Effects of groundwater-fed irrigation on terrestrial hydrology simulated by CLM

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Motivation

- Local water management practices including groundwater pumping and irrigation could significantly alter the quantity and distribution of water resources at the continental scale, with potential impacts on weather and climate through land-atmosphere feedbacks

- In this study, we aim to assess the impact of irrigated agriculture on spatiotemporal variability of water resources over the conterminous United States using the Community Land Model version 4 (CLM4), by enhancing its irrigation module with a groundwater pumping scheme;

Irrigation module in CLM4

Sacks, 2011; Leng et al., JGR, 2013

- For each day in the growing season, the target soil moisture content for irrigation is:

$$W_{\mathrm{target},i} = (1 - F_{irrig}) \times W_{o,i} + F_{irrig} \times W_{sat,i}$$

where $W_{o,i}$ is the minimum soil moisture content resulting in no water stress for crops and $W_{sat,i}$ is the soil moisture content at saturation in that layer.

- The total water deficit ($W_{deficit}$) is caculated as the difference between the target and current soil moisture contents integrated over the entire root zone at 6 am.

- $W_{deficit}$ is then administrated to the surface of the irrigated column at a constant rate, q_{irrig} , over a period of four hours in the same day to mimic a drip irrigation system

- Calibration: perturbing F_{irrig} with the range of (0,1) and comparing the simulated irrigation demands to Agricultural census

Implementing a groundwater pumping scheme

Leng et al., JHM, 2014

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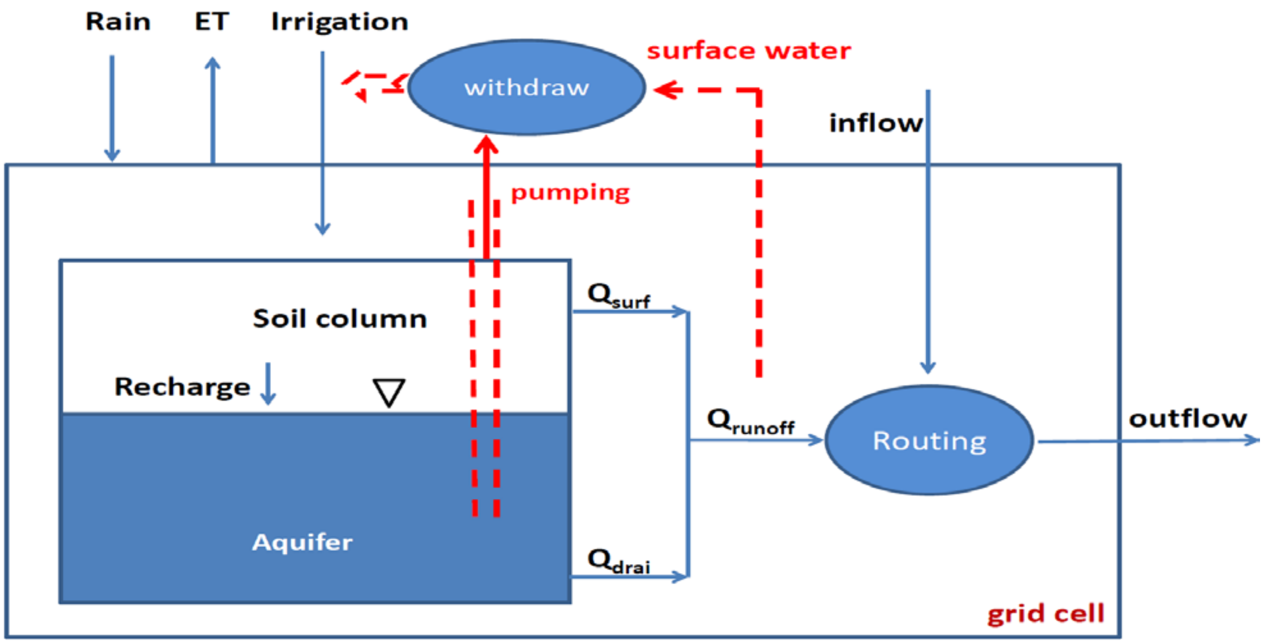
- q_{irrig} is partitioned to surface- and groundwater withdrawals (q_{wdr_srf} and q_{wdr_grd}) based on prescribed ratios.
- $q_{wdr,srf}$ is subtracted from the total runoff in CLM4
- $q_{wdr,grd}$ is added as a sink term to update the groundwater storage



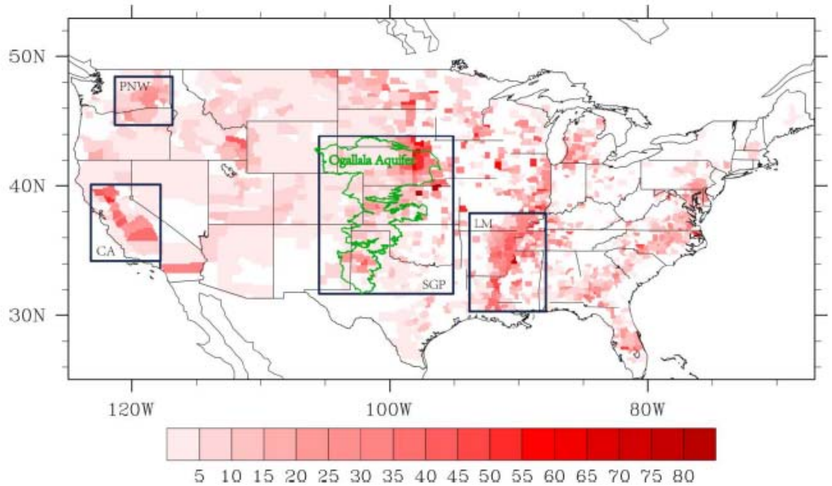
Case study over the CONUS

- Inputs:
  - North America Land Data Assimilation System phase II meteorological forcing.
  - MODIS-based Irrigated fractional area map at the 500 m resolution over CONUS (Ozdogan and Gutman 2008);
  - Fractions of surface and groundwater withdrawals based on county level NASS Census in 2000.
- Calibration:
  - County-level total withdrawal for irrigation
- Validation
  - The MODIS-based ET product (Tang et al. 2009);
  - GRACE monthly gridded total water storage (TWS), bias-corrected;
  - Area-weighted water level change of the Ogallala aquifer from USGS

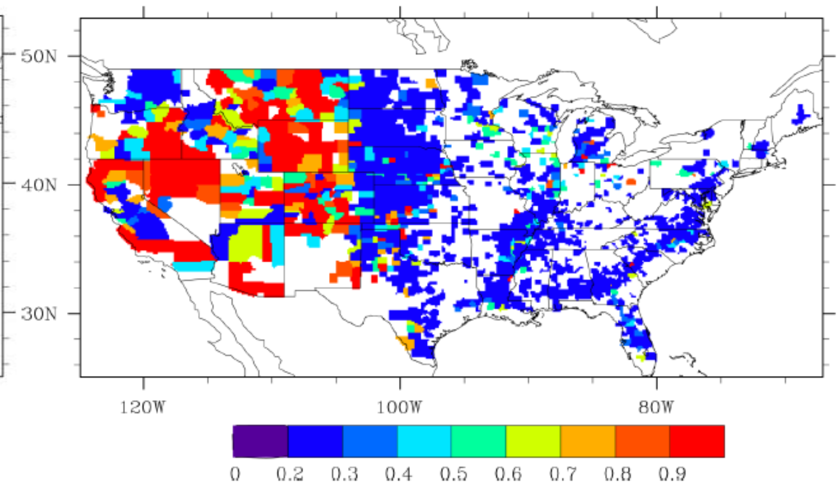
Name	Irrigation scheme	Groundwater pumping scheme	Weighted factor (F_{irrig})	Simulation Period
$IRRIG_{nocal}$	Yes	No	Default	2000
$IRRIG_{cal}$	Yes	No	Calibrated	2000
CTRL	No	No	—	1979-2011
IRRIG	Yes	No	Same as $IRRIG_{cal}$	1979-2011
PUMP	Yes	Yes	Same as $IRRIG_{cal}$	1979-2011

Distribution of parameters

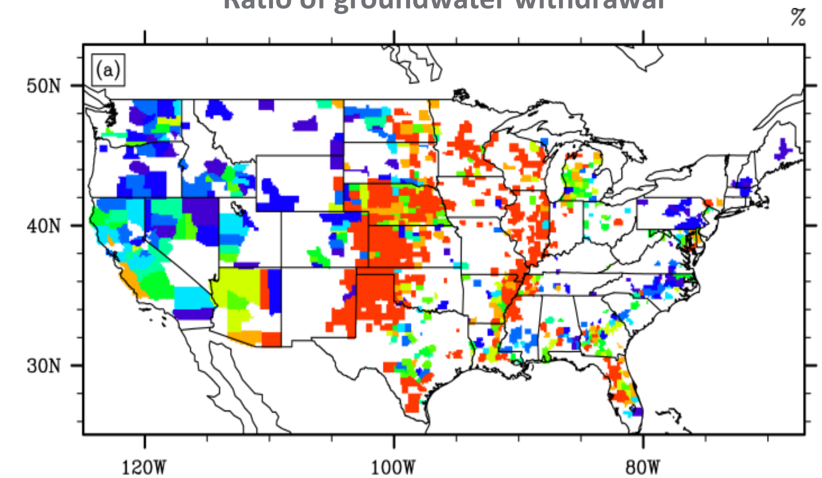
Spatial distributions of irrigated fractional area



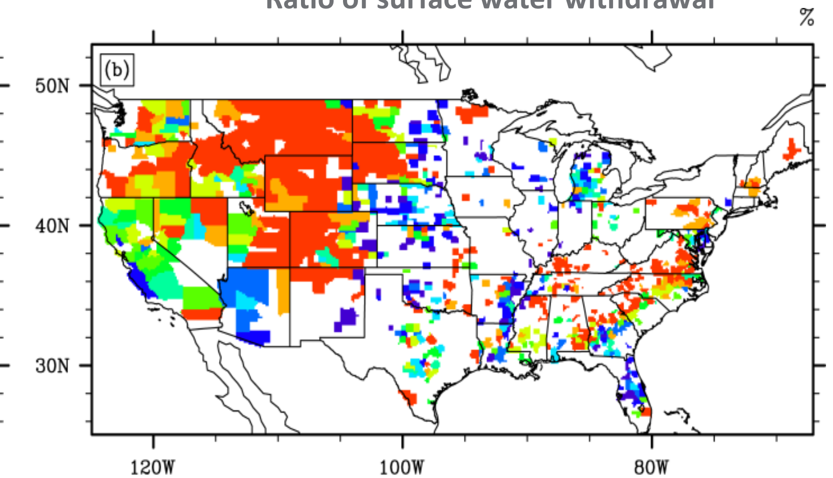
Spatial distributions of the calibrated *Firrig*

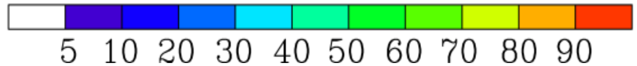


Ratio of groundwater withdrawal



Ratio of surface water withdrawal





Comparison of annual irrigation amounts in year 2000 (km^3/year)

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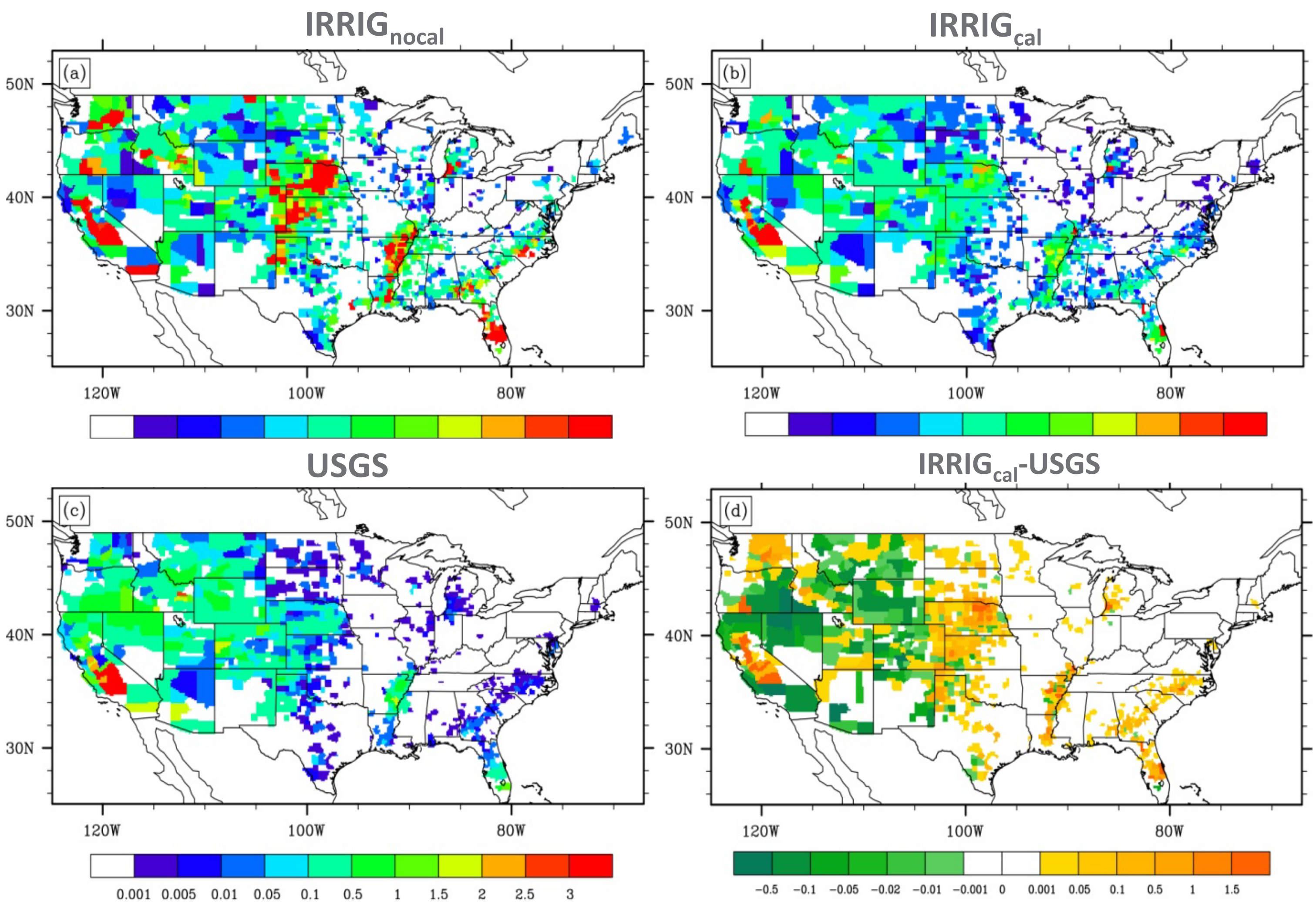
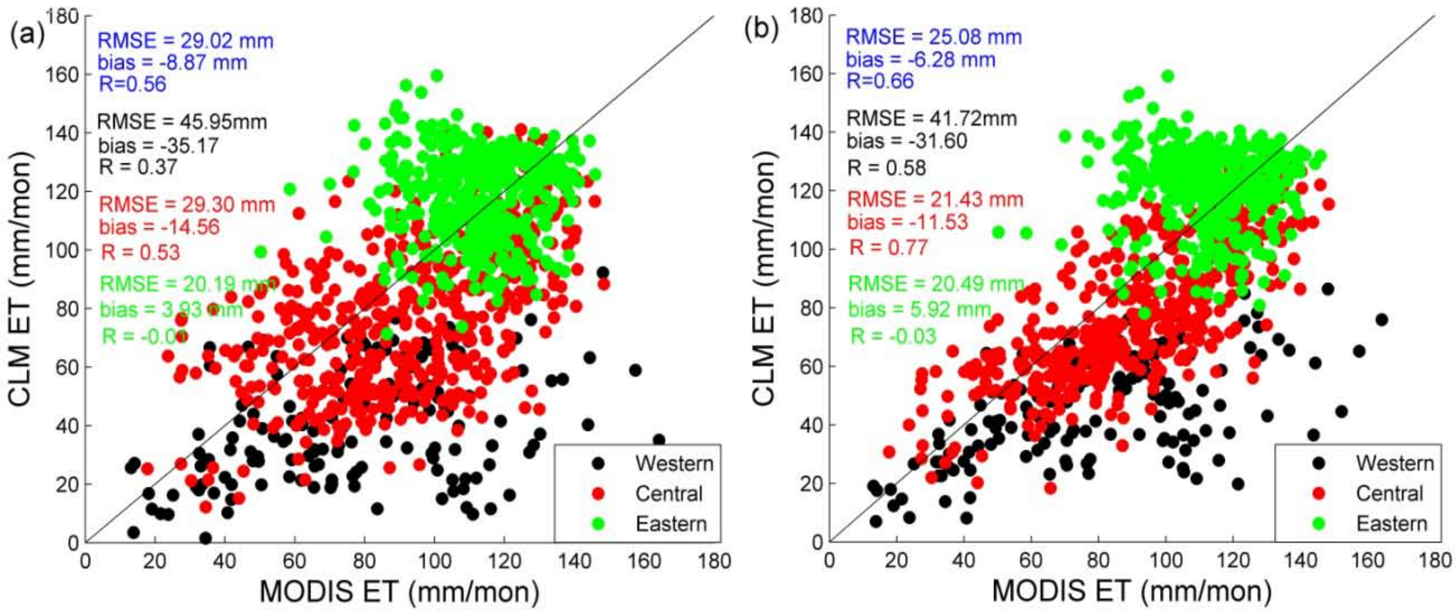
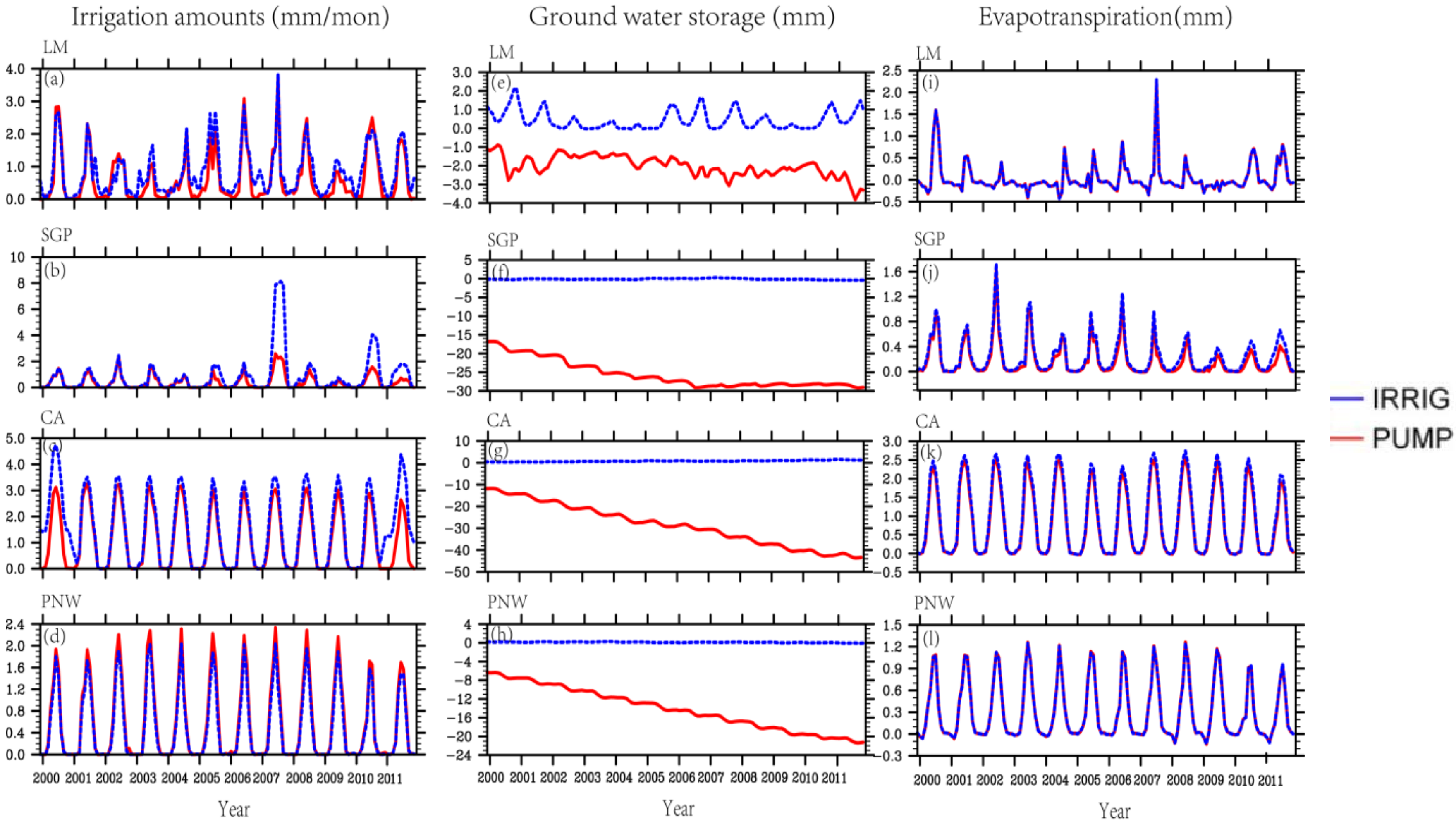


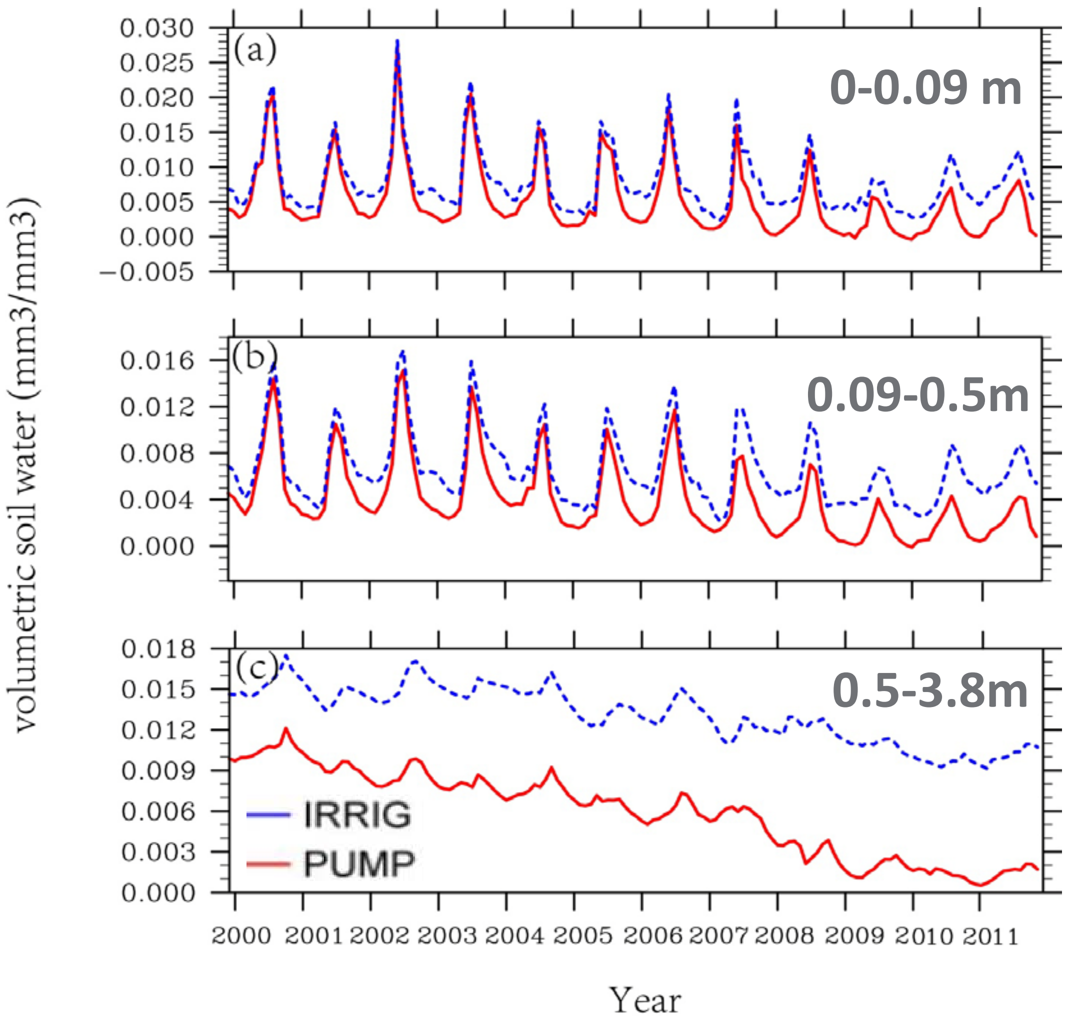
Simulated ET versus MODIS based ET in the irrigated counties: the effect of calibration



Effects on groundwater water storage and ET over four selected regions

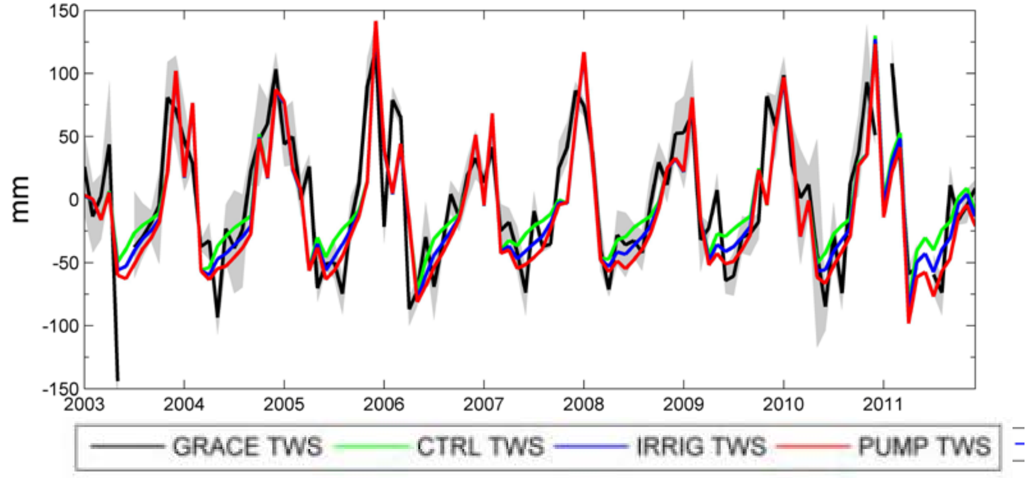


Impact on soil moisture over irrigated area in SGP

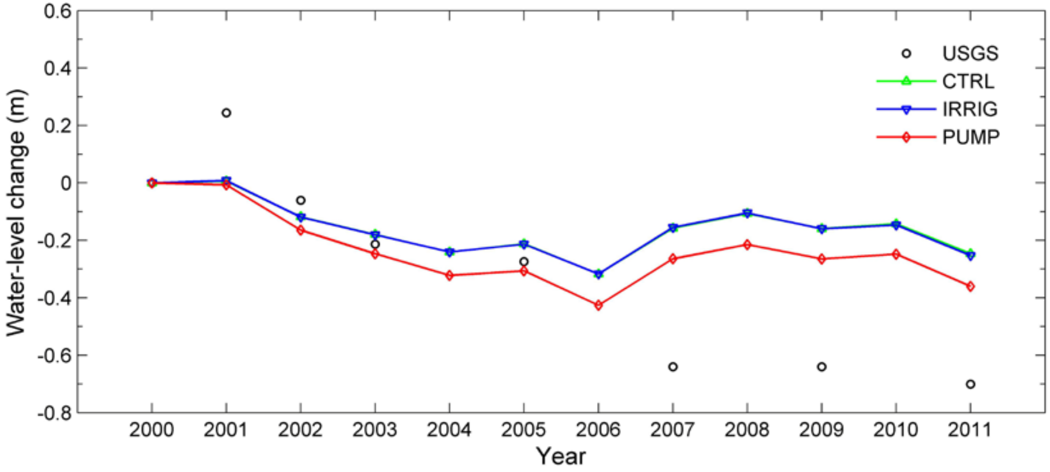


Comparison with GRACE and USGS observations

Anomalies in Total Water Storage, California



simulated vs. observed water level change over the Ogallala aquifer



Completed and on-going numerical experiments at the global scale

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- Inputs:
  - CRUNCEP forcing (1991-2010) at 0.5 degree
  - A surface dataset at 0.5 degree created based on NCAR raw datasets
  - Other inputs are assumed to be consistent with the I2000 condition
  - Irrigation fraction and ratio of groundwater withdrawal:

    Global Map of Irrigation Areas (GMIA) version 5 (Siebert et al., 2013)

- Calibration: FAO statistics at administrative units level (Siebert et al., 2010)

Name	Irrigation scheme	Groundwater pumping scheme	Weighted factor (F_{irrig})	Simulation Period
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PUMP	Yes	Yes	Same as $IRRIG_{cal}$	1991-2010

On-going

Siebert, S., Henrich, V., Frenken, K., Burke, J. (2013): *Update of the Global Map of Irrigation Areas to version 5.* Project report, 178 p.
Siebert, S., Burke, J., Faurès, J.-M., Frenken, K., Hoogeveen, J., Döll, P., Portmann, F.T. (2010): *Groundwater use for irrigation - a global inventory.* Hydrology and Earth System Sciences, 14, 1863-1880.

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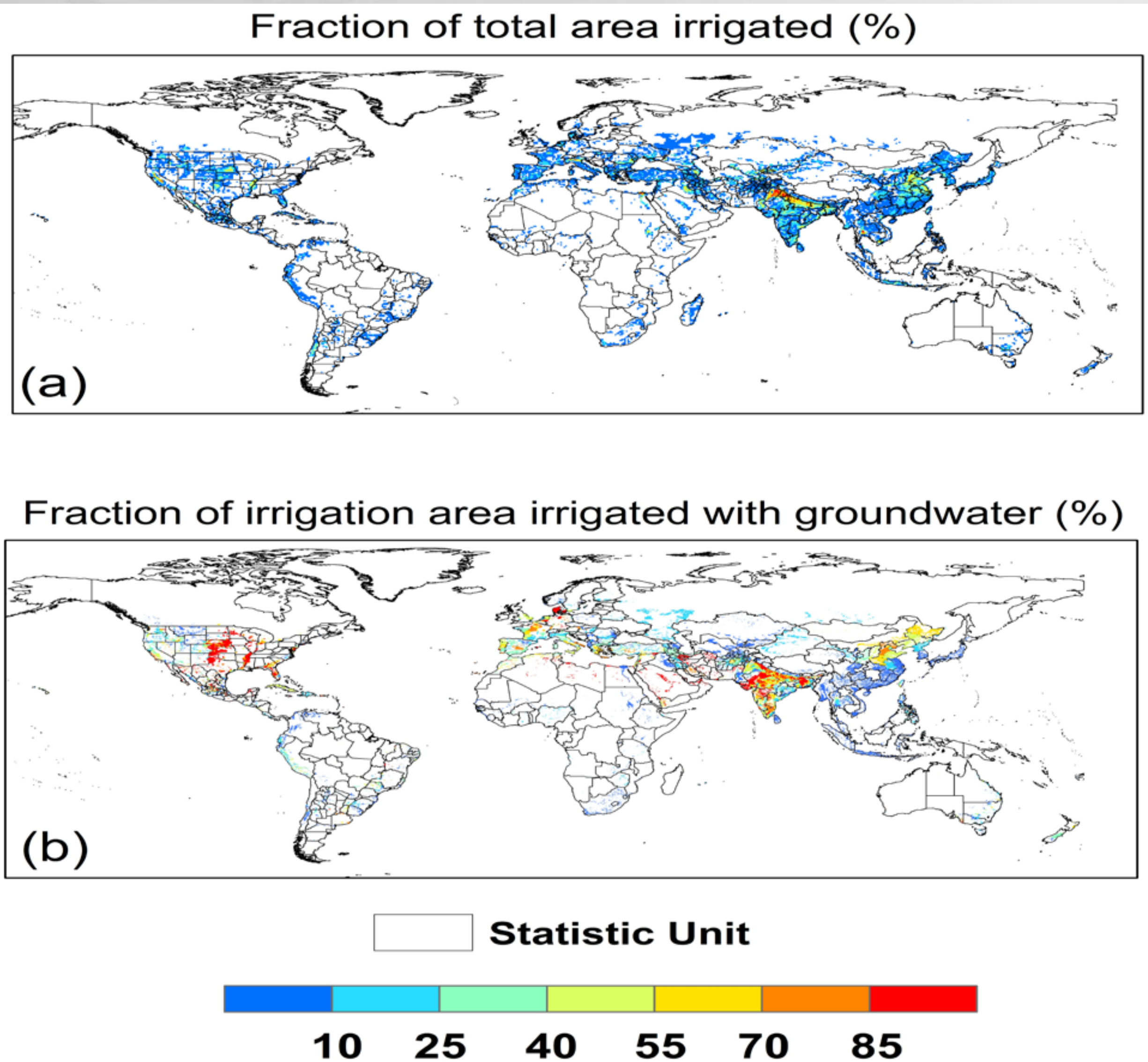
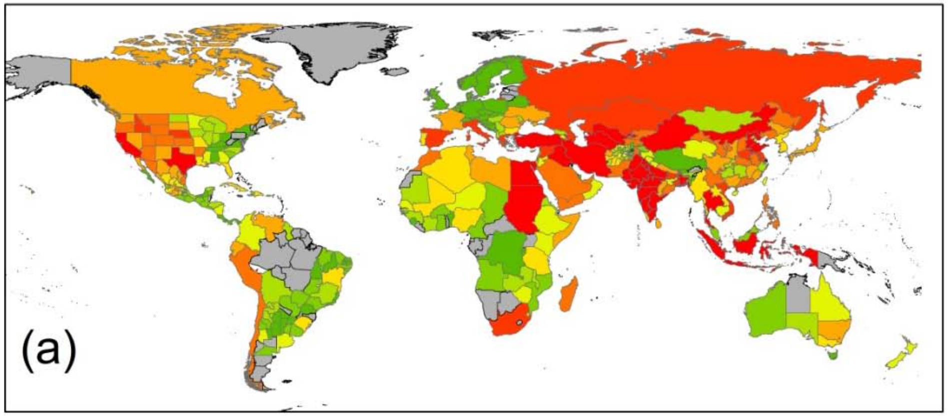
Key Datasets for global testing

from Global Map of Irrigation Areas (GMIA) version 5

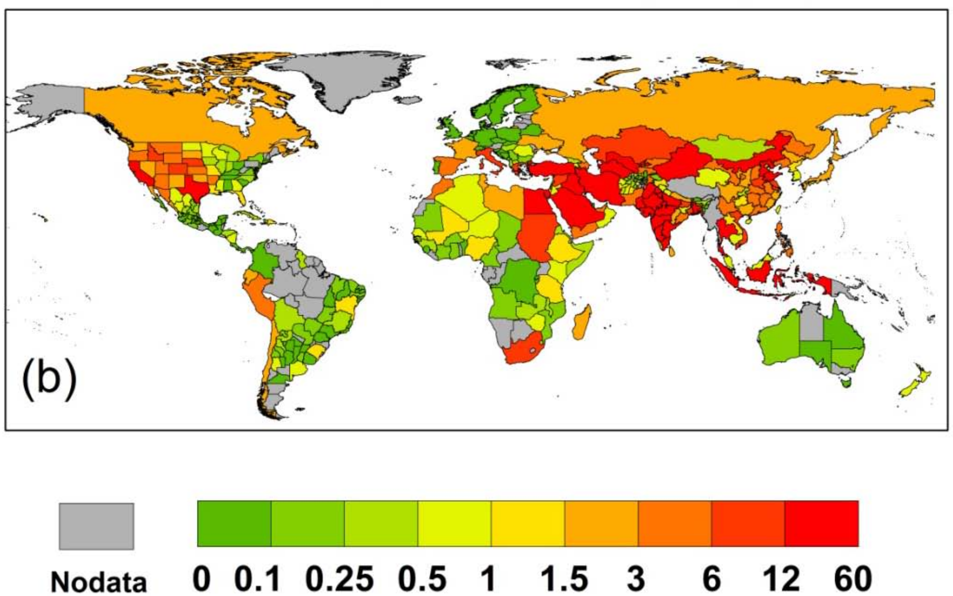


Preliminary results

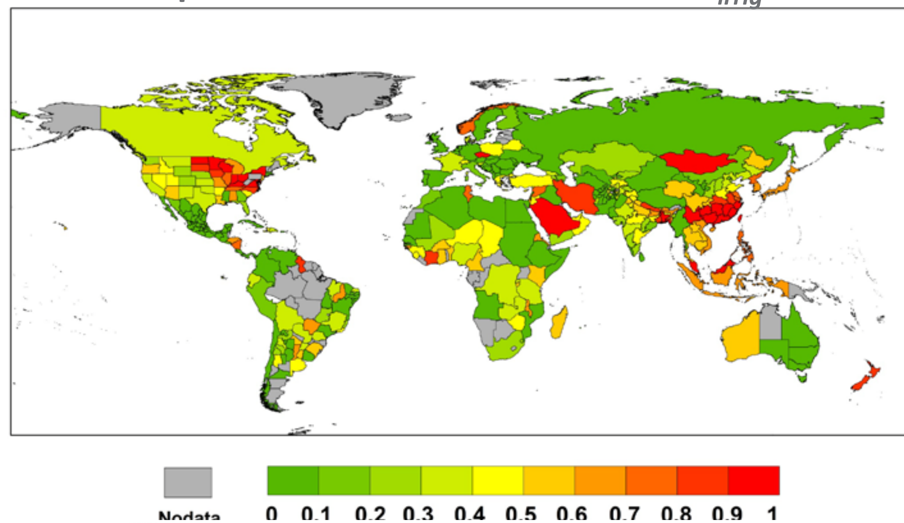
Simulated irrigation amounts (Km3 yr-1)

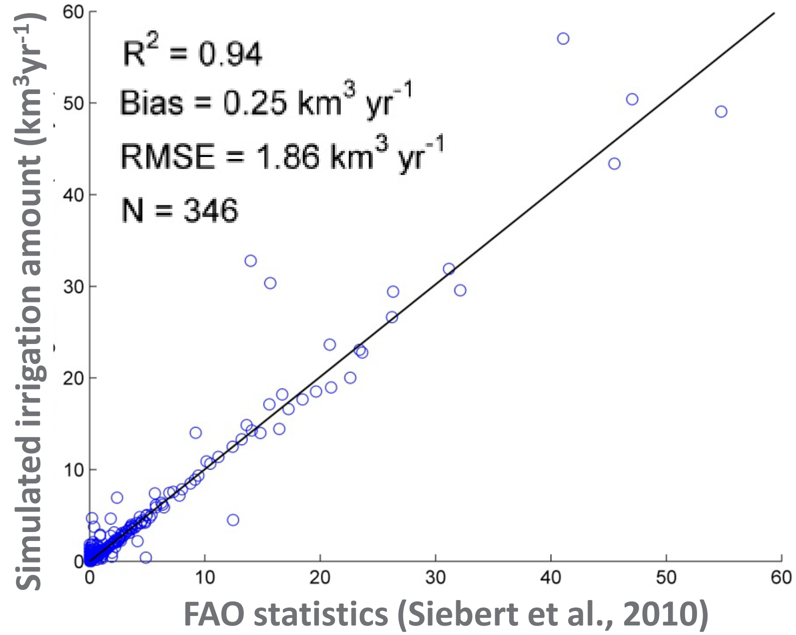


Observed irrigation amounts (Km3 yr-1)



Spatial distribution of calibrated F_{irrig}





Summary and conclusion

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- CLM is enhanced with a groundwater pumping scheme coupled to its irrigation module to simulate land surface water and energy budgets;
- Groundwater pumping can lead to fast depletion and unsustainable groundwater use in agricultural regions that have low recharge rate and deep groundwater table. Therefore, large-scale pumping should be included in earth system models to simulate the effects of irrigation on the regional water cycle.
- The results showed that a CLM4 irrigation simulation can be improved by calibrating model parameter values and more accurate representations of the spatial distribution and intensity of irrigated areas, as well as sources of irrigation water.
- Key areas for model improvement in the future: (1) enhancing the subsurface hydrologic representations, (2) considering efficiency of different irrigation techniques, and (3) linking to river routing and water management modules.
- Effects of groundwater-fed irrigation on global terrestrial hydrology will be assessed upon the completion of planned numerical experiments at the global scale.

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Effects on groundwater table, recharge, and land surface flux