Remote sensing and data assimilation for the characterization of human management impacts

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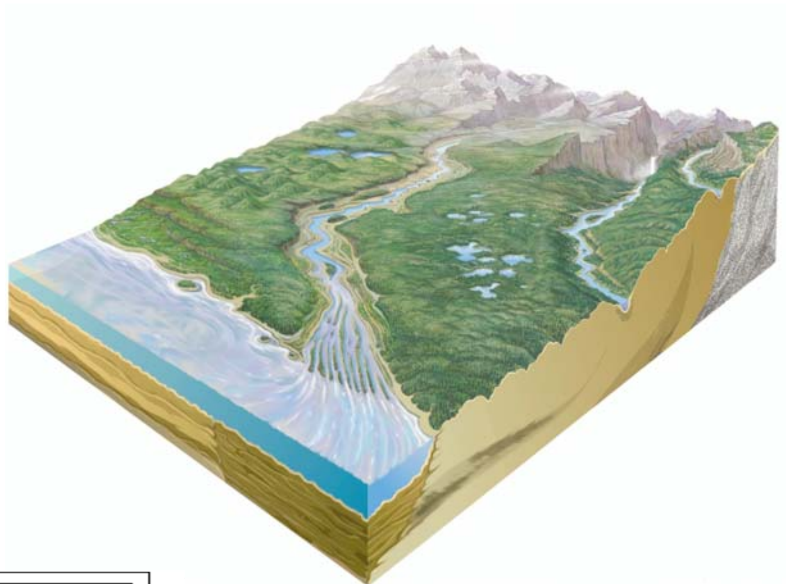
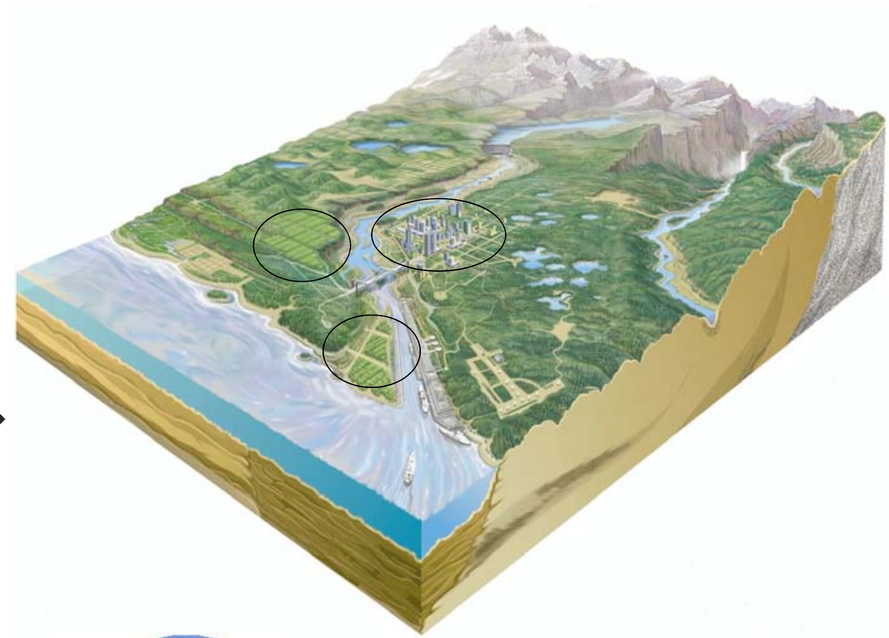
Representation of human managed landscapes

Human impacts from expansion of agriculture and infrastructure have significantly (>50%) transformed the natural features of the land surface





Land surface models : fairly utopian; hard to realistically represent subjective practices

Remote sensing: practical method to observe these 'unmodeled' features

Using irrigation/agricultural activity as an example of a human engineered, often unmodeled process ….

There are several remote sensing measurements that offer direct and indirect measurements of water availability:

- Soil moisture from microwave sensors
- Surface temperature from thermal/near infrared remote sensing
- Measurements of vegetation conditions from visible/TIR sensors

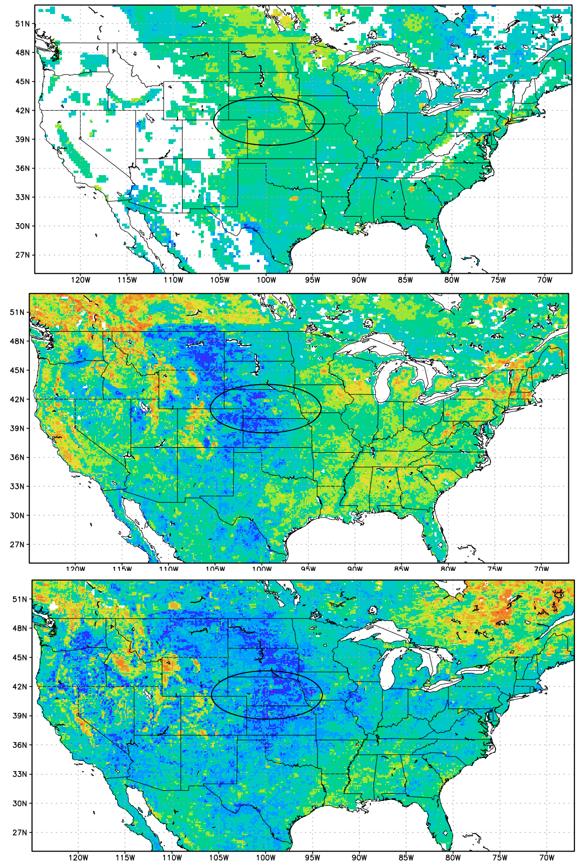
Application of irrigation would increase soil moisture, increased evaporation, reduction in surface temperature and increased vegetation indices

Can microwave soil moisture retrievals detect irrigation?

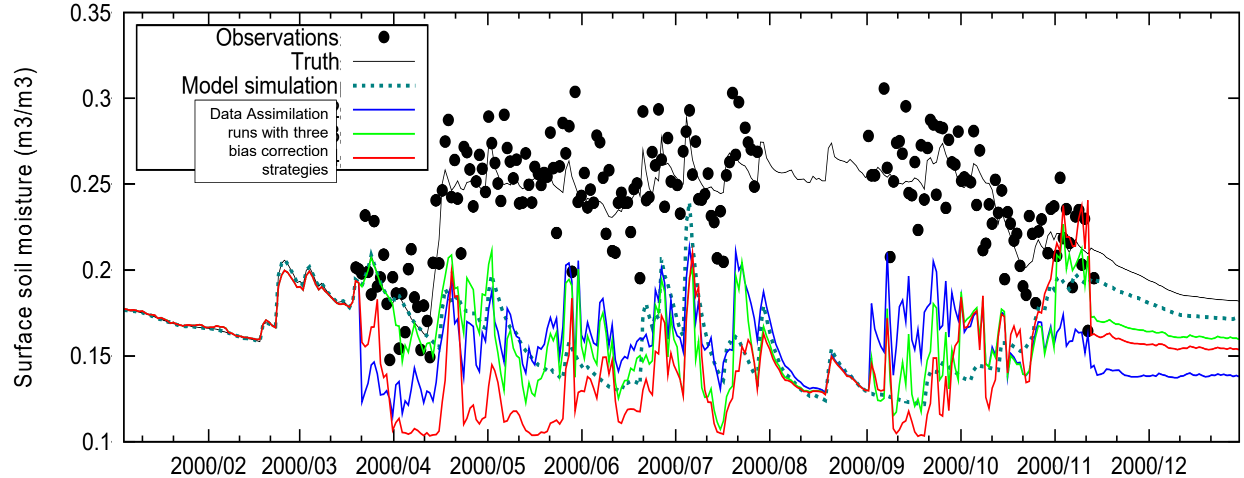
ASCAT

AMSR2

SMOS



Unitless degree of difference between the remote sensing product and a model simulation that lacks irrigation



The skill of the passive microwave soil moisture retrievals in detecting features of large-scale seasonal irrigation was mixed, with ASCAT retrievals more effective than SMOS and AMSR2 products.

Current bias correction practices in land data assimilation systems do not account for unmodeled but real signals. In this experiment, signals of irrigation were mistakenly determined to be too wet and therefore not properly accounted for.

Model prognostics with "observability" are needed, to reduce the need for statistical rescaling approaches

Kumar, S.V., C.D. Peters-Lidard, J.A. Santanello, R.H. Reichle, C.S. Draper, R.D. Koster, G. Nearing, and M.F. Jasinski, 2015: Evaluating the utility of satellite soil moisture retrievals over irrigated areas and the ability of land data assimilation methods to correct for unmodeled processes. *Hydrol. Earth Syst. Sci.*, 19, 4463-4478, doi:10.5194/hess-19-4483-2015

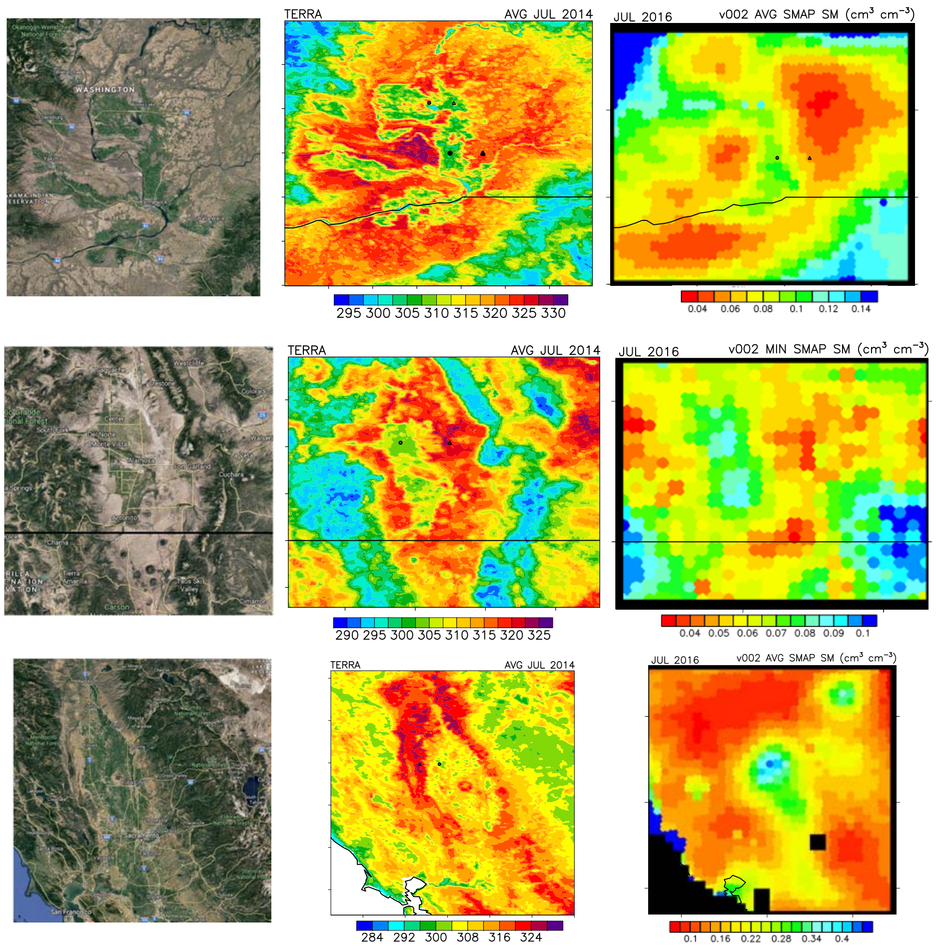
Irrigation Detection from SMAP

Terra LST | SMAP SM

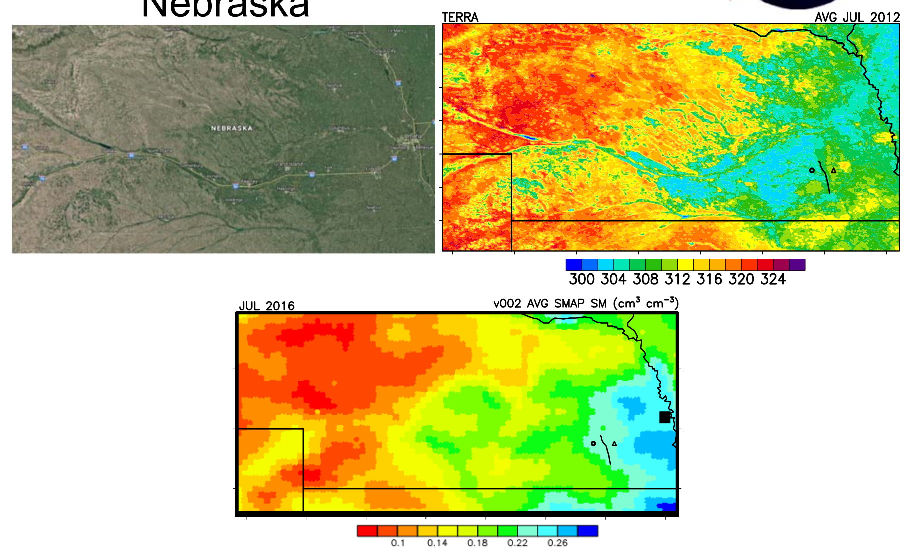
Washington

Colorado

California



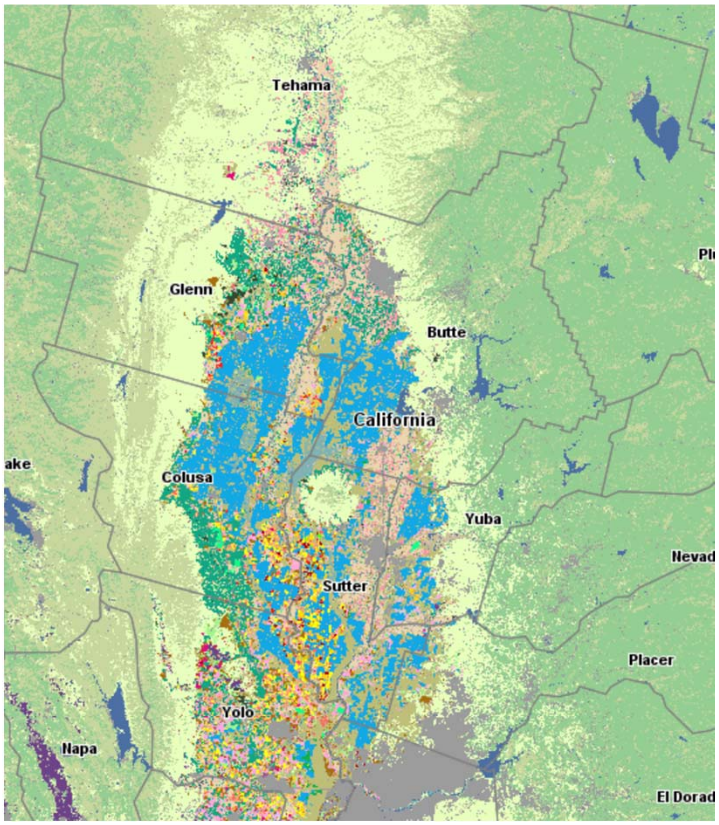
Nebraska



- To date irrigation detection from satellite has proven difficult even over well known, expansive regions
- SMAP Enhanced SM can detect irrigation timing and areal extent in three, semi-arid regions

Lawston, P. M., Santanello, J. A., Jr, & Kumar, S. V. (2017). **Irrigation signals detected from SMAP soil moisture retrievals.** Geophysical Research Letters, 44. https://doi.org/10.1002/2017GL075733

Case Study 1: Sacramento Valley



Credit: CropScape (USDA NASS)

Credit: Cal Rice News

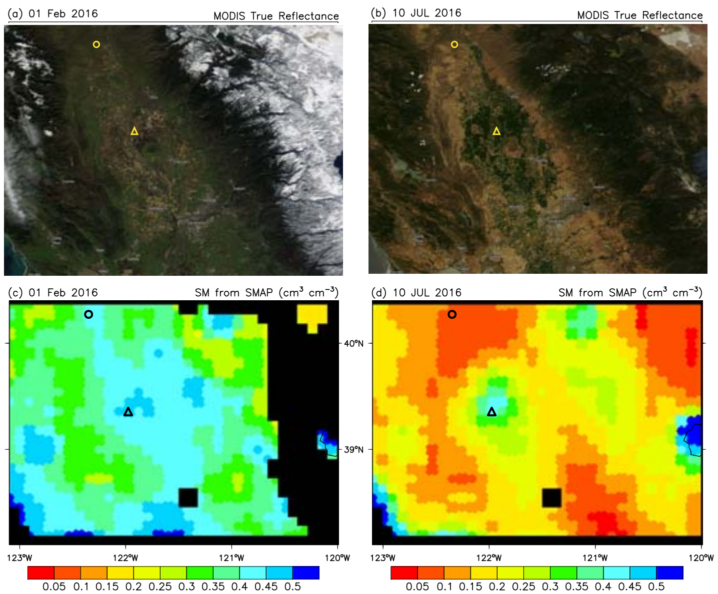
Results: Sacramento Valley

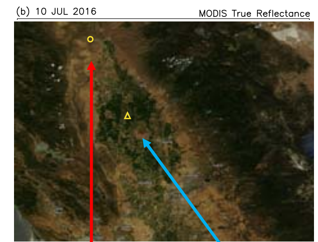
MODIS True color reflectance

SMAP Soil Moisture

01 Feb 2016

10 July 2016

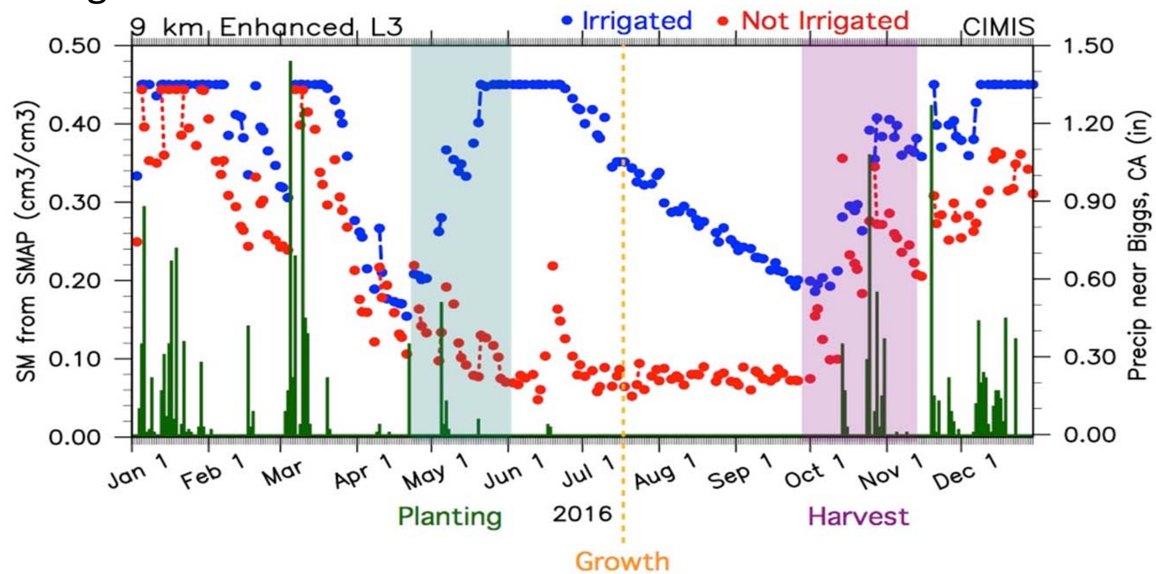




Irrigated

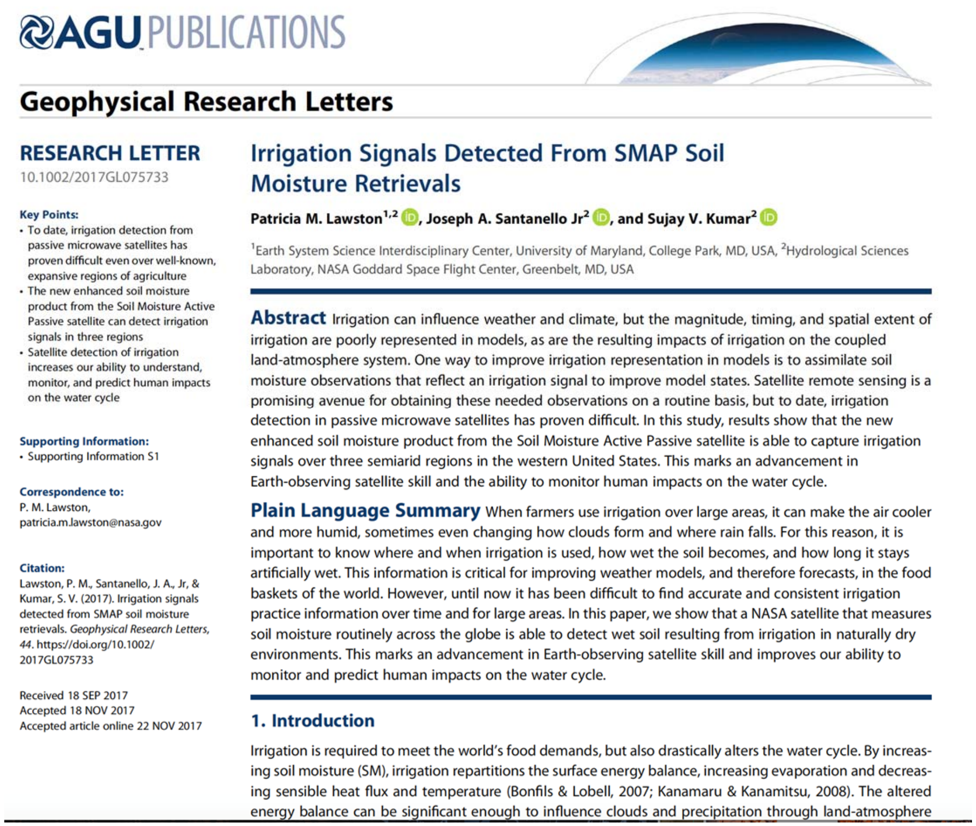
Not irrigated

Irrigated



SMAP detects the onset of flood irrigation in May and sustained, elevated soil moisture in the flooded rice paddy in summer.

Ability of SMAP to detect irrigation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Geophysical Research Letters

RESEARCH LETTER
10.1002/2017GL075733

Key Points:
- To date, irrigation detection from passive microwave satellites has proven difficult even over well-known, expansive regions of agriculture
- The new enhanced soil moisture product from the Soil Moisture Active Passive satellite can detect irrigation signals in three regions
- Satellite detection of irrigation increases our ability to understand, monitor, and predict human impacts on the water cycle

Supporting Information:
- Supporting Information S1

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Citation:
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Received 18 SEP 2017
Accepted 18 NOV 2017
Accepted article online 22 NOV 2017

Irrigation Signals Detected From SMAP Soil Moisture Retrievals

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Abstract Irrigation can influence weather and climate, but the magnitude, timing, and spatial extent of irrigation are poorly represented in models, as are the resulting impacts of irrigation on the coupled land-atmosphere system. One way to improve irrigation representation in models is to assimilate soil moisture observations that reflect an irrigation signal to improve model states. Satellite remote sensing is a promising avenue for obtaining these needed observations on a routine basis, but to date, irrigation detection in passive microwave satellites has proven difficult. In this study, results show that the new enhanced soil moisture product from the Soil Moisture Active Passive satellite is able to capture irrigation signals over three semiarid regions in the western United States. This marks an advancement in Earth-observing satellite skill and the ability to monitor human impacts on the water cycle.

Plain Language Summary When farmers use irrigation over large areas, it can make the air cooler and more humid, sometimes even changing how clouds form and where rain falls. For this reason, it is important to know where and when irrigation is used, how wet the soil becomes, and how long it stays artificially wet. This information is critical for improving weather models, and therefore forecasts, in the food baskets of the world. However, until now it has been difficult to find accurate and consistent irrigation practice information over time and for large areas. In this paper, we show that a NASA satellite that measures soil moisture routinely across the globe is able to detect wet soil resulting from irrigation in naturally dry environments. This marks an advancement in Earth-observing satellite skill and improves our ability to monitor and predict human impacts on the water cycle.

1. Introduction

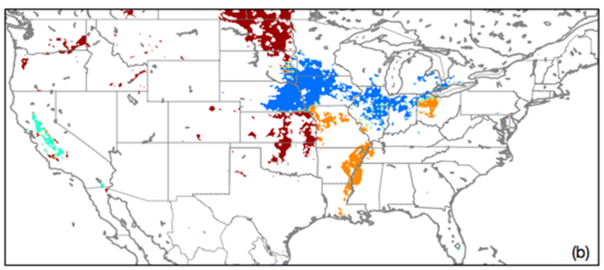
Irrigation is required to meet the world's food demands, but also drastically alters the water cycle. By increasing soil moisture (SM), irrigation repartitions the surface energy balance, increasing evaporation and decreasing sensible heat flux and temperature (Bonfils & Lobell, 2007; Kanamaru & Kanamitsu, 2008). The altered energy balance can be significant enough to influence clouds and precipitation through land-atmosphere

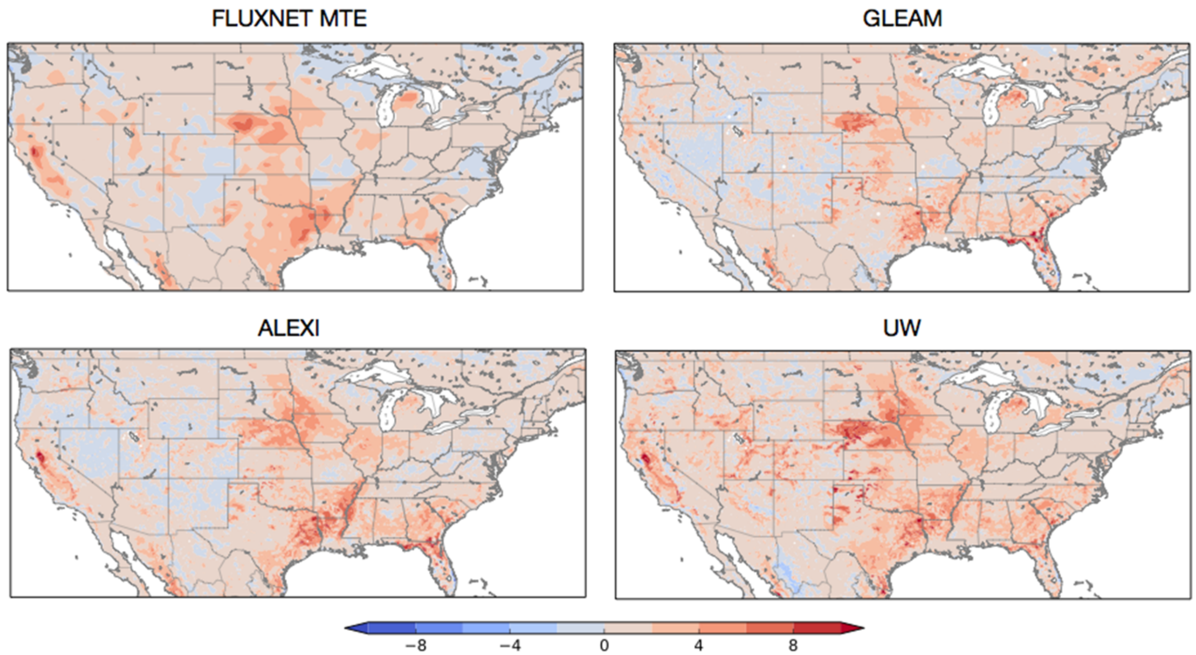
- SMAP shows promise in detecting the bulk seasonal timing and spatial signal of irrigation via elevated soil moisture relative to adjacent non-irrigated regions
- More skillful in arid/semi-arid regions
- Flood irrigation is easiest to detect

Use of remotely-sensed vegetation information for representing management impacts

MODIS-based LAI estimates from the University of Maryland Global Land Cover Facility (GLCF) GLASS project are employed for assimilation within Noah-MP LSM over the CONUS domain

Change in RMSE (W/m2) Warm colors indicate improvements; cool colors indicate degradations from DA

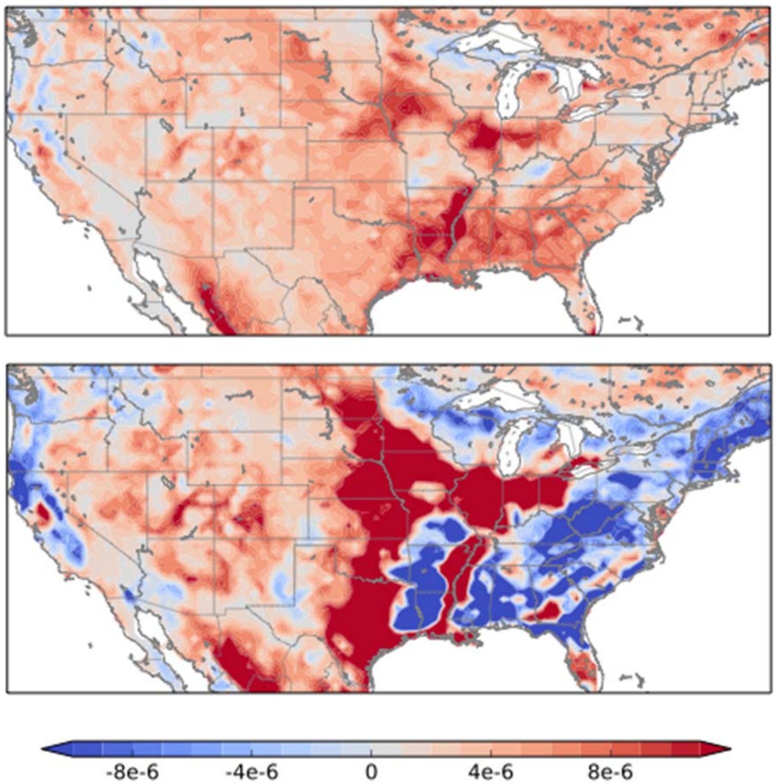




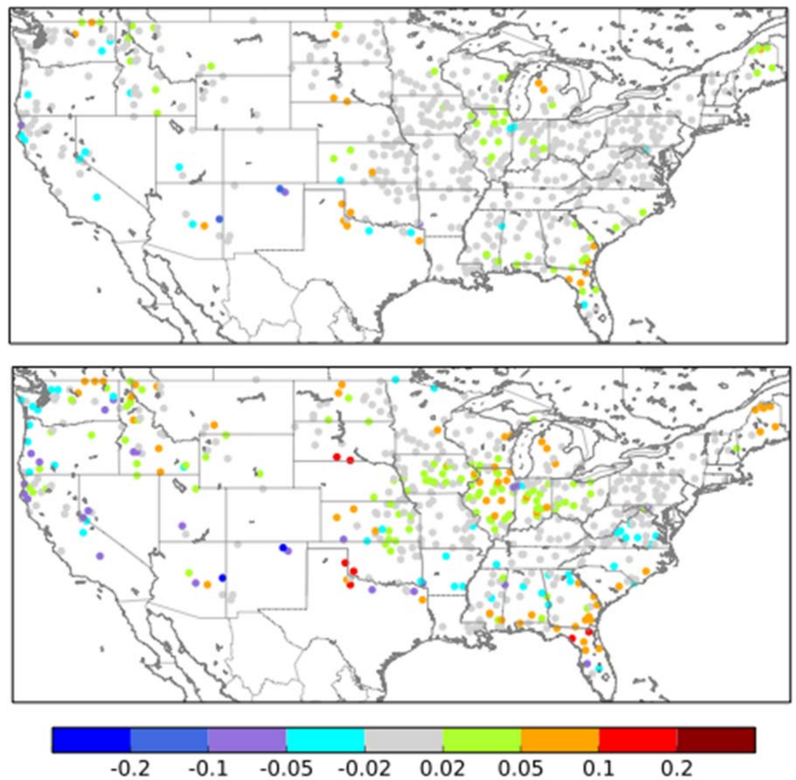
- Systematic and consistent improvements over the Central Plains, lower Mississippi, central California valley. Larger improvements are over agricultural areas of maize and soybean

Kumar, S.V., D. Mocko, S. Wang, C.D. Peters-Lidard (2019), Assimilation of remotely sensed leaf areas index into the Noah-MP land surface model: Impacts on water, energy and carbon fluxes and states over the Continental U.S., *J. Hydromteorology,* 10.1175/JHM-D-18-0237.1

LAI assimilation impacts on GPP, streamflow



Change in RMSE (g/m2) of GPP and NEE compared to FLUXCOM. Warm colors indicate improvements; cool colors indicate degradations from DA



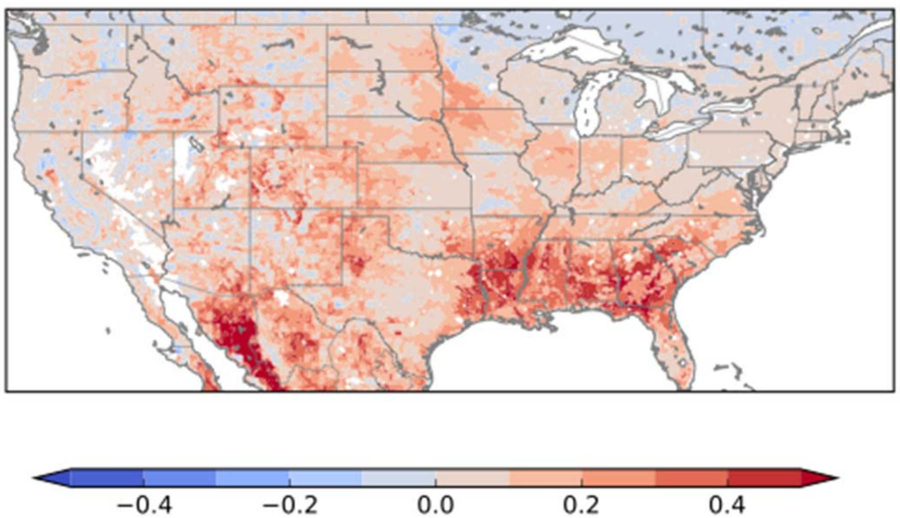
Normalized improvements in streamflow NSE and RMSE (using USGS streamflow as the reference)

Strong improvements in GPP over irrigated agricultural areas

Streamflow skill is improved over several river basins (upper Mississippi, Ohio, Columbia, upper Missouri, south Atlantic)

Evaluation of GPP vs remotely sensed Solar Induced Fluorescence (SIF)

Change in R from LAI DA; Warm colors indicate improvements; cool colors indicate degradations from DA

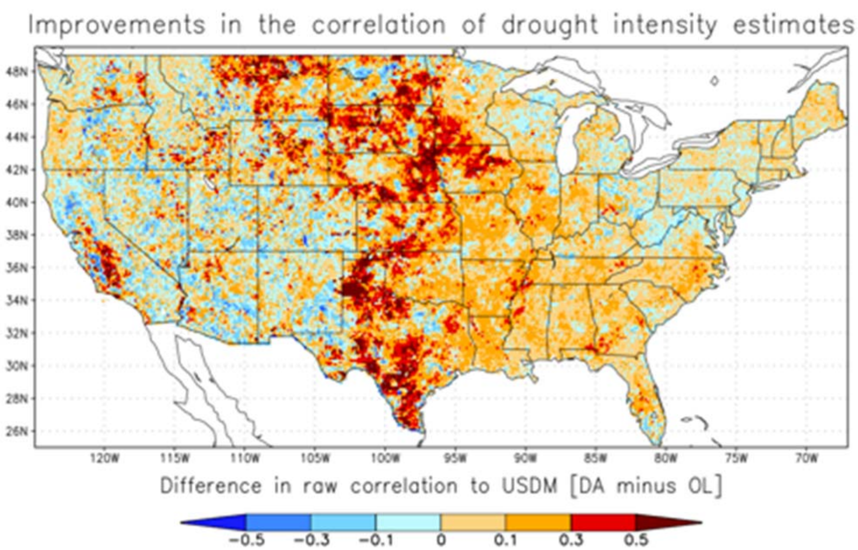


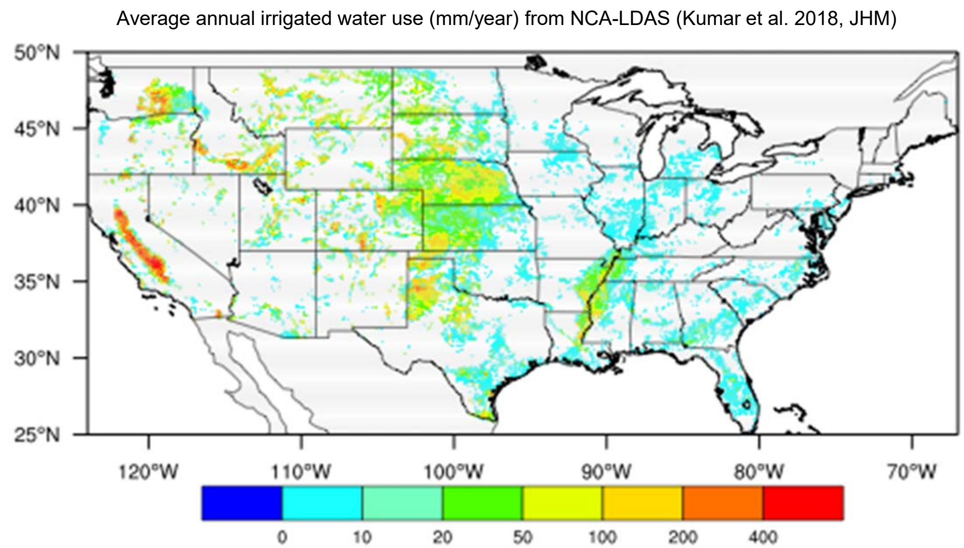
Solar Induced Fluorescence (SIF), part of the solar radiation absorbed by chlorophyll and reemitted as fluorescence is a functional analog of GPP

The simulated GPP is compared against the SIF retrievals from the Global Ozone Monitoring Experiment-2 (GOME-2) aboard the MetOp-A satellite.

The comparison confirms the positive impact of LAI assimilation, with strong improvements in the Southeast U.S., parts of Midwest, southwest Mexico and the central U.S. plains.

Impact of LAI assimilation on drought representation (vs USDM)

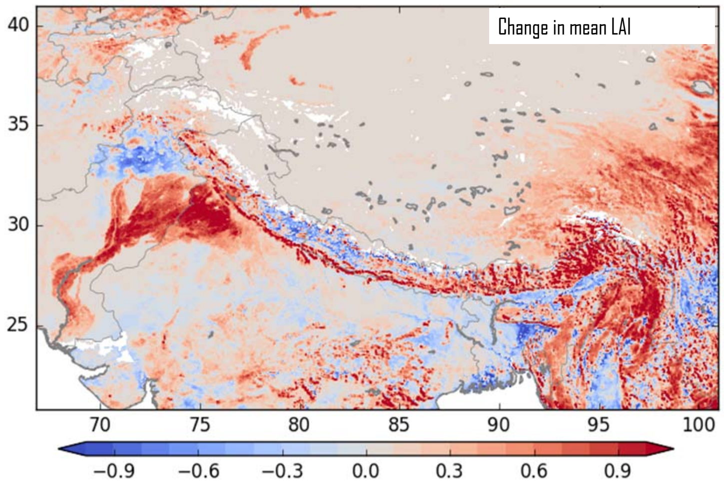




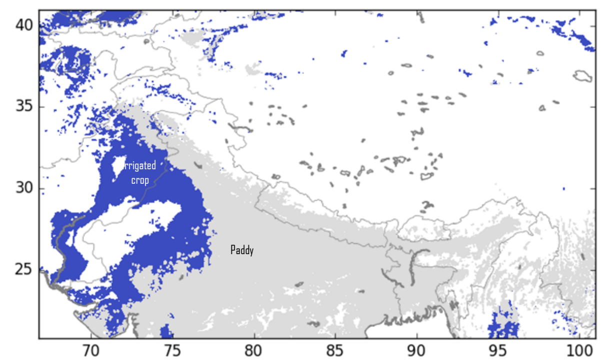
Irrigated area in NCA-LDAS is determined by MODIS. Areas with both high irrigated amounts and improvements in the raw correlation of soil moisture percentiles against USDM from LAI data assimilation include:

- Central California valley
- Nebraska
- Lower Mississippi basin
- Northwest Texas

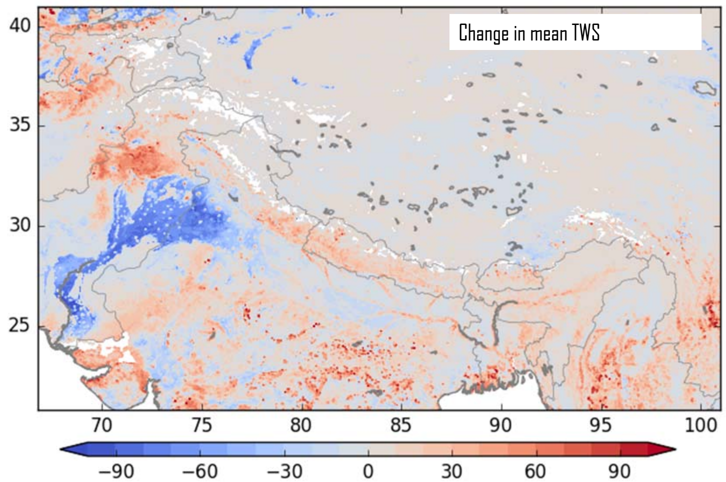
Applying LAI-DA over the Indus valley domain



Irrigation type map from Salmon et al. (2015)



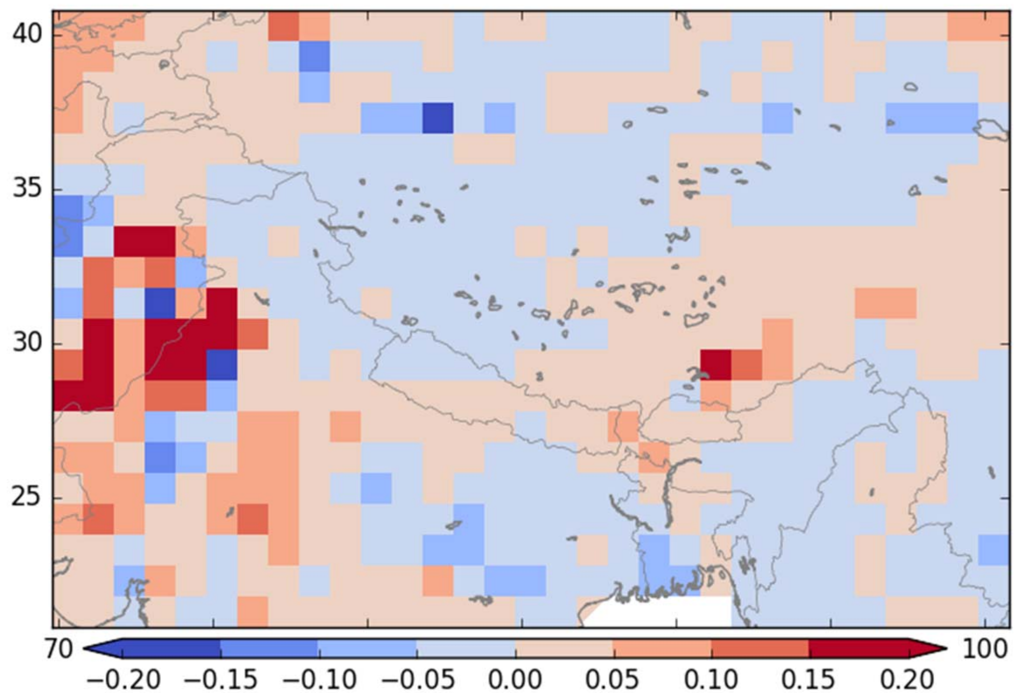
Increased vegetation density in the western HMA over the INDUS irrigation basin (consistent with the independent GRIPC irrigation type map)



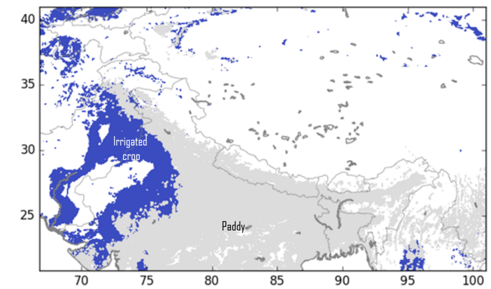
A prominent TWS decrease over western HMA is observed as a result of the vegetation changes.

There is a dual peak to the vegetation seasonality in western HMA due to the winter and summer cropping schedules.

Impact of LAI assimilation – comparison with GRACE



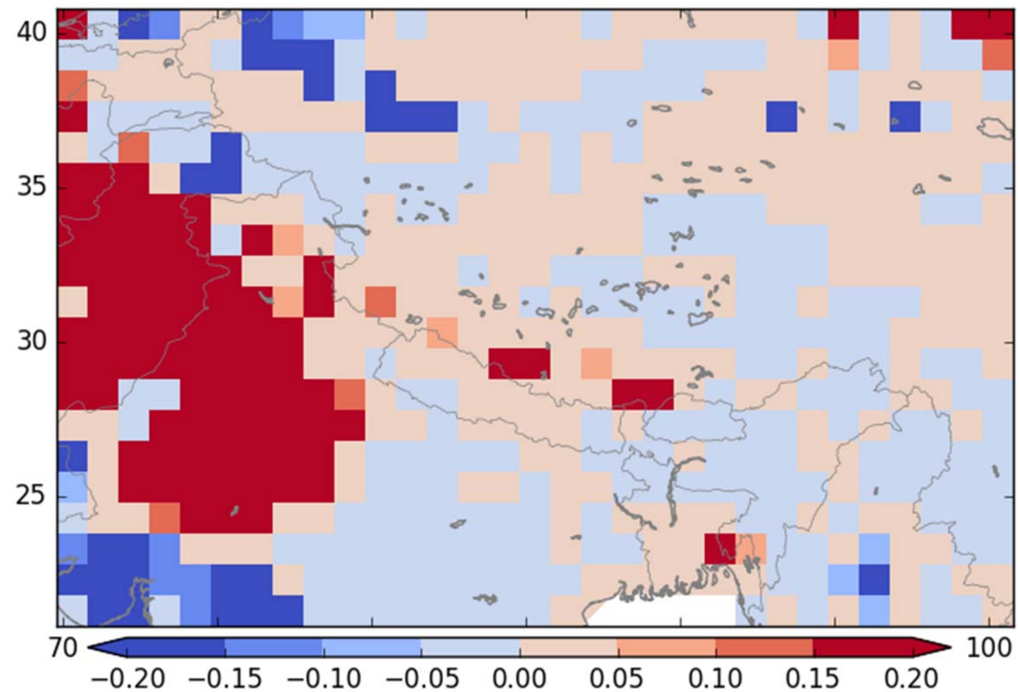
Irrigation type map from Salmon et al. (2013)



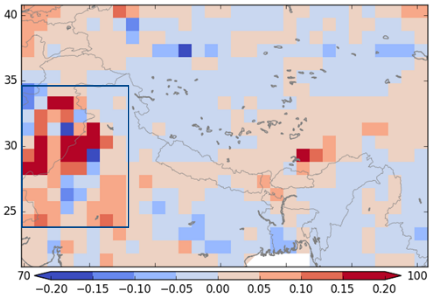
Locations with improvements in anomaly R relative to GRACE are strongly correlated with the irrigated crop areas in the western HMA

Simulating irrigation (with groundwater pumping) within models

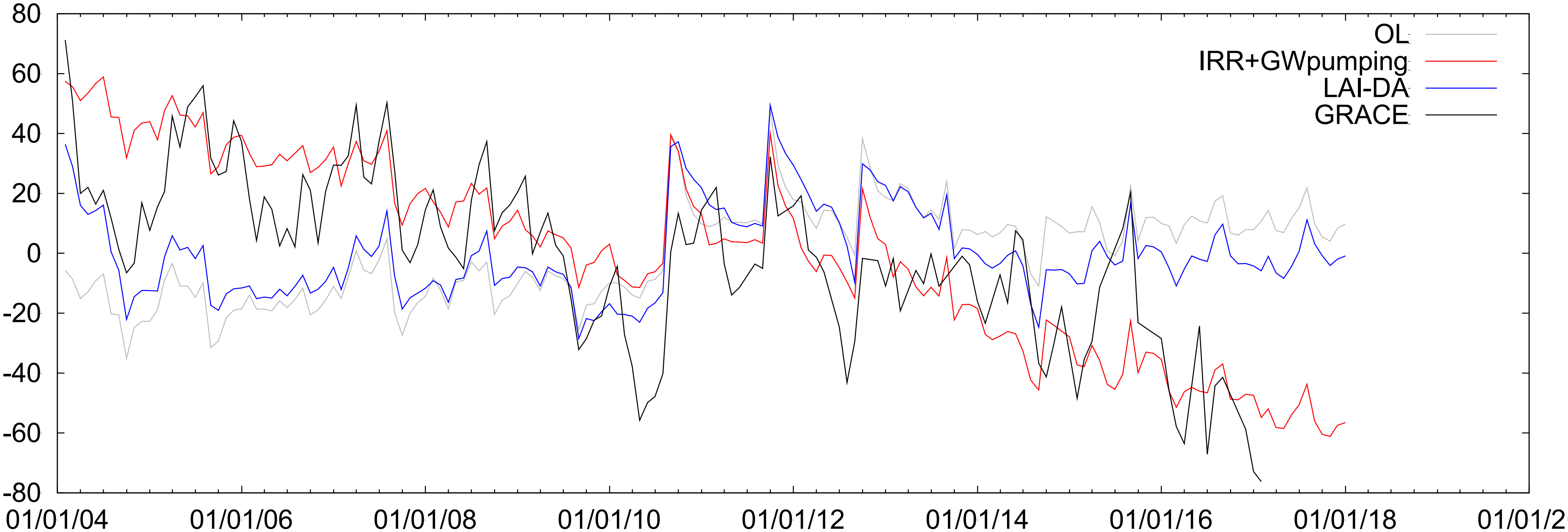
- Demand driven ("sprinkler") irrigation scheme in the LSM employs the scheme from Ozdogan et al. (2010)
- Irrigation is triggered when the root zone soil moisture falls below a specified threshold during the growing season
- The irrigation water requirement is computed as an equivalent height of water and added to the precipitation forcing
- Nie et al. (2018) developed a variant of this scheme where the irrigation water requirement is used as groundwater abstraction
- Here we use 10% of the computed irrigation water requirement as the groundwater pumping estimate (consistent with reports)



Strong improvements in correlation with GRACE TWS anomalies when groundwater pumping scheme is enabled



Vegetation assimilation and groundwater pumping schemes confirm the role of irrigation in groundwater depletion



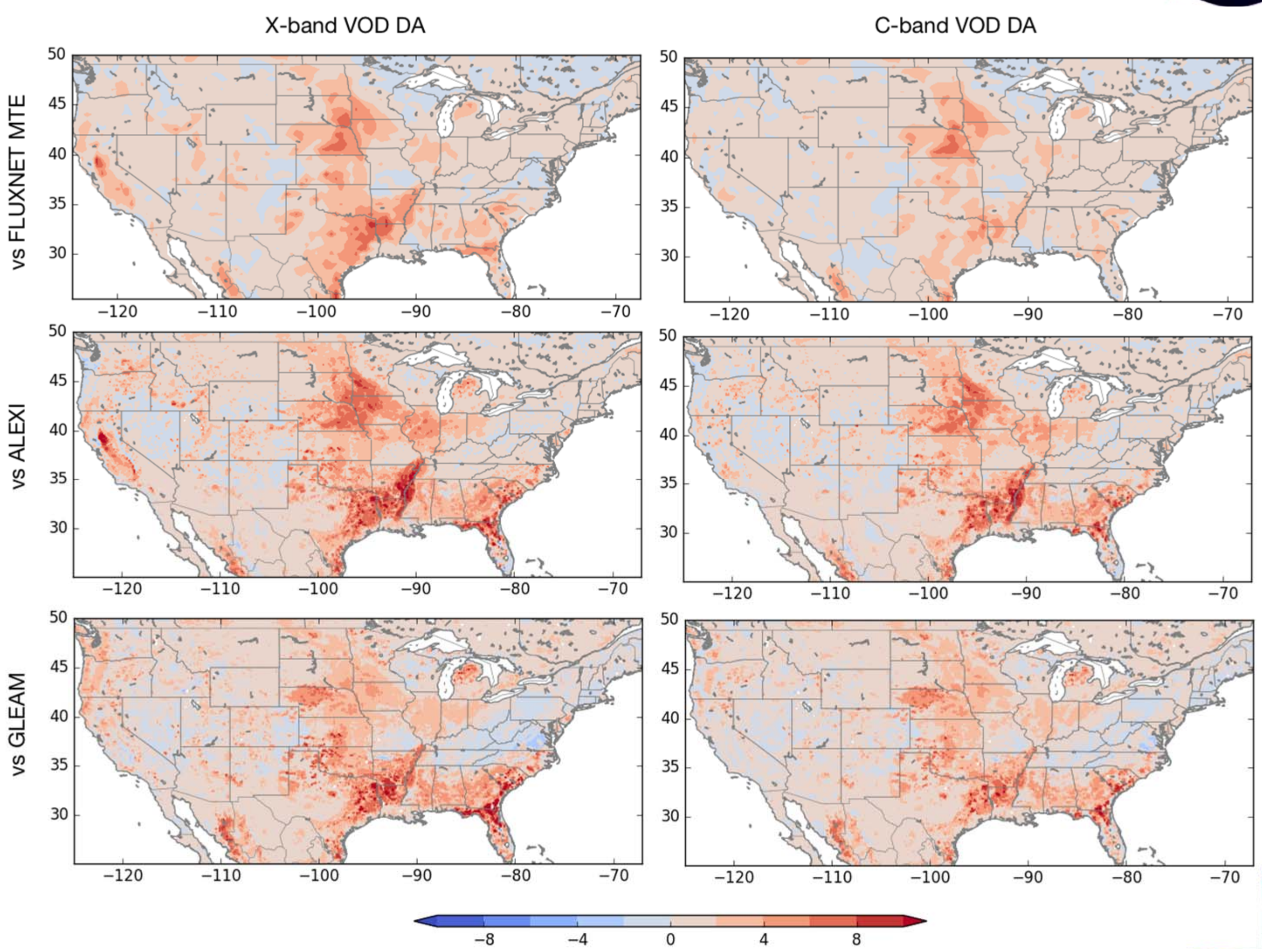
Assimilation of vegetation optical depth

VOD describes the vegetation attenuation of the passive microwave signal. It is directly related to the water content of the vegetation. VOD retrievals from X, C and L-band (SMAP) was assimilated into Noah-MP

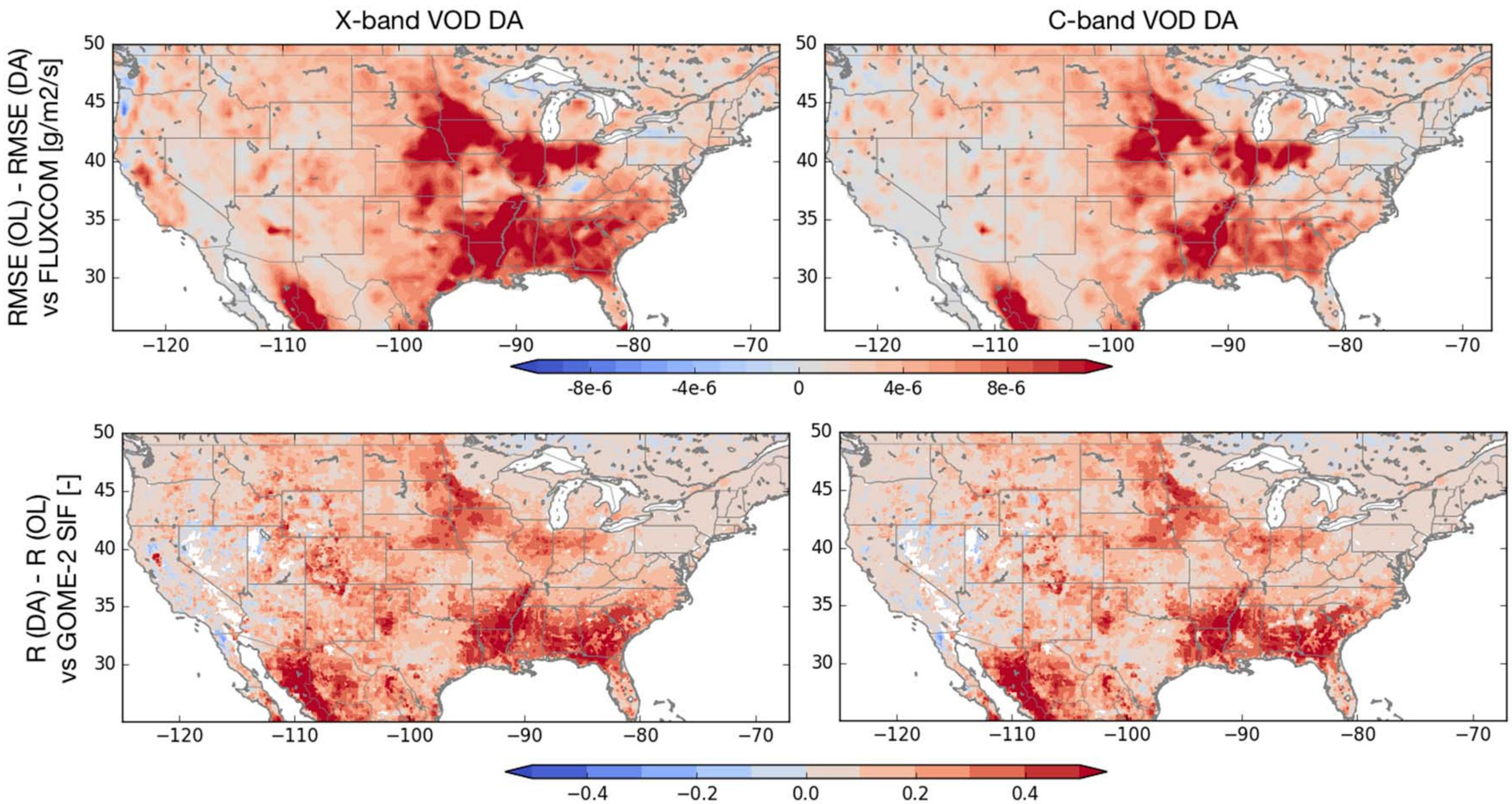
Since the model does not have a direct VOD prognostic, the VOD retrievals were rescaled (with CDF matching) into the GLASS LAI climatology

VOD from microwave radiometry provides an all-weather capability for vegetation sensing

Systematic improvements in ET, particularly over agricultural areas from VOD assimilation



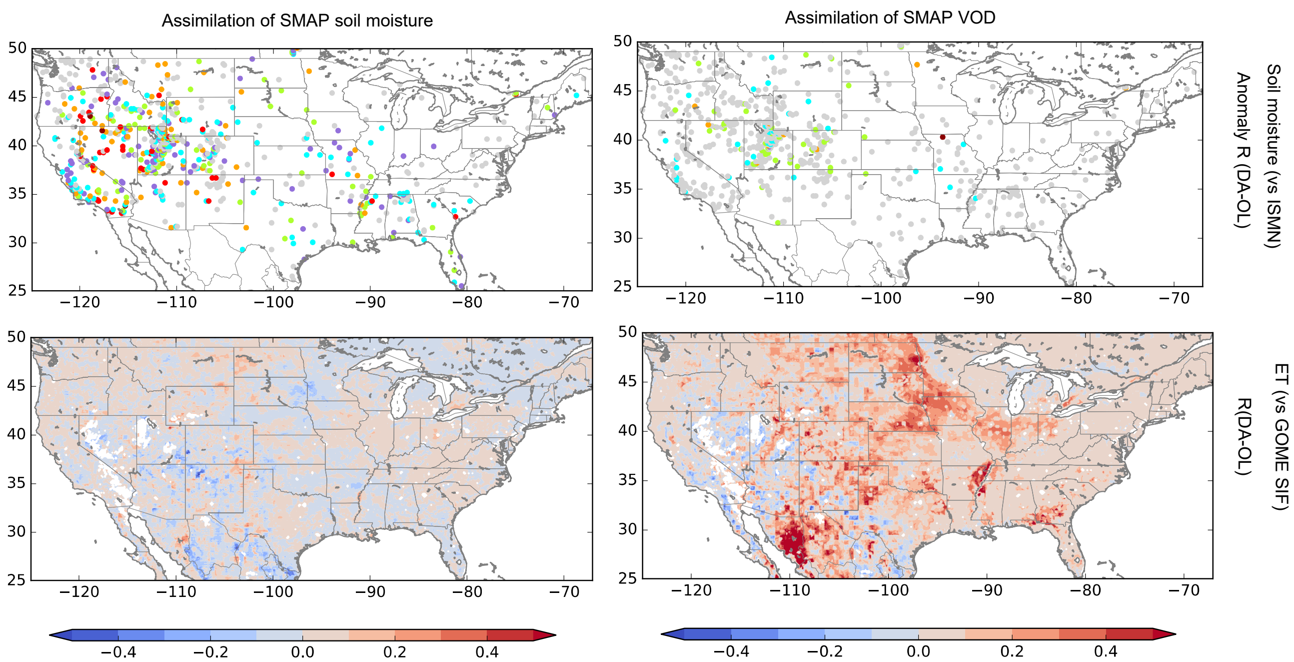
Assimilation of VOD – impacts on GPP



Similar to the patterns in ET, improvements in GPP estimates are obtained from VOD assimilation over the agricultural areas. These improvements are largely a result of the improvements to the cropping seasonality.

Kumar, S.V., et al. (2019), Assimilation of vegetation optical depth retrievals from passive microwave radiometry, *in prep.*

Assimilation of L-band VOD (SMAP)



- Stronger improvements (and degradations) in soil moisture and streamflow from soil moisture DA
- Comparatively smaller improvements in ET relative to the assimilation of X-band and C-band VOD
- More impacts (particularly over agricultural areas) from SMAP VOD assimilation.

Summary

- Remote sensing provides key measurements of human management impacts

- Bias issues are dominant in hydrology. These bias "errors" are also significant sources of valuable signals. Approaches to handle them appropriately is needed in data assimilation systems

- Having "observability" of model prognostics is needed to enable more direct utilization of remote sensing measurements.