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Building digital twins from field to watershed scales to support sustainable water resource management and agrifood systems

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Statements (699 words):

Climate change and land use intensification have been threatening water resources worldwide. Sustainable management for water resources is urgently needed to meet the United Nations' Sustainable Development Goal 6 (SDG 6) and other water-related SDGs. Technology advancement is one of the core commitments in the Water Action Agenda from both public and private sectors. Digital twin is an emerging integrated technology that has a great potential to support sustainable water resource management and agrifood systems. A digital twin is a digital representation of a real-world physical system that can be used to optimize the real-world decision-making in the digital counterpart. The backbone technologies for building a digital twin include integrated monitoring systems, integrated modeling and model-data fusion systems, advanced digital and engineering technologies, and their seamless integration.

The integrated monitoring systems use a combination of observational techniques to speed up data collection with less cost, compared with traditional station-based data collection. Deploying inexpensive internet of things sensor networks ensures distributed ground data collection over a large area. Increasing use of high spatial-temporal-resolution remote sensing data from Unmanned Aerial Vehicles, airplanes, and satellites provides unprecedented monitoring capacity from local to global scales. When proper data quality control and data harmonization are implemented, these multi-source observational data can serve as a multi-angle lens to depict the dynamics of the real-world complex system.

The integrated modeling and model-data fusion systems, like a human brain, make the digital twin physically and scientifically reasonable and thus smarter. As observational data usually cannot give a full picture of the real-world complex systems, it remains necessary to integrate the observational data stream with process-based models to predict the behavior of the real-world complex systems. Process-based modeling is the key to enable prediction under different interventions. Specifically, process-based models should represent sufficient and necessary processes related to the environment, human interventions, and their interactions,

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and emphasize mechanistic representation to improve the extrapolation capability of the models. Additionally, process-based models should simulate as many measurable variables as feasible, such that the model simulation can be thoroughly validated, and measurable constraints can be easily incorporated to further improve the model simulation. Model-data fusion (MDF) is the technology that integrates observational data streams with process-based models to improve the prediction performance. Recent advances in developing AI-based surrogates and knowledge-guided machine learning models, as well as computational techniques, strongly support the scaling of MDF from local to regional scales.

Advanced digital and engineering techniques, including but not limited to high-performance computing, cloud computing, data architecture and management, artificial intelligence, computer vision, computer graphics and visualization, augmented reality, virtual reality, autonomous and robotic systems, and decision support systems are critical components to ensure the scalability, realisticity, and executability of the digital twins. Only with advancement of these digital technologies can we create the digital replica of real-world complex systems. These digital technologies not only enhance the intelligence of digital twins, but also enable good user interface and user experience with the digital twins.

Finally, seamless integration of the above-mentioned technologies is the key towards successfully building digital twins and providing near-real-time science-driven decision making support. Digital twins can help optimize different water resource management scenarios and make more informed decisions related to sustainable water resource management from field to watershed scales. Field or farm/ranch-level digital twins help farmers/ranchers manage their crops and livestocks in a precision and cost-effective way, especially for precision irrigation and nitrogen fertilizer application and moving of livestock herds for adaptive grazing. Watershed-scale digital twins improve flooding forecasting and water resource allocation, and help conservationists and landscape resource managers to optimize the different conservation strategies to improve both water quantity and quality.

The Agroecosystem Sustainability Center (ASC) is an interdisciplinary research center at Institute for Sustainability, Energy, and Environment, University of Illinois at Urbana-Champaign aiming to be a world leading innovation powerhouse in advanced monitoring and modeling of agroecosystems for improving sustainability under climate change. ASC is initiating an ambitious ReDesign-Ag program that aims to build digital twins of the agricultural landscape to help optimize the management of every agricultural land parcel around the globe. ASC is ready to contribute to the UN's 2030 agenda for sustainable development by leading scientific and technology innovations in these areas.