**NASA Science Mission Directorate**
**Research Opportunities in Space and Earth Sciences -2024**
**NNH24ZDA001N-LCLUC24**
**A.2 Land Cover/Land Use Change - ESTO/AIST**

This synopsis is for the Land-Cover and Land-Use Change (LCLUC) solicitation jointly with ESTO/AIST as part of the NASA Research Announcement (NRA) ROSES-2024 NNH24ZDA001N. This NRA offered opportunities for conducting research over the globe with multi-source remote sensing technologies to improve understanding of human interaction with the environment, and thus provide a scientific foundation for understanding the sustainability, vulnerability and resilience of land-cover and land-use systems, and contribute to the development of Land Digital Twins. NASA LCLUC research contributes toward the goals of the U.S. Global Climate Research Program (USGCRP) by providing critical scientific information about LCLUC-climate interactions and the consequences of land-cover and land-use change on environmental goods and services, the carbon and water cycles and the management of natural resources. NASA received 32 proposals and selected 13 proposals for a total funding of $3 Million for three years. More details are available at: http://nspires.nasaprs.com.

---

**John Albertson/Cornell University**
**Improving Operational Prediction of Urban Rainfall and Heat Extremes Through Multi-Source LCLU Remote Sensing**
**24-LCLUC24_2-0001**

Urban areas have both the greatest spatial complexity of land surface features and the highest concentrations of people and economic activity exposed to urban heat islands (UHI) and extreme precipitation events. However, the forecast problem is complicated by urban areas having: i) a high fraction of the LCLU variability (buildings, greenspace, water features) at scales finer than the horizontal grid resolution of operational numerical weather prediction (NWP) models, and ii) a strong vertical aspect to the surface features and their interaction with meteorological processes. Results from our recent NASA IDS project revealed the causal links in how anthropogenic heating and the impact of the vertical dimension of urban spaces on upward motion impact the position, spatial extent and magnitude of UHI and extreme precipitation events. Current "operational" NWP models fail to capture these effects. We seek here to represent these effects in the operational NWP models and deliver this important capability to NASA's Land-Earth System Digital Twins (L-ESDT) effort. We focus the study on the DOE's four Urban Integrated Field Laboratory (UIFL) cities.

Recent progress in hybrid physics - machine learning models suggests that improved representations of the LCLU can be learned from high-resolution research grade NWP models and the wealth of available remote sensing data. The overarching goal of this project is to design an optimal data-model pipeline between the stream of satellite remote sensing data and operational NWP models to accurately capture the effect of LCLU on UHI and extreme precipitation. The research objectives are: 1) Develop a comprehensive set of urban surface forcing fields relevant to UHI and precipitation extremes over the four UIFL study regions for model training and validation; 2) Develop a machine learning solution that computes optimal "effective" LCLU parameters at the coarse operational NWP scale from high resolution remote sensing data for use in classic land surface models (e.g. NOAH-MP); 3) Augment the physics-based LSM with a machine learning booster stage that captures the net effect of interactions between high resolution LCLU information and meteorological processes at the sub-grid scale for operational NWP; and 4) Demonstrate skill improvement to operational NWP for UHI and extreme precipitation, including an attribution decomposition that demonstrates the relative contributions to the skill improvement across the different remote sensing data sources and model components.

The land surface remote sensing data are at a much finer resolution than the scales of the NWP models.  This project will use high resolution research grade WRF with a multilayer urban canopy model to generate target surface flux fields and UHI and precipitation fields for a range of conditions at each of the UIFL study regions. Once validated, these fields will form the targets to train a model to identify effective LCLU parameters for the coarse operational NWP models (NAM) and for learning a hybrid physics - machine learning supplement to the land surface model to capture the subgrid scale effects.

The outcome will be an optimal representation of the evolving LCLU information of urban regions in the NASA's Land-Earth System Digital Twins (L-ESDT) effort. The impacts of this work will be directly felt in in two important societal areas: 1) use of land digital twin for urban design scenario analysis to explore the mitigative value of alternative zoning regulations, potential new regulations for building energy efficiency, and proposed green infrastructure retrofits; and 2) improved operational NWP forecasts will drive the model predictive control logic of smart infrastructure systems to realize a significant improvement in urban resilience.

---

**Guofeng Cao/University of Colorado, Boulder**
**Understanding the Effects of Agricultural Land Use Transformations on Weather Dynamics in Southern High Plains**
**24-LCLUC24_2-0004**

The Southern High Plains (SHP), a critical region for agriculture and energy production in the U.S., is grappling with several climate-related challenges that pose significant risks to its sustainability and viability. These challenges are multifaceted, most prominently including the depletion of the primary agricultural water source (Ogallala aquifer), a warm and dry climate trend with an increasing frequency of extreme weather events (as exemplified by the recent Smokehouse Creek Fire in the Texas Panhandle), and the transition towards renewable energy. Various adaption strategies have been investigated to cope with these challenges while sustaining the productivity, including transitioning to less water-intensive crops and farming practices, and integrating wind energy infrastructure. All of the strategies require significant shifts in land use patterns that can further propagate in atmospheric dynamics. The discussions on these adaptation strategies have primarily centered on economic viability, often overlooking the potential effects on weather dynamics that in turn can have profound impact on sustainability. Understanding the nexus between agricultural land use, weather dynamics and economic productivity in the face of climate change and water scarcity is crucial for developing sustainable adaption strategies in the SHP region.

In this project, we aim to address the complex nexus in the SHP region through an Earth System Digital Twin (ESDT) approach by incorporating continuous agricultural land use and land cover (LULC) dynamics captured by time series of satellite imagery, geospatial artificial intelligence (GeoAI) and advanced land surface and weather models. Our goals are threefold: (1) to delineate the pathways through which agricultural LULC influences atmospheric dynamics and the subsequent outcome for extreme weather risks and agricultural and wind energy productivity; (2) to enhance the accuracy of regional weather forecasting through the integration of novel and high-resolution agricultural LULC datasets and refined parameterization for common and emerging crops in the area; and (3) to enable ESDT-based, uncertainty-aware, comprehensive assessments under various hypothetical land use scenarios, thereby contributing to the development of sustainable land use management and adaptation strategies.

To achieve the research goals, we first aim to create an agricultural land digital replica of the SHP region through an analysis integrating Landsat, MODIS, Sentinel and high-resolution satellite products, field observations and advanced GeoAI algorithms. The digital replica will characterize the long-term agricultural LULC dynamics, which will include annual 2000-2024 crop type maps, crop phenology maps, and crop-specific green vegetation cover within each growing season, altogether characterizing the life cycles of crops, from planting to harvesting. Second, we will inform the widely used Noah-MP land surface model with timely LULC dynamics to account for associated land-atmosphere interactions in high-resolution weather simulations (1-4 km) from the Weather and Researching and Forecasting modeling system (WRF), which relies on Noah-MP for the land component. WRF simulations will be calibrated using historical records and in-situ measurements. Third, we will integrate the land digital replica and the improved weather models with related datasets into an ESDT prototype. The prototype will enable a comprehensive diagnosis of the causal effects of agricultural LULC changes on weather dynamics. We will develop an uncertainty-aware GeoAI framework to integrate heterogeneous datasets to assess the implications on regional sustainability, with a focus on extreme weather risks, crop production and wind energy potential. With an interactive interface, the prototype will allow stakeholders to engage in an uncertainty-aware analysis of agricultural LULC scenarios to support sustainable land management and planning.

---

**Louise Chini/University of Maryland, College Park**
**Harmonizing Global Land-Use Datasets with Remote-Sensing Observations of Forest-Based Land-Use Changes**

**24-LCLUC24_2-0018**

Land-Cover and Land-Use Change (LCLUC) plays a critical role in driving climate change through both biogeophysical and biogeochemical changes. To advance the ability of Earth System Models (ESMs) to account for the effects of LCLUC, and to contribute to building a "Land-Earth System Digital Twin", it is essential that land-use datasets be improved by increasing their spatial resolution and incorporating the latest novel observations from remote sensing data. The current paradigm for representing land system changes in ESMs is to provide reconstructed and/or projected land-use to the models, where they are then converted into associated land-cover changes. However, with development of the next generation of regionally-refined and kilometer-scale climate models underway, and with a wealth of high resolution remote sensing data of land-cover changes available, there is an opportunity to incorporate these land cover changes directly in models simulating higher-resolution climate over recent decades. In addition, by incorporating these observations into existing land-use datasets as well (such as the Land-Use Harmonization dataset), we can explore the impact that conversions between land use and land cover have on the climate response of ESMs. This is especially important for forest-based changes in the Amazon where deforestation, wood harvesting, shifting cultivation, and reforestation/afforestation are often large and are known to have significant impacts on the local climate. Therefore, to investigate the effects of forest change on the near-surface climate of the Amazon and the impact of high-resolution, remote-sensing-based LCLUC data for achieving a more realistic climate simulation in ESMs, we propose to (1) build a high-resolution Land Digital Twin dataset, based on NASA remote-sensing data (a combination Landsat, ICESat-2, and GEDI data) for forest cover, forest canopy height, and forest biomass changes for the Amazon region for the years 2000-2020; (2) use the Land Digital Twin dataset as an input to prescribe the land surface in a high-resolution, regionally-refined version of CESM, both directly via land cover inputs and via an existing land-use dataset; and (3) validate and evaluate the climate response of CESM to these improved land cover changes over the Amazon region for the years 2000-2020.

---

**Chengbin Deng/University of Oklahoma, Norman**
**Digital Twins Empowered Mesoscale Urban Climate Modeling: Enhancing Dynamic Land Cover and Land Use Representation in WRF Model with Multidimensional Remote Sensing**
**24-LCLUC24_2-0031**

Physics-based urban climate models are essential tools that enable us to understand and predict urban hydrometeorological and climatic conditions, which have become increasingly important with global urbanization. Many mesoscale, regional, and global climate models have incorporated UCMs to better characterize urban climates and the effects of various climate change mitigation and adaptation strategies. Nevertheless, when modeling an entire metropolitan area, the heterogeneous characteristics of the built environment are often oversimplified, posing great challenges to the accuracy and reliability of simulations with UCMs. The street canyon representation in UCMs requires a set of descriptive parameters assigned to each urban land cover class, however, these representative urban parameters may not fully reflect the disparities within the same urban land cover class, as used in the current model. Besides, although the urban land cover and land use (LCLU) evolves both spatially and temporally, most current urban climate simulations use static LCLU data as the boundary conditions. This is partially due to data availability, especially the Global South cities. This lack of dynamic information will likely lead to substantial uncertainties for long-term simulations in urban areas. Furthermore, even with the same set of input data, the derived representative urban parameters can vary at different resolutions. However, the sensitivity of urban climate models to these urban parameters, in particular their performance in long-term simulations across various scales, remains unclear.

The overarching goal of this project is to leverage extensive EO data as dynamic boundary conditions to improve the performance of urban climate modeling, and accordingly, to better understand model sensitivity to different LCLU parameters across scales. Three specific objectives include: (1) Enhance dynamic LCLU representation for numerical models using multidimensional remotely sensed data; (2) Improve urban climate model performance with dynamic LCLU data across different spatial scales. Specifically, we will use the WRF model coupled with a single-layer UCM for long-term urban climate modeling. (3) Objective 3: Build an interactive web-based digital twin (DT) platform to allow interaction with users, and to deliver data based on users' preferences (e.g., output resolution and time span).

The most prominent innovation of our project is that a higher level of dynamic urban land parameters is extracted and updated than what is currently used in most urban climate models. By leveraging the rich information from multi-source and multi-source remote sensing data, we can capture the fine-scale details of building geometry (building height, building roof width, and road width), vegetation cover (LAI), and surface properties (albedo), which can significantly impact the accuracy of urban climate simulations. By enhancing urban canopy representation, parameterization of urban processes, and multimodal EO data processing, the proposed work would enhance the accuracy and reliability of urban climate model simulations. This improvement would lead to more precise predictions of urban temperature, air quality, and other environmental variables, aiding decision-makers in addressing climate-related risks and vulnerabilities in cities. Further, this proposed work will enable researchers to explore climate change impacts and adaptation strategies in urban areas, and accordingly, support efforts to enhance urban resilience and adaptation to climate change. Researchers can use this DT platform to test hypotheses, validate models, and share their findings with the community. Practitioners can apply the insights and findings from researchers to practical applications, bridging the gap between science and practice. This collaborative environment supported by this DT platform can accelerate innovation and the development of new solutions to urban climate challenges.

---

**Andrea Gaughan/University of Louisville**

**Advancing Land Cover/Land Use Characteristics in Short-Range Numerical Weather Prediction Systems for Urban Areas**
**24-LCLUC24_2-0030**

The proposed work will advance the estimation of land use characteristics from remotely sensed data and how they are incorporated into short-range numerical weather prediction systems for urban environments and their surroundings. In addressing sub-elements of the A.2 Land Cover/Land Use Change (LCLUC) call focused specifically on land use data and boundary elements of models and sub-models of Land-Earth System Digital Twins, we intend to accomplish four specific sub-objectives: 1) Incorporate multi-sensor, -seasonal, and -resolution satellite imagery to create land cover and parameter datasets appropriate for uses in large eddy simulation (LES), numerical weather prediction models; 2) Perform simulations within a primary study area of Louisville, KY using LES to determine appropriate spatial aggregations of remotely-sensed data into the lower boundary conditions and determine model sensitivity to these different data; 3) Compare simulations to in situ field reference data values captured by a micronet of meteorological stations; and 4) Use simulations to study urban-heat-island mitigation efforts in the downtown urban study area and use these simulations to test how future interventions might function in this and other urban contexts. Methodologically, we will construct multi-resolution collections of remotely-sensed data, from a variety of platforms, suitable for estimating fractional, sub-pixel coverage estimates for multiple aggregations of land use/cover using machine learning for classification and modeling. These data will enter into boundary layer components of numerical weather simulation models, from which historical weather simulations will be constructed and compared with past and current data collected from a variety of ground-based sources. The veracity of the simulations will be tested against a modernized network of meteorological sensors distributed across the project domain. The proposed modernization of the network will consist of updates to 20 existing micronet stations, including aspirated radiation shields and cellular data transmission to prioritize the accurate representation and real-time collection of air temperature. In addition to modernizing the existing stations, ten easily deployable all-in-one weather sensors will be added to the micronet. These stations will be reserved for poorly sampled areas within the domain or local climate zones (LCZs) with low representation. While this experimental design will primarily support the validation of the LES model, it will also serve a wide range of projects aimed at understanding the influence of the urban landscape on the planetary boundary layer. Together, these methods and objectives situate the research as extremely responsive to the current LCLUC call for providing new ways to incorporate remotely sensed data into sub-elements of Land-Earth System Digital Twins (L-ESDTs), specifically focused on weather generating mechanisms and boundary layer interfaces, a highlighted NASA Advanced Information Systems Technology (AIST) Program Use Case. While we use Louisville, KY as a case study for sensitivity and validation, these methods and applications will be directly relevant to models for urban environments across developed contexts and scales.

---

**Cenlin He/University Corporation For Atmospheric Research**

**Quantifying Impacts of Agricultural Land Use and Irrigation Practice on High-Resolution Regional Weather Prediction**
**24-LCLUC24_2-0012**

The US Corn Belt is one of the most important food baskets in the world where agricultural management practices have substantially altered the landscape and regional weather and climate through land-atmosphere interactions. Evidence showed that the expansion and intensification of croplands and irrigation practices in this area have resulted in notable changes in regional weather patterns (e.g., temperature cooling and precipitation increase). However, the intricate interplay among crop dynamics, irrigation, groundwater, and the atmosphere in this region and associated impacts on short-term weather prediction have not been fully understood or quantified particularly at high-resolution. Moreover, current weather prediction models suffer from errors caused by inaccurate, static, outdated, and/or coarse resolution input data of agricultural land use and irrigation activities, as well as the lack of model representation of crop and irrigation dynamics during prediction periods. Our proposal team members have recently developed a series of machine learning (ML) based techniques to create field-scale accurate historical and in-season crop and irrigation maps based on satellite observations. This provides a promising opportunity and foundation for this proposed project to enhance agricultural land use and irrigation input maps for weather prediction models based on NASA satellite data.

This project aims to leverage a suite of remote sensing data and ML techniques to develop a suite of dynamic high-resolution annual crop and irrigation data over the continental US (CONUS) during 2000-present and incorporate them into the state-of-the-art community WRF/NoahMP-Crop model to improve convection-permitting weather prediction and the knowledge of agriculture-weather interactions. We will use the US Corn Belt as a testbed and address two science questions:

- Could we improve weather prediction by developing and implementing dynamic high-resolution annual crop and irrigation maps in WRF?
- What are the key factors and mechanisms controlling agricultural impacts on weather prediction and associated uncertainties, particularly for extreme events?

Accordingly, we will conduct three tasks:
Task 1. We will replace the current static and outdated crop and irrigation input maps in WRF by developing a suite of annual maps (2000-present) for field-scale (30-m) historical and in-season crop types with rotation patterns, state-level crop planting and harvesting dates, and 4-km crop growing degree days (GDDs), as well as 5-yearly field-scale (30-m) irrigation area maps.
Task 2. We will implement the new data (Task 1) into the widely-used community WRF/NoahMP-Crop model to conduct short-term (1~7 days) convection-permitting (4-km) numerical weather predictions/hindcasts and detailed model evaluation over the US Corn Belt during major crop seasons (May-September) for representative years (e.g., wet, dry, normal years).
Task 3. We will conduct a series of model sensitivity simulations to quantify key factors in affecting weather prediction, associated mechanisms, and uncertainty, during both

non-extreme and extreme conditions (i.e., extreme precipitation, heat waves, and droughts).

---

**Atul Jain/University of Illinois, Urbana-Champaign**
**Advancing Understanding of Land Cover and Land Use Changes and Management Impacts on Land-Surface Biophysical Variables and Climate in South and Southeast Asia (SSEA)**
**24-LCLUC24_2-0034**

Over the past four decades (1980-present), South and South East Asia (SSEA) have witnessed rapid changes in land cover and land use (LCLUC) due to factors such as population growth, the green revolution, industrialization, and deforestation. These changes in land use have significant impacts on climate, particularly through alterations in continental energy and water surface budgets. While the biogeophysical (BGP) effects of LCLUC have garnered increased attention at regional and global levels in recent decades, their precise implications remain uncertain, influenced by various factors. These include the spatial distribution of land covers, the scale of perturbation (e.g., conversion from forest to agricultural land and vice versa), and the geographical location (e.g., tropics, temperate, or boreal regions).

The primary objective of this research is to employ WRF_ISAM, a process-based regional-scale weather forecasting model, to assess the relative impacts of LCLUC, meteorological/climate datasets, and model parameters on various BGP variables. Specifically, our investigation will center on changes in the surface energy balance (SEB) during boreal summer (JJA) and winter (DJF), alterations in surface albedo (SAL), latent heat (LH) flux, sensible heat flux (SH), surface temperature (Ts), and total runoff from the surface and subsurface flows (Runoff). These variables are crucial for understanding the radiative and non-radiative impacts of LCLUC.

The model will be driven by three distinct sets of Land Cover and Land Use Change (LCLUC) data: Landsat, CCI, and LUH2. Additionally, it will utilize three different sets of reanalysis data, including NASA's MERRA-2, ECMWF's ERA5, and NCEP/NCAR reanalysis datasets. To address uncertainties arising from model parameters, our study will focus on three sets of parameters that are not adequately constrained by observational datasets: surface albedo, water table depth, subsurface runoff, and Roughness length.

Through a series of 63 model experiments spanning the years 2016-2018, we will decompose the individual components of uncertainty, including LCLUCs, reanalysis inputs, and model parameters.

The proposed study aims to identify future research priorities to enhance the quality of the data products and model performance, with the overarching goal of advancing the development of Land Digital Twins. This initiative will contribute to creating comprehensive digital representations of land systems to facilitate better understanding and management of environmental processes and phenomena.

---

**Matthew Johnson/NASA Ames Research Center**
**Improving Numerical Weather Forecasts with More Representative Land Surface Modeling: Implementation of Updated Satellite-Derived Land Cover and Land Use Change Maps**
**24-LCLUC24_2-0037**

This project will evaluate the: a) compounding impacts of different landscape transformation processes driving land cover land use change (LCLUC) on local- to regional-scale meteorology and b) improvements in numerical weather forecast model accuracy when driven with more representative LCLU information derived from satellites. We will focus on three major anthropogenic and natural landscape transformation processes: 1) urban expansion, 2) agriculture and irrigation, and 3) wildfire and timber harvesting. Recent research has demonstrated that implementing satellite-derived, high spatiotemporal LCLU data into numerical weather forecast systems such as the Weather Research and Forecasting (WRF) model, replacing outdated and coarser spatial scale data sets, results in improved meteorological forecast skill. We hypothesize that lessons learned from more robust testing of numerical weather model forecasting skill when applying multiple high spatiotemporal resolution, satellite-derived maps of LCLU will create new knowledge necessary for developing NASA's Land-Earth System Digital Twin (L-ESDT). The improved representation of LCLU, and methods of how to quantify the impacts of LCLUC on meteorology, gained from this project can be applied in the L-ESDT development which will aid users in various applications and decision-making processes which have societal implications, such as the impact of LCLU on local- to regional-scale weather/climate (e.g., urban heat effects, humidity levels, precipitation perturbations).

Nearly 30% of LCLU and land surface characteristics in the contiguous United States (CONUS) have been altered by anthropogenic activities largely from resource production (e.g., cropland, timber production and harvesting), built-up urban areas, irrigation, and lands used for recreation. Furthermore, wildland fires over the last few decades have significantly impacted land cover characteristics throughout the CONUS. LCLU, and associated short- and long-term changes, have direct impact on local- to regional-scale meteorology. However, the impacts of LCLU on weather and short-term climate are challenging to assess given there is no tool available which is specifically designed to test the impact of different LCLUC processes on weather. The L-ESDT being developed by NASA would be such a tool. A primary goal of this project is to demonstrate the increased accuracy of numerical weather forecasts when supplementing coarse spatial scale and outdated LCLU information currently used in numerical weather forecast models such as WRF with updated and improved satellite-derived maps. This will provide critical information for the development of NASA's L-ESDT in regard to what LCLU maps are applied in the system and the ability for users to test the impact of LCLUC on meteorology. The project will apply numerous LCLU data products from satellites (e.g., Landsat, MODIS, VIIRS, SMAP, Sentinel-1, GEDI) in high spatial resolution (1 km × 1 km) WRF simulations to demonstrate the best methods for: 1) improving forecast skill when using specific LCLU maps and 2) applying time series of LCLU maps, and altered states of these LCLU variables, for users of the L-ESDT to quantify the impact of LCLUC on weather and short-term climate.

This proposal is responsive to the ROSES-24 A.2 Land Cover Land Use Change solicitation and will provide critical information for the development of NASA's L-ESDT. This proposal will also address some of the Most Important Science and Applications Questions and Objectives in the Decadal Survey 2017-2027 and NASA's Earth Science Plan 2020-2024. The proposal team is interdisciplinary and has extensive experience in numerical weather modeling, satellite-derived LCLU data products, and the implementation of high spatial resolution LCLU maps in numerical weather models to improve forecast skill.

---

**Toshihisa Matsui/University of Maryland, College Park**
**Earth System Digital Twin Development of NASA's Unified WRF for Assessing the Impact of Land-Cover and Land-Use Changes on Regional Weather**
**24-LCLUC24_2-0015**

Land Cover and Land Use Change (LCLUC) has profoundly affected large parts of the Earth's surface, driven by the need to provide food, fiber, water, and shelter for human civilization. Agricultural expansion and intensification are the primary drivers, impacting billions of hectares worldwide. Cropland now covers nearly 11% of the total land area, while urban areas occupy less than 5%. Other contributors to LCLUC include irrigated areas and wildfires, which rapidly convert forests to agriculture or shrubland. These changes are not uniformly distributed, leading to significant regional landscape perturbations. LCLUC influences weather and climate through alterations in surface albedo, heat fluxes, and temperatures, affecting the planetary boundary layer, local wind circulation, and broader meteorological patterns. The feedback between LCLUC and the atmosphere is complex and varies with surface flux changes and synoptic weather conditions.

This project aims to develop a cloud-based Land Earth System Digital Twin (L-ESDT) through Google Earth Engine (GEE) and NASA's Science Managed Cloud Environment (SMCE). GEE will facilitate the identification, processing, and transfer of LCLUC data, while SMCE will utilize the NASA Unified Weather Research and Forecasting (NU-WRF) model and Machine Learning (ML) and Artificial Intelligence (AI) to assess the impact of LCLUC on regional weather. The goal is to create an agile, generalized L-ESDT applicable globally where satellite remote sensing is available, focusing on specific regions. Existing LCLUC satellite datasets will be utilized through the GEE cloud system to assess the impact on regional weather using the NU-WRF and AI/ML platforms within NASA SMCE. This cloud platform will allow various stakeholders to utilize a high-end ESDT with minimal computational resources and knowledge.

The project aligns with LCLUC objectives by leveraging AI/ML, Big Data Analytics, and cloud computing for L-ESDT development. It will combine real-time LCLUC and biophysical data analysis within GEE with regional Earth-system model simulations and innovative AI/ML change-detection methods within SMCE. Concurrent visualization of L-ESDT flows will enable users to conduct impact assessments without significant computational resources. The project will provide near real-time, high-resolution mapping of LCLUC and biogeophysical data for regional weather forecasting. This platform will enable stakeholders to explore scenarios, test hypotheses, and simulate outcomes without requiring significant computational resources. The proposed cloud-based L-ESDT will enhance our ability to monitor and manage land cover changes, contributing to improved environmental and socio-economic outcomes.

---

**Mutlu Ozdogan/University of Wisconsin, Madison**
**A Multi-City Digital Twin Study of the Role of Green Infrastructure in Coupled Land-Atmosphere Prediction**
**24-LCLUC24_2-0014**

Urban green spaces are areas of land that are covered with vegetation, including parks, gardens, and other natural areas. These spaces are essential for the health of urban environments, as they provide a range of benefits to both the environment and public health including reducing pollution, regulating temperature, and providing habitats for wildlife, among other benefits. What is less known however, is the influence these green spaces have on environmental energy and water flows that affect urban hydrology and climate. To fill this gap, we propose a multi-city digital twin study of the role of green infrastructure in coupled land-atmosphere prediction. Our proposal has three objectives. First, we plan to document recent and future changes in green infrastructure in select urban areas (Baltimore, Chicago, Houston, and Phoenix as part of the DOE intensive study) using medium- and high resolution satellite observations with the help of deep learning algorithms. Our goal here is to both map highly detailed urban elements such as trees, paved areas, buildings, turf and natural grasses, and to develop biophysical variables such as leaf area index, albedo, emissivity, building heights, and roughness lengths associated with these land use components as inputs to our modeling effort. Second, we will develop a new land model capable of representing green infrastructure at the scale of an entire city. The model will be based on the widely utilized Noah-MP land surface model and integrates previously overlooked surface hydrological processes that are common in urban hydrology. This Noah-MP for Heterogeneous Urban Environments (HUE) includes impervious area-to-vegetation water transfers (e.g., disconnected downspouts) and tree canopy overhanging pavement. HUE also includes more management centric solutions that are common in urban green infrastructure and will allow us to conduct a more realistic hydrologic treatment of urban areas, resolve urban vegetation process like pavement shading and canopy interception, allow for urban energy partitioning that is more representative of real world urban environments, and conduct a realistic coupling between surface and atmospheric conditions within urban regions. HUE is currently coupled with the Weather Research and Forecasting (WRF) model, making it possible to quantify the effects that adaptation policies surrounding urban vegetation and green infrastructure have on the fine-scale urban climate and hydrology for the first time. Finally, we will explore Impacts of urban green spaces on the coupled land-atmosphere system using detailed depictions of land use elements and their biophysical/structural attributes derived from remote sensing and the newly developed Noah-MP HUE coupled with WRF with detailed treatments of urban land use. The proposed work contributes directly to NASA's goal of studying Earth from space to advance scientific understanding and for societal benefits, and NASA's objectives of quantifying global land cover change. It also contributes to NASA's AIST program in developing Earth System Digital Twins (ESDTs) by advancing the incorporation of land-use information in numerical weather forecasting and climate models that contribute in the development of the Land-Earth System Digital Twin (L-ESDT). By providing more realistic representations of urban areas undergoing green transformation, our proposed work will have the potential to offer a digital replica (also known as a digital twin) to monitor and simulate land-atmosphere interactions in urban environments with unprecedented spatio-temporal resolution. We will accomplish this goal by making 1) significant advances in translating Earth observations into land use components; and 2) significant advances in modeling a comprehensive set of processes that are at the heart of improving our understanding of regionalized weather, hydrology, and climate change, as well as advancing forecasting skills.

---

**Nicholas Parazoo/Jet Propulsion Laboratory**
**Land Cover and Land Use Feedbacks to Development of Flash Drought**
**24-LCLUC24_2-0029**

Flash droughts have been responsible for some of the most damaging droughts in the U.S. in the past two decades. The rapid emergence and onset of land drying and vegetation stress associated with flash drought is difficult to predict and monitor, and often results in significant damage to natural and managed vegetation, which has direct and immediate impacts to natural resources, food supplies, and the economy. Recent observational and modeling evidence indicates a stronger than expected influence of vegetation-atmosphere feedbacks on the development and amplification of flash drought, however the role of land cover and land use practices such as irrigation on flash drought severity have not been fully investigated and remain poorly understood.

We propose a direct insertion of land cover type and irrigation data in Digital Twin numerical experiments to determine the impact of land cover and land use (LCLU) on vegetation-atmosphere feedbacks and flash drought development in the U.S. Great Plains. We will apply the NASA Unified Weather Research and Forecasting (NU-WRF) coupled regional model to simulate land-atmosphere feedbacks and conduct sensitivity experiments to determine the impact of land cover type, irrigation fraction, irrigation strategy, and initial conditions on the onset and amplification of flash drought. We will also apply random forest modeling with Shapley Additive exPlanations (SHAP) to rank the primary sources of drought predictability, providing quantitative insight on vegetation vs atmospheric mechanisms. We target a subset of flash drought case studies, including the 2011, 2012, and 2017 events in U.S. Great Plains. We will design our prototype Land

Digital Twin to examine a range of scenarios for exploring land use impacts on short range weather conditions (atmospheric temperature, aridity, boundary layer growth, cloud development, and precipitation) and flash drought development. The proposed effort builds on recent work by the PI and Co-I by providing a more detailed examination of LCLU feedbacks to drought. Ultimately, we aim to better inform decision-making under forecasted drought by improving society drought preparedness through changes in land management strategies.

Our main objectives are to (1) Develop a prototype land digital twin for LCLU impacts on flash drought, (2) Perform and evaluate LCLU sensitivity experiments, and (3) Identify dominant atmospheric and LCLU flash drought drivers across different case studies and irrigation scenarios.

This project will determine LCLU impacts on short-range and sub-seasonal weather using direct insertion of land cover data from NASA (MODIS) and irrigation data from the Food and Agriculture Organization of the United Nations and a NASA coupled weather model (NU-WRF). As such, our project addresses the Weather element of the Land Use for Digital Twins (LU4DT) Sub-Element: Incorporation of land-use datasets as boundary conditions in regional short-range weather forecast models and evaluation of the impact on the quality of forecasts.

---

**Xiaojing Tang/James Madison University**
**Improving Urban Climate Simulation by Integrating Remotely Sensed High-Resolution Albedo into the Weather Research and Forecasting (WRF) Model**
**24-LCLUC24_2-0027**

With more than 50% of the global population living in cities and the continued urbanization trends, urban areas represent critical hotspots of water, energy, and health challenges facing humanity in the 21st century. A better understanding and prediction of urban microclimate and hydrology within the context of global environmental change plays a key role in tackling these challenges. Although correctly characterizing the albedo of building materials is identified as the most important factor to improve urban simulation results, most urban land surface models used in weather and climate models (e.g., the single-layer urban canopy model in the Weather Research and Forecasting or WRF model) still employ tabulated albedo values, which have extremely limited spatial variability. We propose to improve urban albedo characterization in weather models using remote sensing data. Specifically, we will (1) develop a new, high-resolution urban albedo dataset based on Landsat and Sentinel-2, (2) separate roof from impervious ground in the NLCD impervious surface dataset, (3) conduct and analyze WRF simulations with the new urban albedo dataset, and (4) implement the new albedo dataset into publicly released WRF versions. The proposed research will improve the characterization of the albedo parameters in WRF, improve the simulation of urban meteorological variables at the weather scale, and thus empower stakeholders and researchers to better navigate urban planning and policies in a changing climate.

**Lei Zhao/University of Illinois, Urbana-Champaign**
**Spatiotemporally Explicit Urban Surface Constraints and Their Uncertainties for Earth System Modeling**
**24-LCLUC24_2-0016**

Climate change coupled with urbanization represents the biggest challenge of our generation, nationally and globally. To address this key Global Grand Challenge, it is urgent to better understand urban land cover land use change, its impacts on cities across the globe, and its interactions with climate systems across scales. Cities do not necessarily have to be a problem, but rather, should be a key to solutions, with the ability to shield urban residents from broader scale climate change. Realizing this goal, however, requires advanced data and tools, both to better understand urbanization and their impacts and for planning effective climate adaptation and mitigation strategies. Such tools, however, are largely lagging behind due to three critical barriers: (i) missing global high-resolution urban surface constraints for Earth system modeling, (ii) inability to simulate dynamic urban land change in state-of-the-art Earth system models (ESMs), and (iii) limited high-resolution modeling capabilities over urban landscapes in advanced ESMs and Earth System Digital Twins (ESDTs). Here we propose to leverage a suite of satellite observations and satellite-derived products to represent spatiotemporally continuous biophysical properties of urban areas in Earth system models to advance high-resolution urban modeling capabilities at large scales. The specific objectives of the proposed project are: (i) to advance spatiotemporally explicit urban representation in ESMs by providing multiple realizations of high-resolution (~1 km) urban land surface datasets as boundary conditions, and (ii) to develop km-scale climate modeling capability of urban land cover land use change (LCLUC). To achieve these objectives, we design a cohesive workflow to develop the first-of-its-kind km-scale transient urban land surface datasets leveraging remote sensing products and machine learning techniques, and to model the climatic impacts of urbanization across scales with assessment of the associated robustness and uncertainties, primarily focused on the Community Earth System Model and the Energy Exascale Earth System Model. We will focus on the inclusion of various geospatial and satellite-derived data sources to develop multiple realizations of these urban surface constraints. This will generate a range of historical urban climate simulations and provide statistically robust estimates, which is critical for complex non-linear systems.

Rapid urban development in the future will subject urban areas and their residents to substantial climate risks, but also presents a historic and time-sensitive opportunity to mitigate the negative impacts of climate change and urban growth. The proposed work is both broadly significant and timely -- occurring at the confluence of two of the most dominant forces shaping the globe today, urbanization and climate change. The proposed research is closely relevant to the NASA LCLUC Program and directly addresses the sub-element 1 Land Use for Digital Twins (LU4DT) of the solicitation, specifically the Type 2 proposal of this sub-element -- "incorporation of land-use datasets as boundary conditions as a function of time, e.g. on an annual basis, in multiannual climate model runs for the last decade or longer and comparison of the hindcast results with the observed climate variables". Outcomes of this work will be essential to accurately resolve urban climate impacts in ESMs. Datasets created from this project will all be publicly released and promote high-resolution (km-scale) Earth system modeling. Additionally, with the incorporation of more human systems within ESMs through representation of urban areas, this will lead to the development of complete Land-Earth System Digital Twins. The results and insights derived from the proposed work would contribute to advance the fundamental understanding of how large-scale climate variability and change coupled with urbanization affects the urban environments across scales.

---