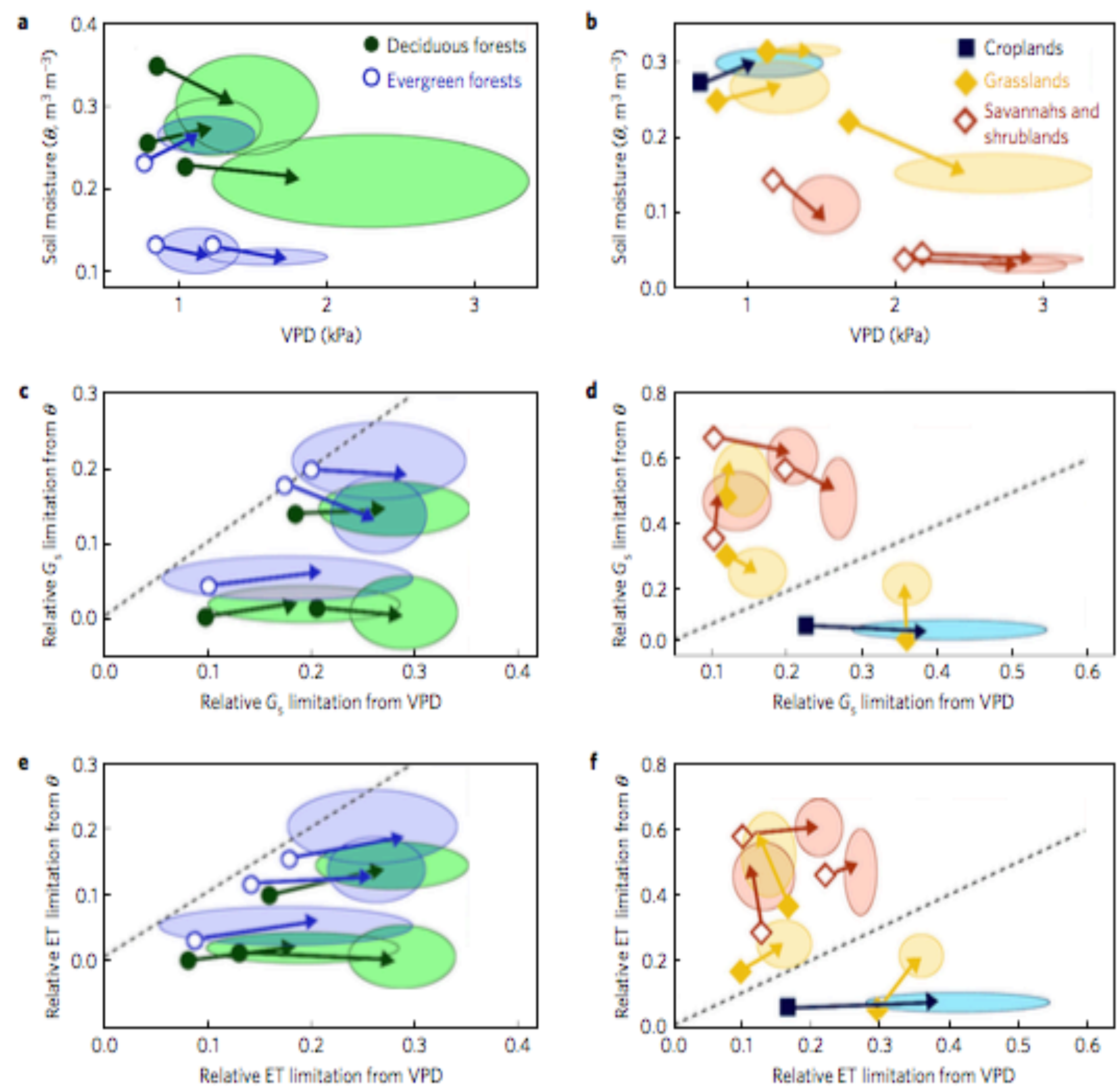
Keenan *et al* 2015



Wolf *et al.*, 2016



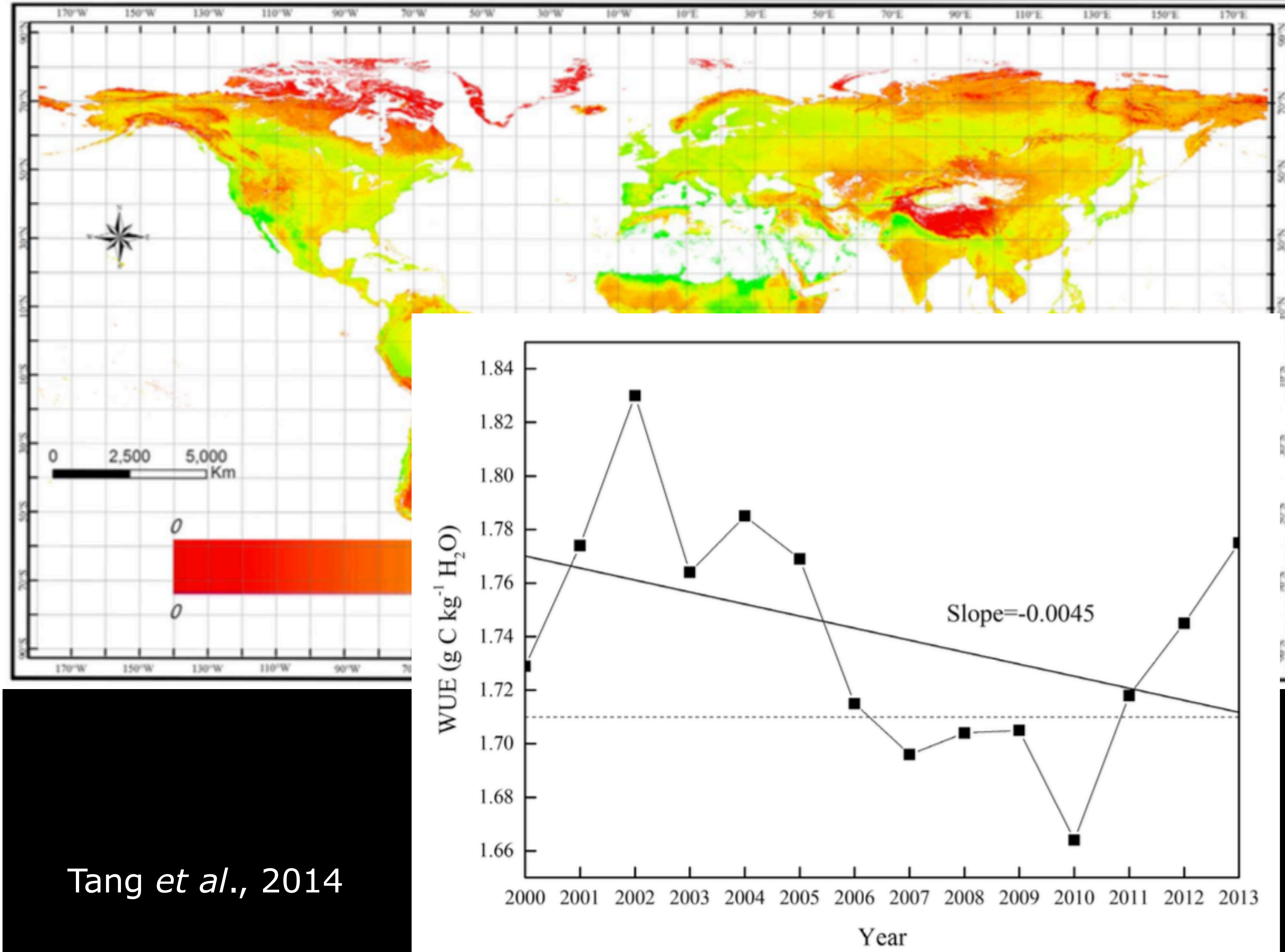
Ficklin and Novick, 2017



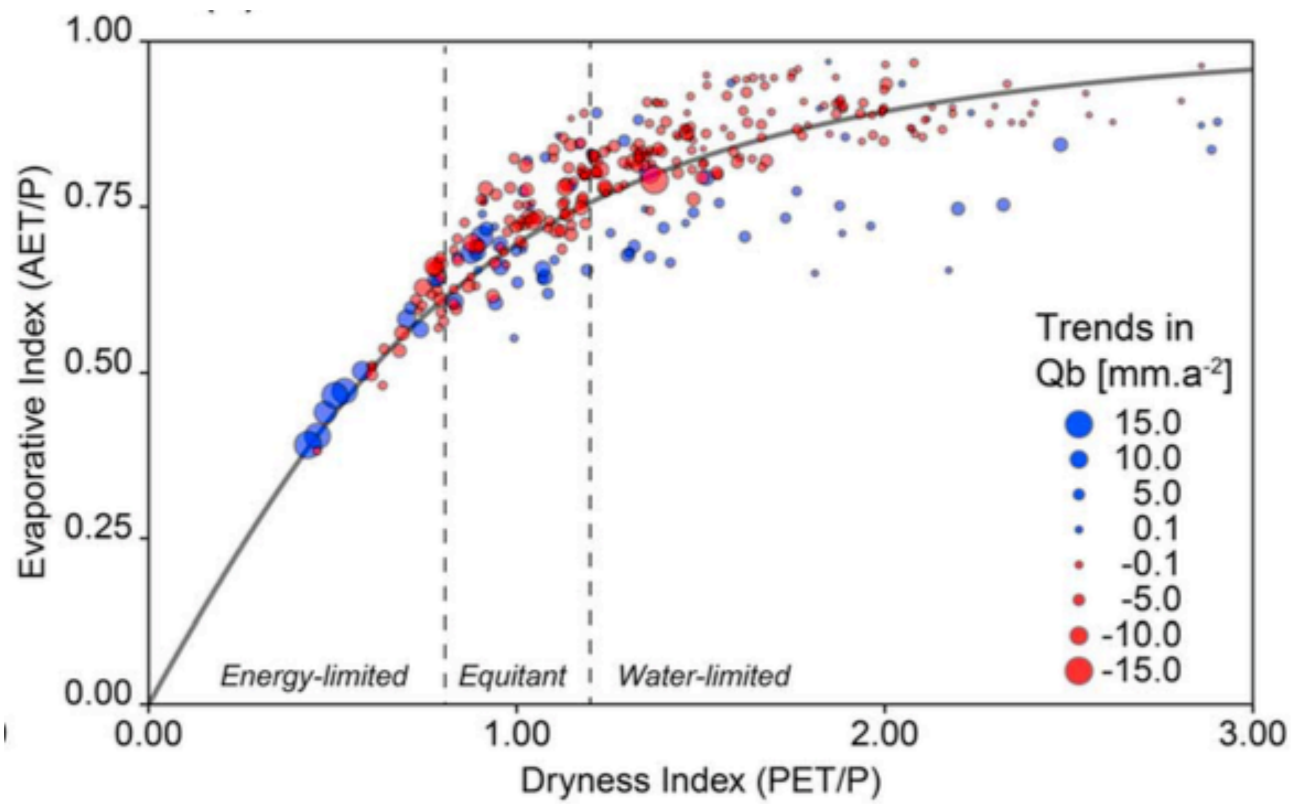
Novick *et al.*, 2016

Others show the opposite

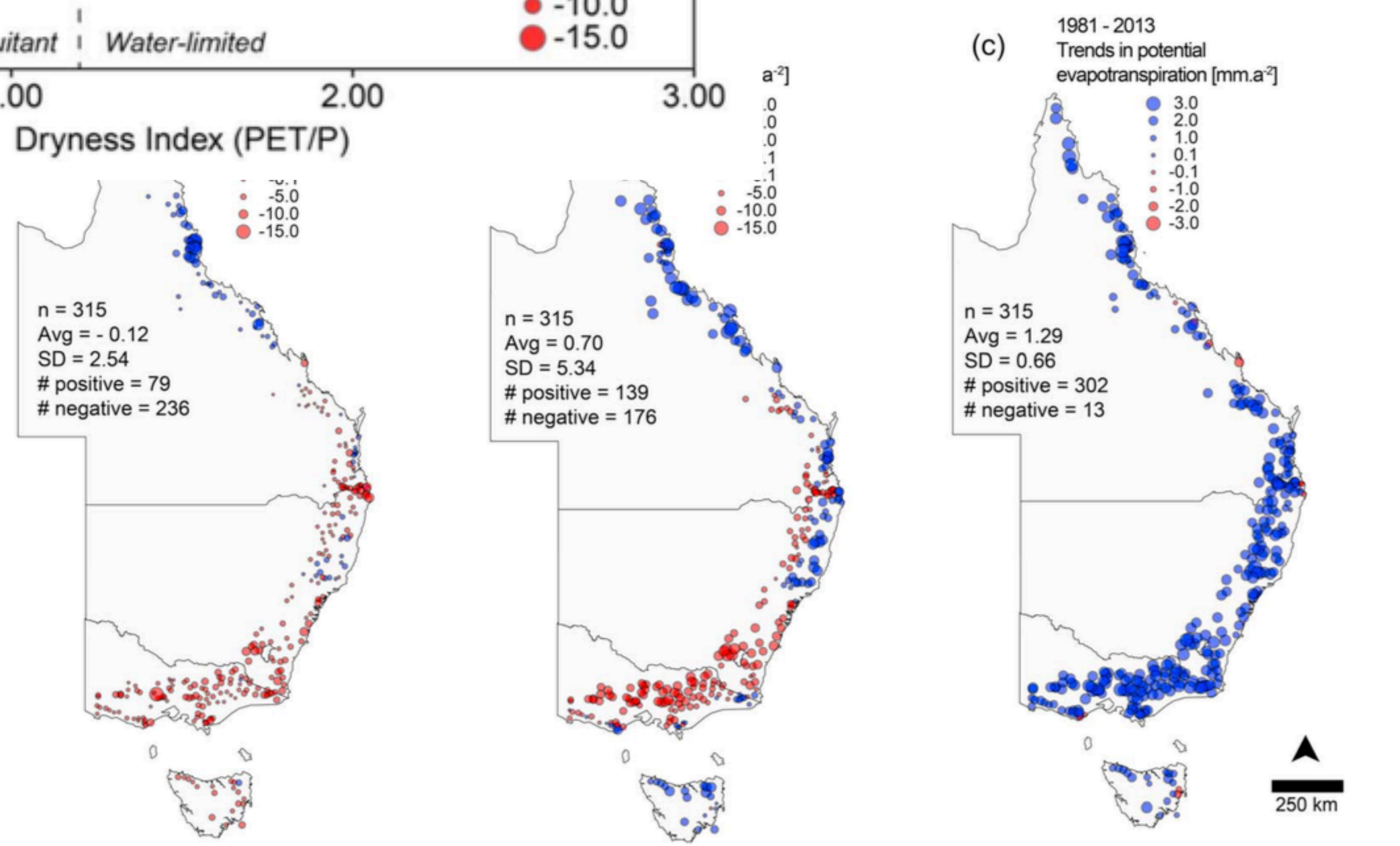
- Higher CO_2 fertilizes growth, plants trade water for carbon to maximize this, and as a result have limited change in stomatal response
  - Evidence: *Increased transpiration, reduced baseflow, decreases in water use efficiency*
- Longer growing seasons leads to longer actively transpiring period
  - Evidence: *Plant phenology shifts, earlier use of soil moisture*



Tang *et al*., 2014



Trancoso *et al.*, 2017



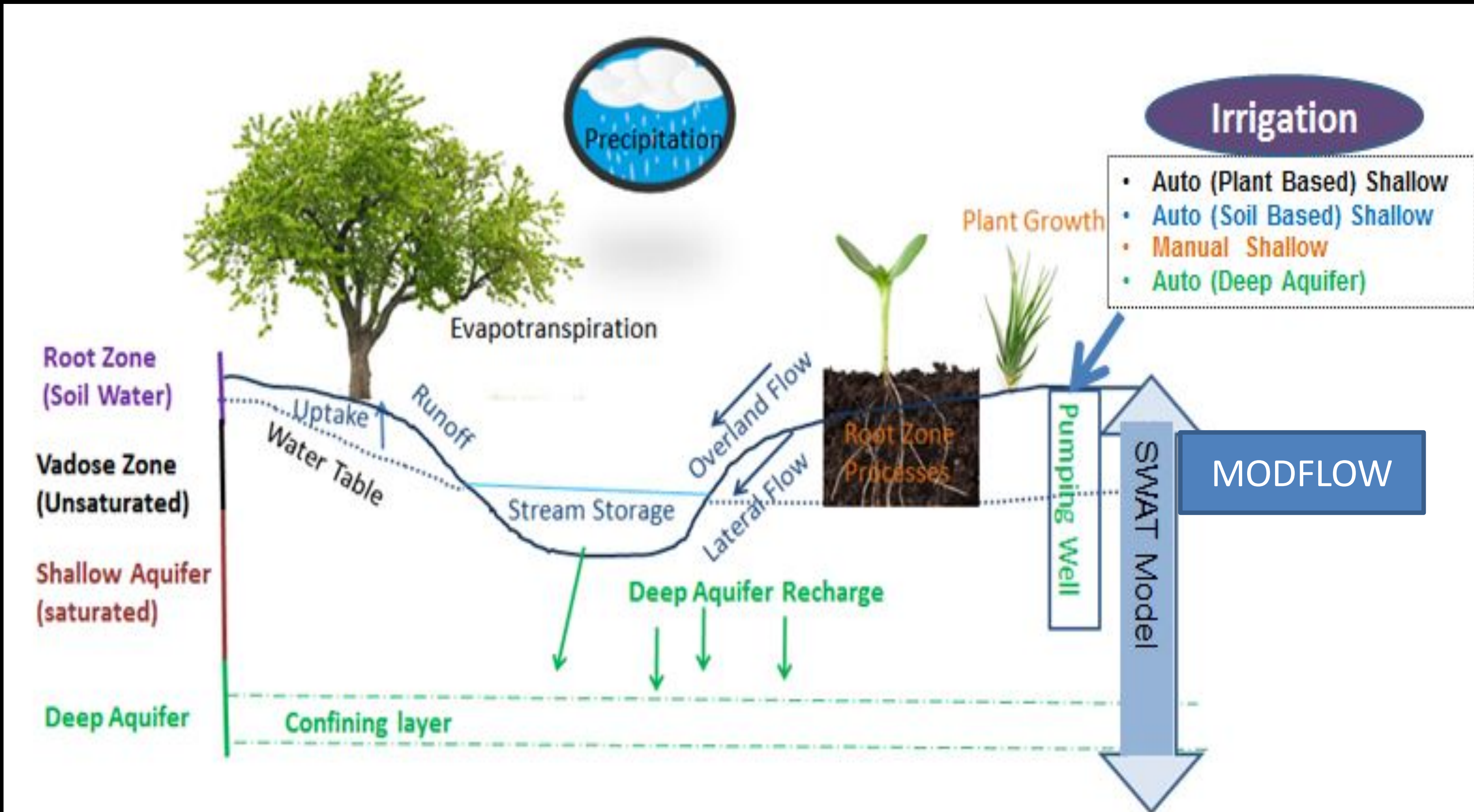
Answer

- It depends
  - On plasticity of species response (isohydric/anisohydric continuum)
  - Either way, plant water use *will* change in response to intensifying hydrological cycles, which will influence global water budget and local land-atmosphere feedbacks
  - Implications for management of water for agriculture, forestry, drought
  - Multi-scale, long-term experiments and observations are needed (Ameriflux, NEON, LTER)

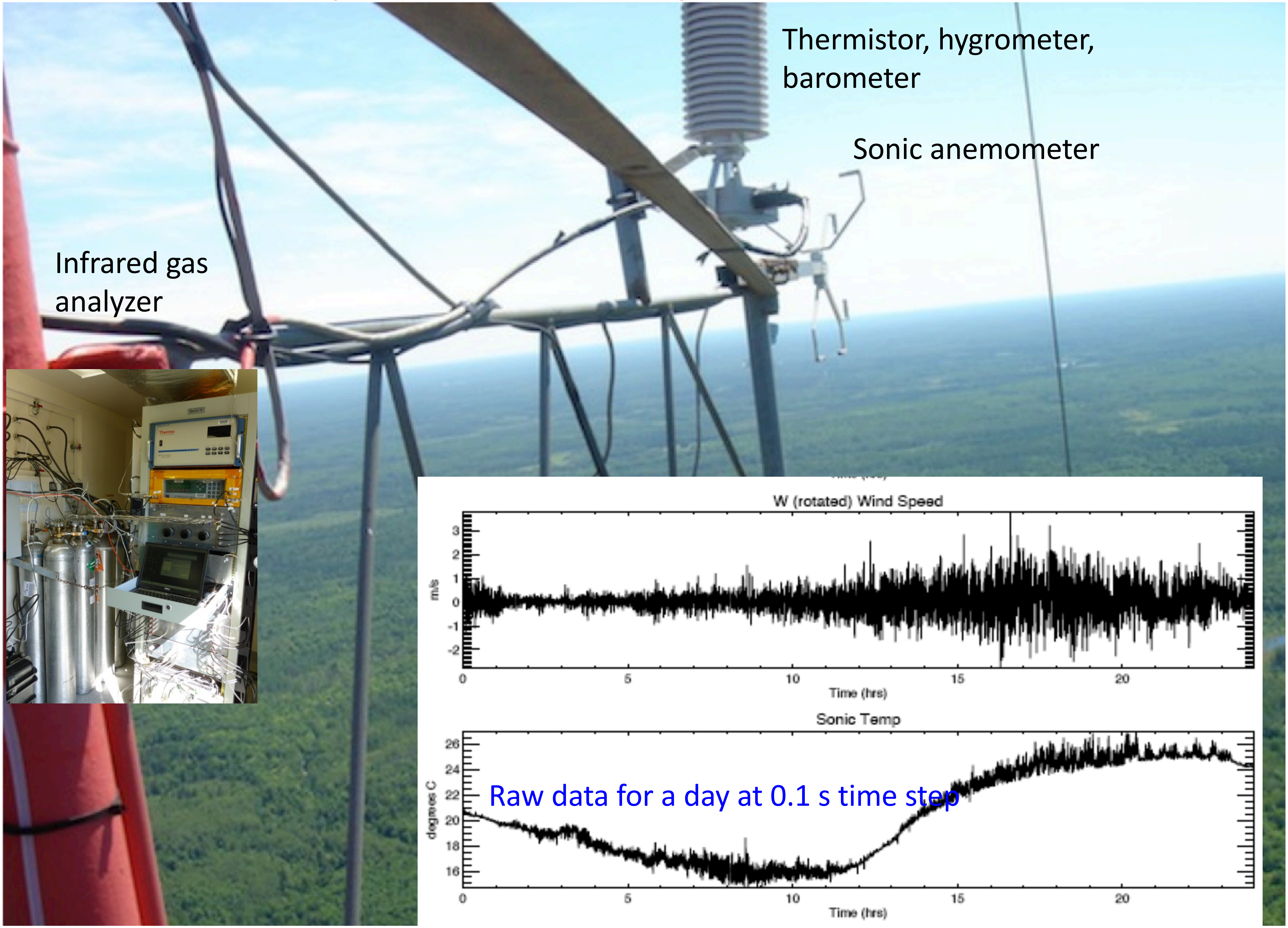
How do we solve this?

- Take continuous long-term ET observations
- Confront models with it

Conceptual Framework for Hydrologic Model

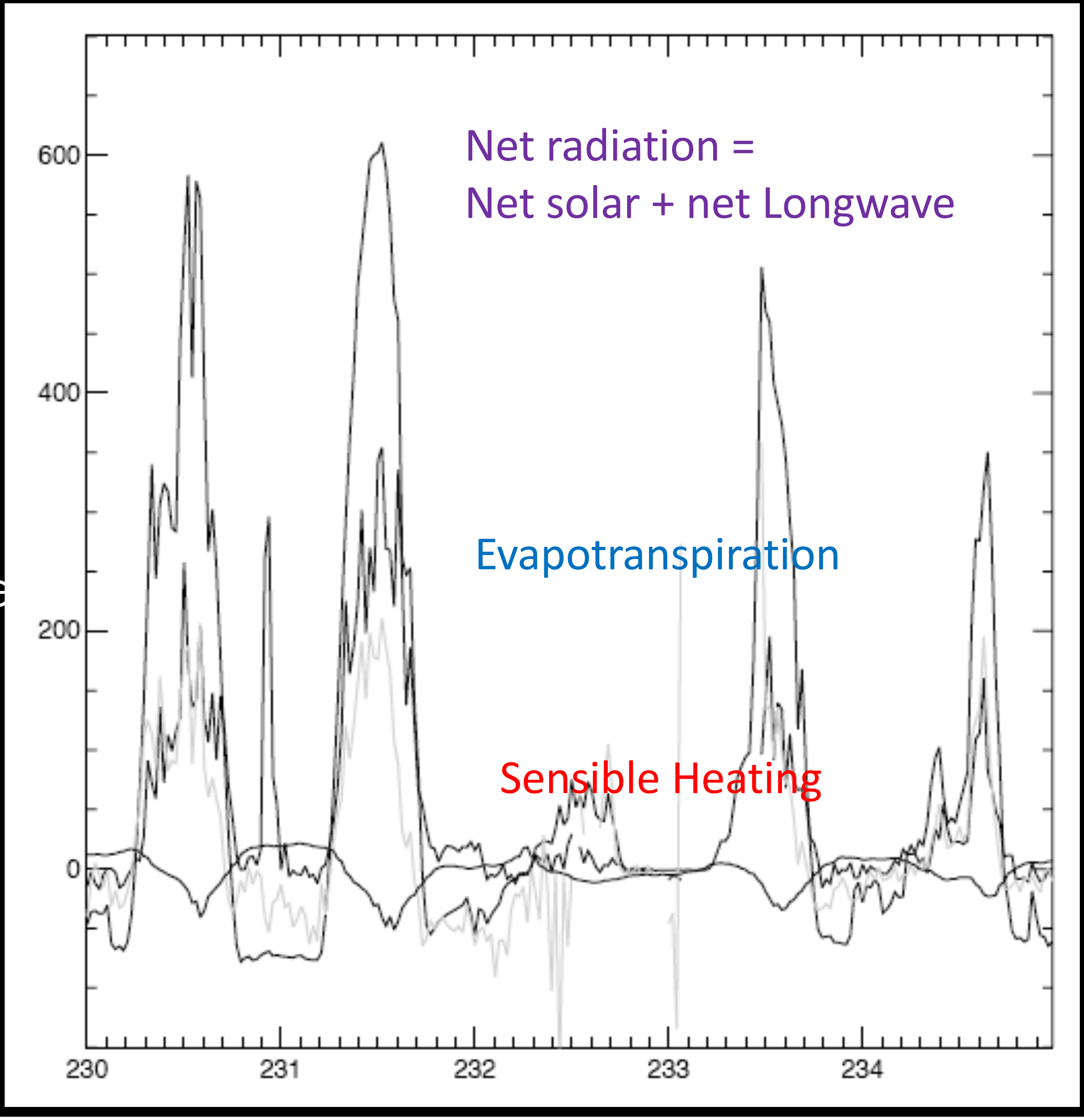


WLEF tall tower site (Park Falls, WI est. 1996)



Five days of observations

Watts
Per
Square
Meter



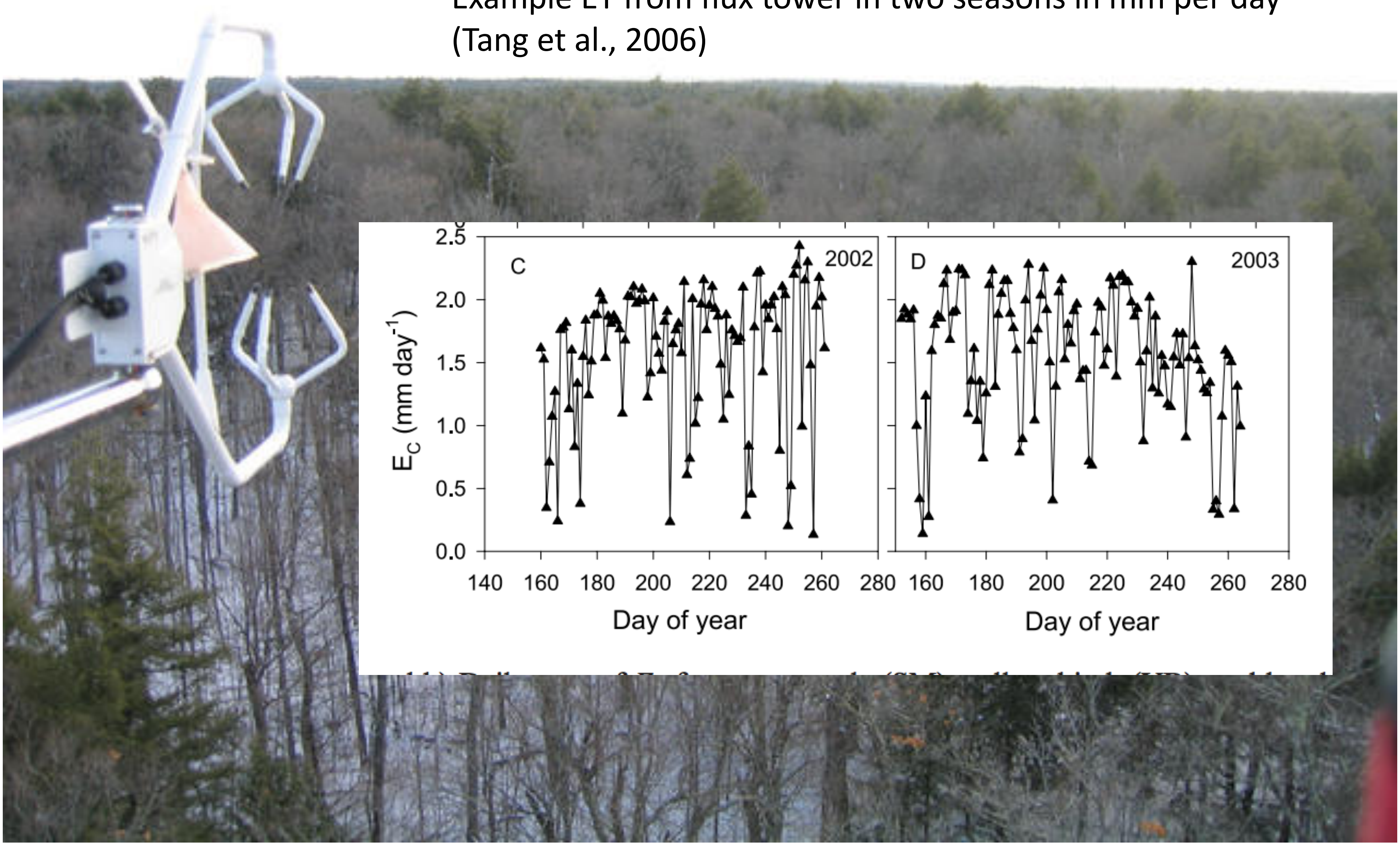
We can convert to

millimeters per day

For ET

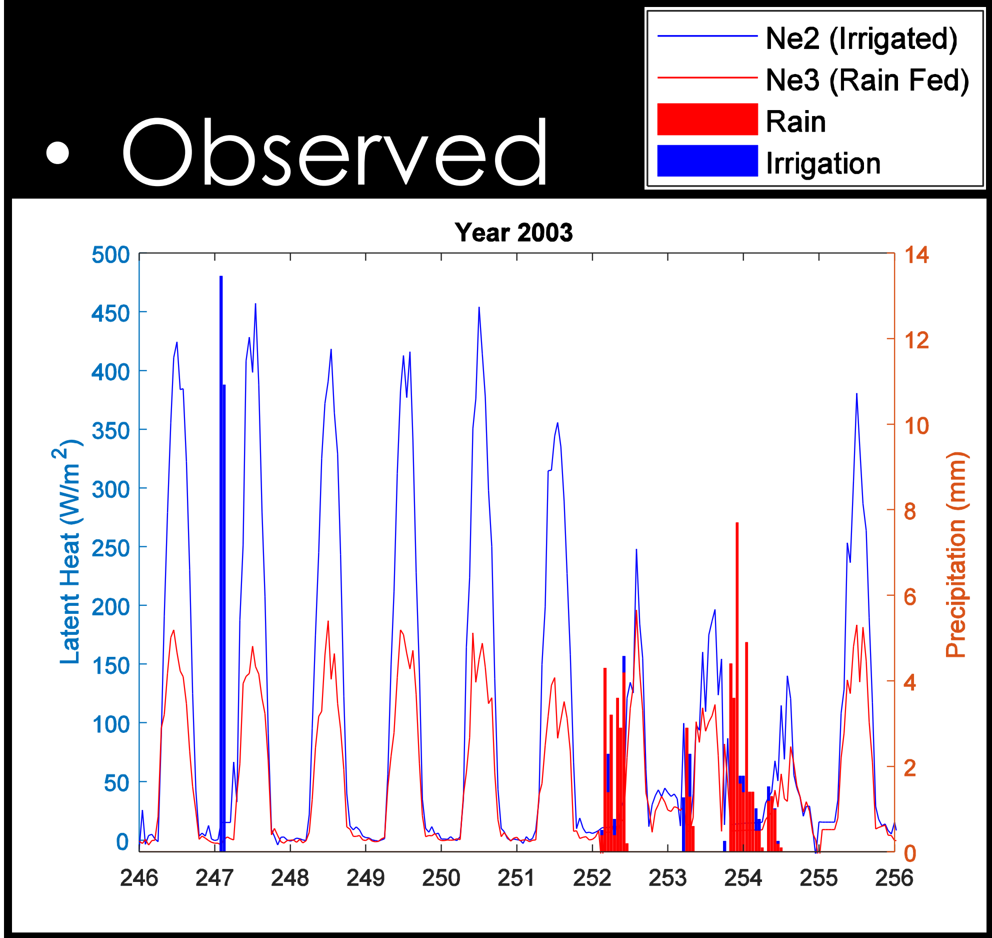
Sylvania Wilderness site in UP Michigan (Watersmeet, MI), est. 2001

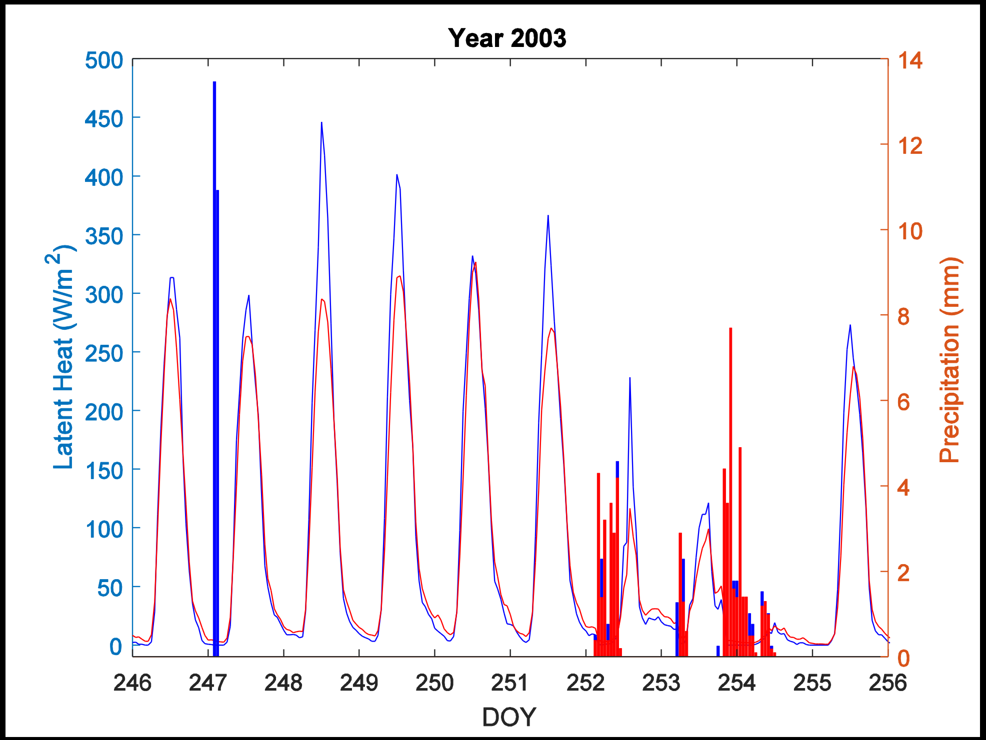
Example ET from flux tower in two seasons in mm per day (Tang et al., 2006)



Paired site studies in Nebraska show us effect of irrigation on ET

- Observed
- Model

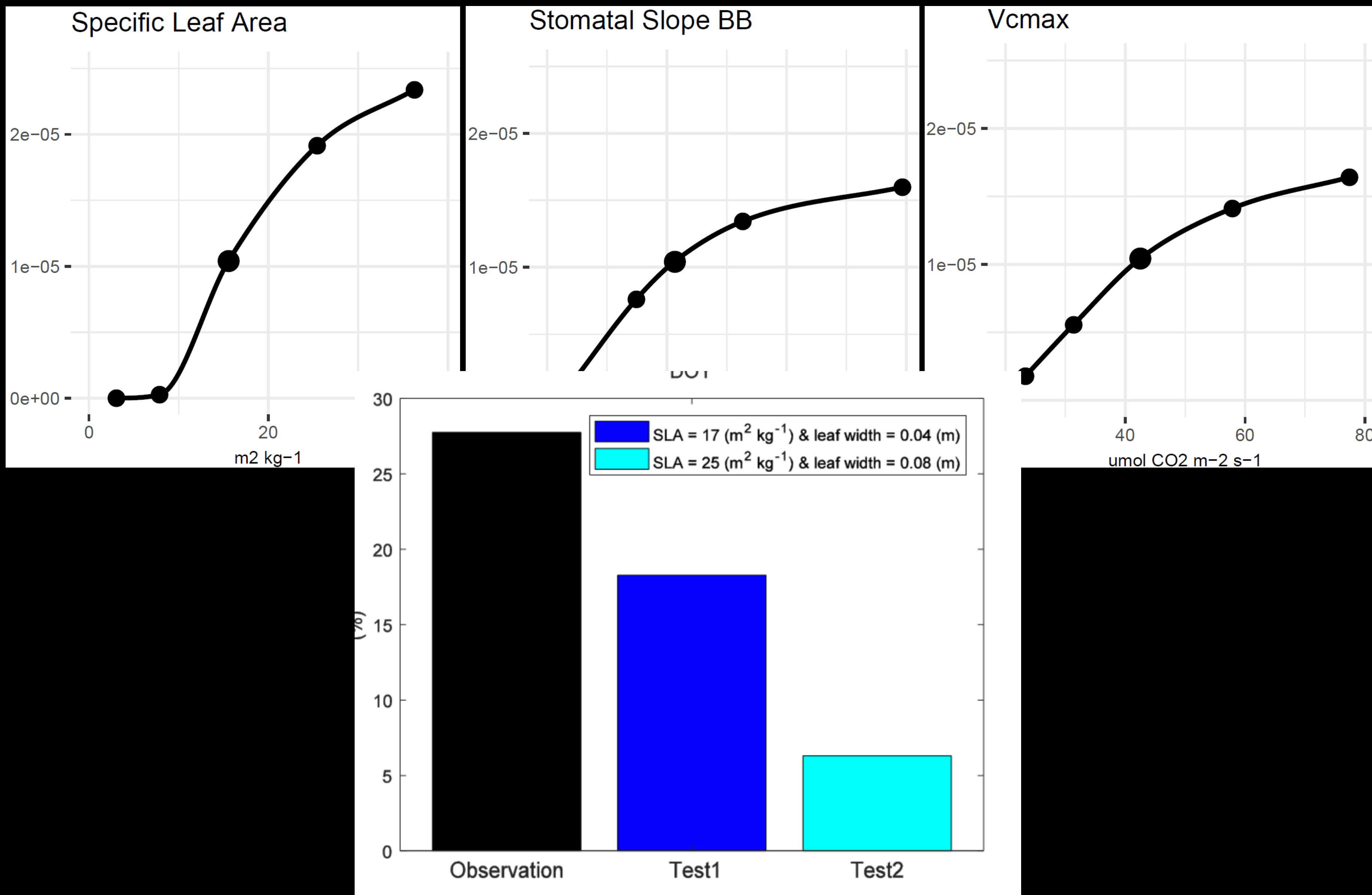




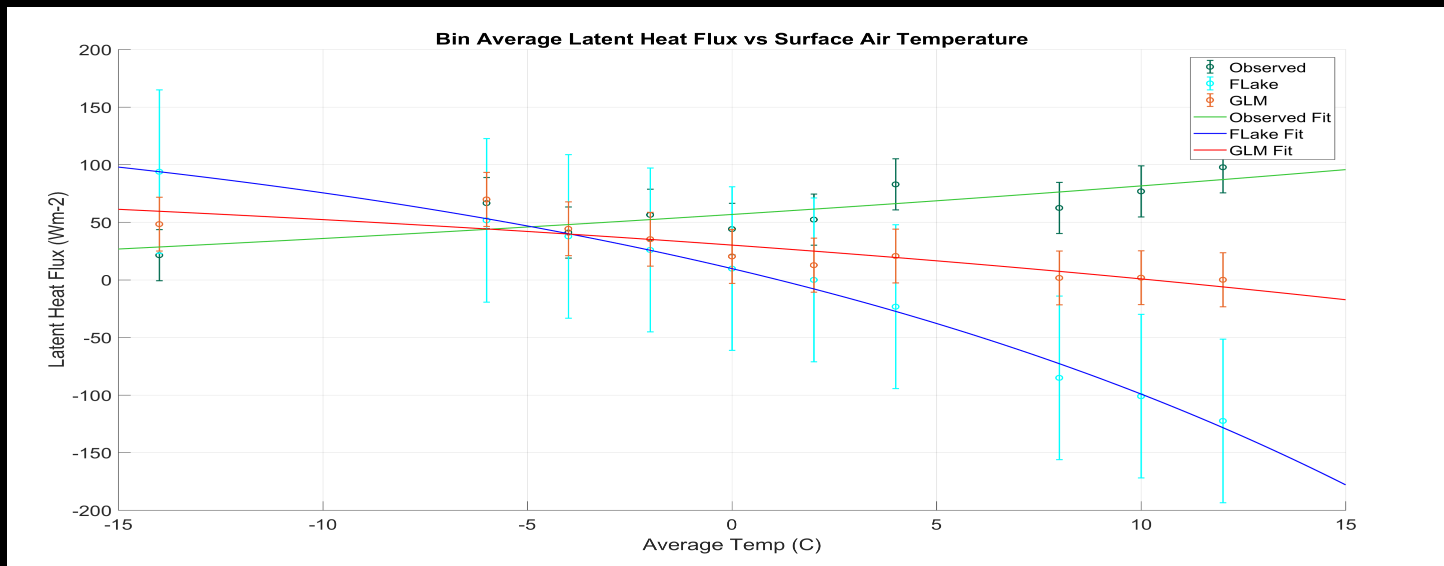
Molly Aufforth

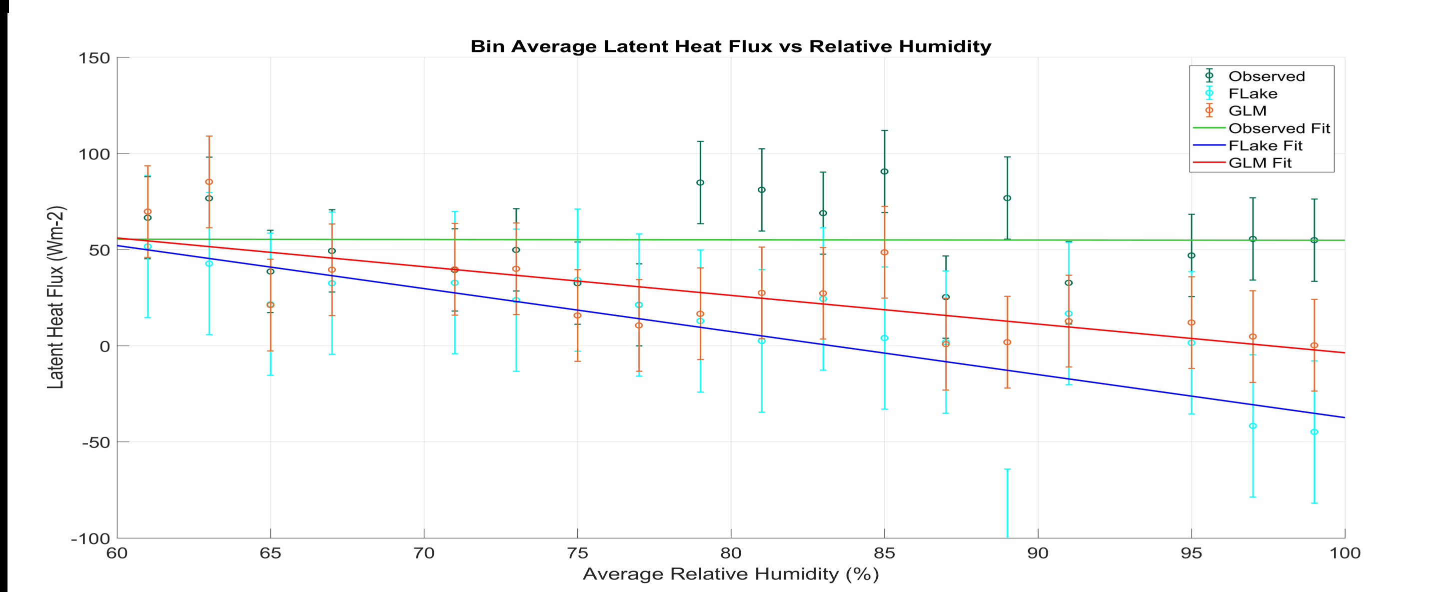
Model: BIOCRO

Use data to constrain sensitive parameters

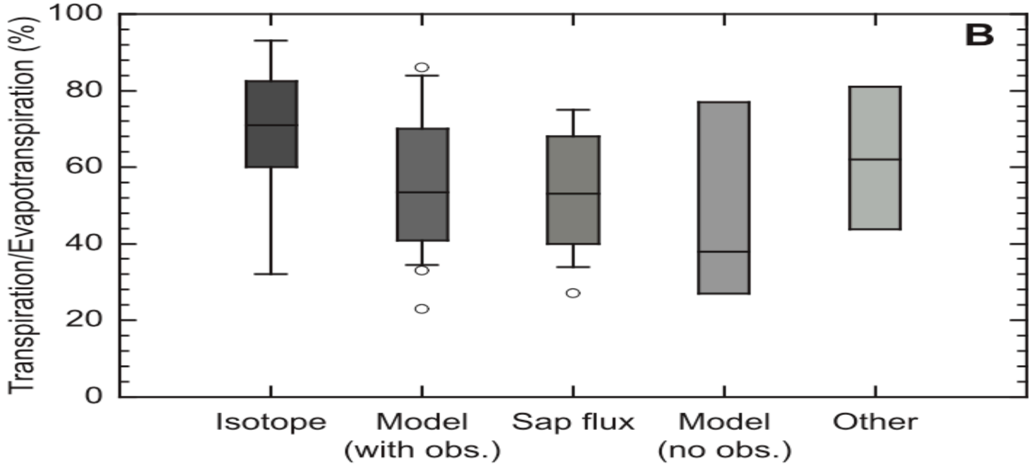


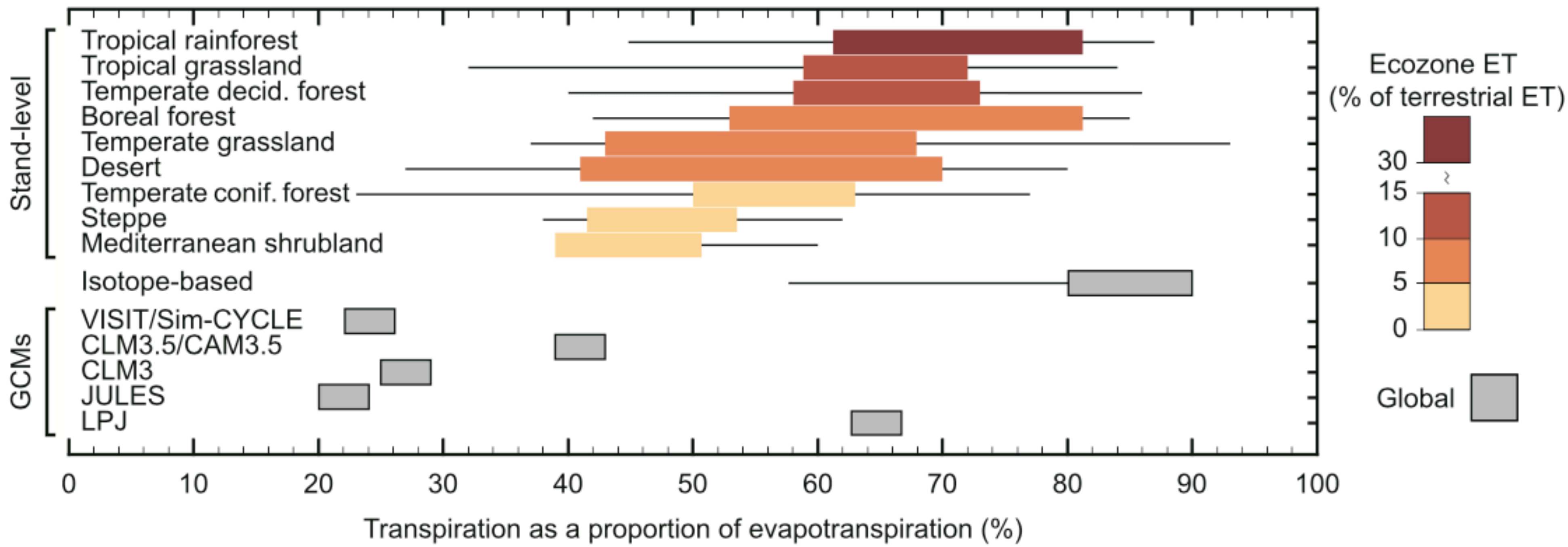
Another example: Lakes





Zack Taebel





Short communication

Transpiration in the global water cycle

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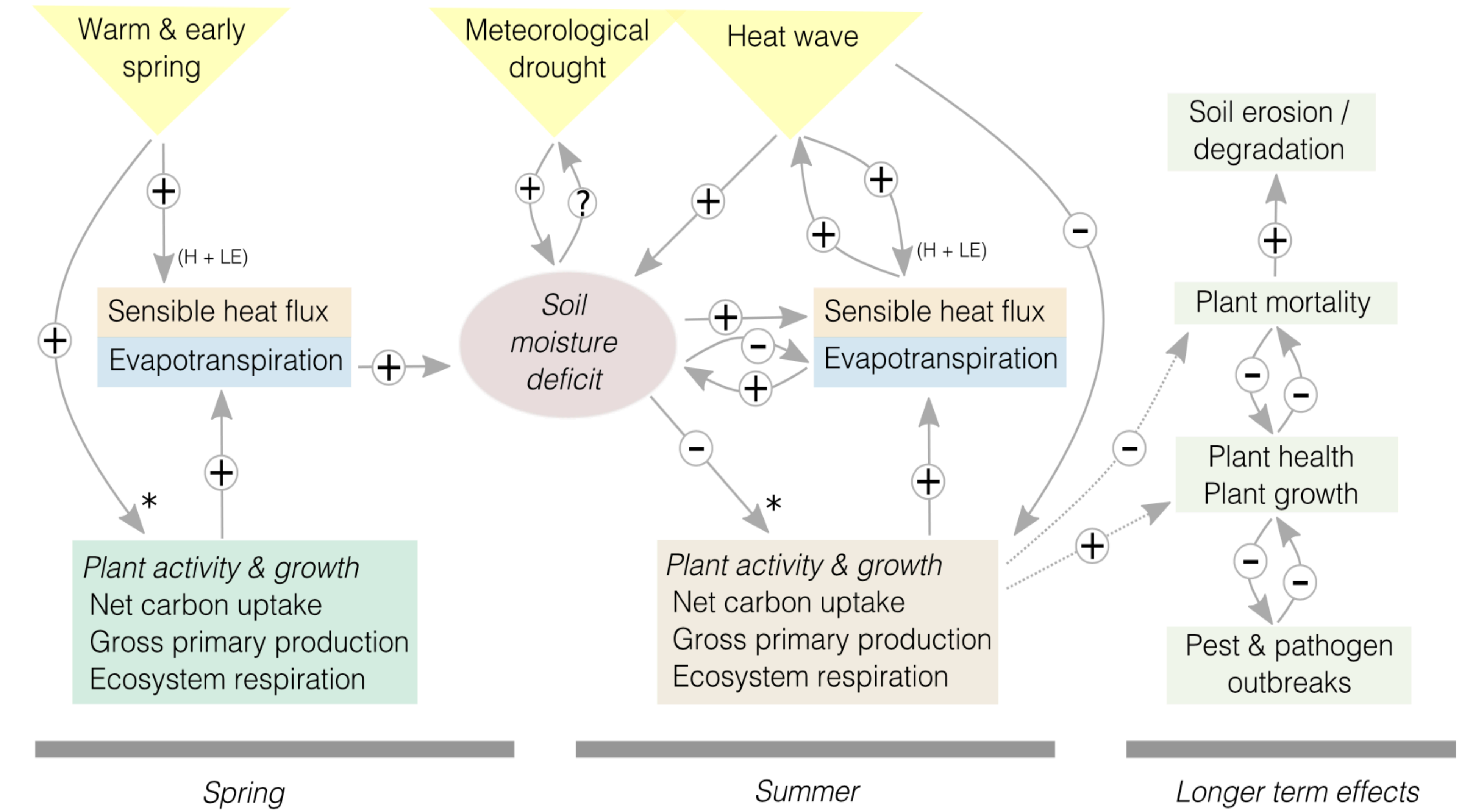
And now we can evaluate hypotheses



* Climate effects on ecosystem carbon fluxes are shown only in qualitative terms. Individual fluxes might be affected differently by climate extremes (see text).

Sippel *et al*., 2016

Flux towers have pros/cons

- PRO: Easy to deploy on a tripod in a field, on solar power, no moving parts, and mostly off-the-shelf technology, nearly 500 long running sites worldwide, “gold standard”
- PRO: It is one of the only ways to directly measure ET at hourly time scale, and at the same time, we also measure the surface heat exchange, carbon dioxide flux (productivity), and climate
- CON: It is relatively expensive (total around $40-50K to purchase), requires significant expertise (technical personnel), and regular maintenance
- CON: EC measures only upwind of the tower and when the atmosphere is “turbulent”, requiring application of methods to fill in data gaps and quality control data

Thank you

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