NASA Earth System Digital Twins (ESDT) Prototypes

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Earth System Digital Twins:

Earth System Digital Twins (ESDTs) are information systems for understanding, forecasting, and conjecturing the complex interconnections among Earth systems, including anthropomorphic forcings and impacts to humanity.

An ESDT includes …

- Continuous observations of interacting Earth systems and human systems from many disparate sources driving inter-connected models at many physical/temporal scales
- Fast, powerful and integrated prediction, analysis and visualization capabilities using Machine Learning, causality and uncertainty quantification
- Models running at scale in order to improve our science understanding of those systems, their interactions and their applications
- An Information System Framework with several users' dynamic and interactive interfaces.

What now?
Digital Replica . . .
An integrated picture of the past and current states of Earth systems.

What next?
Forecasting . . .
An integrated picture of how Earth systems will evolve in the future from the current state.

What if?
Impact Assessment . . .
An integrated picture of how Earth systems could evolve under different hypothetical what-if scenarios.

ESDT Drivers

- Fully utilize wealth of Earth Science data as well as data from policy and impact sectors
- Improve spatial and temporal resolution of Earth Science models, e.g., using Machine Learning (ML) with Physics-based models
- Provide easy-to-access and interactive actionable information to traditional and non-traditional users, and support decision-making

Prototypes to:

- **Identify & Develop ESDT "Building Blocks"**
- **Address Overarching Questions**

- How will various data, models, ESDTs be accessed/interoperate/be federated?
- Which basic interfaces, standards, and protocols will be required? At syntactic, semantic, legal and organizational levels?
- How to facilitate quick, automated and seamless access to data and data products?
- Which computational resources will be required? Cloud, GPU's, Quantum, Neuromorphic, edge computing, etc.?
- How will continuous data be integrated? How often should digital replica be refreshed?
- Which user interfaces will be needed? UI/UX, impact assessment, decision support, visualization?
- How will ESDTs be validated (e.g., using historical data, etc.)? How will ESDTs' performance be measured? To which level of fidelity do they represent the current, future and hypothetical states of Earth systems? How to quantify uncertainty?
- Which sustainable digital twin governance model should be adopted to address software configuration changes, security and full life cycle management?

IDEAS/FloodDAM DT for Flood Prediction & Monitoring – PI's: Huang (NASA JPL) & Rodriguez-Suquet (CNES)

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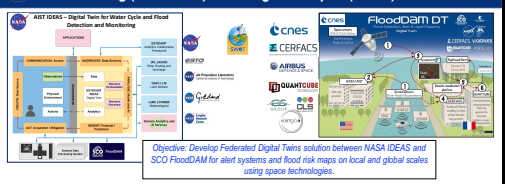

Objective: Develop Federated Digital Twins solution between NASA IDEAS and SCO FloodDAM for alert systems and flood risk maps on local and global scales using space technologies.

- Advanced numerical models and analysis
  - NASA: JPL's RAPID, GSFC's LIS , LaRC's POWER, IPCC Sea Level Prediction coastal flooding data
  - Joint CNES and SCO's FloodDAM: Automated service to reliably detect, monitor and assess flood events globally
  - Joint JPL – CNES: Flood detection and prediction ML algorithms
- Data from: GPM, SMAP, MODIS, Landsat-8, Sentinel-1&2, HLS, SWOT, OPERA, USGS in-situ gauges, VorteX.io from the Garonne river and SEDAC socio-economic data
- **Improve** ML flood prediction model from the JPL-CNES Joint Data Science pilot
- **Scenario-based prediction** for infrastructure & population impacts

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Digital Twin Infrastructure Model for Agricultural Applications – Bindlish (NASA GSFC)

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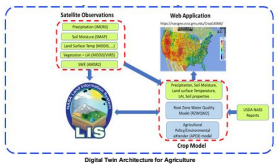
This project proposes the development of a Digital Twin Agriculture prototype by integrating land/hydrology process models, agricultural models, and remote sensing information. The development of the agricultural digital twin infrastructure will allow us to assess the socio -economic impact from naturally occurring and human activities on agriculture and food security.

- Establish a digital twin framework that enables the NASA remote sensing data products and land surface model products to be directly coupled with or assimilated into the crop growth model
- Assimilate high-resolution remote sensing inputs (e.g., precipitation, temperature, soil moisture, etc.) through the NASA Land Information System (LIS) to estimate land surface variables (water and energy fluxes) at daily time scales
- Implement crop growth models, Root Zone Water Quality Model and Decision Support System for Agrotechnology Transfer to estimate crop growth states, biomass, and crop yield under long-term weather conditions and projected future climate scenarios
- Implement Bayesian Neural Network (BNN) model to predict final county level crop yield
- Develop tools to conduct 'what if' investigations to provide agricultural guidance
- Develop capability for disseminating non-confidential crop progress data, biomass and crop yield maps using an operational web application



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Predicting What We Breathe; Digital Twin for Air Quality and Transportation – PI: Holm (City of Los Angeles)

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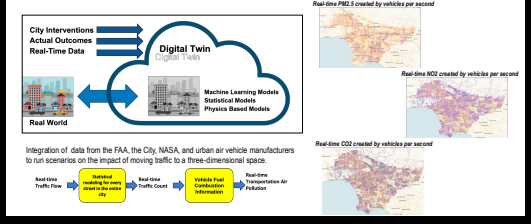
This project will develop a prototype digital twin including AI models, data analytics and ML algorithms, statistical models, and data visualization to replicate the real-world system and its behavior, and to understand and predict urban air pollution.



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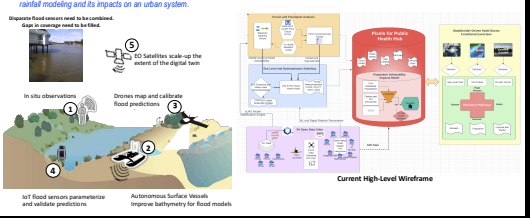
Pixels-for-Public-Health: Analytic Collaborative Framework and Digital Twin to Enhance Coastal Resiliency of Vulnerable Populations in Hampton Roads, Virginia – PI: Allen (Old Dominion University)

IST

This project will integrate multi-source, high-velocity data: Earth Observations(Virginia Open Data Cube), hydrodynamic models, and sensor networks to predict human health impacts of coastal flooding. It will prototype a coastal Digital Twin that integrates sea-level change, hydrodynamics, and extreme rainfall modeling and its impacts on an urban system.



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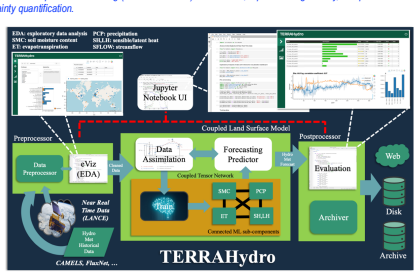
Building AI-based Earth Systems Models and the TERRAHydro Terrestrial Digital Twin – PI: Pelissier (SSAI)

IST

This project will develop a coupled water, energy, and vegetation ESDT (TERRAHydro) using tensor-based modeling that leverages the speed and accuracy of ML inference to provide unprecedented capabilities including (but not limited to) assimilation, rapid-reconfigurability, comprehensive scenario and What-if Analyses, and uncertainty quantification.

- Couples the current state-of-the-art hydrometeorological ML Tensor Network models using 3 coupling strategies (direct coupling, shared model structure, and PDE learning).
- Develops a modern Python-based information systems encapsulating the proposed land surface model that is open-source, cloud-ready, portable, and enables open-science.
- Assesses and demonstrates capabilities on the 2006-2010 Syrian drought and water storage changes in the Himalayan mountains.



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Coastal Zone Digital Twin (CZDT) – PI: Walter (NASA LaRC) – Collaboration with CNES and NOAA

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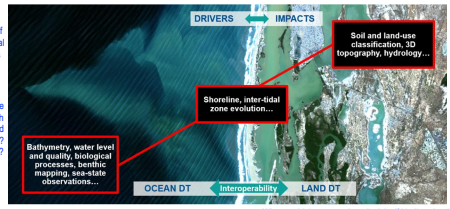
An Earth System Digital Twin of local and regional coastal zones considering both natural and human systems to understand changes in coastal flooding severity, land and marine morphology, nutrients and water quality, ecological makeup, sea level, and short and long-term risks to climate change adaptation, sustainable development, disaster management, tourism and recreation, quality of life, ecosystem management, and coastal infrastructure management.



What is the effect/impact of changing climate on coastal environment under various sea level and storminess scenarios?

What would be the economic health changes if flood risks were lowered? Increased?

What are the shifts in phytoplankton types under different natural/human forcings with improved HAB forecasting?

What would be the water quality changes under different water management structures/policies?

What are the impacts of management on blue carbon ecosystems to support climate mitigation and adaptation and improve resiliency to climate impacts?

What would be the changes in ecological makeup if cities reacted to increased flood risk?

What would the economic outlook be if biodiversity changed as a result of city or industry change?

How can we support cities to mitigation if flood risk increased?

What would be the flood risk changes if global temperature goals were met? Not met ?

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Standards for Interoperable Digital Twins 2023 Workshop at:
Presentations: https://esto.nasa.gov/files/AIST/ESDT%20Standards%202023.pdf
Video: https://www.youtube.com/watch?v=qdpL0Ui-jqc

2022 ESDT Workshop Report available at::
https://esto.nasa.gov/files/ESDT_Workshop_Report.pdf

Architecture Framework Document available at:
https://esto.nasa.gov/files/AIST/ESDT_ArchitectureFramework.pdf