Using satellite-based estimates of evapotranspiration and groundwater changes to determine anthropogenic water fluxes in land surface model

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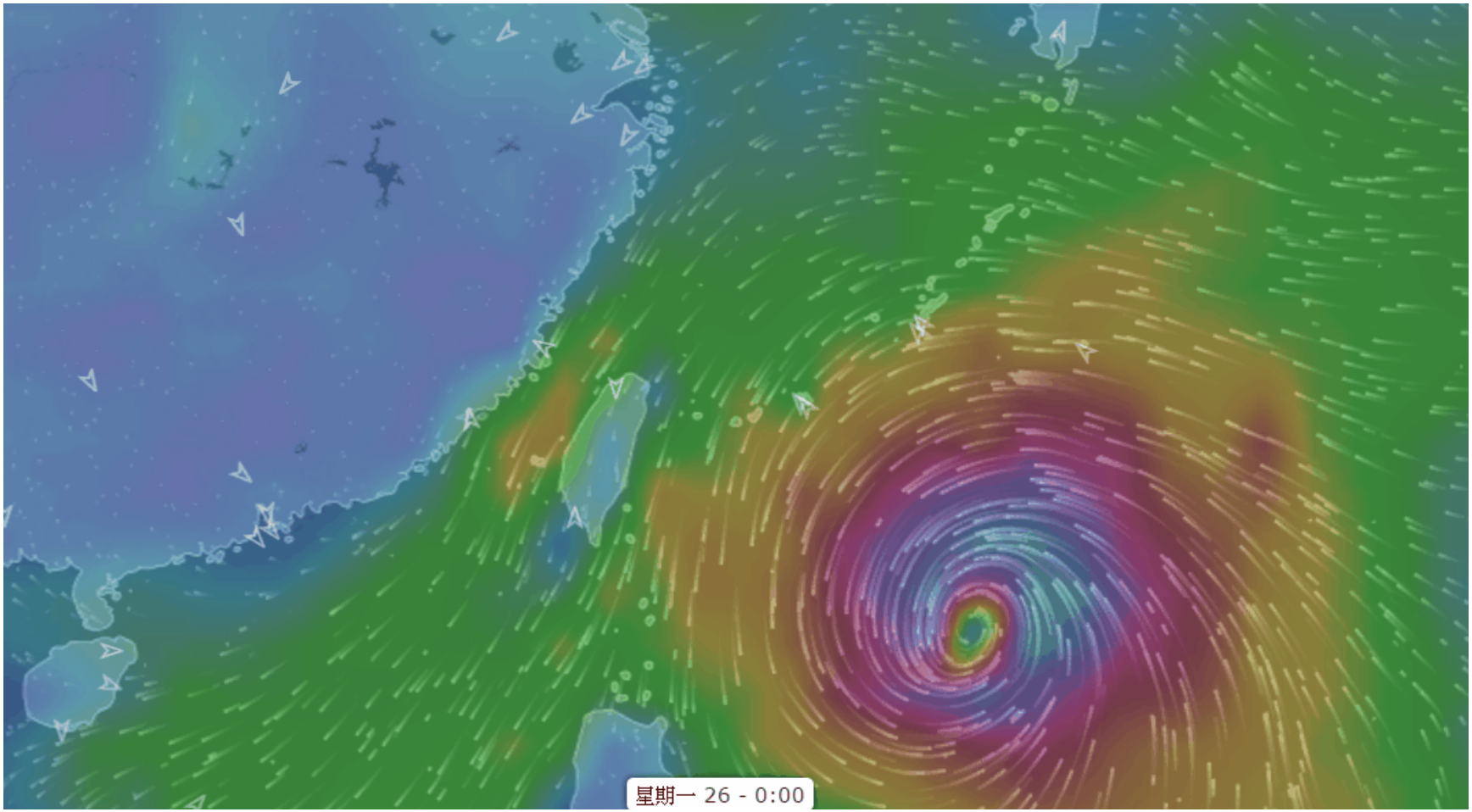
Department of Atmospheric Sciences, National Taiwan University, Taiwan

2016/09/29 @ the GEWEX workshop of Including Water Management in Large Scale Models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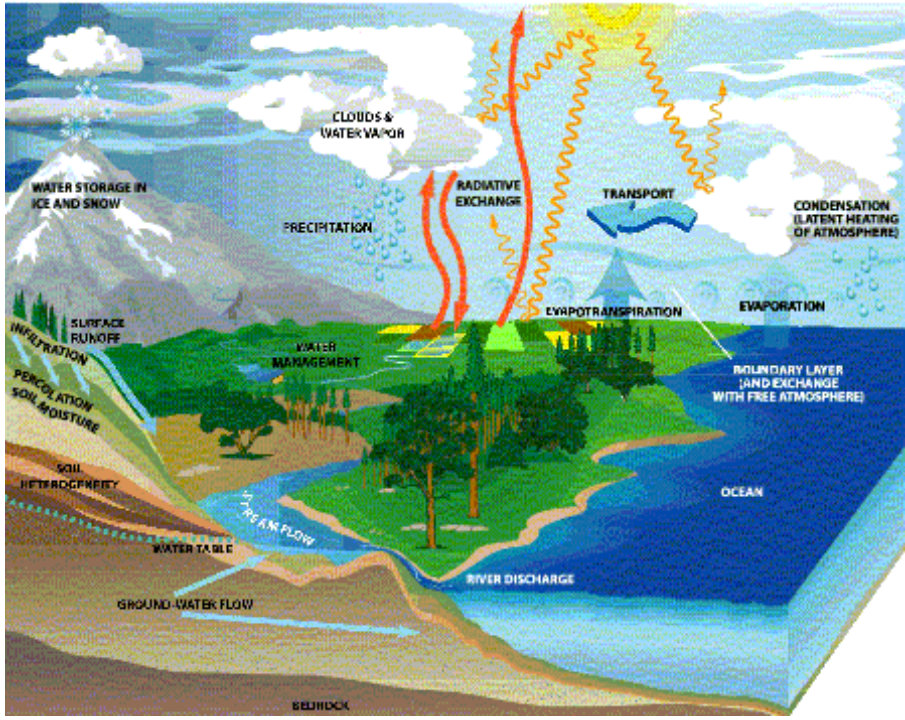
Land Surface Processes

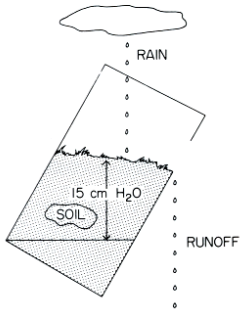
Land surface processes function as

- lower boundary condition in Atmospheric Models
- upper boundary condition in Hydrological Models
- interface for coupled Atmospheric / Hydrological / Ecological Models



Evolutions of Land Surface Model (LSM)

Earliest LSMs: prescribed soil moisture condition



1965
1970 → A bucket model was developed as a lower boundary condition for a GCM by Manabe et al., [1965]

1980 → Soil-vegetation-atmosphere transfer (SVAT) model[Dickinson et al, 1986 and Sellers et al., 1986.]

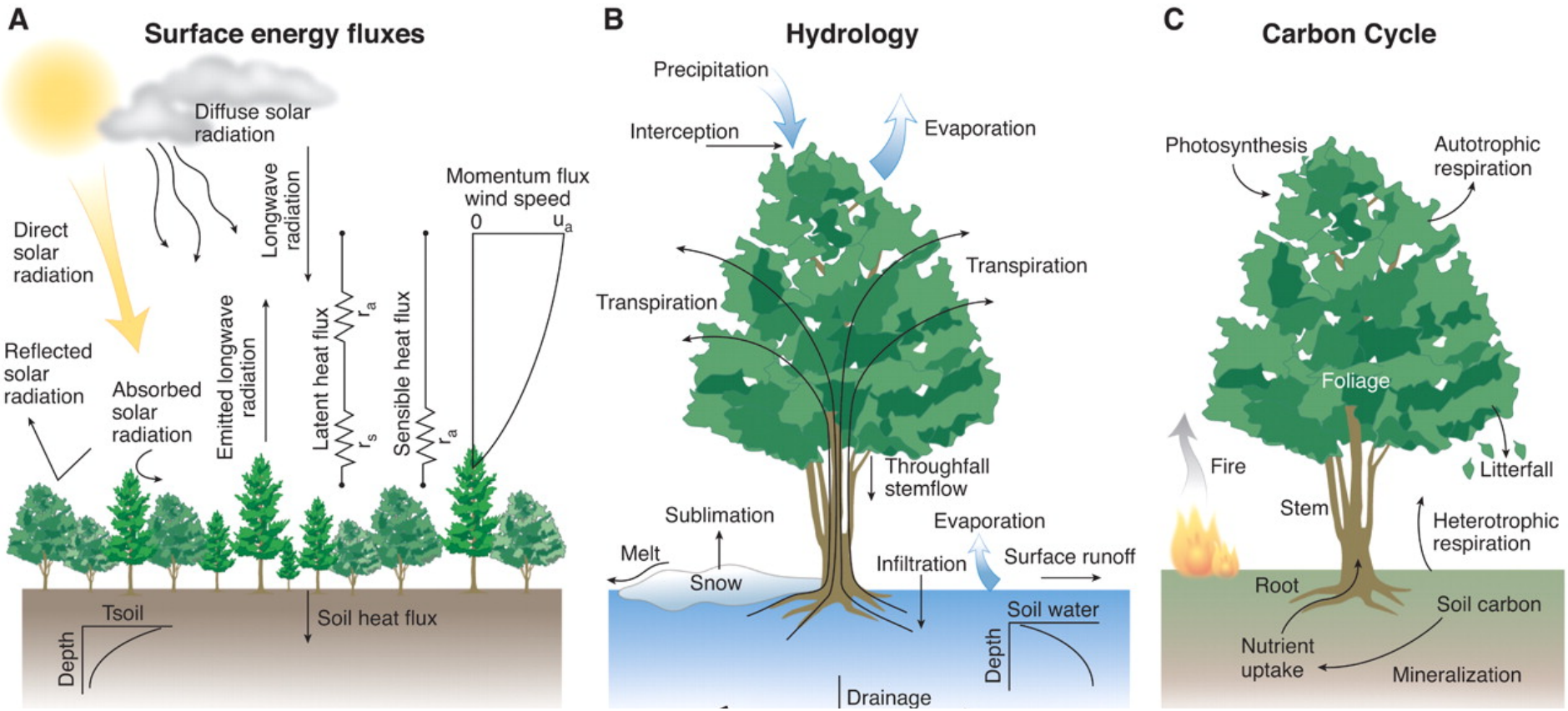
1990 → Heterogeneity hydrologic processes [Famiglietti and Wood, 1991; 1994; Liang et al., 1994]

2000 → Detailed ecological processes. [Bonan, 1998]

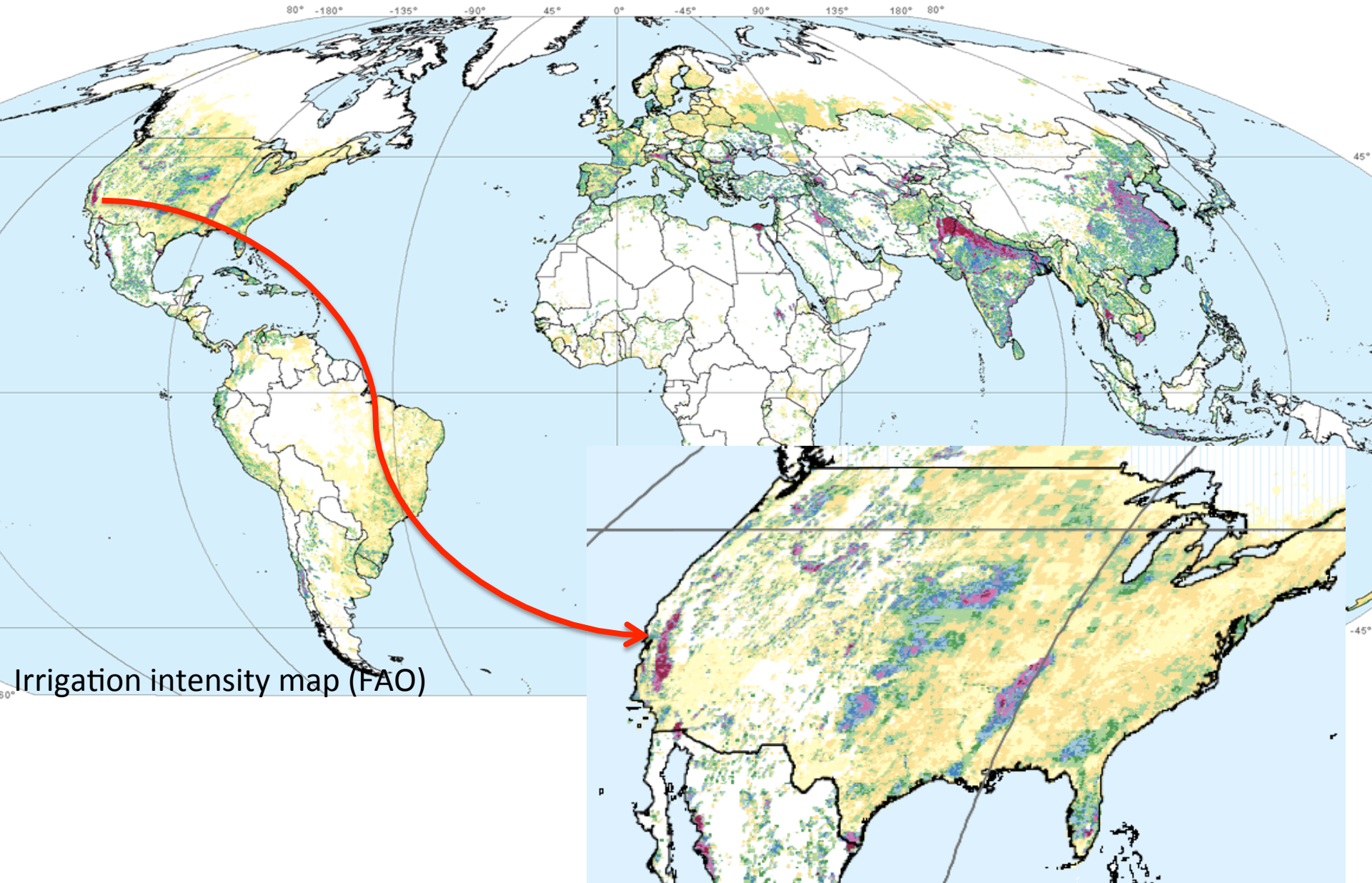
2010 → Subsurface process [Yeh and Eltahir, 2005; Niu et al., 2007; Lo et al., 2008; Pokhrel et al., Campoy et al., …]

I-GEM (Impact of Groundwater in Earth system Models) 2015-2018 between France ANR (Agnès Ducharne) and Taiwan NSF (Min-Hui LO)

Physical processes in land surface model



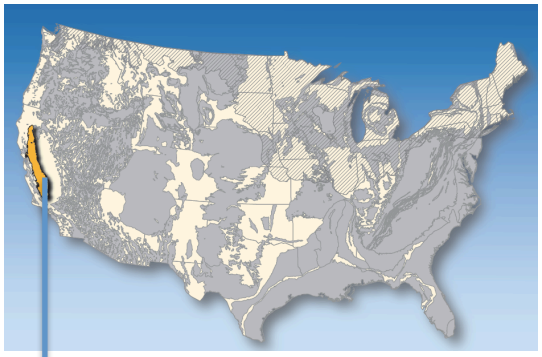
Bonan(2008)



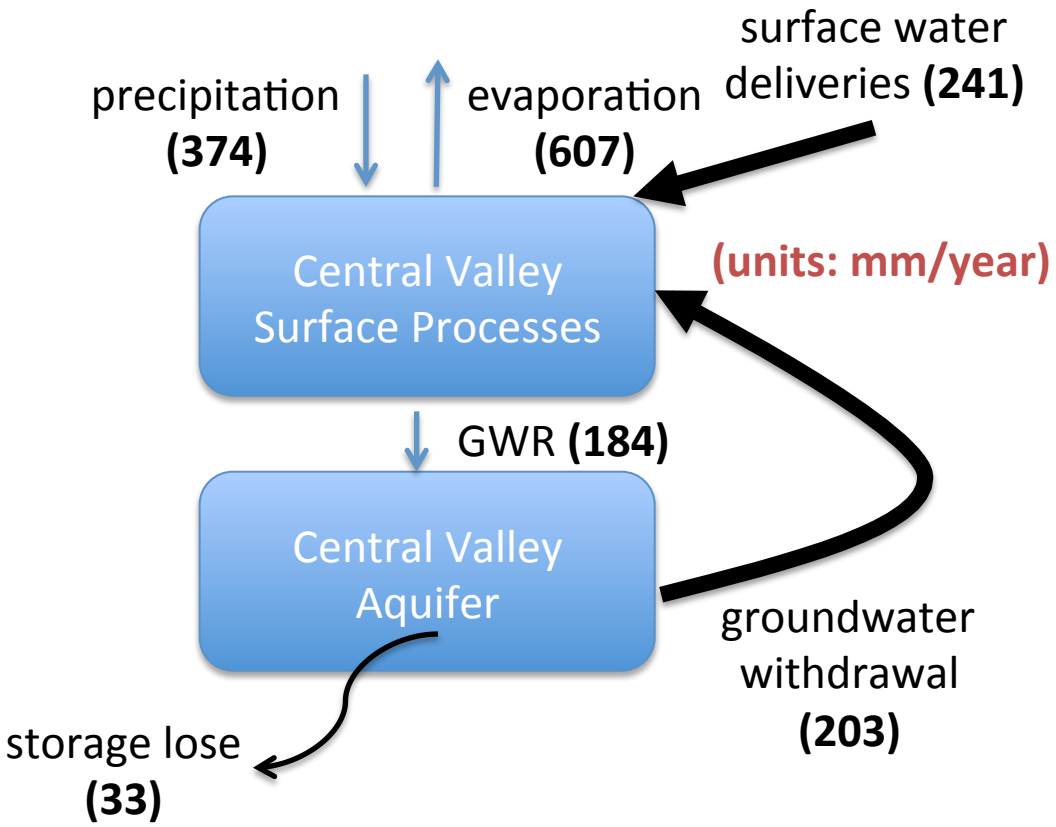
Irrigation intensity map (FAO)

water budget in heavily irrigated system

using California as an example



California's Central Valley
(52,000 km^2)

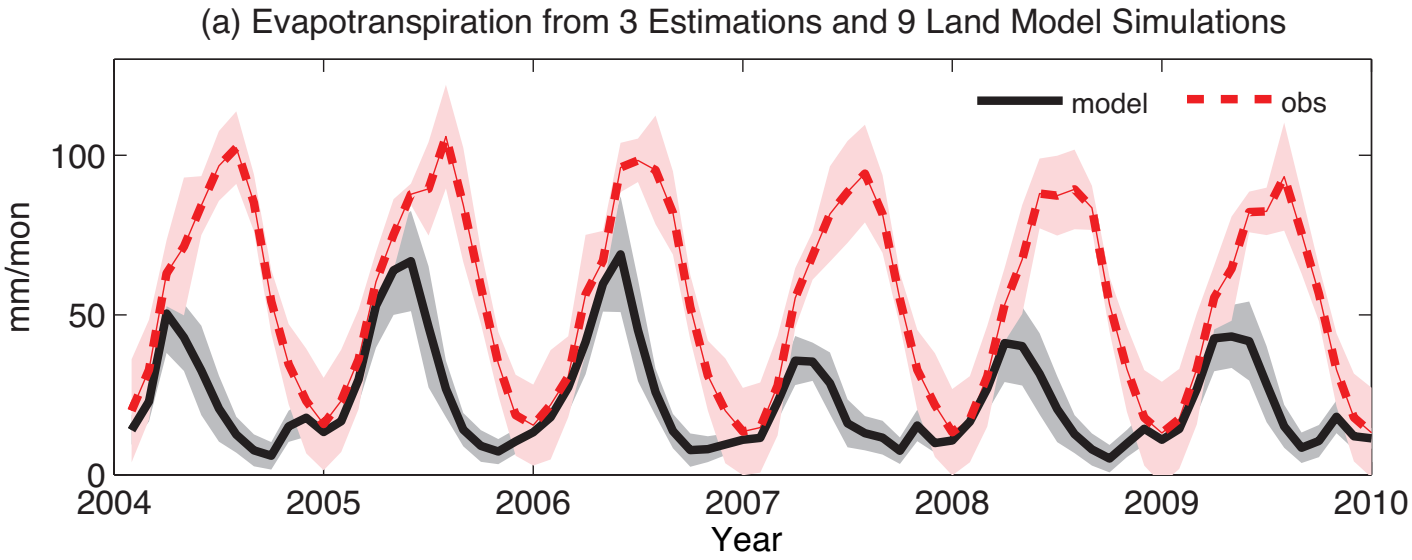


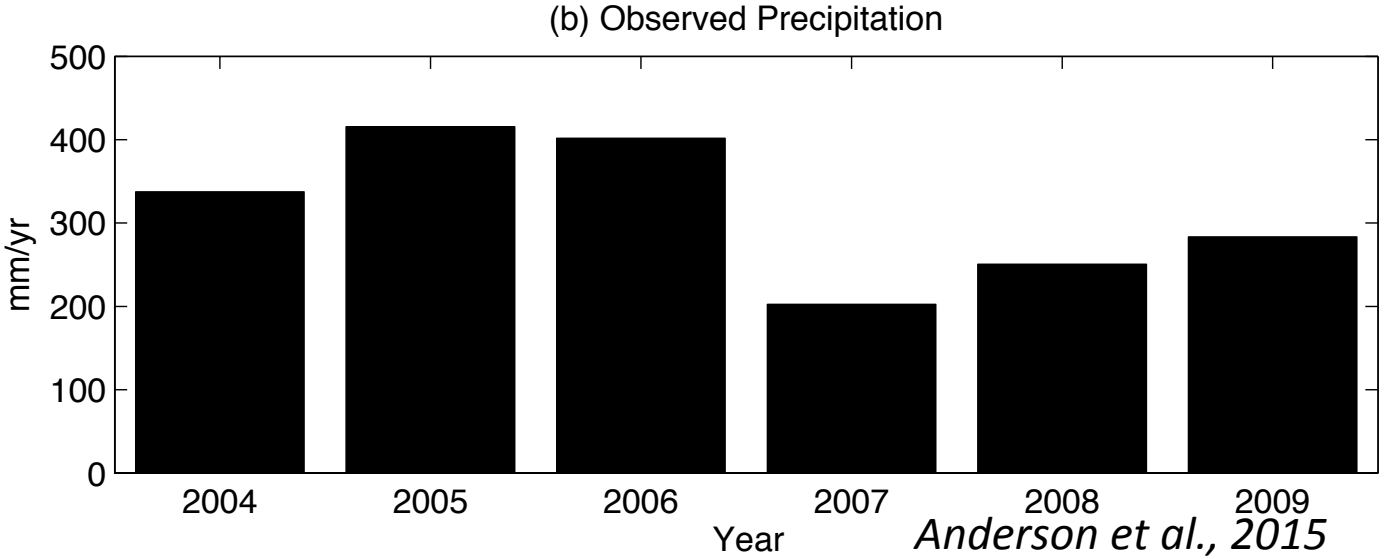
modified from *Faunt et al.* [2009]

(Famiglietti et al., 2011; Anderson et al., 2012; Lo and Famiglietti, 2013; Lo et al., 2013; Anderson et al., 2015)

Can current models simulate reasonable evaporation?

can models simulate reasonable evaporation?



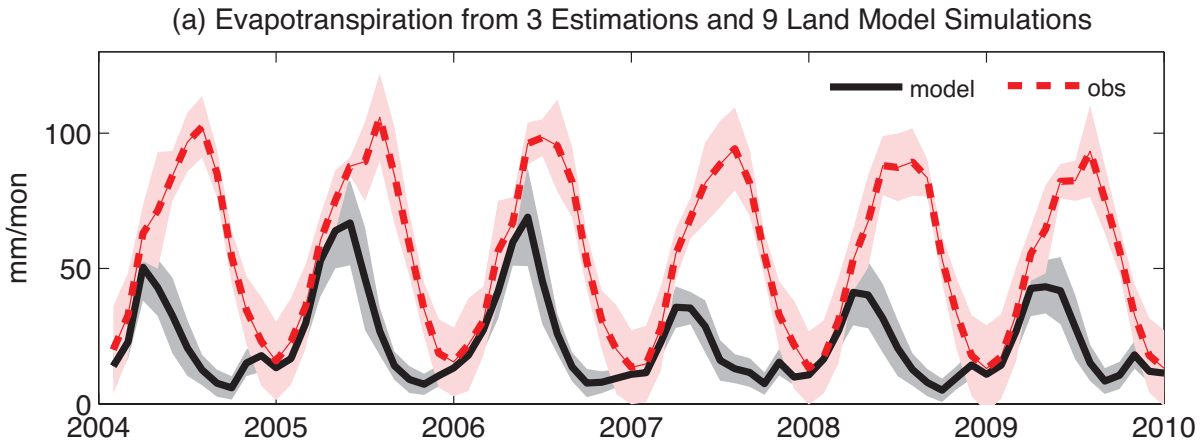


The surface energy balance algorithm for land (SEBAL), Anderson et al., 2012

United States Agricultural Monitoring (USAM), Tang et al, 2009

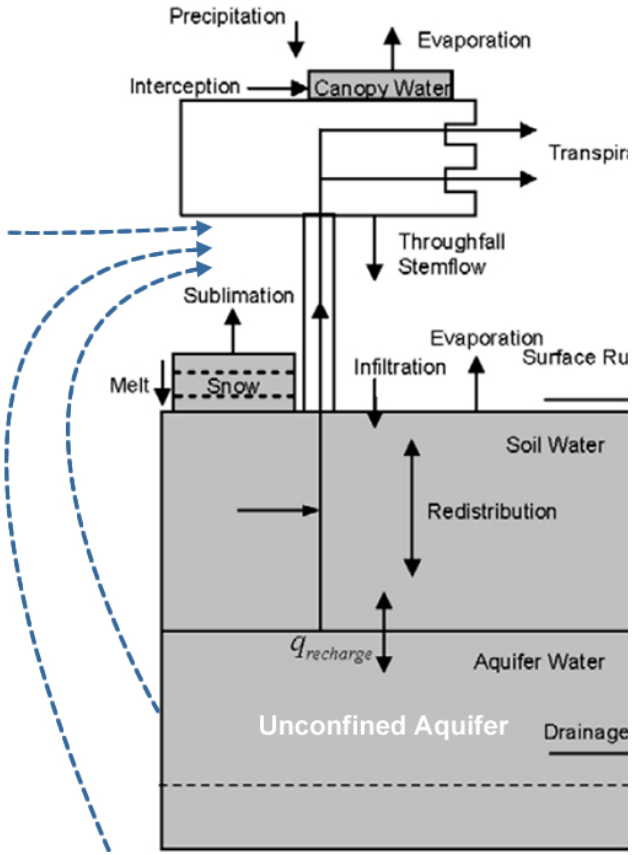
Anderson et al., 2015

lower envelope estimate of irrigated water demand



650 mm/yr vs 280 mm/yr

How much water *at least* needs to be applied
(The difference between actually ET & model ET)



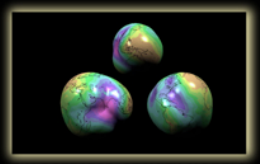
$$\frac{dS}{dt} = In - Out$$

Measuring Earth's Gravity from Space

GRACE

Gravity Recovery and Climate Experiment

The Gravity Recovery and Climate Experiment (GRACE), an international mission with Germany, uses twin satellites to precisely measure the Earth's gravity field. This will lead to increased knowledge of the motion of water on land and on the oceans. This information can be used to better understand climate, agricultural and global changes.



EXAGGERATED GRAVITY MODELS

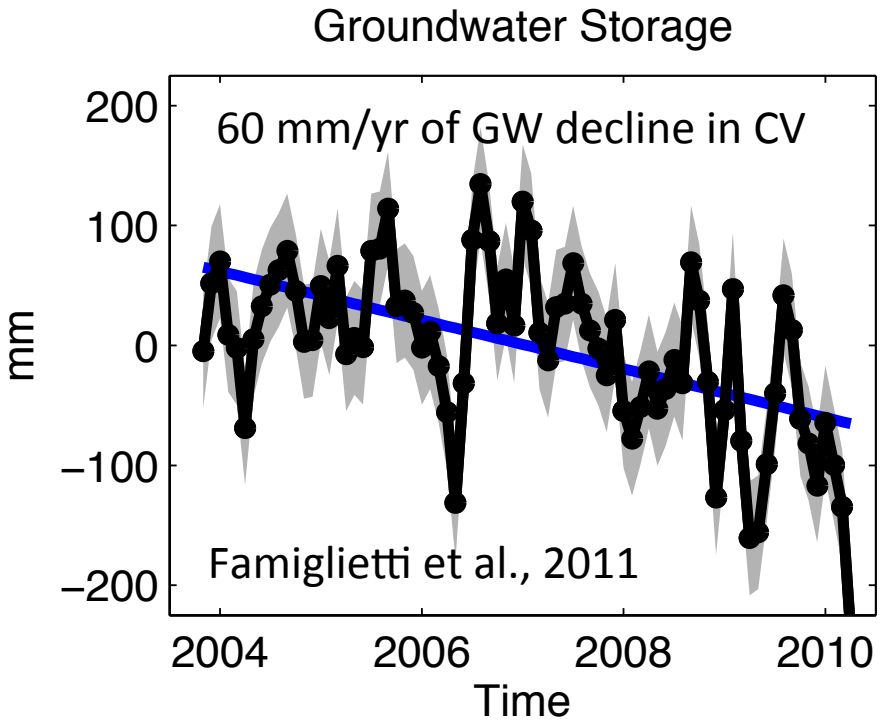
OCEAN CURRENT MAPPING

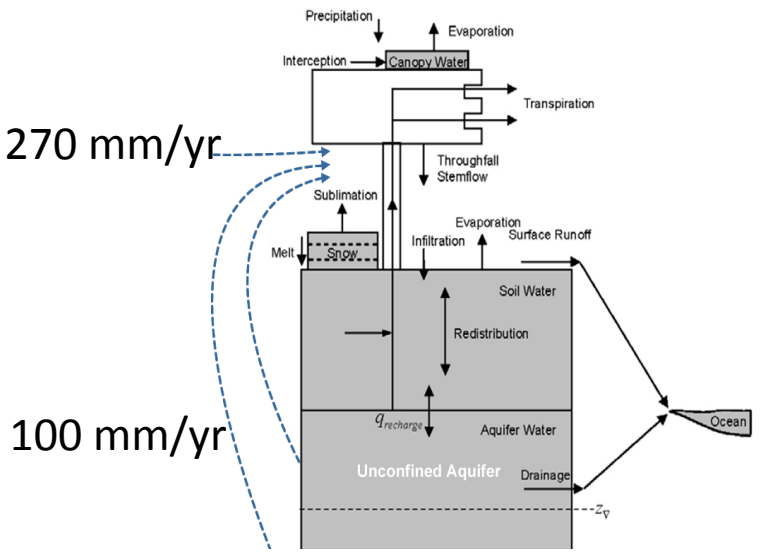
GROUNDWATER MONITORING

http://www.csr.utexas.edu/grace/

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

GRACE estimated groundwater pumping rate



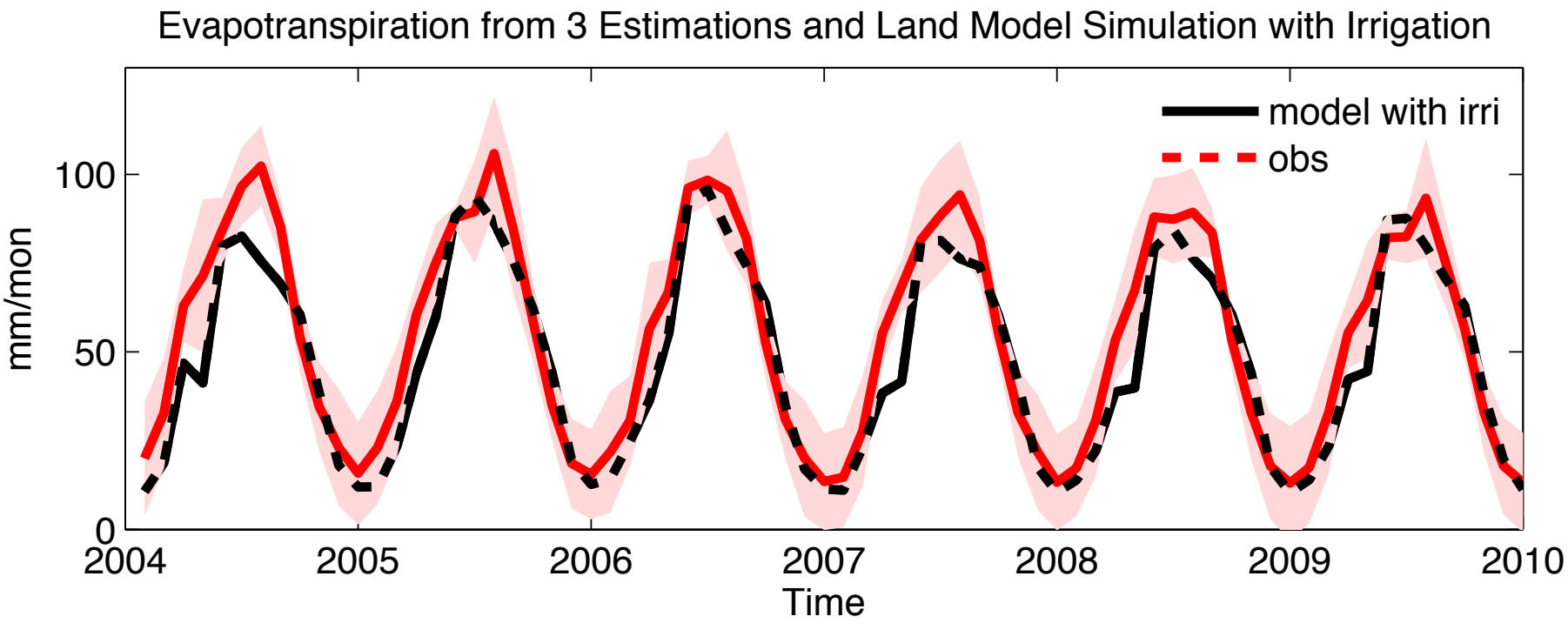


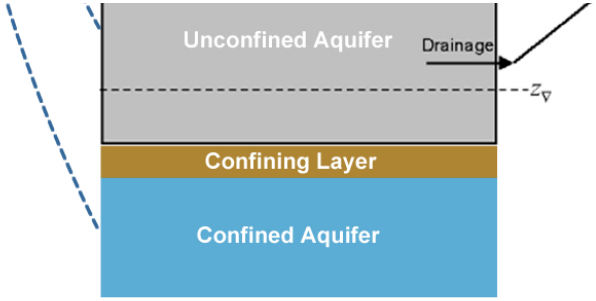
$$\frac{dGW}{dt} = GWR - pumping$$

Surface water use statistics (240 mm/yr) from State Water Project, US Bureau of Reclamation, and canal streamflow data from California Data Exchange.

Total irrigated water demand (~400 mm/yr) in CV, (Wisser et al., 2008)

representation of irrigation fluxes

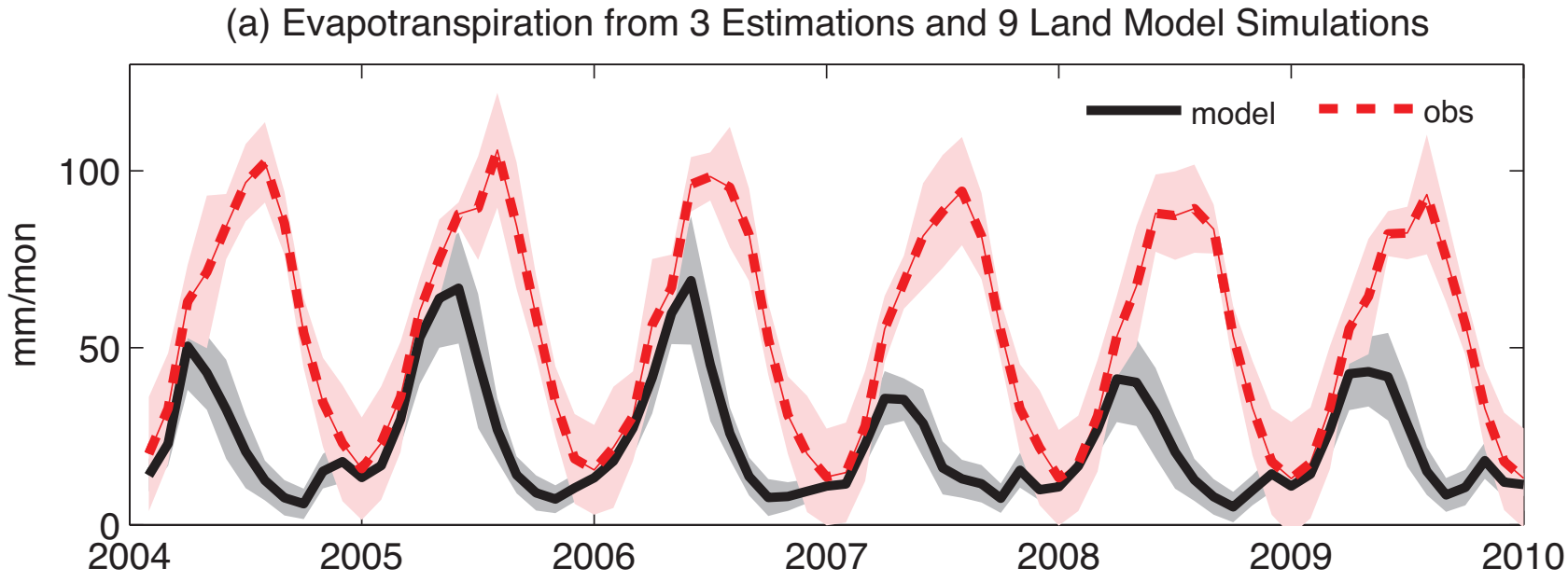




Anderson et al., 2015

recap

- Current models have sophisticated physical parameterizations.
- HOWEVER, lack of anthropogenic processes leads to underestimated evaporation.



Caveat:

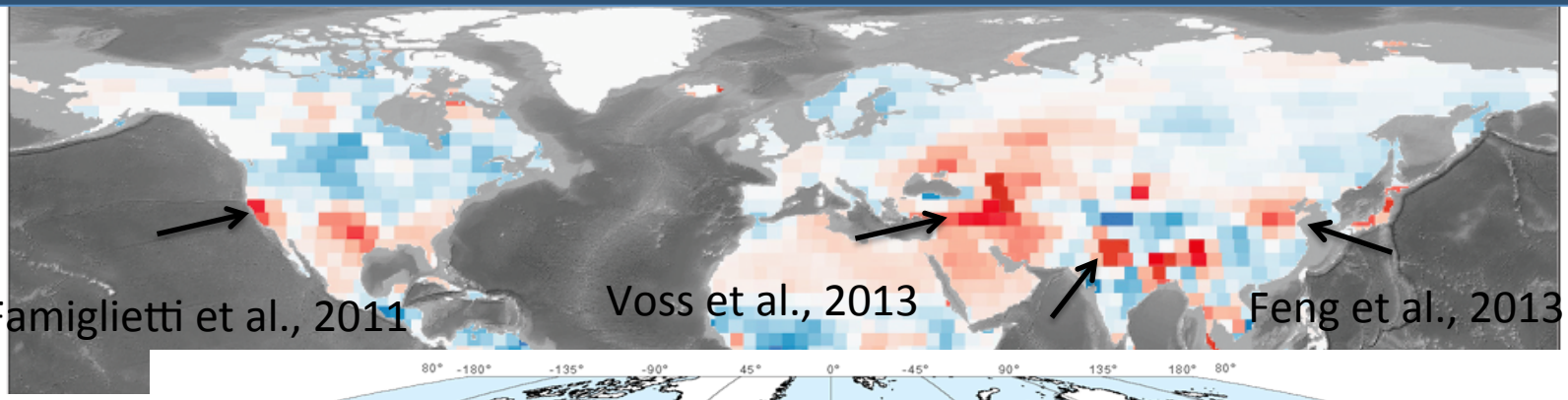
- Constant irrigated water?
- GW withdrawal from confined and unconfined aquifers globally?

Next Step:

- Apply this approach globally
- Couple to GCM to see human fingerprint on the climate

GRACE trend map:

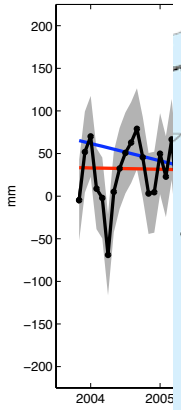
spatial distribution of land water storage change (2003-2014)

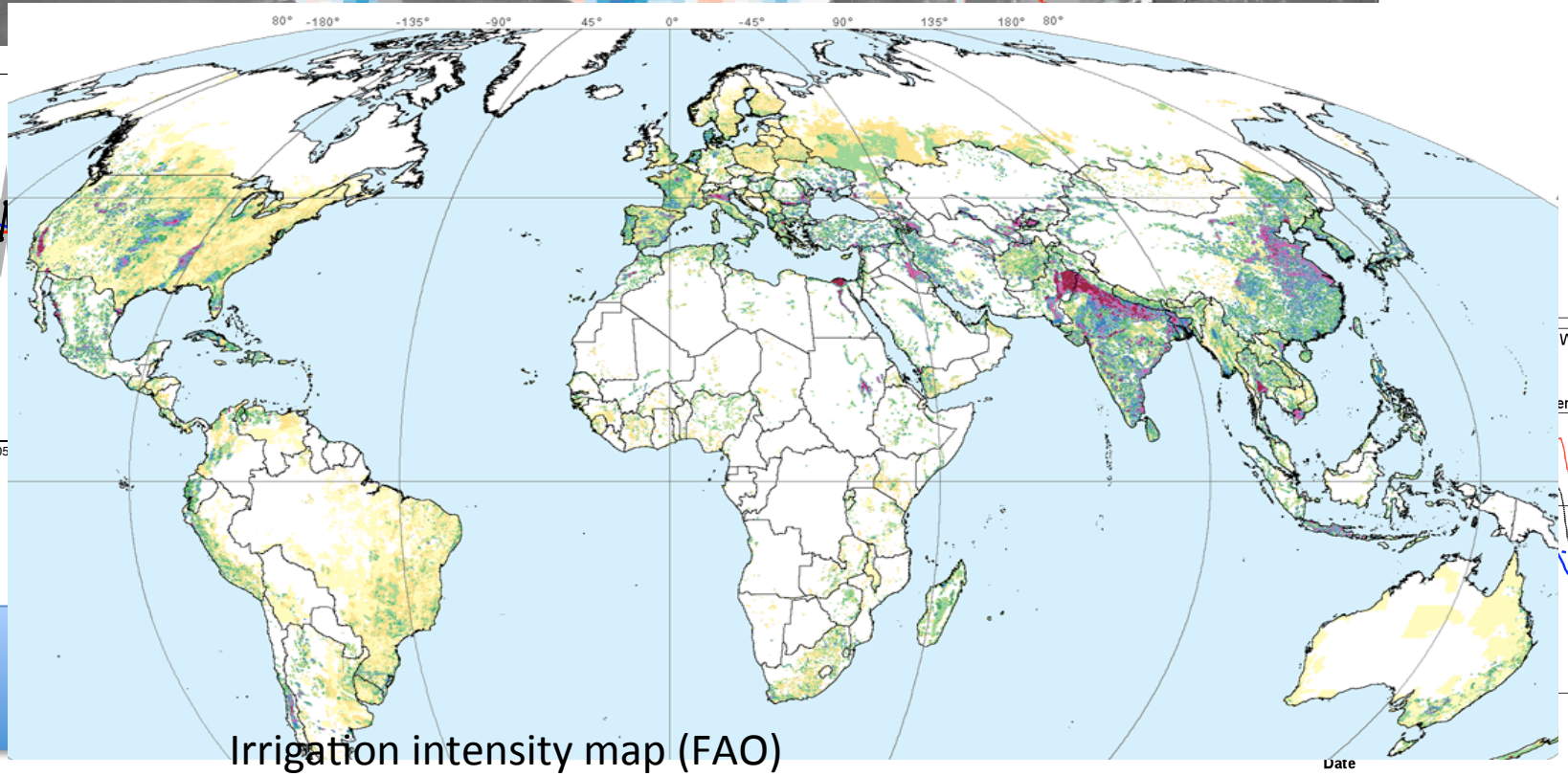


Famiglietti et al., 2011

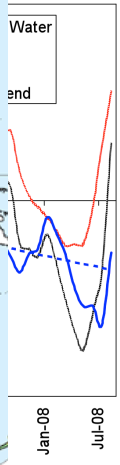
Voss et al., 2013

Feng et al., 2013





Irrigation intensity map (FAO)



Caveat:

- Constant irrigated water?
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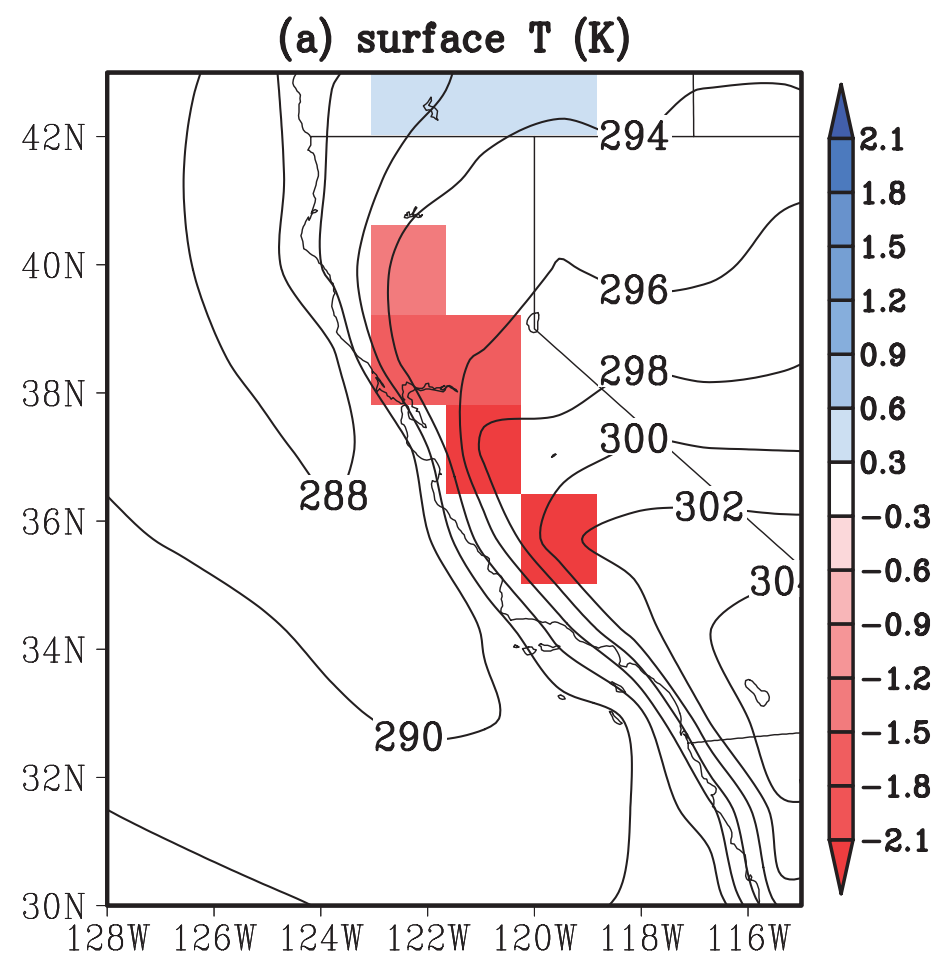
climate model simulations

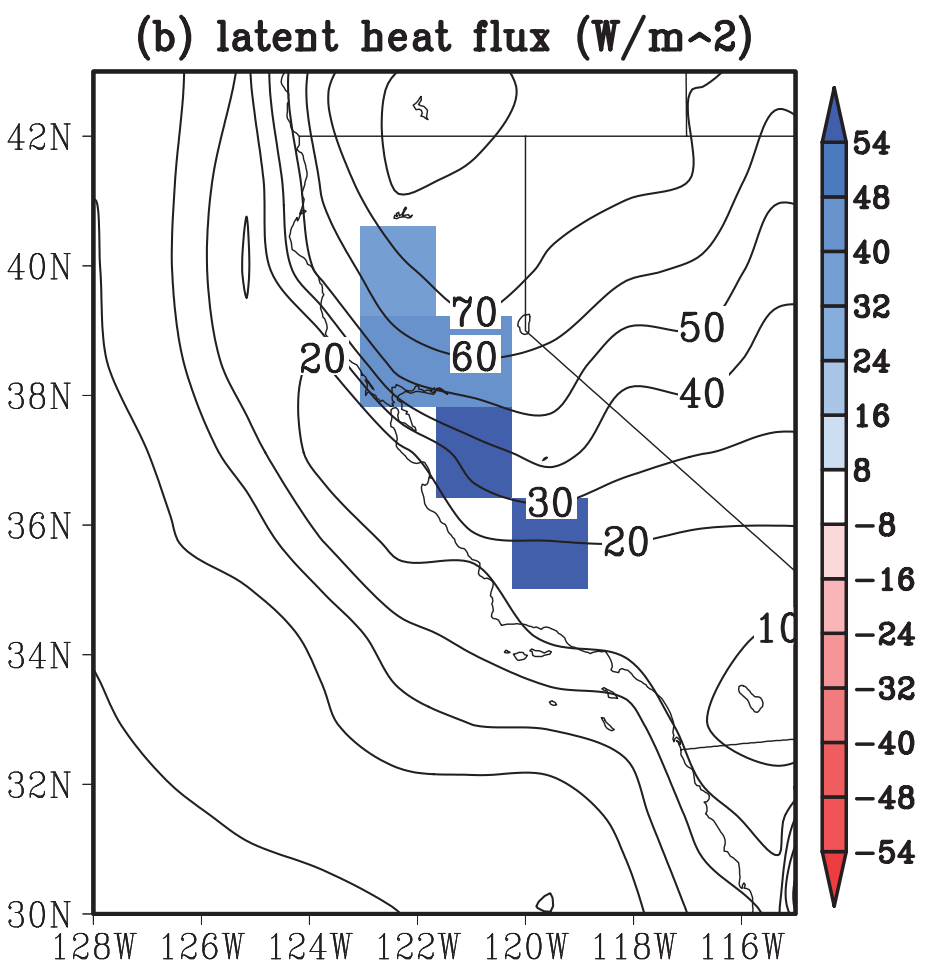
- Model:
  - NCAR AGCM (Community Atmosphere Model, 1.4 lat x 1.4 lon)
- Experiments:
  - Exp01 (CTR): CAM coupled land surface model
  - Exp02 (IRRI): CAM coupled land surface model + Irrigation
- Methodology:
  - Both simulations are conducted for 90 years
  - Analysis of the differences between Exp01 and Exp02 for the west of US and for summer only.

changes in local surface energy budget

decrease in surface temperature

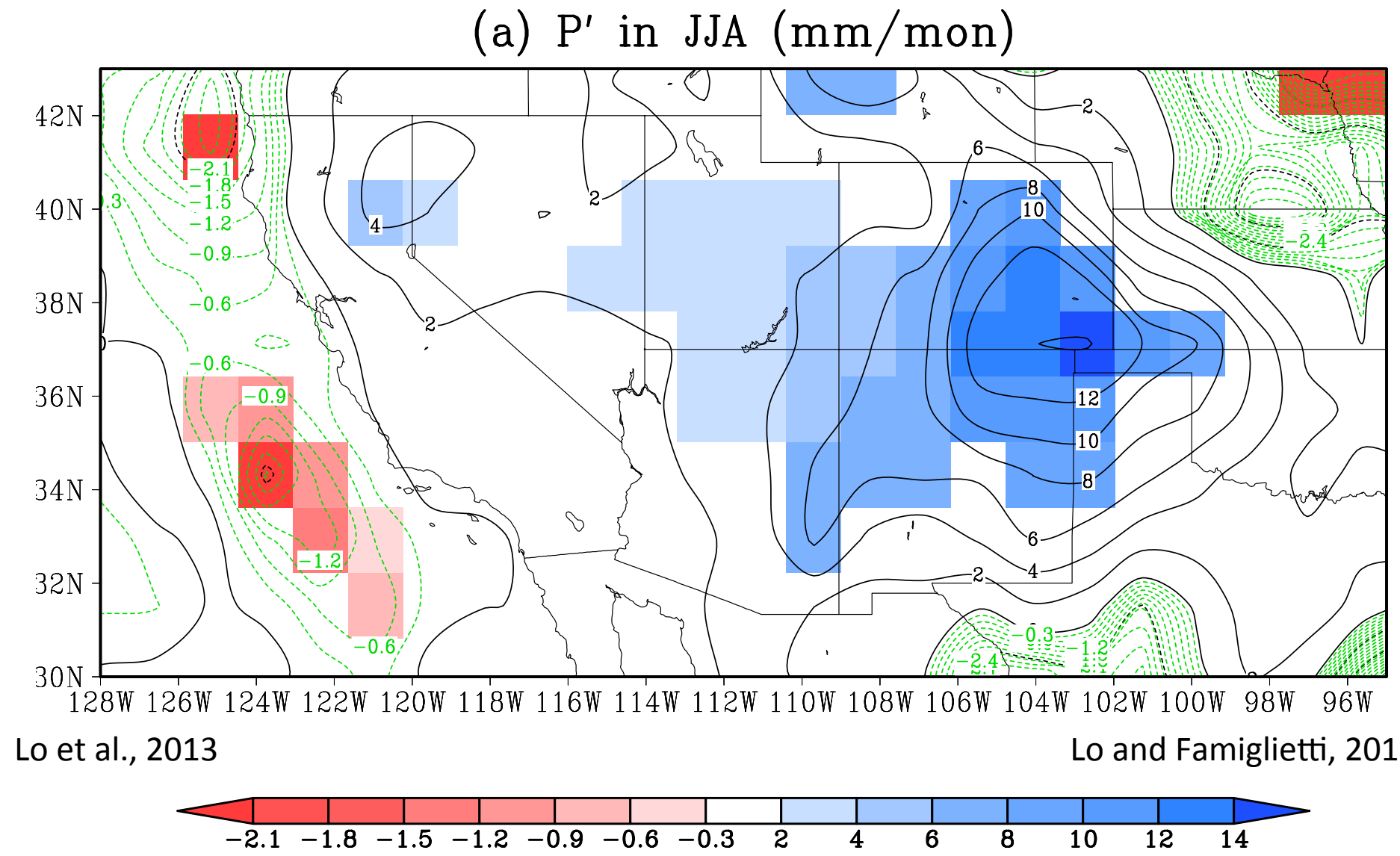


increase in latent heat flux



Lo et al., 2013

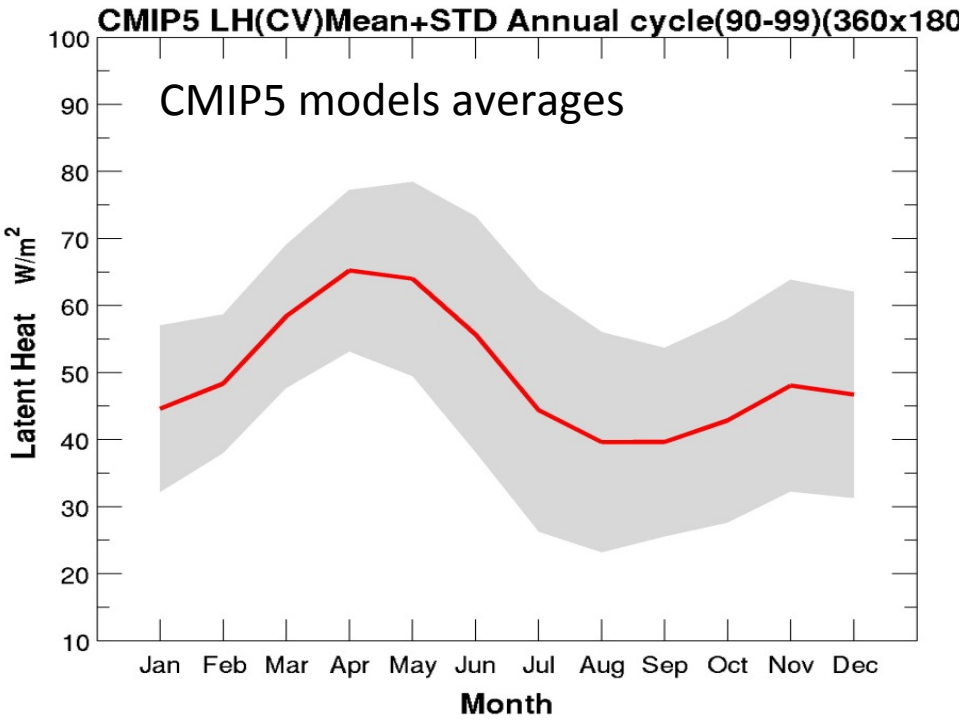
asymmetric responses in rainfall

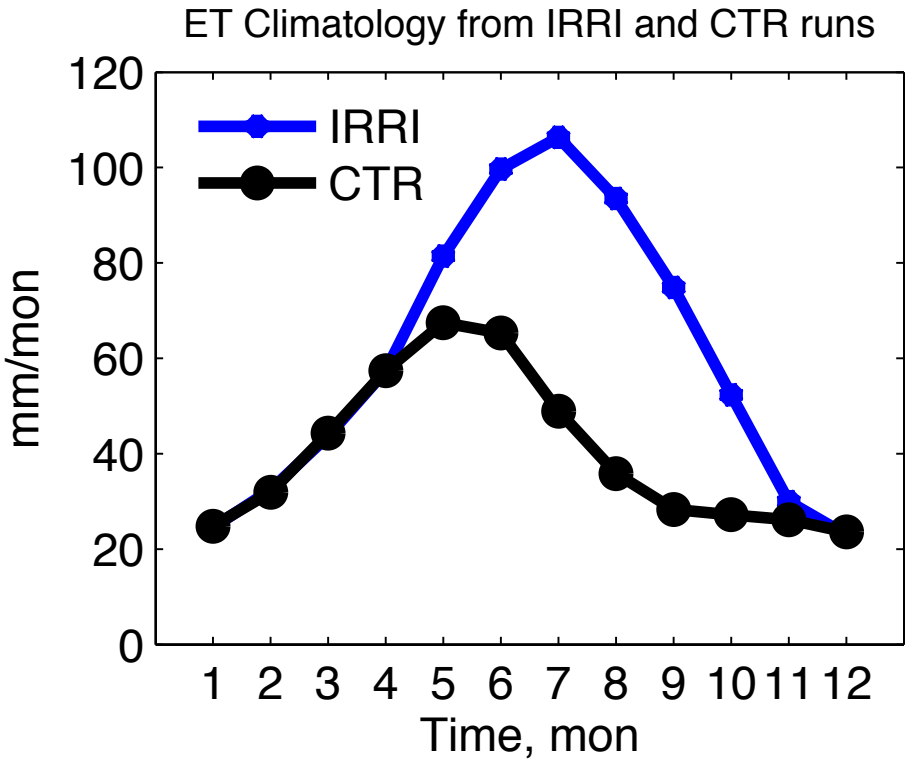


Lo et al., 2013

Lo and Famiglietti, 2013

applications on current climate moels





simulated costal stratocumulus might be overestimated?

simulated US southwest rainfall might be underestimated?

summary

- GRACE trend map provides an invaluable information
  - Some of those negative regions indicate the anthropogenic activities
  - How to best utilize the GRACE data in climate models?

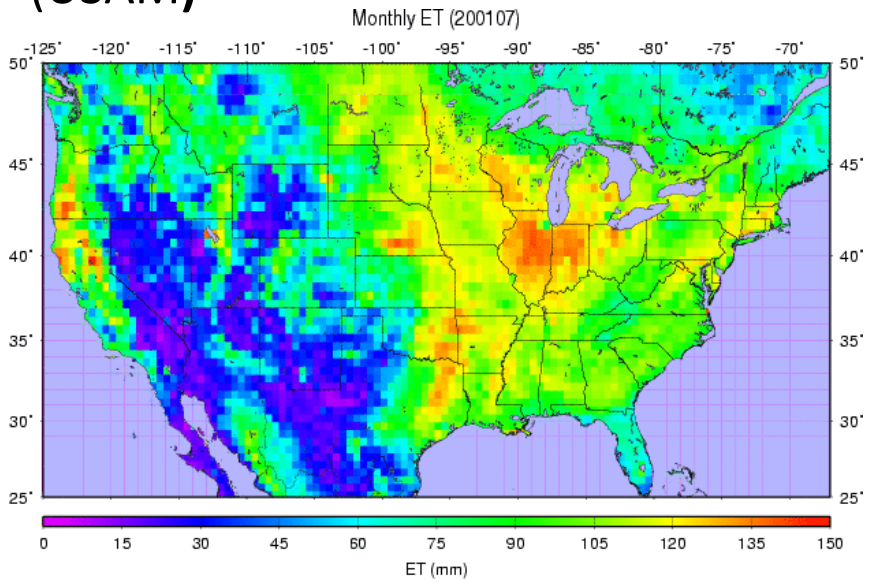
- When coupling to the climate model,
  - the results show the importance of subsurface hydrological and anthropogenic processes in the climate and water cycle.

Thanks for listening!

Min-Hui Lo
minhuilo@ntu.edu.tw

ET Estimate

United States Agricultural Monitoring (USAM)

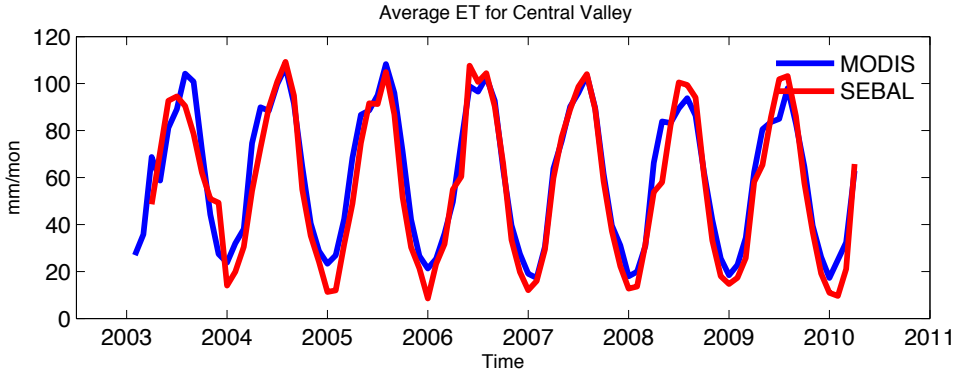


The MODIS data include Land Cover Type, Surface Reflectance, *Land Surface Temperature*/Emissivity, Vegetation Indices, and Albedo.

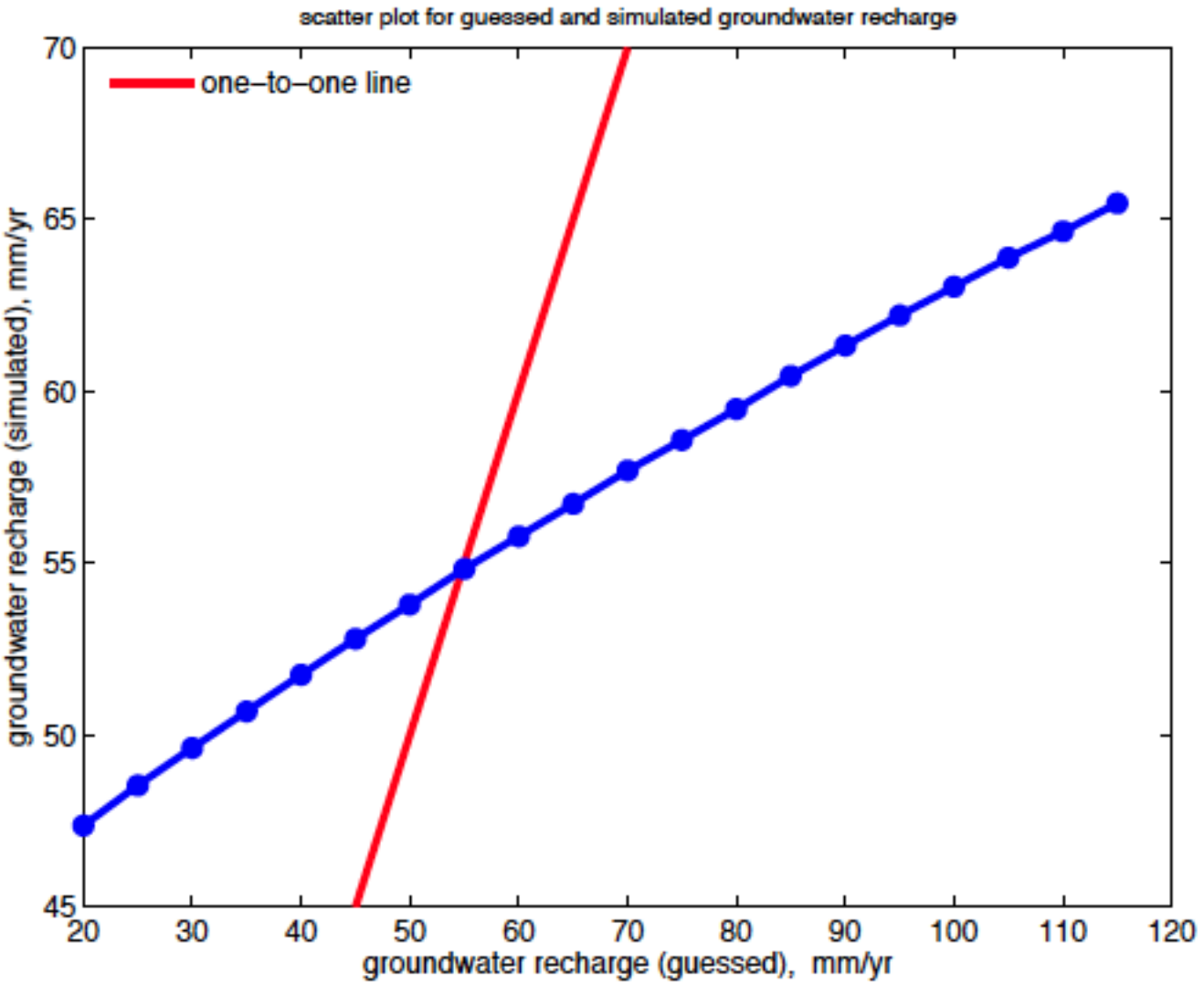
Surface radiation components are obtained from Surface Radiation Budget Data.

The surface energy balance algorithm for land (SEBAL)

From Ray Anderson

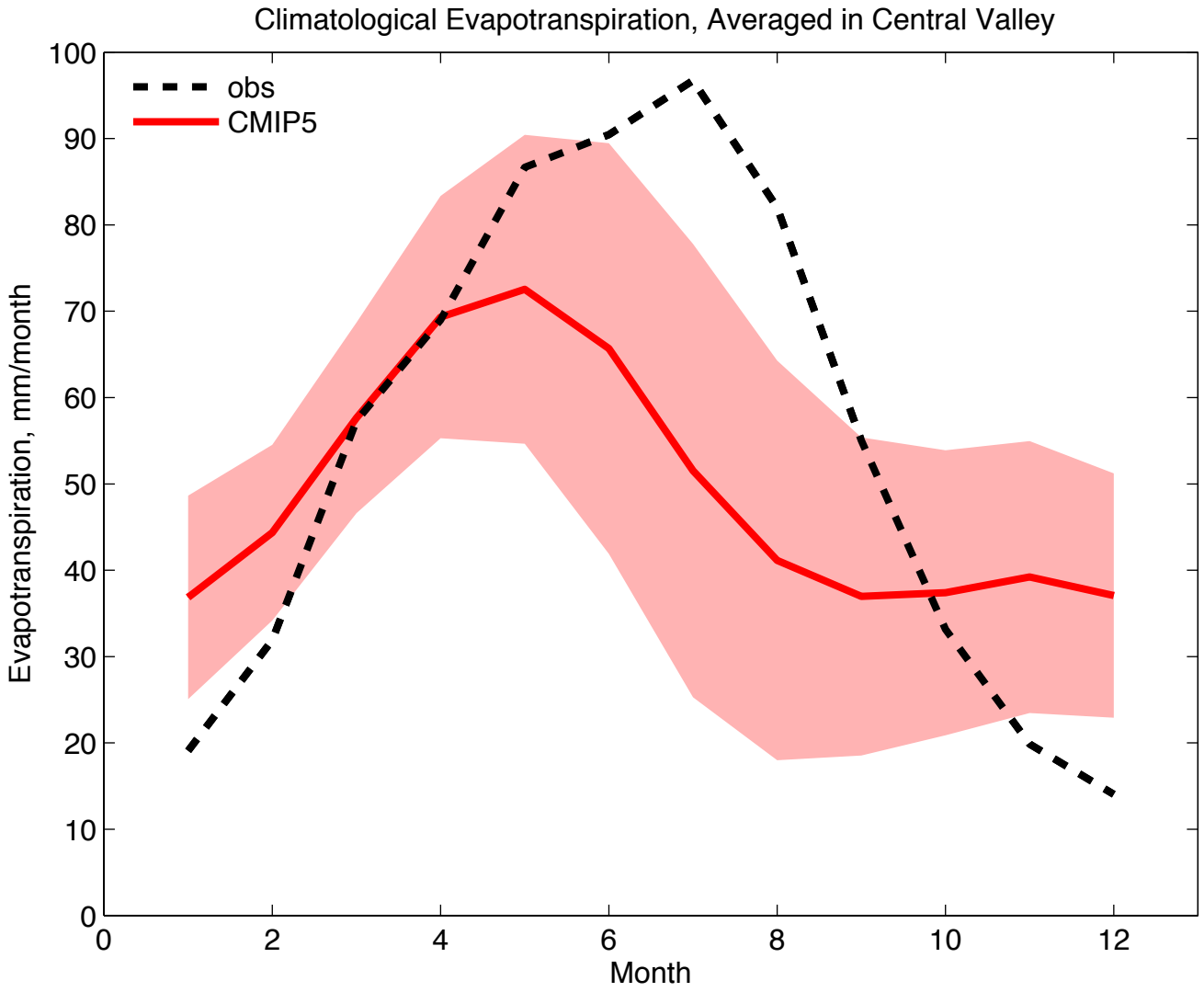


Input data:
Surface T, surface emissivity, veg indices, and albedo from MODIS.
Incoming solar, air humidity, net longwave radiation, and air temperature data from CIMIS (The California Irrigation Management Information System)



Anderson et al., 2015

Simulations of Evapotranspiration in CMIP5



from Anderson et al., 2015