NASA Earth Science Technology for Earth System Digital Twins (ESDT)

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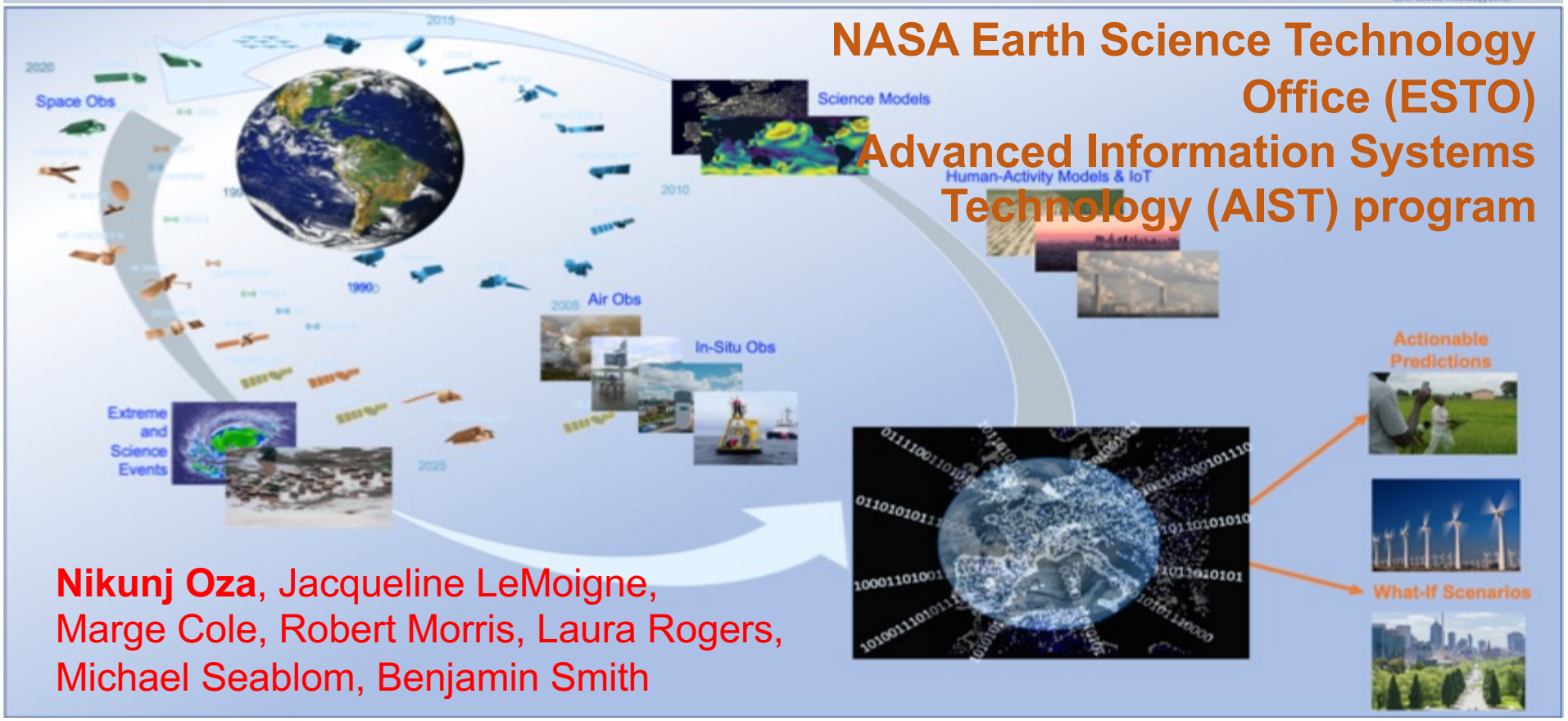
Abstract

As part of NASA's Earth Science Technology Office, the Advanced Information Systems Technology (AIST) Program defines an Earth System Digital Twin (ESDT) as an interactive and integrated multidomain, multiscale, digital replica of the state and temporal evolution of Earth systems that dynamically integrates: Relevant Earth system models and simulations Other relevant models (e.g., related to the world's infrastructure and human activity); continuous and timely (including near real time and direct readout) observations (e.g., space, air, ground, over/underwater, Internet of Things (IoT), socioeconomic) Long-time records Analytics and artificial intelligence tools. Effective ESDTs will enable users to run hypothetical or "what-if" scenarios to improve the continuous assessment and prediction of Earth system processes, natural phenomena and human activities as well as their many interactions, and to ensure optimal mitigation and response to these phenomena. Toward this goal, the AIST Program is developing individual technologies and a few pilots. Some of the technologies that are being considered include: agile interoperability between measurement acquisition and science investigations; moving from mono-discipline to multi-discipline interconnected models; digital thread developments to provide communication links to all digital twin capabilities and to enable design requirements, records, provenance, and system reconfigurations to be easily coordinated; concepts and technologies for developing "federated ESDTs"; multi-scale simulations, statistics, uncertainty quantification, and causality methodologies; high-end computing and surrogate models to optimize the computational efficiency of "what-if" investigations; and innovative user interfaces and visualization methods capable of visualizing complex systems of systems.

NASA Earth Science Technology for Earth System Digital Twins (ESDT)



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AIST Thrusts

Optimize measurement acquisition using many diverse observing capabilities, collaborating across multiple dimensions and creating a unified architecture

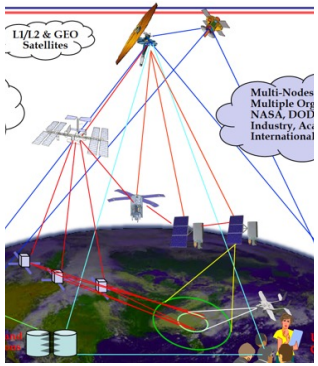
Assimilate Observations

Enhance and enable focused Science investigations by facilitating access, integration and understanding of disparate datasets using pioneering visualization and analytics tools as well as relevant computing environments

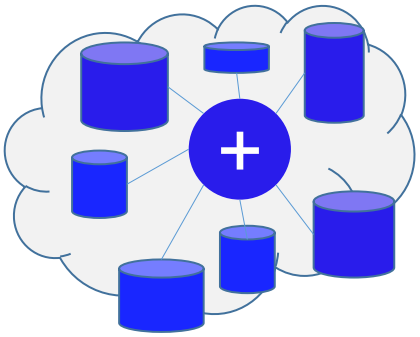
New Observing Strategies (NOS)

Acquire coordinated observations

Track dynamic and spatially distributed phenomena



Analytic Collaborative Frameworks (ACF)



Assimilate many various data into models and analytic workflows.

What additional observations are needed?

Observation Requests

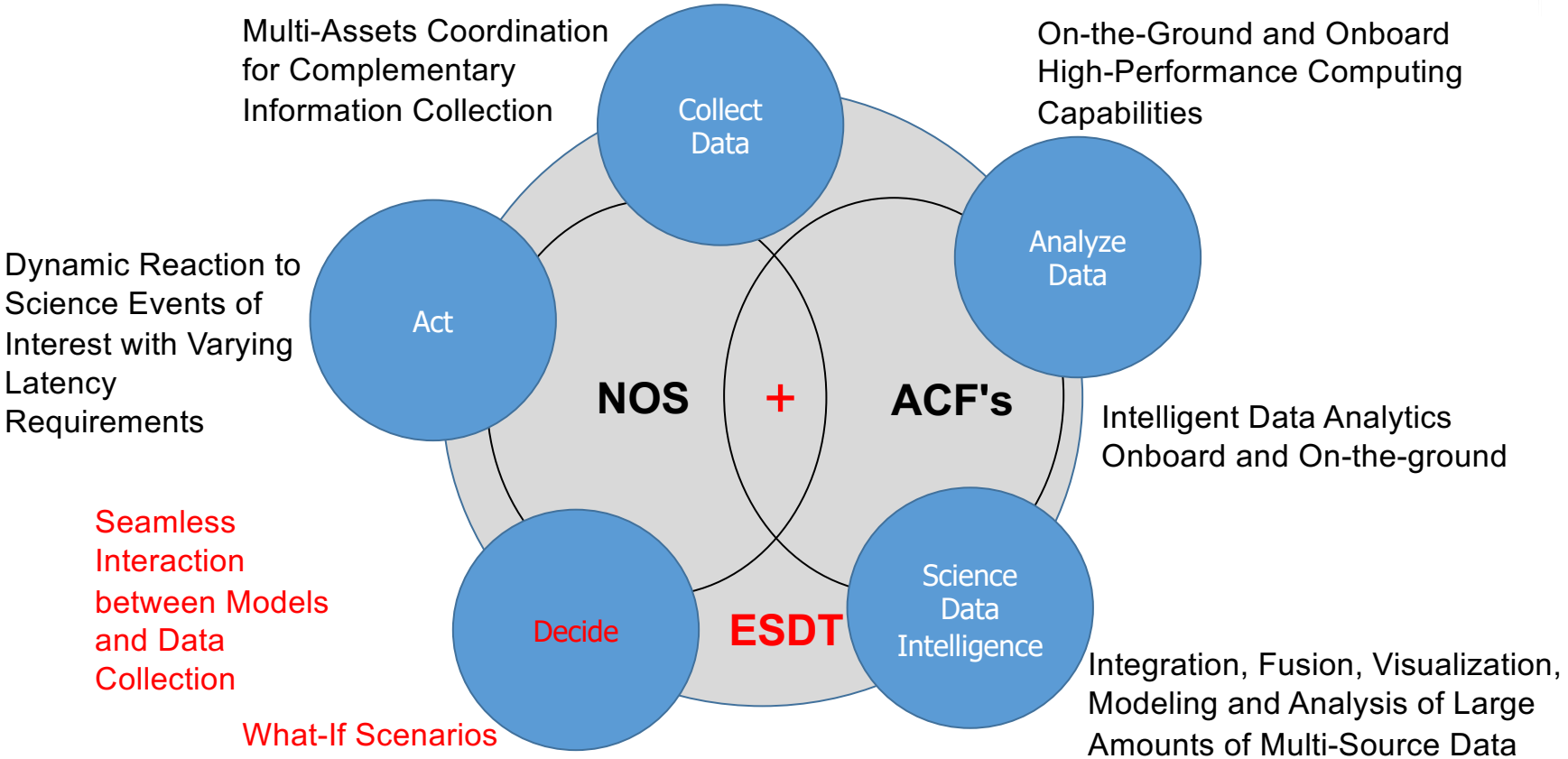
Example: NOS testbed for fire hazard detection *(https://esto.nasa.gov/forums/estf2021/Presentations/June10/Grogan_NOST_ESTF2021.pdf)*

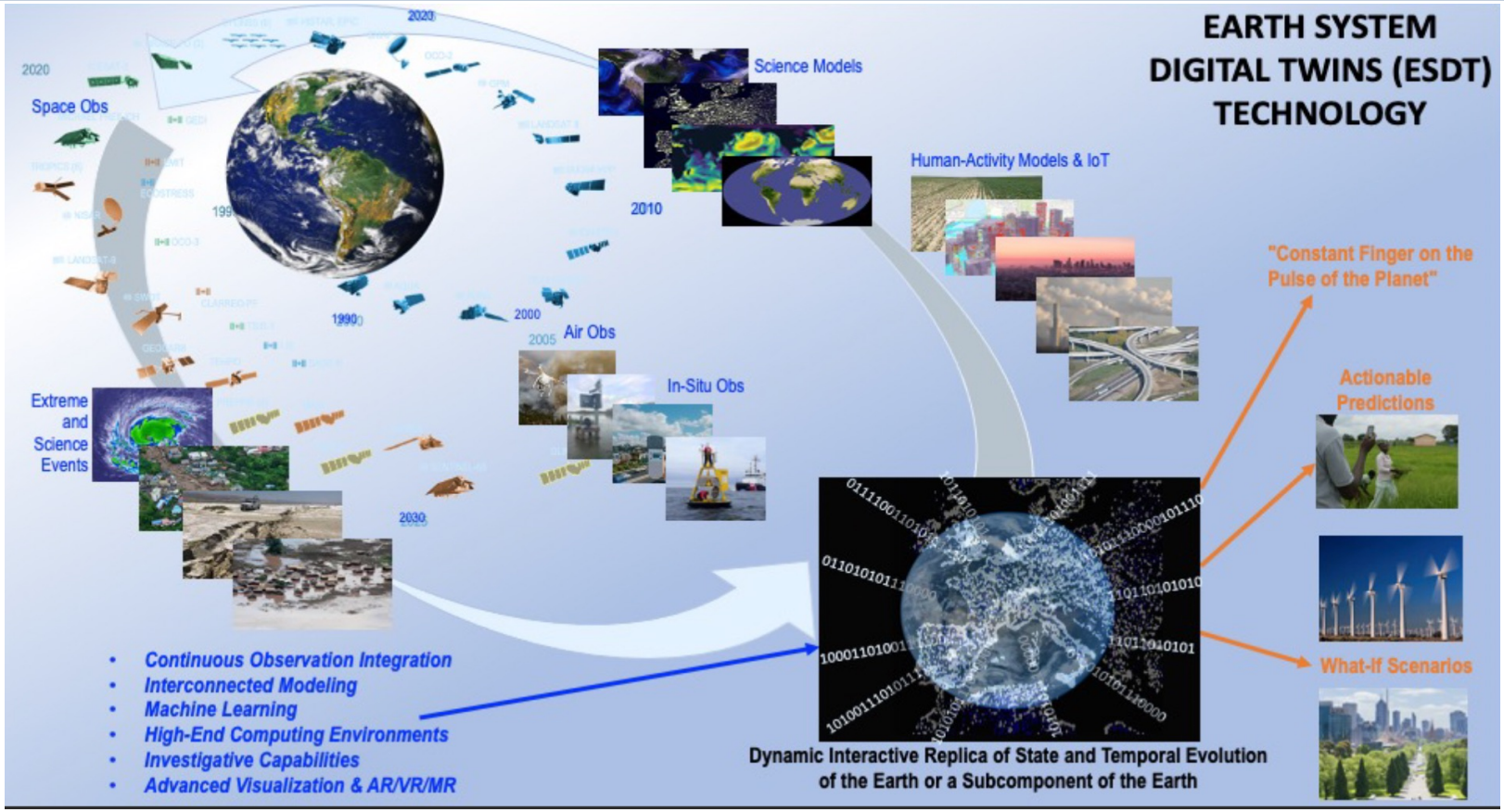
Example: OceanWorks, ACF for Ocean Science https://oceanworks.jpl.nasa.gov

NOS+ACF acquires and integrates complementary and coincident data to build a more complete and in-depth picture of science phenomena

ESDT = New AIST-21 Thrust

Continuous Integration of NOS and ACF Technologies




EARTH SYSTEM
DIGITAL TWINS (ESDT)
TECHNOLOGY
Space Obs
Science Models
Human-Activity Models & IoT
Air Obs
In-Situ Obs
Extreme and Science Events
"Constant Finger on the Pulse of the Planet"
Actionable Predictions
What-if Scenarios
2020
2010
2000
1990
2030
Continuous Observation Integration
Interconnected Modeling
Machine Learning
High-End Computing Environments
Investigative Capabilities
Advanced Visualization & AR/VR/MR
Dynamic Interactive Replica of State and Temporal Evolution
of the Earth or a Subcomponent of the Earth

Earth System Digital Twin (ESDT)

- Interactive, integrated, multidomain, multiscale, digital replica of the state and temporal evolution of Earth systems. Dynamically integrates
  - Relevant Earth system models and simulations
  - Other relevant models (e.g., related to human activities)
  - Continuous and timely observations (e.g., space, airborne, ground, over/underwater, socioeconomic, IoT)
  - Long-time data
  - Analytics, Artificial Intelligence (AI) tools
- Allow running hypothetical (“what-if”) scenarios to improve the understanding, prediction of, and mitigation/response to Earth system processes, natural phenomena, and human activities and their interactions.

ESDT Key Technologies

- Agile interaction and interoperability between measurement acquisition (NOS) and science investigations (ACF)
- AI to enable quickly requesting, integrating, fusing diverse and timely Earth observations into ESDTs
- Frameworks for data ingest from multiple, integrated models, and/or moving to multi-discipline, inter-related systems
- Leveraging Model-Based System Engineering (MBSE)
- Digital Thread developments
  - Link digital twin capabilities
  - Enable design requirements, records, provenance to be easily reviewed and address issues within digital twin
- Technologies for federated ESDTs

ESDT Key Technologies (2)

- Enable “what-if” investigations
  - Multi-scale simulations, statistics, uncertainty quantification, causality
  - Computational hardware and software to enable faster runs
  - Statistical models, machine learning models, surrogate modeling
  - User interfaces, visualization, augmented reality (AR), mixed reality (MR) for complex systems of systems

Related Information

- References on Digital Twins and related: https://esto.nasa.gov/files/0_2021-07-22_ESDT_References.pdf
- AGU'2021 Invited Session, SY14 - "Towards Earth System Digital Twins (ESDT)"
  - SY14A: "Toward Earth-System Digital Twins I – Oral", Chairs: J. Le Moigne and M. Cole, https://agu.confex.com/agu/fm21/meetingapp.cgi/Session/127107
  - SY14B: "Toward Earth-System Digital Twins II – eLightning", Chairs: M. Seablom and L. Friedl, https://agu.confex.com/agu/fm21/prelim.cgi/Session/127120
- Special Issue of Journal “Frontiers in Water” on “Understand and Improve Infrastructure Resilience to Hydrological Extremes Using Artificial Intelligence and Digital Twins”
  - Full papers due April 30, 2022
  - https://www.frontiersin.org/research-topics/25358/understanding-and-improving-infrastructureresilience-to-hydrological-extremes-using-artificial-intelligence-and-digital-twins