MONITORING FIELD-SCALE CROP WATER USE USING A SATELLITE DATA-DRIVEN MECHANISTIC MODELING APPROACH

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EXECUTIVE SUMMARY

High-spatiotemporal-resolution evapotranspiration (ET) products with reliable accuracy have many potential applications in agriculture. The research team developed BESS–STAIR, a new framework to estimate high-spatiotemporal-resolution ET that can be used for field-level precision water resources management. BESS–STAIR couples a satellite-driven water–energy–carbon-coupled biophysical model (BESS) with a generic and fully automated fusion algorithm (STAIR) to generate gap-free 30-m-resolution daily ET estimations. Comprehensive evaluation of BESS–STAIR ET estimations revealed: (1) reliable performance over 12 flux tower sites across the U.S. Corn Belt; and (2) reasonable spatial patterns, seasonal cycles, and interannual dynamics. The proposed BESS–STAIR framework has demonstrated its ability to provide significant advancements with regard to daily field-level estimations of ET at regional and decadal scales. When scaled up, which is in process, BESS–STAIR ET products could be very useful for precision water resources management and other precision agriculture applications for the U.S. Corn Belt and elsewhere.

RESEARCH CHALLENGE

With increasing crop water demands and drought threats, mapping and monitoring of cropland evapotranspiration (ET) at high spatial and temporal resolutions becomes increasingly critical for water management and sustainability. However, estimating ET from satellite data for precise water resources management is still challenging owing to limitations in both existing ET models and satellite input data. Specifically, the process of ET is complex and difficult to model, and existing satellite remote sensing data cannot fulfill high resolutions in both space and time.

METHODS & CODES

To address the above two issues, the research team developed a new high-spatiotemporal-resolution ET mapping framework, BESS–STAIR, that integrates the satellite-driven water–carbon–energy-coupled biophysical model BESS (Breathing Earth System Simulator) [1,2] with a generic and fully automated fusion algorithm STAIR (SaTallite dAta IntegRation) [3]. In this framework, STAIR provides daily 30-m multispectral surface reflectance by fusing Landsat and MODIS satellite data to derive fine-resolution leaf area index and visible/near-infrared albedo, all of which,

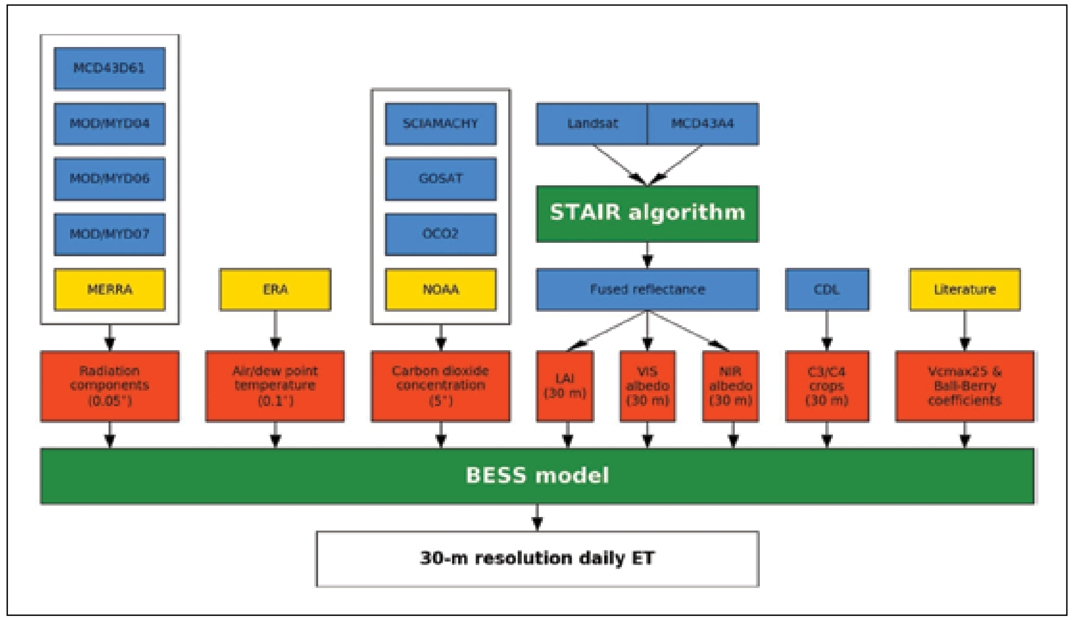

Figure 1: The BESS–STAIR framework for field-scale (30-m) evapotranspiration mapping.

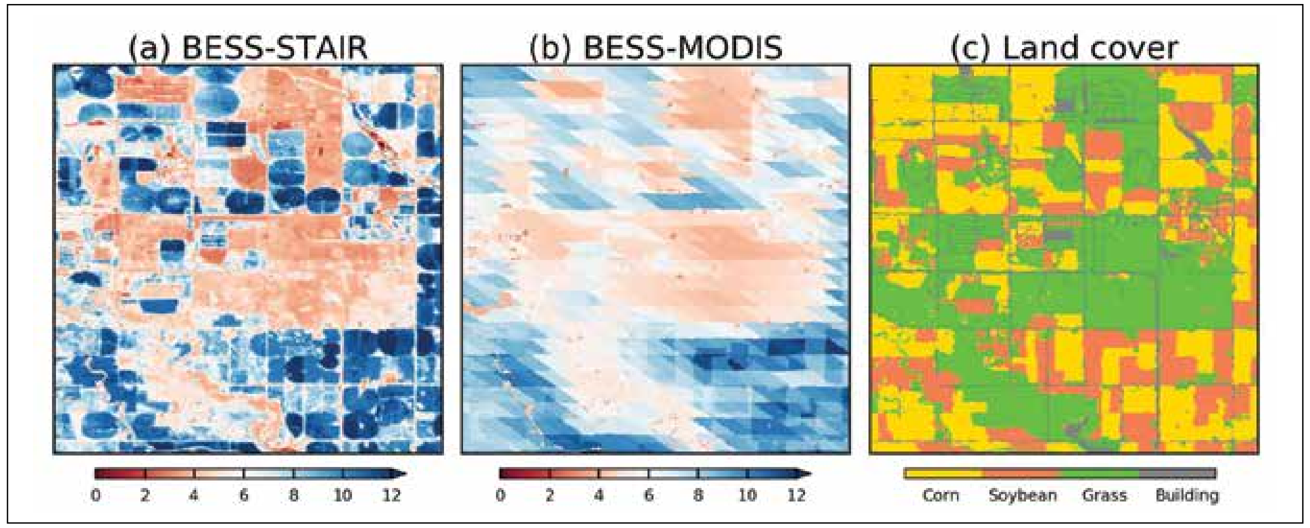

Figure 2: Example daily evapotranspiration (MJ m-2 d-1) derived from: (a) BESS–STAIR (30 m) and (b) BESS–MODIS (500 m) at Mead, Nebraska.

along with coarse-resolution meteorological and CO_2 data, are used to drive BESS to estimate gap-free 30-m resolution daily ET. The team applied BESS–STAIR from 2000 through 2017 in six areas across the U.S. Corn Belt and validated BESS–STAIR ET estimations using flux tower measurements over 12 sites (85 site-years). Results showed that BESS–STAIR daily ET achieved an overall R2 = 0.74, with RMSE = 0.96 mm d-1 and relative error = 28.6%. In addition, BESS–STAIR ET estimations captured the spatial patterns, seasonal cycles, and interannual dynamics of ET well when benchmarked with the flux measurements. The high performance of the BESS–STAIR framework primarily resulted from: (1) the implementation of coupled constraints on water, carbon, and energy in BESS; (2) high-quality daily 30-m data from STAIR fusion algorithm; and (3) BESS's applicability under all-sky conditions. BESS–STAIR has great potential to be a reliable tool for water resources management and precision agriculture applications for the U.S. Corn Belt, and even for other agricultural regions worldwide, given the global coverage of its input data.

RESULTS & IMPACT

This project represents the first attempt to couple a satellite-driven, physical process-based model with data fusion techniques to provide daily 30-m-resolution ET estimations at regional and decadal scales. To the research team's knowledge, there is no explicit bottom-up, biophysically-based high-spatiotemporal resolution, long time series, and regional level methodological framework to estimate daily ET at a 30-m resolution. Other existing methodologies such as ALEXI–STARFM and SEBS–ESTARFM are LST (land surface temperature)-based models, and thus suffer from gap-filling and spatial-sharpening issues. Moreover, validation results from the project show that the BESS–STAIR framework can actually outperform those existing LST-based ET estimations.

The research team currently is upscaling the BESS–STAIR framework to the entire state of Illinois and other parts of the U.S. Midwest. They can foresee a number of potential applications of the high-resolution (30m) ET estimation either for small-scale precision agriculture or large-scale water resource planning and management.

WHY BLUE WATERS

Blue Waters is essential for this research since other resources, such as those available from XSEDE, are not suitable for the project, considering the petabyte-level storage demand, data availability, intensive I/O, and computation demands.

PUBLICATIONS & DATA SETS

C. Jiang, K. Guan, M. Pan, Y. Ryu, B. Peng, and S. Wang, "BESS-STAIR: A new framework to estimate daily, 30-meter, and all-weather evapotranspiration using multi-source satellite data for the U.S. Corn Belt," *Hydrol. Earth Syst. Sci. Discuss.*, in press, 2019, doi: 10.5194/hess-2019-376.

Y. Luo, K. Guan, and J. Peng, "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," *Rem. Sensing Environ.*, vol. 214, pp. 87–99, 2018.