SYMFONI - A "System-of-Systems" Solution to Quantify Carbon Outcome for Bioenergy Feedstock Production at the Field Level

- an ARPA-E SMARTFARM Initiative

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Major Contributors: Bin Peng, Evan DeLucia, Zhenong Jin, Wang Zhou, Sheng Wang, Jingyun Tang, Robert Grant, Chongya Jiang, Licheng Liu, Carl Bernacchi, DK Lee, Wendy Yang, Lisa Ainsworth, Ziqi Qin, etc

SMARTFARM Vision:

Make it possible and profitable to optimize for yield *and* carbon intensity.

Technical Goal:
Reliable, accurate, and cost-effective quantification of feedstock carbon intensity at the field level.

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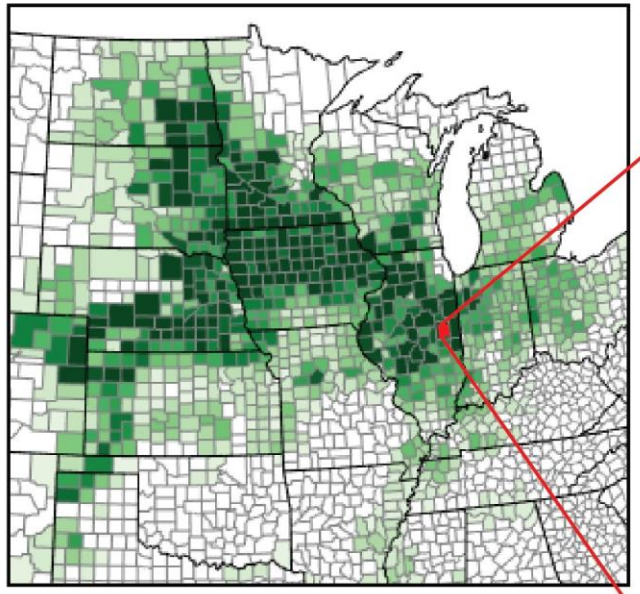
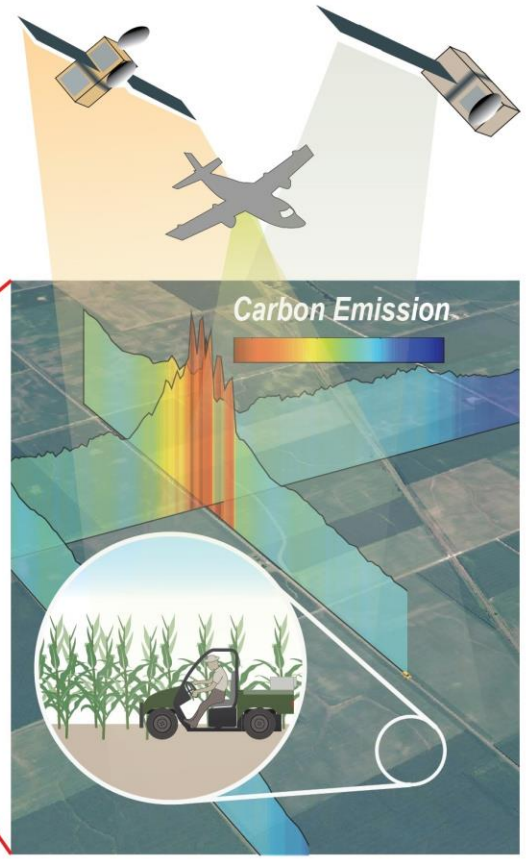
Focus on emissions drivers (N_2O) and net-negative strategies (soil carbon)

Our solution - "system of systems" approach:

Field accuracy + Scalability + Cost-effective



Full scalability to cover every field in large regions



SYMFONI

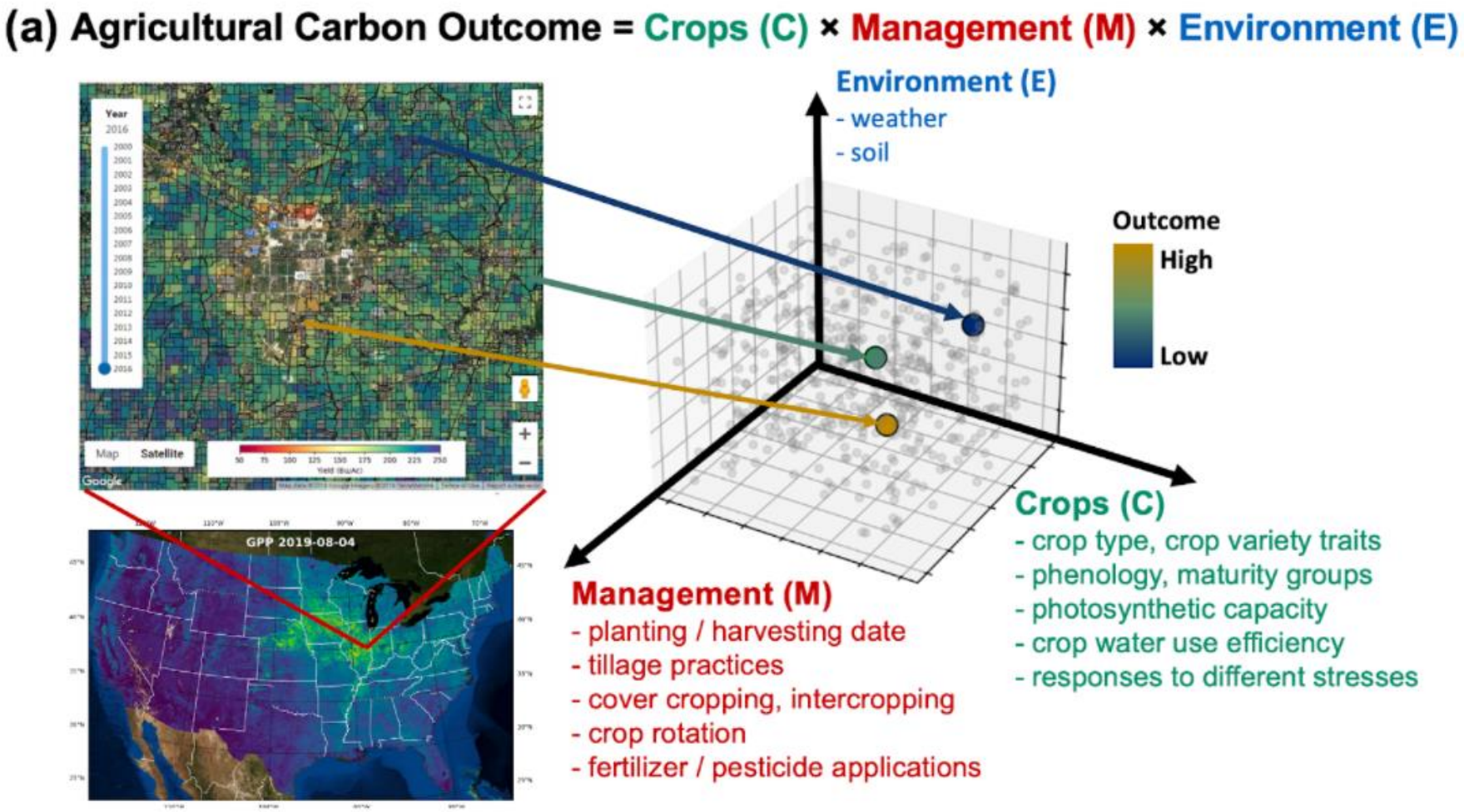
A "system of systems" commercial solution of quantifying field-level carbon credit for farmland

PI: Kaiyu Guan (University of Illinois)

University of Illinois Urbana-Champaign | University of Minnesota Driven to Discover℠
University at Buffalo | Berkeley Lab

arpa·e

SYMFONI framework to quantify field-level carbon credit



Guan, Jin, et al. (2022): white paper can be downloaded here: https://eartharxiv.org/repository/view/2905/

Airborne-satellite integrated framework to quantify crop traits

Hybrid approach to utilize machine learning and radiative transfer models to quantify crop nitrogen across scales

Leaf scale

Airborne scale

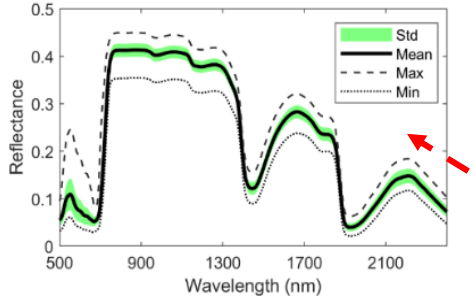
Satellite scale

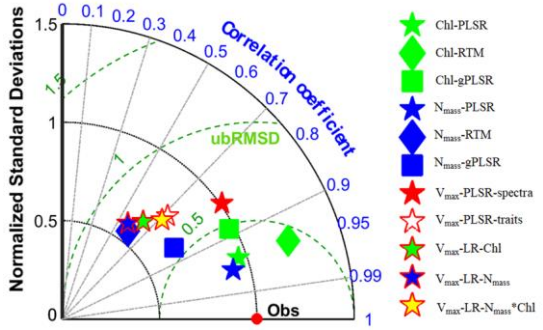
Accuracy for corn nitrogen

R^2 = 0.93
rRMSE = 6.83%

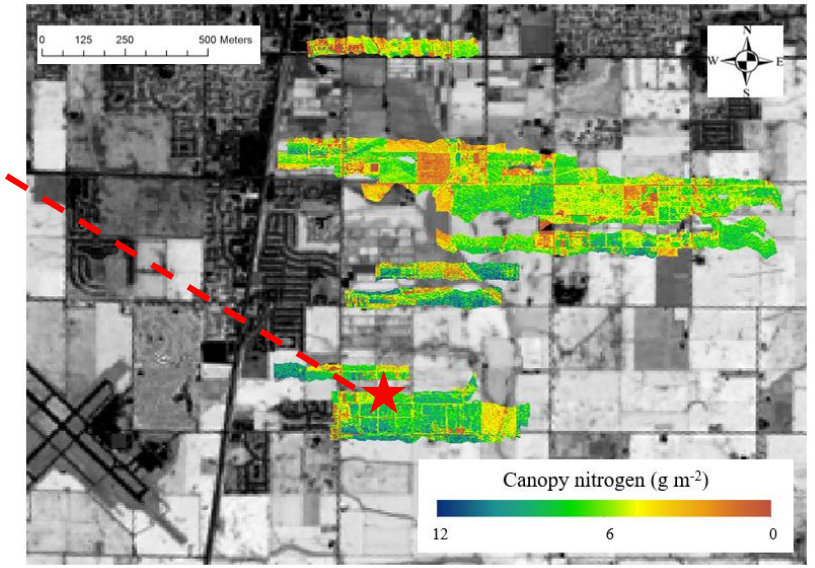
R^2 = 0.85
rRMSE = 9.63%

R^2 = 0.72
rRMSE = 15.67%

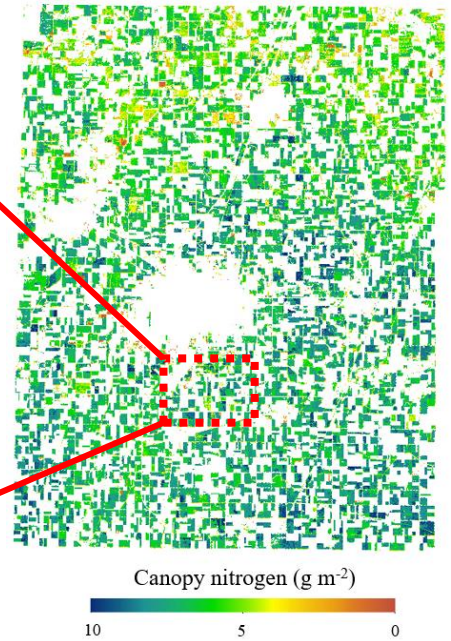




Leaf reflectance



UIUC South Farm fields



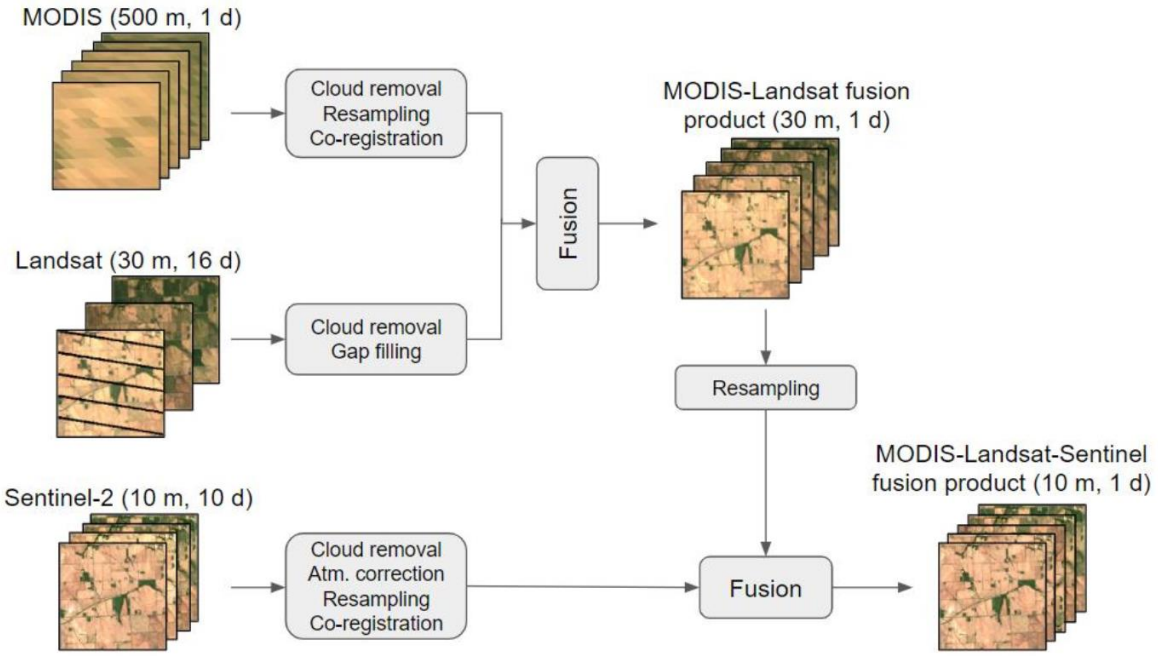
Champaign county

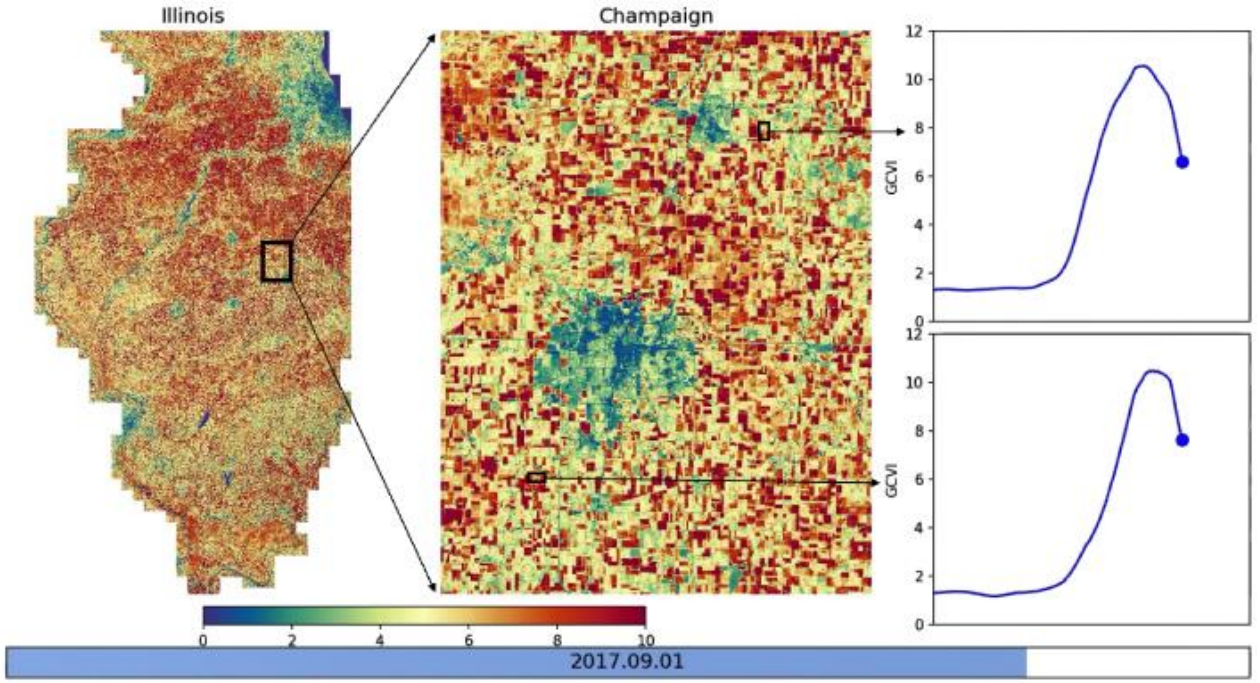
Wang, Guan, et al.. 2021, JXB

Wang, Guan, et al. IJAEOG

Sensing & Monitoring:
2. Satellite fusion technology, to enable large-scale deployment

Scalable fusion algorithm combines various public satellite data to generate daily, 10-30 meter, gap-free/cloud-free images from 2000 to present.



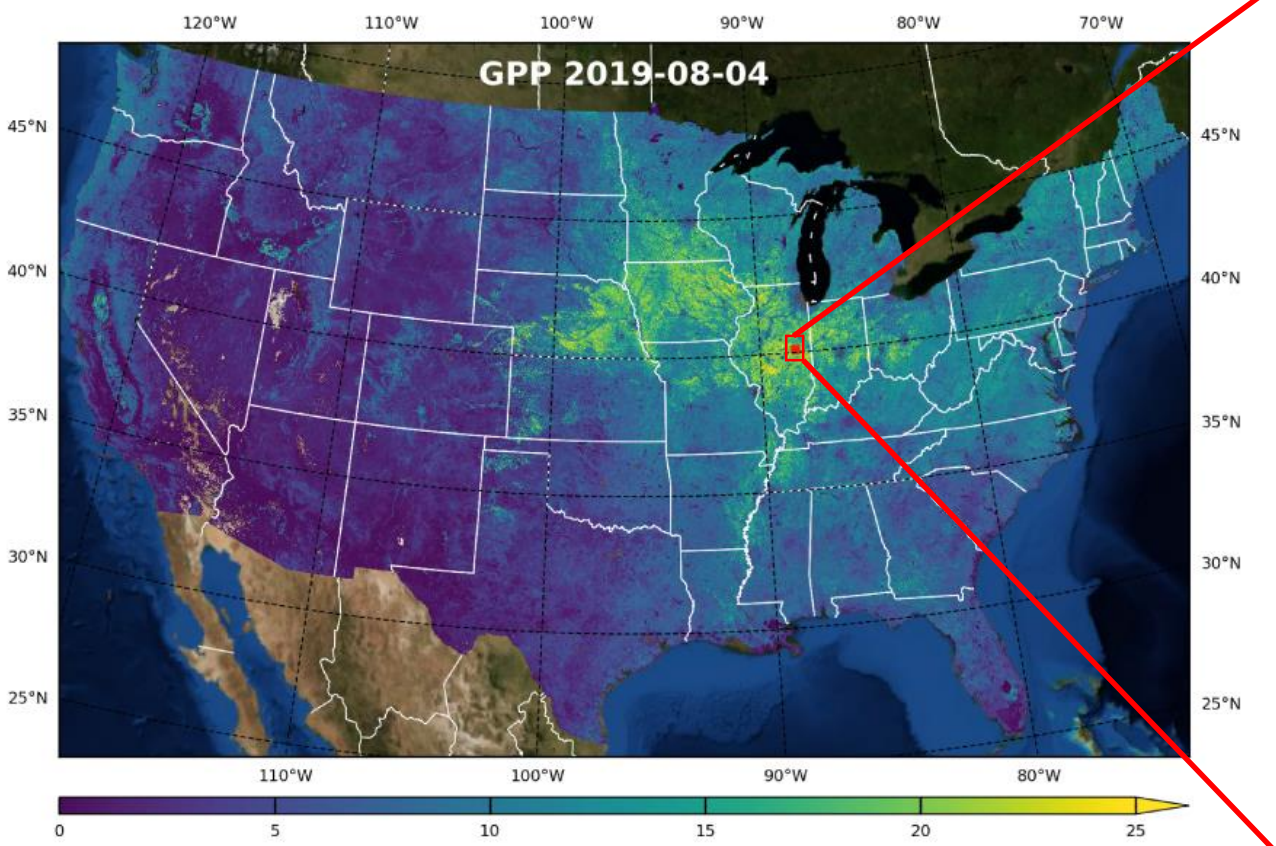


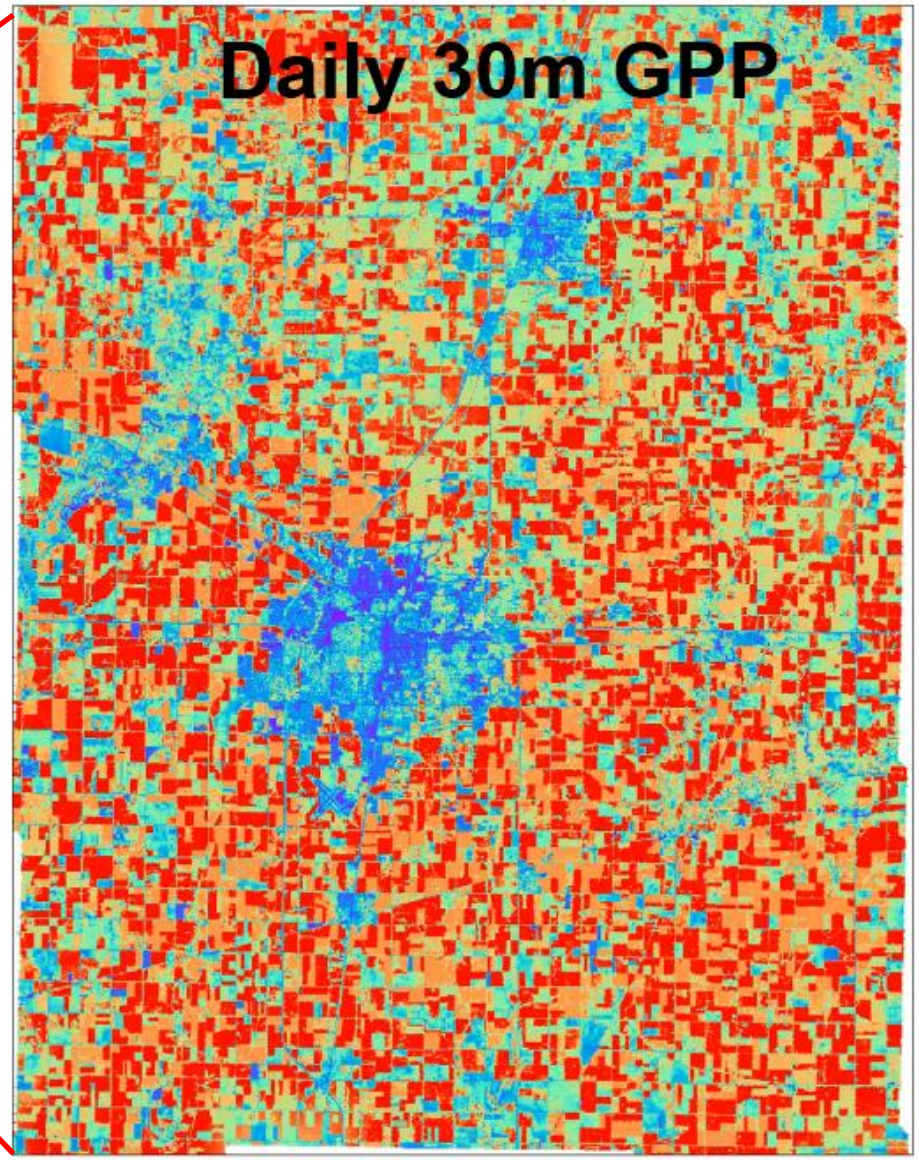
Luo, Y., **Guan, K.***, and Peng, J.* (2018) "STAIR: A generic and fully-automated method to fuse multiple sources of optical satellite data to generate a high-resolution, daily and cloud-/gap-free surface reflectance product", ***Remote Sensing of Environment***.

Check the demo video on YouTube: https://youtu.be/IXVEVWlMQg4

(PI: Guan, NASA NIP, 2016)

Farmland Carbon Uptake (i.e. GPP, Photosynthesis)
10 meter resolution daily, real-time, covering every farmland in the United States





Champaign, IL (2017)

Jiang, C.*, Guan, K.*, Wu, G., Peng, B., and Wang, S. (2020) “A daily, 250 m, and real-time gross primary productivity product (2000–present) covering the Contiguous United States”, Earth System Science Data.

Wu,G., Guan,K.*, Jiang,C.*, Peng,B., Kimm,H., Chen,M., Yang,X., Wang,S., Suyker.A.E.,Bernacchi,C. and Moore, C.E. (2019) "Radiance-based NIRv as a proxy for GPP of corn and soybean", Environmental Research Letters.

You also heard of using models.

1. Quantifying the carbon outcome is complex enough that requires process-level understanding.
Models need to have the necessary processes!

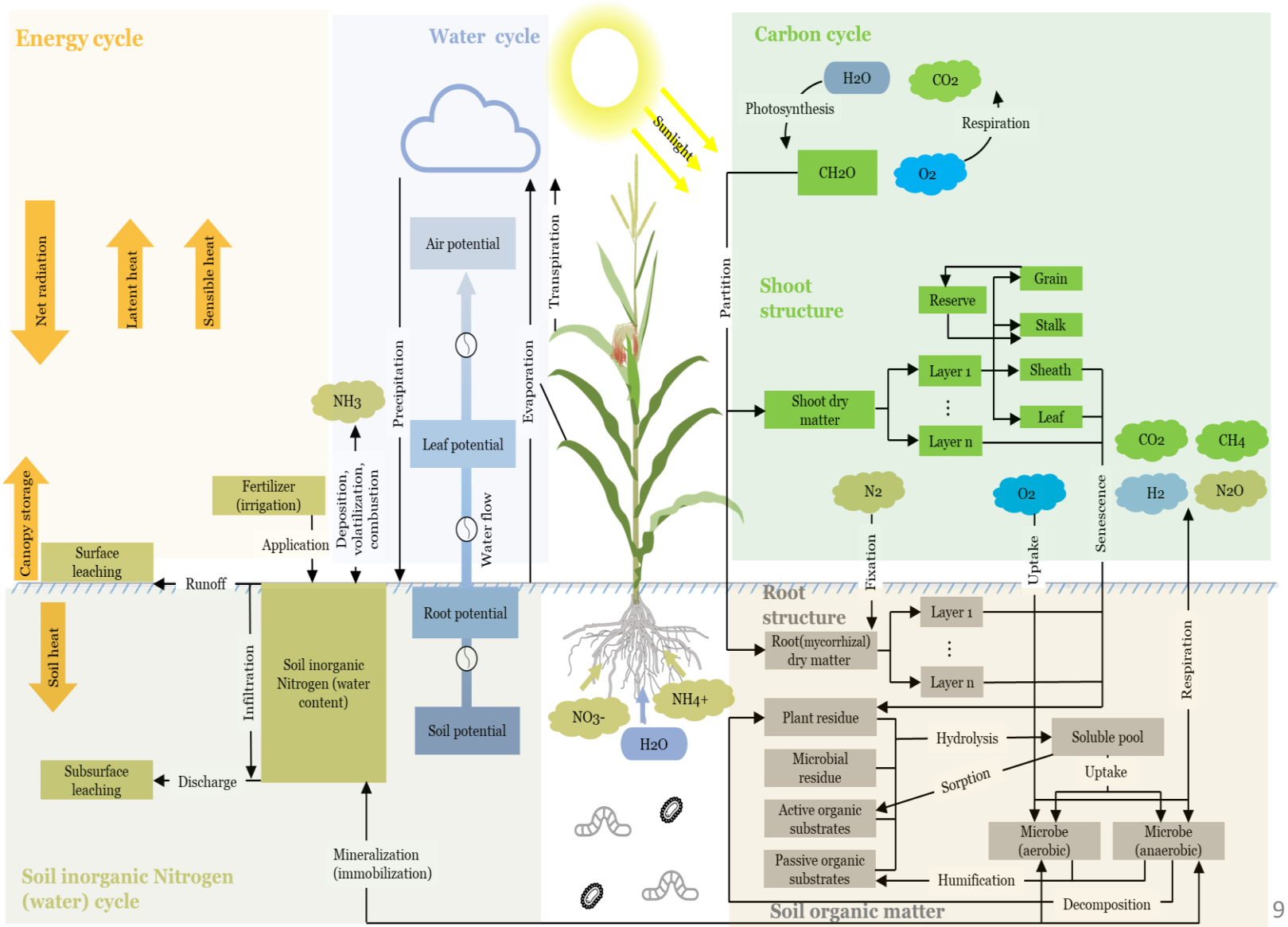
2. The biggest problem of how models are used is:
NO CONSTRAINTS to the model!

Modeling & Quantification: Model-Data Fusion

***Ecosys* model**

Ecosys is an advanced mechanistic ecosystem model developed to simulate water, energy, carbon, and nutrient cycles simultaneously for various ecosystems at the hourly step with multiple soil and canopy layers. It can simulate the influence of different crop management practices (i.e. tillage, fertilizer, and irrigation) under different environmental conditions.

(https://ecosys.ualberta.ca/)



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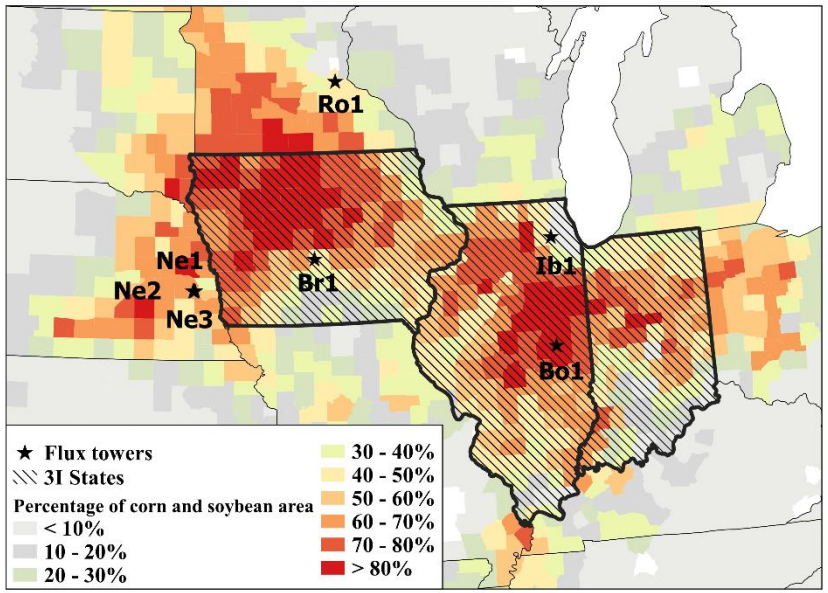
Performance of Simulated Carbon Budget at Flux Tower Sites

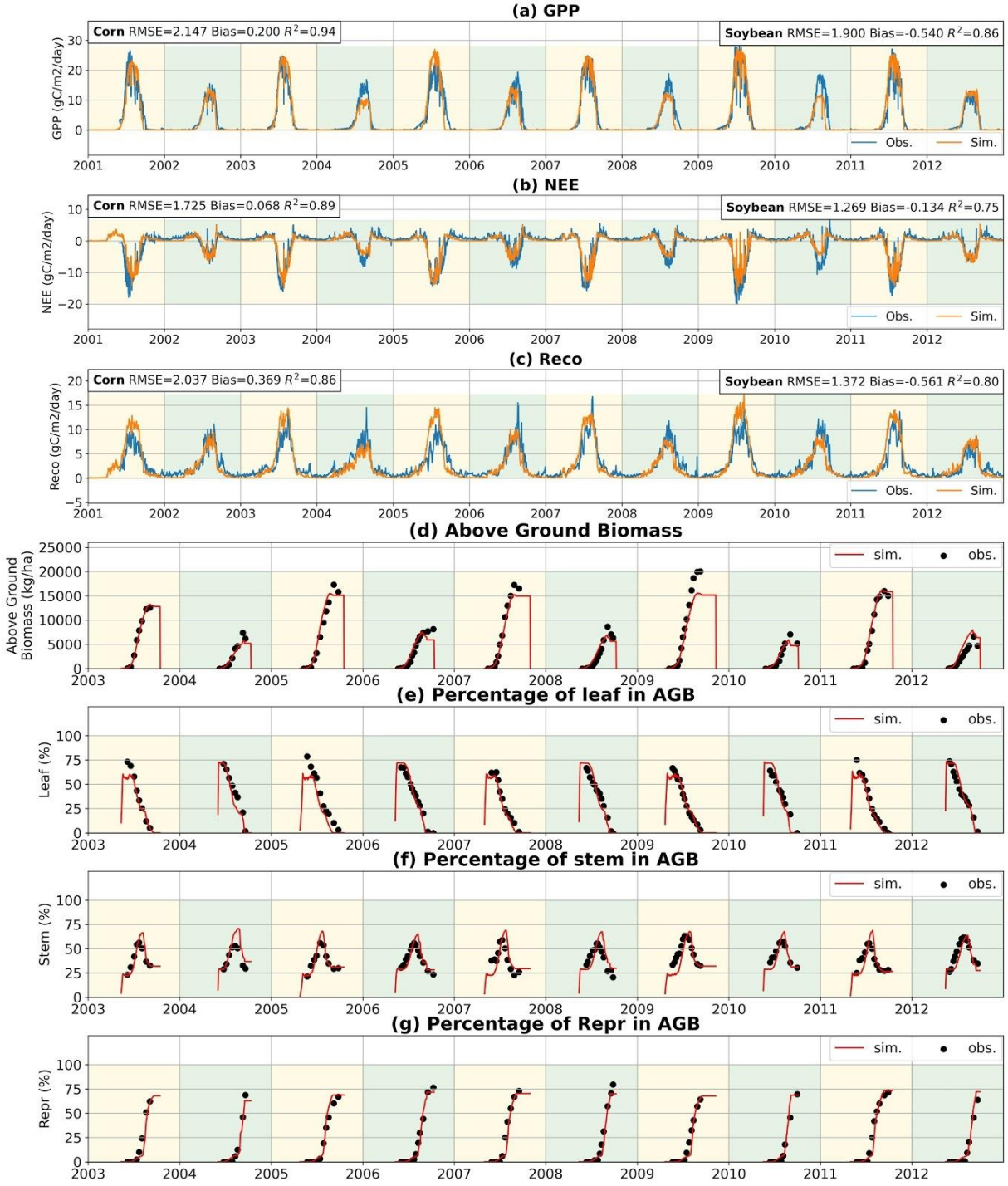


Locations of the seven flux towers and the three I states in the U.S. Midwest.

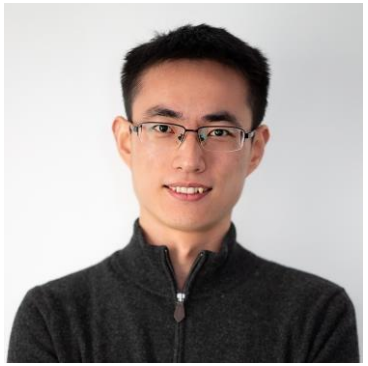
Comparing *ecosys* simulated GPP, NEE, Reco, and carbon allocation with site observations at Mead Ne3 site in Nebraska for both corn (light yellow shaded) and soybean (light blue shaded).

(Wang, Guan, et al. AFM, 2021)

(PI: Guan, NSF CAREER, 2020)



AI-based data-model fusion technology (II) – Knowledge-Guided Machine Learning (KGML)



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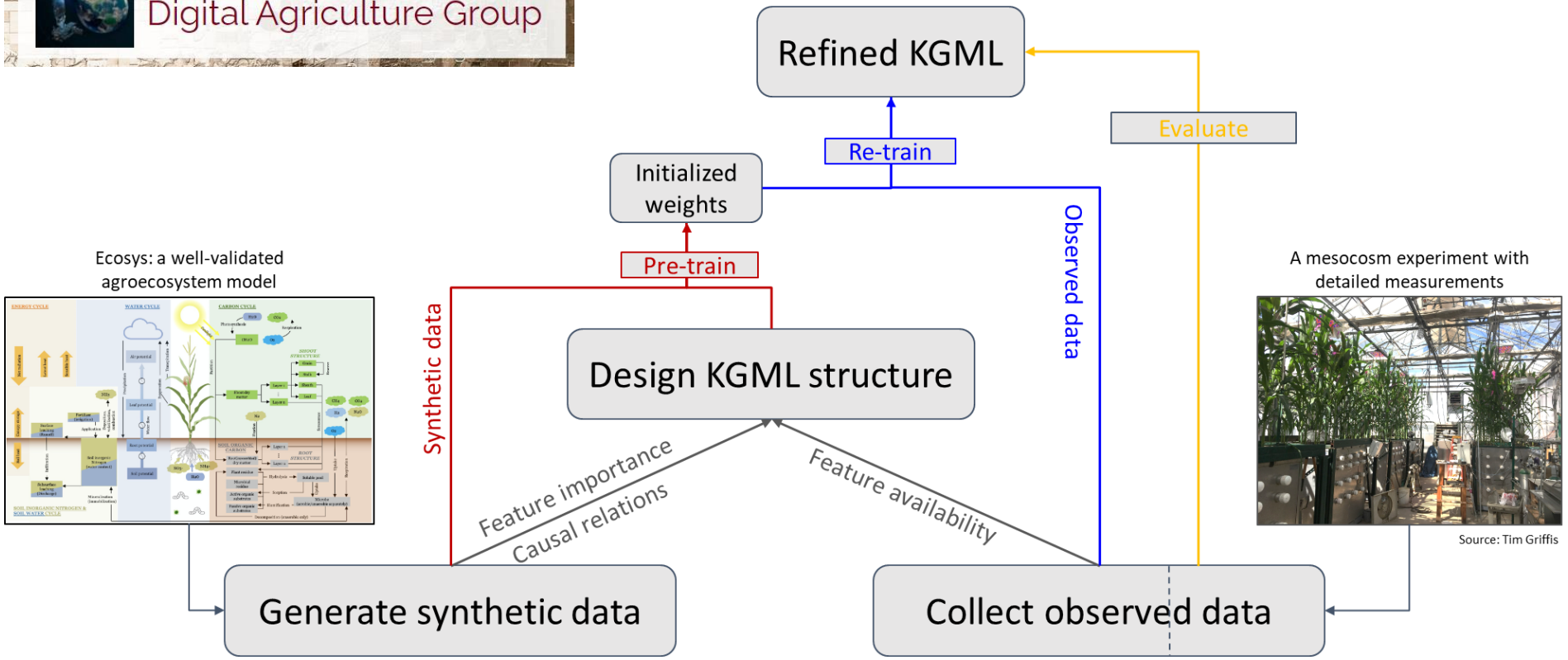
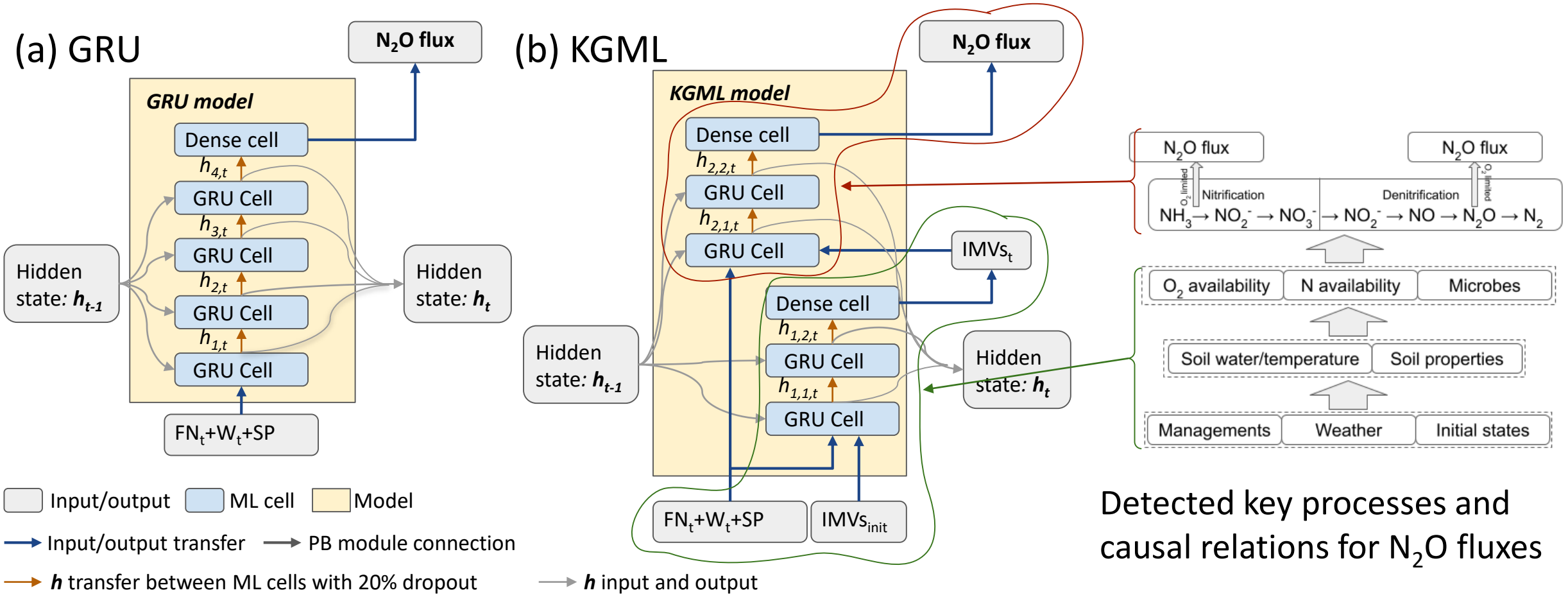
Digital Agriculture Group



Liu L, … Guan K, …, Jin Z* (2022) KGML-ag: A Modeling Framework of Knowledge-Guided Machine Learning to Simulate Agroecosystems: A Case Study of Estimating N2O Emission using Data from Mesocosm Experiments. ***Geoscientific Model Development***

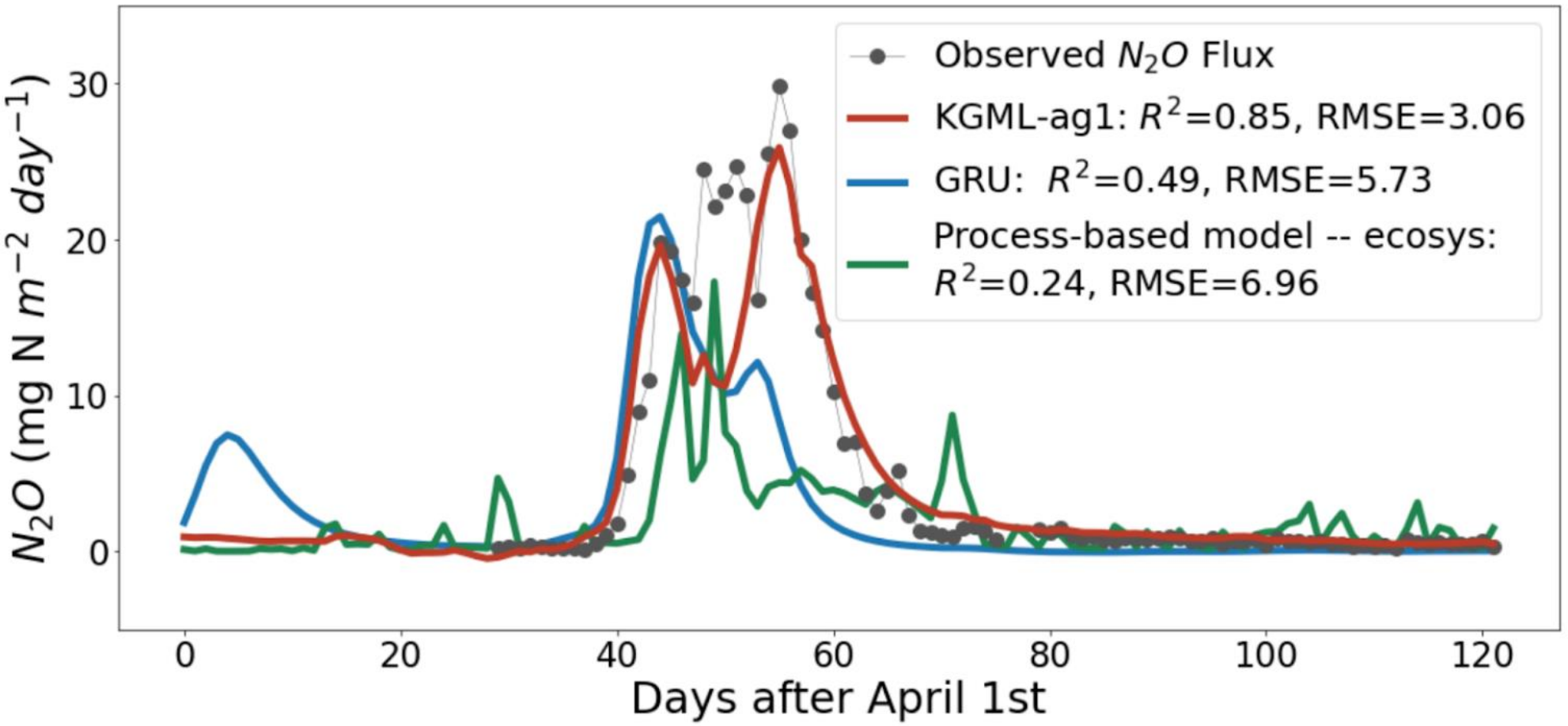
Why KGML outperform others



Detected key processes and causal relations for N_2O fluxes

- GRU outperformed LSTM with its simpler structure in N_2O simulation
- GRU model was used to do feature importance tests
- Physical guided initialization and architecture constraints were applied

The KGML model outperformed the pure ML model



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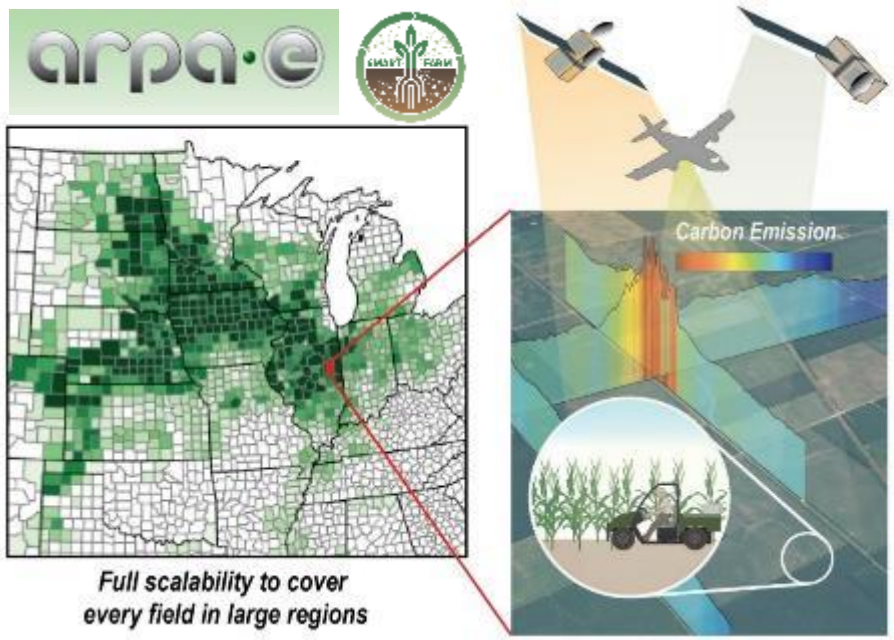
HABITERRE

(previously “Aspiring Universe”)

- A UIUC-based startup that licensed the technology for commercialization

HabiTerre is the only Tech-to-Market (T2M) partner for the SYMFONI – the DOE ARPA-E SmartFarm grant for developing commercial-level carbon credit method.



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HabiTerre incorporates strong remote sensing capacity with advanced process-based modelling to achieve the lowest uncertainty, and utilizes AI to offer cost-effective scalable solutions.

Point of Contact: **Nick Reinke**, CEO of HabiTerre (nick.reinke@habiterre.com)

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