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Commentary

Delta-Flux: An Eddy Covariance Network for a Climate-Smart Lower Mississippi Basin

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Core Ideas

- The Lower Mississippi River Basin (LMRB) is agriculturally important and ecologically unique.
- The Delta-Flux network will coordinate the activities of 17 eddy covariance towers.
- The network addresses the need for scaled C and water cycle observations.
- The network aims to promote sustainable, climate-smart land management.
- Delta-Flux is open to collaborators from strategic sites and relevant disciplines.

Abstract: Networks of remotely monitored research sites are increasingly the tool used to study regional agricultural impacts on carbon and water fluxes. However, key national networks such as the National Ecological Observatory Network and AmeriFlux lack contributions from the Lower Mississippi River Basin (LMRB), a highly productive agricultural area with opportunities for soil carbon sequestration through conservation practices. The authors describe the rationale to create the new Delta-Flux network, which will coordinate efforts to quantify carbon and water budgets at seventeen eddy covariance flux tower sites in the LMRB. The network structure will facilitate climate-smart management strategies based on production-scale and continuous measurements of carbon and water fluxes from the landscape to the atmosphere under different soil and water management conditions. The seventeen instrumented field sites are expected to monitor fluxes within the most characteristic landscapes of the target area: row-crop fields, pasture, grasslands, forests, and marshes. The network participants are committed to open collaboration and efficient regionalization of site-level findings to support sustainable agricultural and forestry management and conservation of natural resources.

The Lower Mississippi River Basin's (LMRB) alluvial plain (known regionally as the Delta) is a highly productive agricultural region characterized by a broad range of cropland, including row crops, pasture, and softwood timber. It also contains swaths of the remaining bottomland hardwoods in the region. Arkansas, Louisiana, and Mississippi together generate $19.5 billion of the United States' $403 billion in agricultural sector output; this production includes 70% of the rice (*Oryza sativa* L.), 40% of the sugarcane (*Saccharum officinarum* L.), and 19% of the food grains grown in the United States (USDA-ERS, 2017). The LMRB's high level of agricultural productivity, supported by warm, humid conditions and copious water resources, creates an important regional carbon sink through substantial photosynthetic fixation of atmospheric carbon dioxide (CO_2) and its subsequent storage as biomass and as soil organic matter, although studies focusing on this region are lacking. The region offers additional opportunities for sequestering carbon into the soil through land management such as higher-yielding cropping systems, efficient tillage strategies, and cover or intercropping methods that are climate smart (Franzluebbers, 2005) and thus consider future food security in changing environments. However, higher soil temperatures and abundant water also facilitate the decomposition of plant residues and the mineralization of soil organic matter through heterotrophic respiration. The balance between soil carbon sequestration and ecosystem respiration therefore requires a significant expansion of observation-based inquiry.

The magnitude of the regional carbon sink is largely unknown due to the complexity and ephemeral nature of the agricultural and natural landscapes. The region's potential to sequester carbon in soil will likely be sensitive to a number of ongoing and substantial changes to the agricultural landscape.

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Abbreviations: BESS, Breathing Earth System Simulator; ET, evapotranspiration; GPP, gross primary productivity; LMRB, Lower Mississippi River Basin; LTAR, Long-Term Agroecosystem Research; MODIS, Moderate Resolution Imaging Spectroradiometer.

For example, Arkansas, Louisiana, and Mississippi have collectively experienced a 64% increase in irrigated land from 1998 to 2008 (Vories and Evett, 2014), contributing to one of the highest aquifer depletions in the United States (Konikow, 2015). These changes to the water budget may have substantially altered soil carbon sequestration by reducing soil drought conditions and associated crop responses. Modifications to energy and hydrologic cycling could affect regional climate impacts in this region (Boucher et al., 2004). Furthermore, channelization of the Mississippi River system and concomitant floodplain hydrology has reduced bottomland hardwoods by 80% since the 1930s (Faulkner et al., 2011; De Steven et al., 2015); the resulting conservation efforts that include reforestation and floodplain restoration may re-establish certain ecosystem services, including carbon sequestration.

The relevance of the LMRB for regional- to continental-scale carbon and water cycling is highlighted by examining the United States' distribution of actual evapotranspiration (ET) and gross primary productivity (GPP). We used a new global process-based approach to estimating these terms from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery, the Breathing Earth System Simulator (BESS) (Ryu et al., 2011; Jiang and Ryu, 2016), to demonstrate the magnitude of these fluxes from Arkansas, Mississippi, and Louisiana (Fig. 1). These states rank within the top five in terms of annual ET rates and have early spring inception of GPP. Products such as BESS require "boots on-the-ground" flux and landscape observations for validation and support. Although GPP estimates can be derived from satellite imagery, the net carbon balance requires an estimate of ecosystem respiration. This term requires locally based parameterizations (Phillips et al., 2016) that can be provided in part through flux tower measurements.

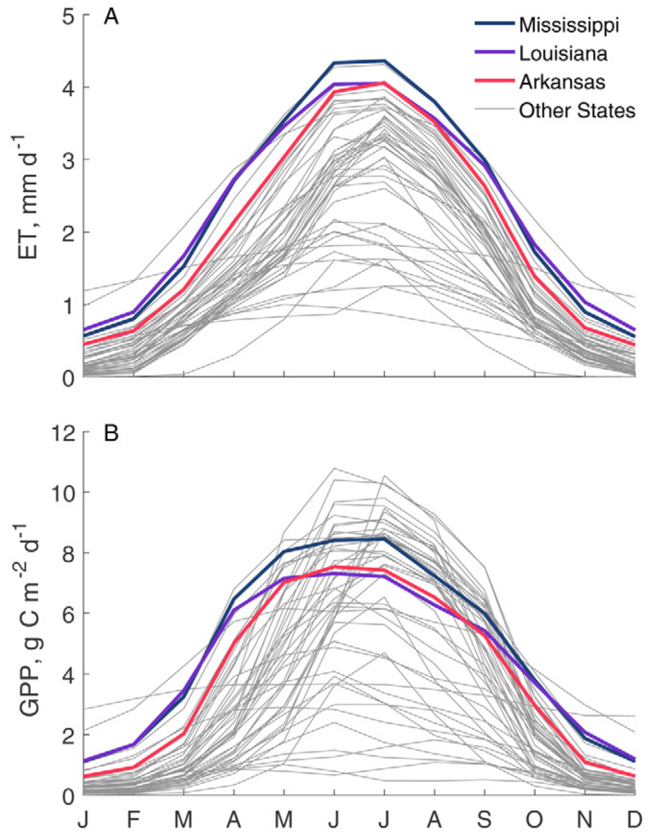

Fig. 1. (A) Average actual monthly evapotranspiration (ET). (B) Gross primary productivity (GPP) for each of the 50 US states, with Mississippi, Louisiana, and Arkansas highlighted. Values average 2001 to 2015 from the monthly, 0.5-degree gridded Breathing Earth System Simulator (BESS) product aggregated from 1 km MODIS pixels (Jiang and Ryu, 2016).

Despite the great potential for regional carbon sequestration in its soils and vegetation stocks, the LMRB region lacks observations of its carbon and water fluxes. This region has been historically underrepresented in national carbon cycling monitoring projects such as the National Ecological Observatory Network (NEON), the Critical Zone Observatory (CZO), the Long-Term Ecological Research (LTER) Network, and AmeriFlux, which is a USDOE network of scientist-managed sites that measure ecosystem fluxes of CO_2, water (H_2O), energy, and sometimes other scalars such as methane (CH_4). Experiment-based observation programs are particularly necessary given the opportunity for human management—agricultural intensification, irrigation water use, and conservation incentive programs—to affect soil carbon sequestration.

Networked observations have demonstrated many benefits—pioneered in flux research through AmeriFlux (since 1996) and similar networks. Networks create a "Big Data" framework that can allow novel insights through data mining and intersite comparison (e.g., Boyd and Crawford, 2012). For example, robust geographic comparisons between sites enhance process-based knowledge and test best management strategies. The cross-disciplinary collaboration and new large-scale datasets generated by research networks are crucial to ecological discovery (Weathers et al., 2016), and they help to scale observations from individual sites to pose regional and continental ecological questions (Peters et al., 2014). We describe here the potential for a newly created network of flux towers in the LMRB to address some of the key gaps in our knowledge of region's carbon and water cycle fluxes. We identify specific research questions that can be targeted with Delta-Flux data, discuss mechanisms by which the individual network node activities will be coordinated, and highlight areas in which additional collaboration is sought.

Observation Network: Delta-Flux

A consortium of researchers, representing US government agencies and state academic institutions, recently formed a regional network of eddy covariance towers named Delta-Flux with the goal to integrate site-level findings on carbon and water fluxes to inform cohesive, regional science needs. The towers provide continuous measurements of net land–atmosphere exchange of energy, H_2O vapor, CO_2, and CH_4 over multiyear to decadal time scales. Measuring CH_4 fluxes, with their significant global-warming potential (Etminan et al., 2016), is an especially important task in this region given the high rice production and other wetland environments. The network includes 17 existing, active towers spread across 11 sites in the region and two recently running towers in the tidal marshes of Louisiana (Holm et al., 2016; Krauss et al., 2016). Most of the Delta-Flux towers were either deployed within the last 3 yr or will begin data collection in 2017 (Fig. 2; Table 1). Two or more of these are planned as part of the USDA-ARS Long-Term Agroecosystem Research (LTAR) LMRB site centered near Stoneville, MS. Each tower at these sites contains at minimum a core eddy covariance measurement system comprising a three-component sonic anemometer and a high-frequency (>10 Hz) infrared gas analyzer to measure CO_2 and H_2O density to generate a dataset on vertical CO_2 and H_2O fluxes (Baldocchi, 2003). Supplementary meteorological instrumentation allows for the continuous measurement of relevant biophysical properties. These data streams will be supported by measurements of biomass production (e.g., plant and root growth) and removal rates (e.g., crop yield, burning, or hay), soil carbon dynamics, and leaf or soil greenhouse gas (CO_2, CH_4, and nitrous oxide [N_2O]) fluxes.

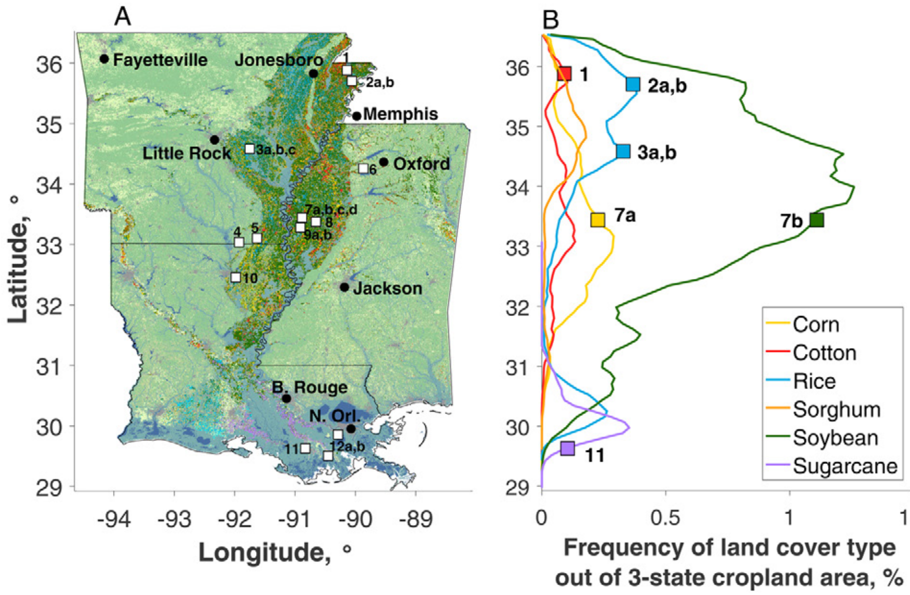

Fig. 2. (A) Project site locations in Arkansas, Mississippi, and Louisiana mapped on the 2015 CropScape crop cover dataset (Han et al., 2014) with selected crops in legend. The numbered sites are summarized in Table 1 and described in the text. (B) The row-crop tower locations are compared to the latitudinal distribution of these crops in the three target states determined from data in plot A. The *x* axis is in percentage of the total three-state cropland area, per 10-km latitude band.

The network towers are placed in commercial fields of rice, soybean [*Glycine max* (Merr.) L.], corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), and sugarcane, as well as pasture, grasslands, and forests. Participating scientists have established these independent towers from a diverse source of funds for each of these sites to answer specific, locally important research questions, much like AmeriFlux itself. Site researchers each have the aim to quantify site greenhouse gas balances, improve mechanistic understanding, and guide carbon and water cycle research and management approaches. Delta-Flux leverages the site-level investments to work simultaneously and collectively toward the network goals of obtaining integrated results for the region. Additionally, Delta-Flux is an open network, and new tower sites in the region are immediately welcomed to integrate

Table 1. Delta-Flux eddy covariance site descriptions and tower locations, with AmeriFlux site abbreviations where available.

Site no.	Location	Experiment	Operation	Project investigators
1	Manila, AR	cotton: pivot-irrigated	2016–present	Reba, Runkle
2a,b	Burdette, AR (US-BdC; US-BdA)	rice—a: conventional; b: AWD†	2013–present	Reba, Runkle
3a,b,c	Humnoke, AR (US-HRC, US-HRA)	rice—a: conventional; b: AWD irrigation; c: winter nonflood	a,b: 2015–present c: winter 2015–2016 only	Runkle, Reba
4	Crossett Experimental Forest, AR (US-CST)	pine forest: intensive management, uneven age	2013–present	Novick
5	Overflow National Wildlife Refuge, AR	grassland, annually mowed, migratory bird habitat	2016–present	Novick
6	Goodwin Creek, MS (US-Goo)	bluff hills pasture and hay field	2002–2006; 2017–present	Rigby, Locke
7a,b,c,d	Stoneville, MS	a, b: common experiment (base, aspirational); corn–soybean rotation; c: mixed agroecosystem; d: soybean and evapostranspiration research	a,b: 2017 (in planning); c: 2015–present; d: 2016–present	Rigby, Locke (a,b); Sui (c); Anapalli (d)
8	Beasley Lake, MS	alluvial plain: row cop and CRP‡	2017 planned	Locke, Rigby
9a,b	Arcola, MS	a: corn/soybean; b: rice/soybean	a: 2015–present; b: 2016–present	Sui
10	Russel Sage Wildlife Area, Monroe, LA (US-ULM)	bottomland hardwood and swamp	2013–present	Bhattacharjee
11	Chacahoula, LA	Sugarcane: continuous cultivation	2016–present	White
12a,b	Coastal Louisiana	Tidal wetlands	2011–2013	Krauss

† AWD , alternate wetting and drying irrigation.

‡ CRP, Conservation Reserve Program.

within the existing network. Delta-Flux will interface closely with other national and international observation networks (e.g., AmeriFlux, Fluxnet, Phenocam, and LTAR), using those networks to help manage data for public availability.

Delta-Flux has three specific aims: (i) to create a high-quality, consistent dataset from tower-based carbon and water fluxes; (ii) to generate a regional carbon balance sensitive to local variations in land use; and (iii) to facilitate research on the relationship among agricultural management, water use, and soil carbon sequestration. The network responds to the argument that the LMRB region's agricultural landscapes offer great potential for climate-smart management that increases yields and adds resilience to climate variability. Examples of climate-smart management include the application of conservation programs, water-saving strategies of irrigation and management, and reducing greenhouse gas production in farm practice. The Delta-Flux network is motivated by recent high-profile, science-based calls for the use of agricultural conservation practices to mitigate global greenhouse gas emissions (Carlson et al., 2016; Paustian et al., 2016). The majority of the recommended conservation practices, including uneven-age forest management, cover-cropping, reduced tillage, crop residue recycling, efficient nitrogen use, and changes in irrigation techniques, are being actively encouraged through conservation incentive programs. One example is the promotion of the Alternate Wetting and Drying irrigation regime in rice production by two USDA-NRCS programs, the Environmental Quality Incentives Program and the Conservation Stewardship Program; this irrigation practice is tested within Delta-Flux by two pairs of towers in Arkansas. Similarly, there has been an increased focus on understanding the carbon sequestration potential of different management practices in southern pine (*Pinus* spp.) forests (e.g., uneven-age management; Bragg and Guldin, 2010). Location-specific observations, such as those provided through the Delta-Flux network, are needed to evaluate the success of these management strategies. Therefore, a key product of Delta-Flux will be a quantitative measure of conservation effectiveness within the region.

The Delta-Flux network's multisite data generation will enable a science-based approach toward context-dependent sustainable production agriculture. First, the network products will encourage sustainable agricultural practices by offering data that demonstrates the outcome of alternative land-use and/or crop management strategies. Second, network findings will aid decision making with respect to climate variables—for example, drought/flood frequency and timing—in the LMRB region to reduce their impact on agriculture. The farm-scale data generated by the Delta-Flux network can be used to parameterize and tune ecosystem models of varying complexity to scale carbon and water use dynamics to the region. Third, through coordinated data sharing—both within Delta-Flux and with the national networks—Delta-Flux will have a widespread impact on sustainable agricultural production around the nation and globally. This network provides data to help forecast landscape responses to future climate scenarios and test the impact of new agricultural strategies.

Significance and Commentary

Successful completion of continuous, field-scale experimental measurements across Delta-Flux's 17 sites is an important step in providing policymakers with comprehensive, actionable information regarding emission reduction approaches. The network's output will enable more holistic approaches to agricultural production and estimates of the regional carbon balance. The Delta-Flux network will broaden the scope of research questions that can be answered by ecosystem scientists, climate modelers, and land use managers. The regional repository approach allows larger-scale ecological questions to be addressed, linking process and pattern at greater spatial and temporal scales (Hampton et al., 2013). The network will achieve an enhanced understanding of the regional carbon balance as influenced by both common and new, climate-friendly agricultural practices.

Importantly, the network will improve the efficiency of data collection, storage, analysis, and publication through cross-site collaboration and comparison. These processes will be enacted through regular meetings and communication among group members. Data management is a known challenge of agroecological field research (Laney et al., 2015), and the benefits of generating a regional network include a uniformity of data types, reduced duplication of effort, and a consistent working vocabulary (Stocker et al., 2016). A high degree of standardization among sites will enable data reuse via sharing (White et al., 2013) by following the Fluxnet approach (Baldocchi et al., 2001) and consistent data processing algorithms (e.g., in gap-filling and flux partitioning; Reichstein et al., 2005). Several sites within the network have already received short-term visits from the AmeriFlux Tech Team and its Portable Eddy Covariance System (Ocheltree and Loescher, 2007), and within-network site visits are ongoing to ensure a high degree of intersite consistency. Networked data collection can also more quickly engender a cultural shift from data "ownership" to "stewardship," transparent data collection, and public critique of practice (Hampton et al., 2015; Michener, 2015). The sites eventually aim to submit all of their data to AmeriFlux and thereby Fluxnet for widespread use.

In future years, the network of observations will set a foundation to regionalize and internationalize the findings to develop optimal agricultural production strategies across a variety of landscape types. These strategies aim to balance both soil carbon sequestration and harvest productivity goals. To achieve these aims, the Delta-Flux network welcomes collaborators with expertise in remote sensing, regional and global climate modeling, soil microbiology, agronomy, and community health. The network is committed to open collaboration for additional tower or site developments within the region as other researchers develop eddy covariance and related observational programs. We aim particularly to incorporate underrepresented habitat types that may currently provide high levels of sequestration, such as afforested land previously in agriculture, riverine swamp forests, or deltaic marshes.

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