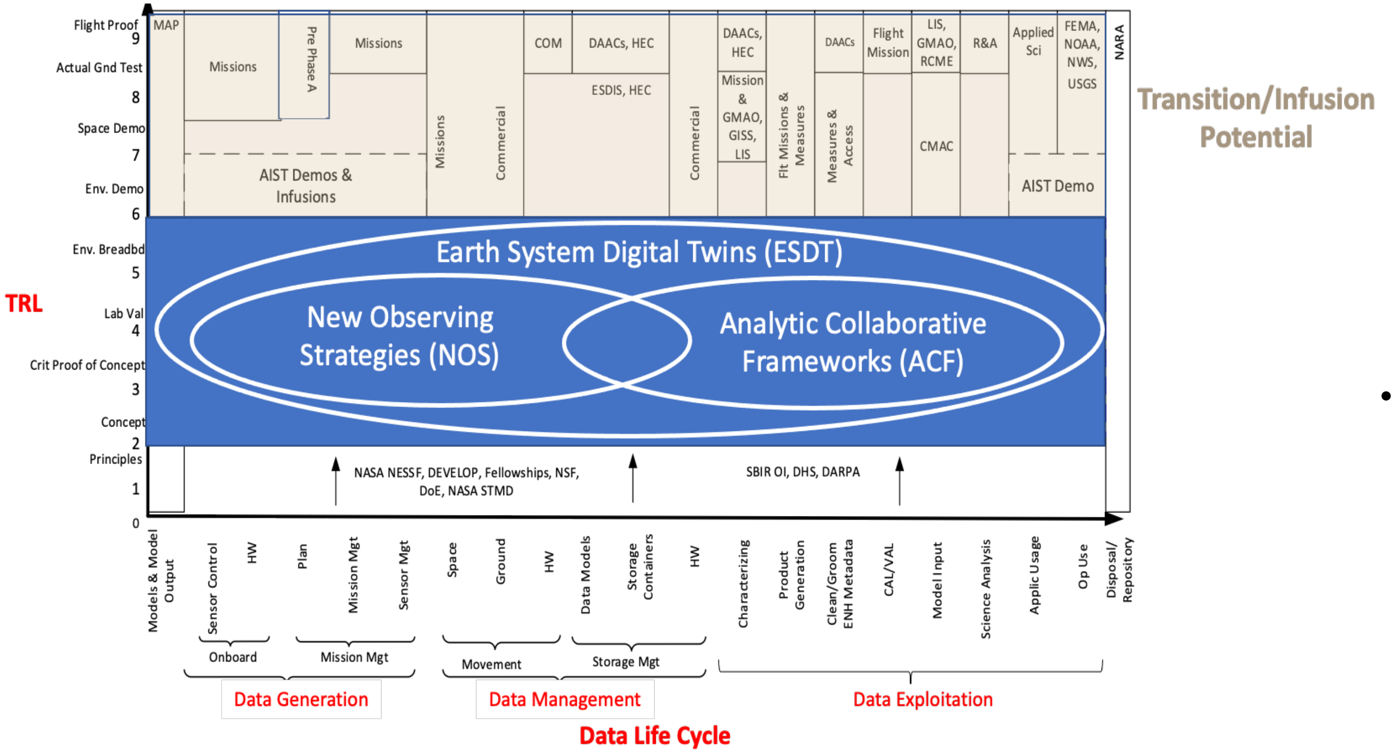
NASA ESTO Advanced Information Systems Technology (AIST)

https://esto.nasa.gov/aist/

Overview & Current and Recent Projects

Octobre 2023

AIST Program Scope



More generally, address general "Science-Data Intelligence":

- From Science Needs to Science Intelligence
- Extracting knowledge and information from Science data to make "Science decisions"

- **Novel Observing Strategies (NOS)**

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

  - Using Distributed Spacecraft Missions (DSM) or SensorWebs at various vantage points
  - In response to Decadal Survey mission design needs, forecast or science model-driven, or event-driven
  - Using NASA- as well as non-NASA data sources/services

- **Analytic Collaborative Frameworks (ACF)**

  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

  - Allow flexibility/tailoring configurations for Science investigators to choose among large variety of datasets & tools
  - Reduce repetitive work in data access and pre-processing, e.g., develop reusable components

- **Earth System Digital Twins (ESDT)**

  Developing integrated Earth Science frameworks to mirror, simulate and predict the Earth temporally and spatially using:

  - State-of-the-art models (Earth system models and others)
  - Timely and relevant observations, Analytic Tools, and
  - Advanced computational and visualization capabilities.

  This thrust will enable near- and long-term science* and policy decisions

NOS and ACF for Science Data Intelligence

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

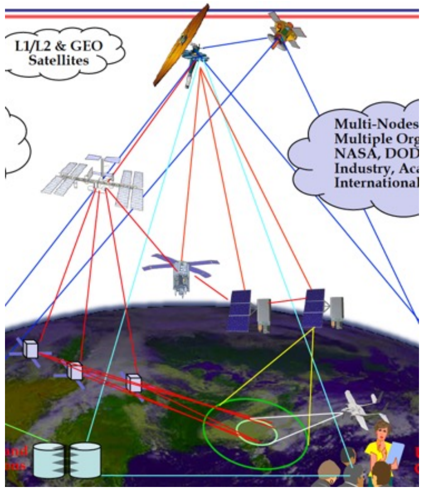
Assimilate Observations

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

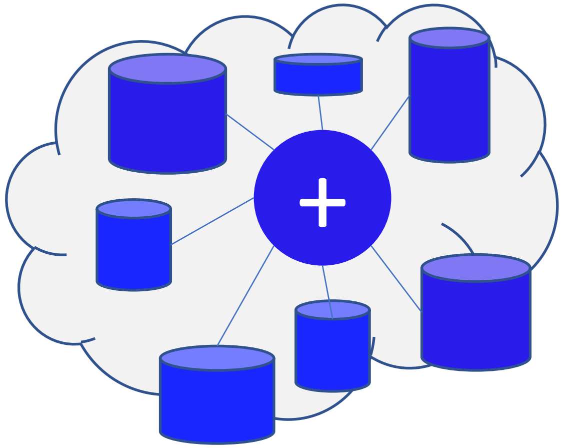
Novel Observing Strategies (NOS)

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?

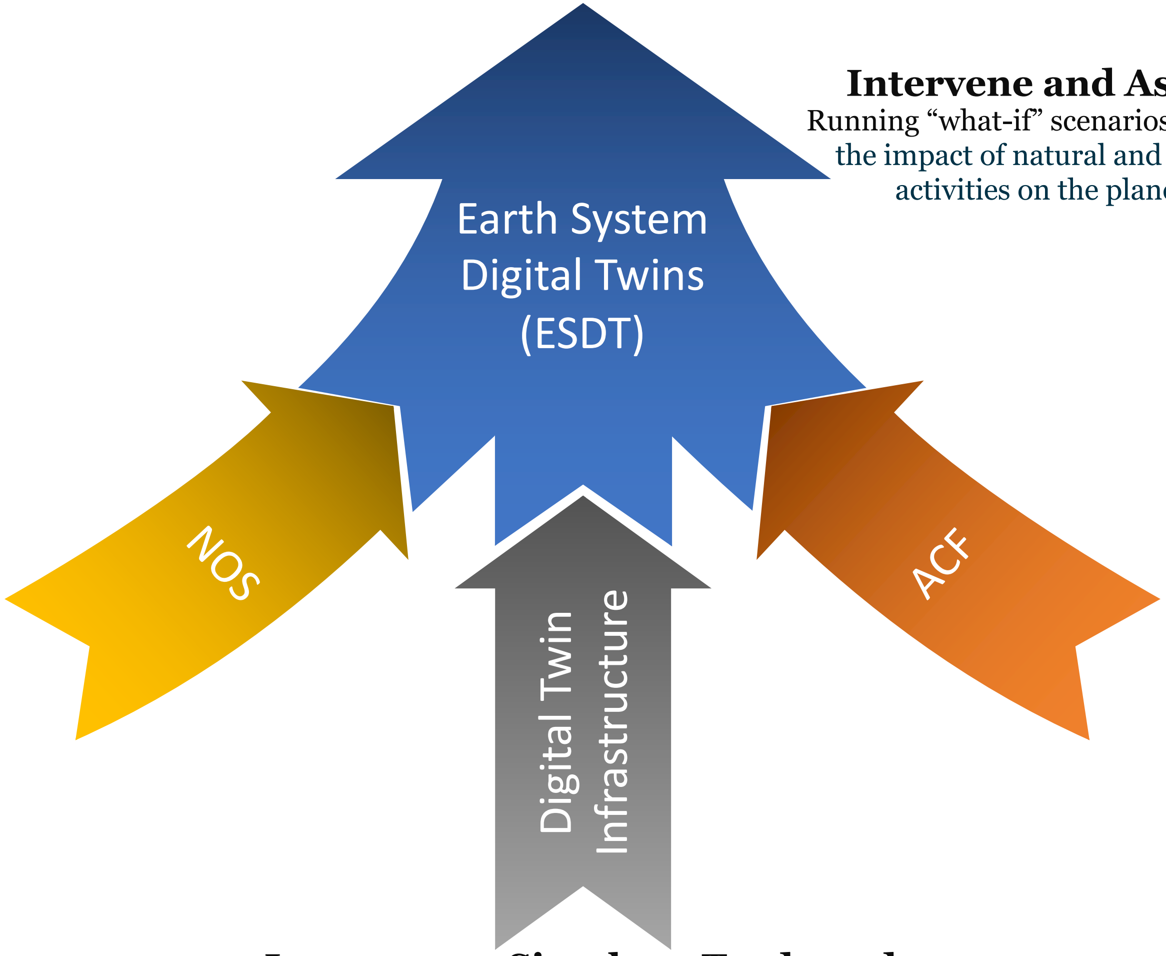
Observation Requests

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

ESDT one of 3 AIST Thrusts

Intervene and Assess

Running "what-if" scenarios to assess the impact of natural and human activities on the planet.



Observe, Target and Coordinate

Edge and on-the-ground intelligent planning, evaluating, coordinating and operating collections of diverse and distributed observing assets

Fuse, Analyze, Share and Collaborate

Simplify access to diverse and large amounts of data, analytics & modeling tools and advanced computational resources for collaborative science

Interrogate, Simulate, Trade and Visualize

Robust tools for interrogating, assessing uncertainties & causality, and for visualization, leveraging diverse data, models and products

NOS = Novel Observing Strategies

ACF = Analytic Collaborative Frameworks

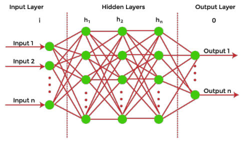
Novel Observing Strategies (NOS)

Novel Observing Strategies (NOS)
... or How to create an Internet-of-EarthThings (IoET)

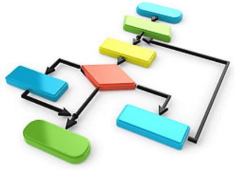
Resources

Data

Sensors & Platforms



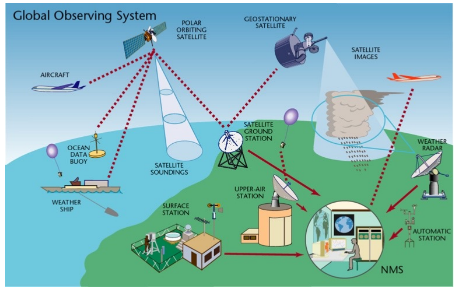
Models



Algorithms

IoT & Social Media

An Observation System is a configuration of resources to answer science questions in order to advance knowledge and benefit society.



Observation System

Novel Observing Strategies (NOS)

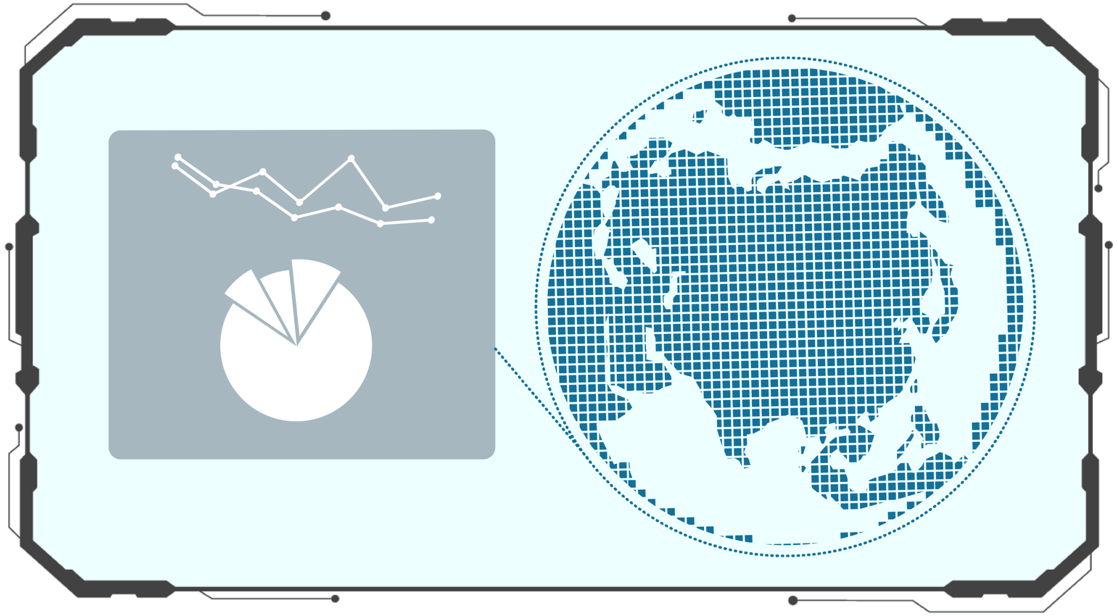
... or How to create an Internet-of-EarthThings (IoET)

OBJECTIVES:

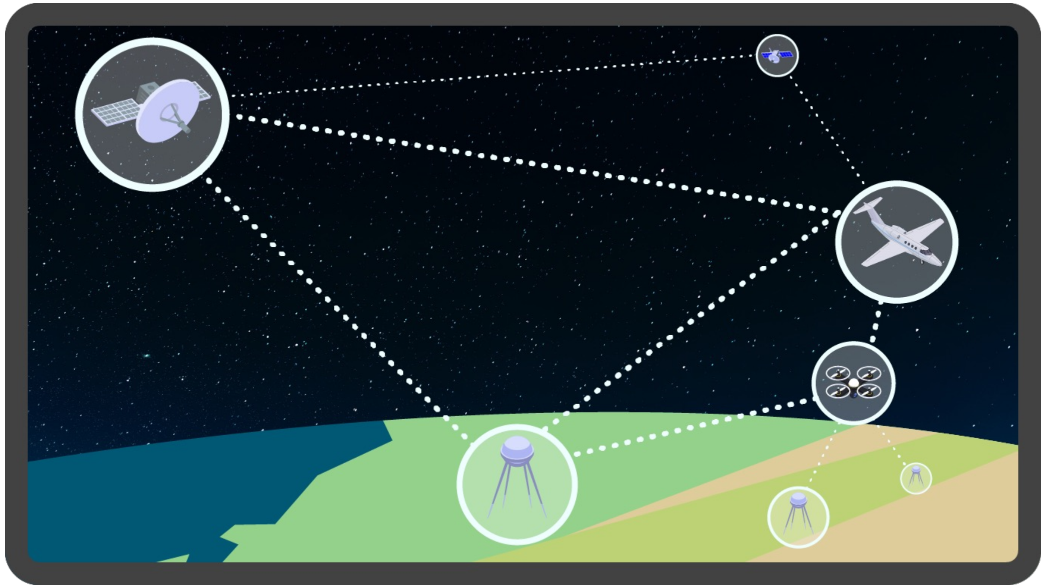
1. **Design and develop New Observing Concepts:**
   - From Decadal Survey or Model; **Various size spacecraft; ** Systems of systems **(*Internet-of-Space*); Various organizations**
   - **Perform trades** on sensor number/type, spacecraft, orbits; resolutions; onboard vs. on-the-ground computing; inter-sensor communications, etc.
   - System being **designed in advance** as a mission or observing system **or incrementally and dynamically over time**
2. **Respond to various science and applied science events of interest:** Various overall observation timeframes; Various area coverages; Dynamic/Timely; Scheduling, re-targeting/re-pointing assets, as possible

System-of-Systems NOS-Testbed for technologies & concepts validation, demonstration, comparison and socialization

Optimize current & future Mission Portfolio and Mission Design



Drive Coordinated, Event-Driven Observations



Novel Observing Strategies (NOS)

... or How to create an Internet-of-EarthThings (IoET)

Earth Observatory Optimization

"Hello NOS, I am the 2027 Earth Science Decadal Survey: I have received many science wishes for new science measurements. With a limited budget, how could I optimize the number and cost of satellites we will need to launch and yet maximize the number of measurements that will satisfy these science requirements?"

Coordinated Observations

"Hello NOS, I am the LIS Model: there was a fire in San Bernardino, CA, last month, and with all the rain lately, I am almost sure that there is going to be a flood in that area: can you ask Capella to retask their sensor so I can improve my prediction of which areas will be flooded next week?"

NOS Application Cases

Various Spatial and Temporal Timeframes

Mission Type ***Timeframe*** ***Application***	**Tactical Observing System** ***Seconds-minutes*** ***Point event/phenomenon***	**Operational Observing System** ***Hours-days*** ***Spatial phenomenon***	**Strategic Observing System** ***Months-years*** ***Spatial-temporal phenomenon***
Example	*Detect and observe volcanic activity*	*Increase spatial observation of primary forest burning as input into long-term Air Quality and Climate models*	*Select observing strategy to optimize all measurements that will improve hydrologic estimates*
Functions	Detect emergent event Deploy observation assets	Deploy observation assets Digest information sources	Design observation system Digest information sources
Capabilities	• Responsiveness • Interaction • Dynamics • Adaptation	• Resource allocation • Coordination • Data assimilation • Prediction/ forecasting	• Platform selection • Coordination • Data assimilation • State estimation (belief)

AIST-18 NOS Awards

- **NOS-T Relevant**

PI's Name	Organization	Title	Synopsis
Mahta Moghaddam	U. of Southern California	SPCTOR: Sensing Policy Controller and OptimizeR	Multi-sensor coordinated operations and integration for soil moisture, using ground-based and UAVs "Sensing Agents".
Jim Carr	Carr Astro	StereoBit: Advanced Onboard Science Data Processing to Enable Future Earth Science	SmallSat/CubeSat high-level onboard science data processing demonstrated for multi-angle imagers, using SpaceCube processor and CMIS Instrument, and Structure from Motion (SfM).
Sreeja Nag	NASA ARC	D-SHIELD: Distributed Spacecraft with Heuristic Intelligence to Enable Logistical Decisions	Suite of scalable software tools - Scheduler, Science Simulator, Analyzer to schedule the payload ops of a large constellation based on DSM constraints (mech, orb), resources, and subsystems. Can run on ground or onboard.
Paul Grogan	Stevens Institute of Technology	Integrating TAT-C, STARS, and VCE for New Observing Strategy Mission Design	Inform selection and maturation of Pre-Phase A distributed space mission concept, by integrating: TAT-C: architecture enumeration and high-level evaluation (cost, coverage, quality); STARS: autonomous/adaptive sensor interaction (COLLABORATE); VCE: onboard computing and networking

- **OSSEs (Observing System Simulation Experiments)**

PI's Name	Organization	Title	Synopsis
Derek Posselt	NASA JPL	Parallel OSSE Toolkit	Fast-turnaround, scalable OSSE Toolkit to support both rapid and thorough exploration of the trade space of possible instrument configurations, with full assessment of the science fidelity, using cluster computing.
Bart Forman	U. of Maryland	Next Generation of Land Surface Remote Sensing	Create a terrestrial hydrology OSSE/mission planning tool with relevance to terrestrial snow, soil moisture, and vegetation using passive/active microwave RS, LiDAR, passive optical RS, hydrologic modeling, and data assimilation, using LIS and TAT-C.
Ethan Gutmann	UCAR	Future Snow Missions: Integrating SnowModel in LIS	Improve NASA modeling capabilities for snow OSSE, to plan and operate a future cost-effective snow mission by coupling the SnowModel modeling system into NASA LIS.

AIST-21 NOS Awards

- **NOS for Smart Sensors and Onboard Intelligence**

PI's Name	Organization	Title	Synopsis
William Blackwell	MIT Lincoln Labs	Sensor-in-the-Loop Testbed to Enable Versatile/Intelligent/Dynamic Earth Observation (VIDEO)	Develops a methodology and test approach for a scene measured by a sensor to be able to configure the sensor in real-time during the scene measurement. Will significantly improve the resolution of the retrieved atmospheric fields in regions in which that improvement is most beneficial, while conserving resources in other regions. Includes two components: (1) Radiometric Scene Generator (RSG) using advanced metamaterial and its associated control software; (2) Intelligent processing and configuration software using feature detection and ML, running onboard the sensor, to detect and react to changes by dynamically optimizing the sensor response functions.
James Carr	Carr Astronautics	Edge Intelligence for Hyperspectral Applications in Earth Science for New Observing Systems	Will use the SpaceCube processor and its Low-power Edge Artificial Intelligence Resilient Node (SC-LEARN) coprocessor powered by Google Coral Edge Tensor Processing Units (TPUs) to implement two AI science use cases in hyperspectral remote sensing: (1) Use learned spectral signatures of clear-sky scenes to retrieve surface reflectance and therefore increase the efficiency of collecting land observations on ~68% cloudy planet (e.g., for SBG); (2) Classify artificial light sources after training against a catalog of lighting types. SC-LEARN will fly on STP-H9/SCENIC to the ISS with a Headwall Photonics HyperspecMV hyperspectral imager.
James MacKinnon	NASA Goddard Space Flight Center	Multi-Path Fusion Machine Learning for New Observing System Design and Operations	Proposes to develop a system based on data fusion and multi-path neural network ML to aid in the design and operation of multi-sensor NOS concepts. Will build ML-enabled analytic tools and advanced computing environment capabilities for NOS workflows that utilize large amounts of diverse airborne and satellite observations. Using multiple neural networks working in parallel, it will first be demonstrated with a forest productivity use case, with fusion of lidar, spectrometry, satellite-derived climatology and ecosystem modeling providing insights into the driving environmental factors that influence productivity. Then will be used for sensitivity studies to guide sensor and mission requirements traceability.
Daniel Selva	Texas A&M Univ.	3D-CHESS: Decentralized, distributed, dynamic and context-aware heterogeneous sensor systems	Proposes to demonstrate proof of concept for a context-aware Earth observing sensor web consisting of a set of nodes with a knowledge base, heterogeneous sensors, edge computing, and autonomous decision-making capabilities. Context awareness refers to the nodes' ability to gather, exchange, and leverage contextual information to improve decision making and planning. Will demonstrate and characterize the technology in a multi-sensor in-land hydrologic and ecologic monitoring system performing 4 inter-dependent missions: studying non-perennial rivers and extreme water storage fluctuations in reservoirs and detecting and tracking ice jams and algal blooms.

AIST-21 NOS Awards (cont.)

- **NOS for UAS Integration and NOS Prototypes**

PI's Name	Organization	Title	Synopsis
Meghan Chandarana	NASA Ames Research Center	Intelligent Long Endurance Observing System	Proposes the development of the Intelligent Long Endurance Observing System (ILEOS) to help scientists build plans to improve spatio-temporal resolution of climate-relevant gases by fusing coarse-grained sensor data from satellites and other sources and plan High-Altitude Long Endurance (HALE) UAS flights to obtain finer-grain data. ILEOS will also enable observations for longer periods and of environments not accessible through in-situ observations and field campaigns. 3 components: (1) the Target Generation Pipeline to identify candidate target scenes; (2) the Science Observation Planner using automated planning and scheduling technology to automatically generate a flight plan; and (3) a Scientists' User Interface.
Carl Legleiter	USGS	An Intelligent Systems Approach to Measuring Surface Flow Velocities in River Channels	Will develop a New Observing Strategy (NOS) for measuring streamflow from a UAS using an intelligent system. Using the USGS/NASA UAS-based payload for measuring surface flow velocities in rivers (USGS & NASA), consisting of thermal/visible cameras, a laser range finder, and an embedded compute (integrated within a common software middleware), it will address both quality control during routine streamgaging operations by quantifying uncertainty, as well as autonomous route-finding during hazardous flood conditions using inter-sensor communications. Will be implemented for real-time processing onboard the platform.
Carrie Vuyovich	NASA Goddard Space Flight Center	A New Snow Observing Strategy in Support of Hydrological Science and Applications	Will develop the Snow Observing System (SOS) considering the most critical snow data needs along with existing and expected observations, models, and a future snow satellite mission. It will estimate SWE and snow melt throughout the season, targeting obs with the greatest impact. It will: evaluate/combine observations from existing missions; create a hypothetical experiment to determine optimal observing strategy; assess value of new potential sensors, e.g., commercial SS for filling gaps and higher frequency obs. Higher density observations for early warning in regions where concerns for flood, drought or wildfires will also be studied.

Other AIST NOS Awards

- **NOS for UAS Integration and NOS Prototypes**

PI's Name	Organization	Title	Synopsis
Yelena Yesha	CARTA NSF I/U-CRC at U. of Miami	Blockchain Distributed Ledger for Space Resource Access Control	This project proposes to apply a distributed ledger (blockchain) within the context of a distributed Earth Observing (EO) system. The blockchain is represented as one or more nodes that participate in a test case execution. Other applications representing components of the federated EO system (e.g., satellite operators, customers, etc.) interact with the blockchain application to request and grant access to resources.
Mahta Moghaddam	SoilTech NSF I/U-CRC at USC	SoilTech: Center for Soil Dynamics Technologies	SoilTech aims to develop next-generation sensor systems capable of in-situ and remote measurement of dynamic variables in managed and unmanaged soils. Its objectives are to make significant advances in sensor development, soil health monitoring, ground penetration, data transmission, data analytics, dynamic models and visualization tools, thus enabling scientists and engineers to gain deeper understanding of dynamic processes in soils. It will develop new, more efficient and more sustainable ways of studying soil properties and managing soils and natural resources for many industries and will lead to broad societal benefits such as reduced soil and water contamination, improvements to agricultural practices and food security, and management of the nitrogen cycle.
Paul Grogan & Derek Posselt (Funded by NOAA)	Stevens Tech Institute & NASA JPL	OSSE / Trade Space Capability for NOAA's Future Mission Design	The objective of this project is to develop automated assessment methods and tools for future NOAA space architectures including distributed mission concepts. In addition to current assessment methods based on steady-state operation, this project seeks to identify and develop new assessment techniques to characterize mission performance for dynamic contexts. Dynamic analysis methods differentiate new operational modes linked to coupling and interaction across traditional system boundaries.

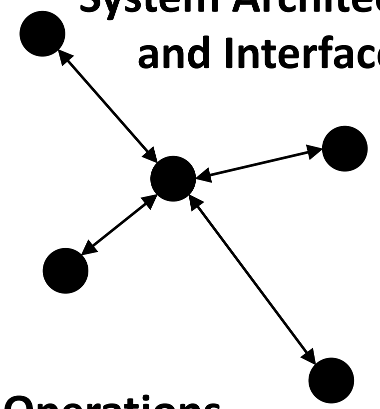
Novel Observing Strategies Testbed

- Technologies to be deployed should be first integrated into a working ***breadboard*** where the components can be debugged and performance and behavior characterized and tuned-up.
- A system of this complexity should not be expected to work without full integration and experimental characterization as a "system of systems"

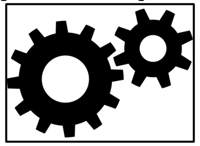
Testbed Main Goals:

1. Validate new DSM/NOS technologies, independently and as a system
2. Demonstrate novel distributed operations concepts
3. Enable meaningful comparisons of competing technologies
4. Socialize new DSM technologies and concepts to the science community by significantly retiring the risk of integrating these new technologies.

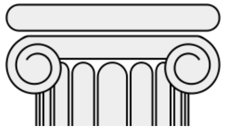
System Architecture and Interfaces



Concept of Operations



Governance Model

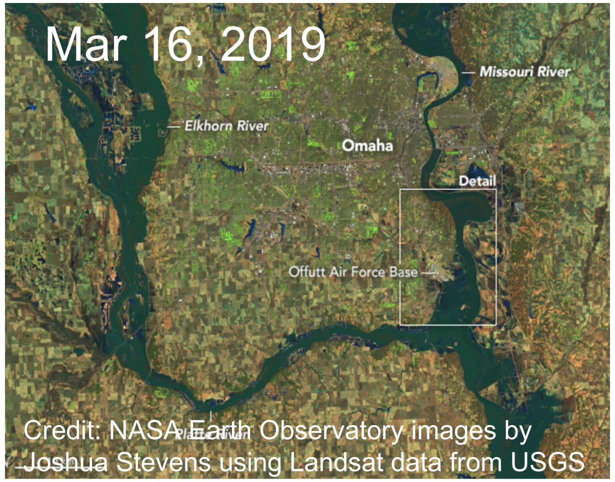


NOS-T framework objective:

Enable disparate organizations to propose and participate in developing NOS software and information technology

NOS-Testbed Hydrology Demonstrations

March 2021 – Historical Nebraska Flood + Live Mid-West Flood



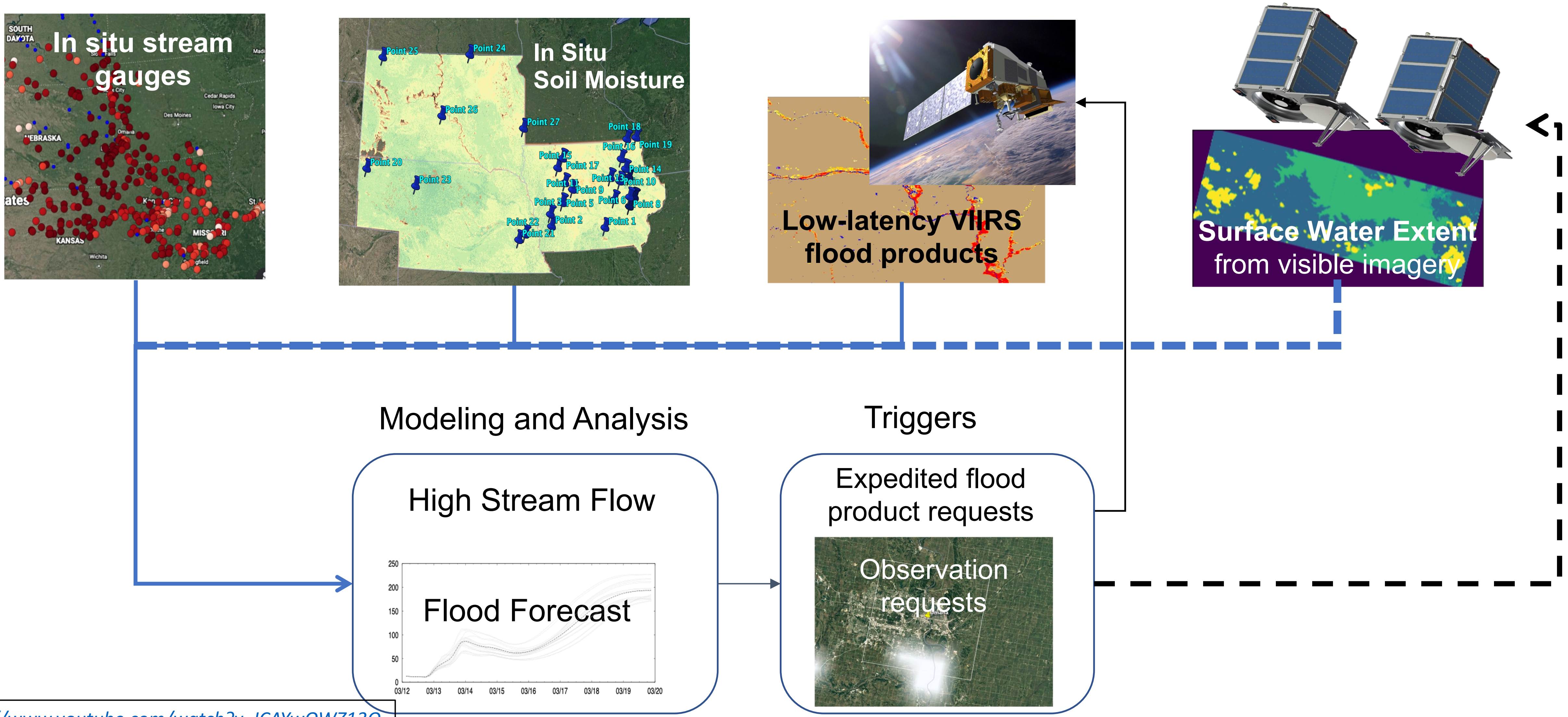
Credit: NASA Earth Observatory images by Joshua Stevens using Landsat data from USGS

Offutt Airforce Base Neb, Mar 17 (Air Force)

Flooding of Eastern Nebraska began on March 14, 2019, due to heavy precipitation, snow melt and river ice jams and resulted in mass evacuations from the area.

NOS-Testbed Hydrology Demonstrations

March 2021 – Historical Nebraska Flood + Live Mid-West Flood



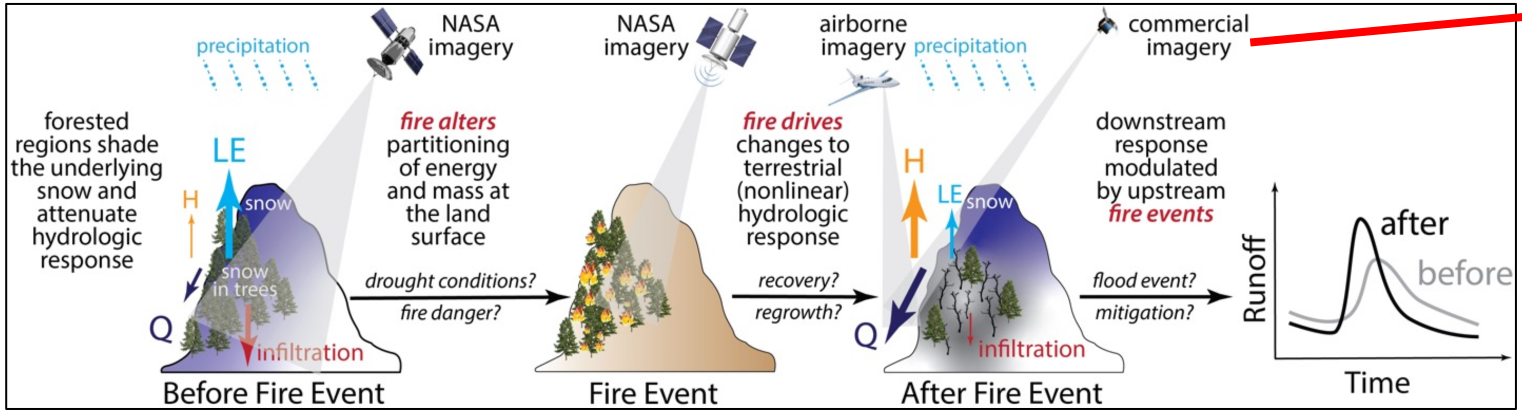
https://www.youtube.com/watch?v=ICAYwOWZ13Q

NOS-Live (NOS-L)

Autonomous, Model-driven Tasking of Flood Events

Live demonstrations of optimized surface water measurement acquisitions in responses to large fires over the Western U.S.

Vegetation disturbance triggered hydrology impacts for NOS-live demonstration



Planet and Capella

Large vegetation disturbances such as fires lead to significant changes in the local hydrology, typically by decreasing evaporation and increasing runoff in post-fire conditions. Such cascading impacts have been responsible for large flooding events in several parts of the world. Targeted remote sensing observations of the relevant processes would likely be of significant utility to capture fire-driven flooding instances.

- *High resolution multi-decadal model retrospective (2003-2021) and short-term over Western U.S., informed by RS precipitation, soil moisture, terrestrial water storage, and leaf area index estimates using the NASA LIS system => Fine scale vegetation disturbances from fires + associated hydrology impacts.*
- *Identification of target locations based on river discharge, spatial position within watershed, size and distribution of wildland fires and population density within a watershed.*
- *Optimized event-driven architecture based on NOS-testbed => automated message and information flow between on-premise and cloud resources, commercial satellite observations and tasking application.*

The system was run continuously in automated fashion for several months from August to December 2022. Based on the targets identified by the model forecasts, commercial imagery was tasked and ordered from Planet and Capella and incorporated into the model estimates.

NOS Demonstrations Roadmap

NOS-T Historical Flood Demonstration

Early Spring 2021:
- NOS-T Node Coordination
- Simulated Trigger Generation
- Integration of *Historical* Data **On Demand**
- GSaaS *Simulation* Demonstration

NOS-T Live Flood Demonstration (If/When Live Event Happens)

Late Spring 2021:
- NOS-T Node Coordination
- **Live** Trigger Generation *(not necessarily autonomous)*
- Integration of **Live** Data **On Demand**
- GSaaS **Live** Demonstration

NOS + NOS-T Live (NOS-L) Live Science Demonstration

2022:
- NOS-T Node Coordination for **Science Application**
- **Actual** Autonomous Trigger Generation
- Integration of **Live** Data **On Demand**
- GSaaS **Live** Demonstration

Future Potential NOS Science Demonstrations

TBD, e.g.:
- NOS **Science Scenario** in coordination with upcoming mission
- “Virtual Mission”
- "Virtual Field Campaign”
- Potential coordination with prototype ESDT

Analytic Collaborative Frameworks (ACF)

Analytic Collaborative Frameworks (ACF)

Focus is on the Science User

NASA ESTO Earth Science Technology Office

Allow flexibility/tailor configurations for Science investigators to choose among a large variety of datasets & tools

User

- Project Definition
- Plan for Investigation

Data

- Catalog
- NASA DAAC
- Other US Govt
- Non-US
- Local or non-public

Project Work Environment

Tools

- Discovery & Catalog
- Work Management
- Data Interfaces
- Analytic Tools
- Modeling
- Collaboration
- Visualization
- Sharing/ Publication
- Local/custom

Reduce repetitive work in data access and pre-processing, e.g., develop reusable components

Computational Infrastructure

- Computing
  - Capacity
  - Capability
- Storage
- Communications

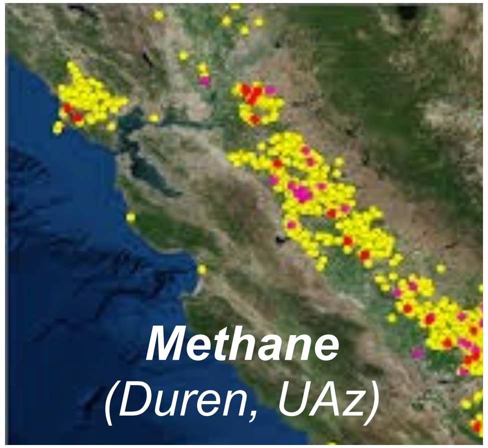
Storage

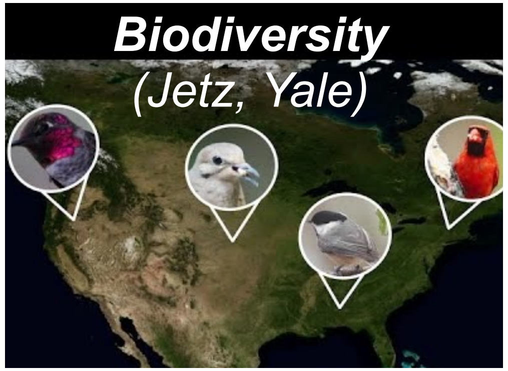
- Data Containers
- Thematic model
- Metadata/Ontology
- Resulting Products
- Published data
- Provenance

Computing

- Local systems
- High End Computing
- Cloud Computing Capability
- Quantum Computing
- Neuromorphic Computing

Analytic Collaborative Frameworks (ACF) support various Earth Science Disciplines





AIST-18 ACF Awards

- **Biodiversity ACF**

Award #	PI's Name	Organization	Title	Synopsis
AIST-18-0007	Schollaert Uz	NASA GSFC	Supporting shellfish aquaculture in the Chesapeake bay using AI for water quality	Provide access to reliable information on a variety of environmental factors, not currently available at optimal scales in space and times, by using various data (sats and others) and AI for Pattern Recognition.
AIST-18-0031	Moisan	NASA GSFC	NASA Evolutionary Programming Analytic Center (NEPAC)	Discover and apply novel algorithms for ocean chlorophyll using AI/ML (Genetic Programming) on satellite/in-situ obs and a user-friendly GUI to connect data and applications with HEC resources for improved science.
AIST-18-0034	Jetz	Yale U.	Biodiversity - Environment Analytic Center	Near real-time monitoring of the biological pulse of our planet, using an online dashboard, taking into account various spatiotemporal resolutions, data uncertainty and biodiversity data biases, and supporting analysis, visualization and change detection across scales.
AIST-18-0043	Townsend	U. Wisconsin, Madison	GeoSPEC: On-Demand Geospatial Spectroscopy Processing Environment on the Cloud	Develop a framework/processing workflow for on-demand cloud-based Hyperspectral/Spectroscopy Science Data Processing in preparation for SBG needs. Will provide options for new atmospheric & other types of corrections, possibilities for users' or commercial code. Will be tested with AVIRIS-Classic and –NG data.
AIST-18-0063	Swenson	Duke University	Canopy condition to continental scale biodiversity forecasts	Characterize canopy condition from various spatio-temporal RS products (including drought indices and habitat structure) to predict supply of mast resources to herbivores (and threatened species) and visualize canopy condition and drought-stress maps

- **Land Cover ACF**

Award #	PI's Name	Organization	Title	Synopsis
AIST-18-0020	Ives	U. Of WI, Madison	Valid time series analyses for satellite data	Develop new statistical tools to analyze large, time series of various remotely sensed datasets and provide statistical rigor and confidence to conclusions about patterns of change and to forecasts of future change, identifying patterns of annual trends, seasonal trends and phenological events, and analyzing the cause of these trends.

AIST-18 ACF Awards (cont.)

- **Air Quality ACF**

Award #	PI's Name	Organization	Title	Synopsis
AIST-18-0011	Martin	Washington U. at St Louis	Development of GCHP to enable broad community access to high-resolution atmospheric composition modeling	Integrate atmospheric chemistry models online into Earth system models (ESMs) and offline using meteorological data, using the high-performance version of the GEOS-Chem global 3-D model of atmospheric chemistry (GCHP) and the Earth System Modeling Framework (ESMF) in its Modeling Analysis and Prediction Layer (MAPL) implementation.
AIST-18-0044	Duren	NASA JPL	Multi-scale Methane Analytic Framework	ACF for methane data analysis spanning multiple observing systems and spatial scales with workflow optimization, analytic tools to characterize methane fluxes and physical processes, tools for data search and discovery, and a collaborative, web-based portal.
AIST-18-0072	Henze	U. of CO, Boulder	Surrogate modeling for atmospheric chemistry and data assimilation	Advance computational tools available for AQ prediction, mitigation, and research by building a robust and computationally efficient chemical Data Assimilation system, merging research in compressive sampling and machine learning for large-scale dynamical systems and integrating multi-source data into an existing model.
AIST-18-0099	Holm	City of Los Angeles	Predicting What We Breathe: Using Machine Learning to Understand Urban Air Quality	Link ground-based in situ and space-based remote sensing observations of major AQ components to classify patterns in urban air quality, enable the forecast of air pollution events, and identify similarities in AQ regimes between megacities around the globe, using science models and ML-based algorithms.

- **Precipitation ACF**

Award #	PI's Name	Organization	Title	Synopsis
AIST-18-0051	Beck	U. Of AL, Hunstville	Cloud-based Analytic Framework for Precipitation Research	Leverage cloud-native technologies from the AIST-2016 VISAGE project to develop a Cloud-based ACF for Precipitation Research using a Deep Learning (CNNs) framework to provide an analysis-optimized cloud data store and access via on-demand cloud-based serverless tools . It will use coincident ground and space radar observations.

AIST-18 ACF Awards (cont.)

• Disaster Management ACF

Award #	PI's Name	Organization	Title	Synopsis
AIST-18-0055	Coen	NCAR	Creation of a Wildfire Fire Analysis: Products to Enable Earth Science	Develop methods to create, test and assess wildland fire reanalysis products (standardized, gridded wildland fire information generated at regular intervals) using fire detection data, as well as coupled weather-wildland fire model and data assimilation.
AIST-18-0001	Donnellan	NASA JPL	Quantifying Uncertainty and Kinematics of Earthquake Systems ACF (QUAKES-A)	Create a uniform crustal deformation reference model for the active plate margin of California by fusing data with widely varying spatial and temporal resolutions, quantifying uncertainty, developing data management and geospatial information services and providing collaboration and infusion into target communities.
AIST-18-0085	Hua	NASA JPL	Smart On-Demand of SAR ARDs in Multi-Cloud & HPC	Enable full resolution time series analysis, high-accuracy flood and damage assessments with remote sensing SAR Analysis Ready Data (ARD), using Jupyter Notebooks and on-demand analysis across multi-cloud environments.

• Cross-Cutting ACF Capabilities

Award #	PI's Name	Organization	Title	Synopsis
AIST-18-0042	Huffer	Lingua Logica	AMP: An Automated Metadata Pipeline	Automate and improve the use and reuse of NASA Earth Science data by developing a fully-automated metadata pipleline integrating ML and ontologies (SWEET) for a semantic, metadata mining from data. Developed in collaboration with GES DISC.
AIST-18-0059	Zhang	Carnegie Mellon U.	Mining Chained Modules in Analytics Center Framework	Build a workflow tool as a building block for ACF, capable of recommending to Earth Scientists multiple software modules, already chained together as a workflow. The tool will leverage Jupyter Notebooks to mine software module usage history, develop algorithms to extract reusable chain of software modules, and develop an intelligent service that provides for personalized recommendations.

AIST-21 ACF Awards

- **ACF Infrastructure**

PI's Name	Organization	Title	Synopsis
Ziad Haddad	NASA Jet Propulsion Laboratory	Thematic Observation Search, Segmentation, Collation and Analysis (TOS2CA) system	TOS2CA is a user-driven, data-centric system that can identify, collate, statistically characterize and serve Earth system data relevant to a given phenomenon relevant to ESO. It will facilitate the collation and analysis of data from disparate sources, help scientists to establish science-traceability requirements, quantify detection thresholds, define uncertainty requirements and establish data sufficiency to formulate truly innovative missions. Components will include: 1) a user-driven thematic data collector; 2) a statistical analyzer; and 3) a user-friendly visualization and data exploration toolkit.
Huikyo Lee	NASA Jet Propulsion Laboratory	Open Climate Workbench to support efficient and innovative analysis of NASA's high-resolution observations and modeling datasets	The Regional Climate Model Evaluation System (RCMES/JPL &UCLA) performs systematic evaluation of climate models and is powered by the Open Climate Workbench (OCW). The goal is to develop OCW v2.0 by extending the capabilities of OCW for characterizing, compressing, analyzing, and visualizing observational and model datasets with high spatial and temporal resolutions. It will run on AWS Cloud with special emphasis on developing two use cases: air quality impacts due to wildfires and elevation-dependent warming.

AIST-21 ACF Awards (cont.)

- **Machine Learning for Modeling**

PI's Name	Organization	Title	Synopsis
Yehuda Bock	Scripps Institute, Univ. of CA, San Diego	Detection of Artifacts and Transients in Earth Science Observing Systems with Machine Learning and Visualization	Proposes to create open-source software to provide a rich, interactive environment where machine learning (ML) models are used as collaborator to direct the attention of the human analyst to non-physical artifacts and real transient events that require interpretation. The proposed system will be realized through two coupled sub-systems: a novel "back-end" ML software called the Transient and Artifact Continuous Learning System (TACLS), and a significant upgrade to existing "front end" interactive MGViz user environment, originally designed to view displacement time series and their underlying metadata, to now interact and display layers of spatiotemporal information. Will use Scripp's archive of thousands of artifacts and transients.
Stephanie Schollaert Uz	NASA Goddard Space Flight Center	Integration of Observations and Models into Machine Learning for Coastal Water Quality	Proposes to build upon ongoing collaborations with state agencies managing water water resources around the Chesapeake Bay to monitor water quality and ecosystem properties and how they change over time and space. Previous AISTpromising results used multispectral optical, medium spatial resolution satellite data trained using geophysical model variables within a machine learning (ML) architecture. Utilizing higher spatial resolution from commercial satellites, feature maps from many sensors of varying spatial, spectral, and temporal resolutions will be derived to determine the minimum set of requirements for RS of water quality, e.g. water clarity, phytoplankton blooms, and the detection of pollutants.
Brian Wilson	NASA Jet Propulsion Laboratory	SLICE: Semi-supervised Learning from Images of a Changing Earth	Proposes to investigate and characterize the efficacy of multiple Self- and Semi-Supervised Learning (SSL) techniques for representative image problems on Earth imagery, and then select the best for further infusion into mission and science workflows. Three top-level goals of the SLICE system are: (1) Establish the SLICE framework and platform on the AWS Cloud and supercomputing environments; (2) Investigate and characterize the accuracy of multiple SSL models (i.e. SimCLRv2, DINO, EsViT) on a variety of relevant remote sensing tasks with minimum labels (e.g., ocean phenomena); (3) Build and publish self- and semi-supervised learning models with a focus on the upper ocean small-scale processes in anticipation of several on-going and upcoming NASA missions (i.e. SWOT, WaCM, and PACE).

AIST-21 ACF Awards (cont.)

- **ACF Prototypes**

PI's Name	Organization	Title	Synopsis
Colin Gleason	Univ. of Massachusetts at Amherst	A hosted analytic collaborative framework for global river water quantity and quality from SWOT, Landsat, and Sentinel-2	Proposes to integrate data from the soon-to-be launched SWOT mission with traditional optical imagery in a single ACF to simultaneously co-predict river water quantity and quality at a scale not currently possible. The existing Confluence system will be extended and the outputs of the proposed ACF will be: (1) Unique seamless data environment for SWOT and optical data; (2) Extended library of algorithms for water quantity; (3) Novel library of computer vision algorithms for water quality; and (4) Automated computational environment to produce river water quantity and quality products, globally. Multiplying the mass flux of water (via SWOT) by its constituent concentrations (via optical data) provides a constituent mass loading (e.g., sediment, algae) in the world's river systems and therefore a direct benefit to society and ecosystems.
Seungwon Lee	NASA Jet Propulsion Laboratory	Ecological Projection Analytic Collaborative Framework (EcoPro)	Proposes to build EcoPro to support multidisciplinary teams conducting ecological projection studies, collaborations, applications, and new observation strategy developments. EcoPro will contain: (1) an analytic toolkit to perform multidisciplinary analyses; (2) a data gateway to organize, store, and access key input and output datasets; and (3) a web portal to publish and visualize the results of the studies and to provide a virtual collaborative workspace. The goals are to provide capabilities to advance ecological projection on multi-decadal timescales, as well as ecological forecasting on shorter timescales.

Other AIST ACF Awards

PI's Name	Organization	Title	Synopsis
Thomas Huang	NASA JPL, with City of LA, Wash U. at St Louis, U. of CO at Boulder & GMU	Air Quality Analytic Collaborative Framework (AQACF)	This project integrates the capabilities developed under several AIST efforts – Predicting What We Breathe (Holm), GEOS-Chem GCHP (Martin), Surrogate Modeling for Air Composition (Henze), and (Yang) to develop an Analytic Collaborative Framework (ACF) for Air Quality (AQACF). It builds on the Apache Science Data Analytics Platform (SDAP) architecture to harmonize air quality data sets and analytics. It formalizes inputs to prediction models, GEOS-Chem, and GCHP, as well as cloud-provisioned ML services and demonstrates data access and analytic services through integration with Jupyter Notebooks.
Chaowei (Phil) Yang	George Mason Univ. (GMU)	A formal study on Machine Learning (ML) and geospatial regression methods for processing Green House Gases (GHG) and air pollutants.	Large among of aerosol and air quality (AQ) diverse data at various resolutions are collected to study air pollutants and various Machine Leaning (ML) models and methods are used for data estimations and analysis studies, but there is no systematic study on which model/algorithm is the best for which pollutants and the size and type of training datasets. This study will: (1) Conduct a formal study on AI/ML and geospatial methods for air pollutants simulation, retrieval or prediction with relevant training datasets and using various ML tools,. (2) Develop and configure a ML open-source package with default configurations for various data. Integrate this package with the AIST Air Quality ACF (AQACF) and the new JPL wildfire digital twin projects. (3) Prepare a few GHG and pollutants (methane, ozone, NO2, SO2, and PMx) Analysis Ready Datasets including uncertainties. (4) Engage high school and community college students.
Sujay Kumar	NASA GSFC with U. of AL at Huntsville (UAH)	Integration of the Cloud Precipitation ACF (CAPRi) in the EIS Freshwater project	This work will integrate the AIST-18 CAPRi capabilities (PI: John Beck/University of Alabama at Huntsville, UAH) within the Earth information System (EIS) Freshwater project while transitioning the CAPRi framework from UAH/Information Technology and Systems Center (ITSC) AWS account to NASA's Science Managed Cloud Environment (SMCE) and then to the MAAP environment.

Earth System Digital Twins (ESDT)

What is an Earth System Digital Twin (ESDT)

ESDT Three Components

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

=> What Now? What Next? What If?

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.

An ESDT includes:

- Continuous observations of interacting Earth systems and human systems
- From many disparate sources
- Driving inter-connected models
- At many physical and temporal scales
- With fast, powerful and integrated prediction, analysis and visualization capabilities
- Using Machine Learning, causality and uncertainty quantification
- Running at scale in order to improve our science understanding of those systems, their interactions and their applications

ESDT Science Use Cases/Scenarios

ESDT Use Case	SCOPE
Wildfires	A digital twin of Earth systems involved in wildfires to represent and understand the origins and evolution of wildfires and their impacts on ecosystem, infrastructure, and related human systems.
Ocean Carbon	An Earth system digital twin of ocean, land, atmospheric Earth systems to understand ocean carbon processes such as carbon export and ocean-atmosphere processes and coupling; land-ocean continuum and interactions with human systems; coastal ecological changes and impacts to ecosystem services; feedback processes (e.g., storm intensification and sea level rise) and impacts on coastal communities and the blue economy; assessing feasibility and impacts of various Carbon Dioxide Removal (CDR) approaches as a strategy to remove and sequester atmospheric carbon.
Water Cycle	A local or regional digital twin to understand all the complexities of the Water Cycle, how it is affected by various Earth Systems at multiple temporal and spatial scales, and how it is impacted by decision making and human influence. It would provide capabilities *such as* zooming out in time and space; helping understand water availability and origin for agriculture; how events such as floods and droughts affects life, property and infrastructure; and more generally how the effects of weather and climate variability can be mitigated under various scenarios.
Central Africa Carbon Corridors	An Earth System digital twin of “Carbon Corridors” (i.e., connected regions of protected forests/vegetation. They store carbon and maintain habitat connectivity for biodiversity) in Central Africa to: understand the current conditions; assess their ability to store carbon and promote biodiversity; forecast future conditions; conduct what-if scenarios to assess the impact of policy decisions and potential climate conditions.
Atmospheric Boundary Layer	An Earth system digital twin of the atmospheric boundary layer to provide a digital replica of the lowest portions of the atmosphere and of their processes and interactions with other systems – land, ocean, and ice surfaces – and how these interactions control exchanges with materials such as trace gases, aerosols; coupled atmospheric systems to understand underlying processes and their relationship to climate and air quality, the role of these interactions on the global weather and climate system; atmospheric systems related to greenhouse gasses (GHG), sources of pollution, and their transport in the atmosphere to understand air quality and human health impacts at multiple scales from hyper local to long term global climate projections; proper characterization of the Planetary Boundary Layer (PBL) is also critically important for modeling nighttime minimum temperatures for agricultural applications, and for prediction of wildland fire risk.
Coastal Zone	An Earth System digital twin of local and regional coastal zones that considers 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 the 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.

Current ESDT Awards

- **Analytic Collaborative Frameworks (ACF) Towards ESDT**

PI's Name	Organization	Title	Synopsis
Thomas Allen	Old Dominion University	Pixels for Public Health: Analytic Collaborative Framework to Enhance Coastal Resiliency of Vulnerable Populations in Hampton Roads, Virginia (VA)	Proposes to design and operationally demonstrate a system linking the VA Open Data Cube, a socio-spatial-health information “Digital Neighborhood” (Hampton Roads Biomedical Research Cons.), hydrodynamic models, and in-situ flood sensor network. Will connect observational and physical environmental domains with human vulnerability.
Arlindo Da Silva	NASA Goddard Space Flight Center (GSFC)	An Analytic Collaborative Framework for the Earth System Observatory (ESO) Designated Observables	Will develop an Analytic Collaborative Framework for the Earth System Observatory (ESO) missions, based on realistic, science-based observing system simulations and the Program of Record (PoR), tied together in a cloud-based cyberinfrastructure. Create a 3D, holistic view of Earth with all ESO unique satellites.
Thomas Huang	NASA Jet Propulsion Laboratory (JPL)	Fire Alarm: Science Data Platform for Wildfire and Air Quality	Proposes to advance AIST's Air Quality Analytics Collaborative Framework (AQACF) to establish a wildfire and air quality ACF, Fire Alarm, focusing on the prediction and analysis of wildfire, burned area and the air quality as an integrated platform to guide decision-makers, science researchers, and first-responders.

Current ESDT Awards (cont.)

- **ESDT Infrastructure**

PI's Name	Organization	Title	Synopsis
Thomas Clune	NASA Goddard Space Flight Center (GSFC)	A Framework for Global Cloud Resolving OSSEs	Will enable global, cloud-resolving Observing System Simulation Experiments (OSSEs) by addressing key computational challenges to enable existing technologies to scale to the spatial resolutions needed by the end of decade, e.g., extending parallel I/O capabilities, adopting a 2-phase Nature Run approach and a flexible API for customization.
Thomas Grubb	NASA Goddard Space Flight Center (GSFC)	Goddard Earth Observing System (GEOS) Visualization And Lagrangian dynamics Immersive eXtended Reality Tool (VALIXR) for Scientific Discovery	Proposes to develop a scientific exploration and analysis mixed augmented and virtual reality tool with integrated Lagrangian Dynamics (LD) to help scientists identify, track, and understand the evolution of Earth Science phenomena in the NASA GEOS model. It will provide both a scientific discovery tool and a model analysis and improvement tool.
Matthias Katzfuss	Texas A&M University (TAMU)	A scalable probabilistic emulation and uncertainty quantification tool for Earth-system models	Proposes to develop a fully automated toolbox for uncertainty quantification in Earth-system models, to provide insight into the largest and most critical information gaps and identify where potential future observations would be most valuable. It would allow interpolation between observed covariate values and running extensive what-if scenarios.
Tanu Malik	De Paul University	Reproducible Containers for Advancing Process-oriented Collaborative Analytics	Aims to establish reproducible scientific containers that are easy-to-use and are lightweight. Reproducible containers will transparently encapsulate complex, data-intensive, process-oriented model analytics, will be easy and efficient to share between collaborators, and will enable reproducibility in heterogeneous environments.

Current ESDT Awards (cont.)

- **AI and ML-based Surrogate Modeling for ESDT**

PI's Name	Organization	Title	Synopsis
Allison Gray	Univ. of Washington, Seattle	A prototype Digital Twin of Air-Sea Interactions	Proposes to develop hybrid physics-informed AI model that ingests several existing flux estimates and observation data products and train against simultaneous ocean-atmosphere data from Saildrones. This will ascertain uncertainty of existing flux measurements and optimize combination of near-real-time existing flux data and observational data => This represents the first step towards a Digital Twin for the Planetary Boundary Layer.
Christopher Keller	Morgan State University (MSU)	Development of a next-generation ensemble prediction system for atmospheric composition	Proposes to develop a next-generation modeling framework for the real-time simulation of reactive gases and aerosols in the atmosphere. Will deploy computationally efficient parameterizations of atmospheric chemistry and transport and will develop generative models based on machine learning (ML) to predict model uncertainties.
Gavin Schmidt	NASA Goddard Inst. for Space Studies (GISS)	Development of digital twin technologies for climate projections	Will develop digital twin technologies that can be used to enhance the development of climate models, the weighting of model projections, the scope of climate projection scenarios, and the ability to extract useful data from those projections. The project will tackle four specific examples that use a variety of Machine Learning (ML) techniques in cases where digital twin technology is likely to make a difference.
Jouni Susiluoto	NASA Jet Propulsion Laboratory (JPL)	Kernel Flows: emulating complex models for massive data sets	Proposes a general-purpose, versatile emulation tool to provide fast, accurate emulation with little tuning, to scale up to very large training sets, and to provide uncertainties associated with outputs. This tool set will facilitate large-scale implementation of forward modeling and retrievals, and of UQ at production scales. To be applied to SBG radiative transfer emulation & convective storm nowcasting.

Current ESDT Awards (cont.)

- **ESDT Prototypes**

PI's Name	Organization	Title	Synopsis
Rajat Bindlish	NASA Goddard Space Flight Center (GSFC)	Digital Twin Infrastructure Model for Agricultural Applications	Will develop an agriculture productivity modeling system over Continental United States as an example of incorporating representations of infrastructure-oriented process, for the understanding, prediction, and mitigation/response of Earth system process variability, with application to crop growth, yield, and agricultural production information, critical to commodity market, food security, economic stability, and government policy formulation.
Milton Halem	*University of Maryland, Baltimore County (UMBC)*	*Towards a NU-WRF based Mega Wildfire Digital Twin: Smoke Transport Impact Scenarios on Air Quality, Cardiopulmonary Disease and Regional Deforestation*	*Will develop and implement a Regional Wildfire Digital Twin (WDT) model with a sub-km resolution to enable the conduct of mega wildfire smoke impact scenarios at various spatial scales and arbitrary locations over N. America. WDT will provide a valuable planning tool for impact scenarios by season, location, intensity, and atmospheric state.*
Thomas Huang	NASA JPL, GSFC and LaRC	Integrated Digital Earth Analysis System (IDEAS)	IDEAS is a NASA ESTO/AIST Earth System Digital Twin project that bridges the physical environment and its virtual representation by continuously assimilating new observations to improve forecast and prediction for integrated science and decision support. Multi-Agency and multi-center partnership, uses water cycle and flood analysis as the prototype application to integrate NASA, CNES, and Space Climate Observatory (SCO) data and science models. Scenario-based prediction for infrastructure and population impacts.
Craig Pelissier	Science Systems and Applications, Inc. (SSAI)	Terrestrial Environmental Rapid-Replicating Assimilation Hydrometeorology (TERRAHydro) System: A machine-learning coupled water, energy, and vegetation terrestrial Earth System Digital Twin	Proposes to develop a terrestrial Earth System Digital Twin (TESDT) that couples state-of-the-art ML with NASA (and other) EO data. It will combine the best ML hydrology models with capabilities for uncertainty quantification and data assimilation to provide ensemble & probabilistic forecasting, sensitivity analyses, and counterfactual “what if" experiments.
Alex Ruane	NASA Goddard Inst. for Space Studies (GISS)	An Urban Information System to Assess Neighborhood Climate Risk and Daily Exposures in Cities	Will develop an urban-focused information system that enables city dwellers to explore the interactions between weather and climate risks and neighborhood-level hazards and the interconnectedness of urban systems. This system will be built to focus on enhancing emergency preparedness as well as applicability to a wide range of urban neighborhoods within and beyond New York City.

ESDT Workshop
October 26-28, 2022

- Includes additional information about ESDT current projects
- Report available on AIST Website:

https://esto.nasa.gov/files/ESDT_Workshop_Report.pdf

For more information contact AIST Program Manager:
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Advanced Information Systems Technology (AIST)
Earth Systems Digital Twin (ESDT)
Workshop Report

Jacqueline Le Moigne – NASA Earth Science Technology Office
Benjamin Smith – NASA Earth Science Technology Office

Workshop Co-Organized with Earth Science Information Partners (ESIP)
Report Edited by ESDT Workshop Participants

October 26-28, 2022
Washington, D.C.

ESTO
EARTH SCIENCE TECHNOLOGY OFFICE

AIST Early-Stage Technology (EST)
AI and Quantum Computing

AIST-21 EST Awards in AI

- **EST in Novel AI**

PI's Name	Organization	Title	Synopsis
Yulia Gel	Univ. of Texas at Dallas	Innovative geometric deep learning models for onboard detection of anomalous events	Proposes to fuse two emerging directions in time-aware machine learning: geometric deep learning (GDL) and topological data analysis (TDA). GDL offers a systematic framework for learning non-Euclidean objects with a distinct local spatial structure allowing for more flexible modeling of complex interactions, while TDA yields complementary information on the time-conditioned underlying intrinsic ES system organization at multiple scales. Ultimately for onboard learning, detection and analysis, e.g., smoke observations.
Alison Gray	Univ. of Washington	DTAS: A prototype Digital Twin of Air-Sea interactions	Proposes to develop a hybrid physics-informed artificial intelligence model that ingests several existing flux estimates and observational data products to train against flux estimates computed from measurements collected by Saildrones, state-of-the-art autonomous platforms for simultaneous ocean-atmosphere observation. The goal is to improve interpretability and to better extrapolate those models beyond the training data. Will focus on the Gulf Stream region and will prepare for a future Digital Twin of the boundary layer air-sea interactions.
Saurabh Prasad	Univ. of Houston	Knowledge Transfer for Robust GeoAI Across Space, Sensors and Time via Active Deep Learning	Proposes to develop a ML framework and associated open-source toolkit for robust analysis of multi-sensor remotely sensed data using deep learning, multi-modal knowledge transfer between sensors, space and time, for semi-supervised and active learning. Will be comprised of a generative adversarial learning-based knowledge transfer framework, multi-branch feed forward networks to transfer model knowledge, and semi-supervised knowledge transfer. Initially developed for EO-based agricultural sensing but widely applicable to other applications.
Yiqun Xie	University of Maryland	Coupled Statistics-Physics Guided Learning to Harness Heterogeneous Earth Data at Large Scales	Will explore new model-agnostic learning frameworks to explicitly incorporate spatial heterogeneity awareness and physical knowledge: (1) Develop statistically-guided framework to automatically capture spatial footprints of data and build a heterogeneity-aware deep network; (2) Improve interpretability and generalizability for data-sparse regions with physics-guided ML architectures to incorporate domain knowledge. Results will be evaluated using Land Cover and Land Use Change (LCLUC) mapping and surface water monitoring.

AIST-21 EST Awards

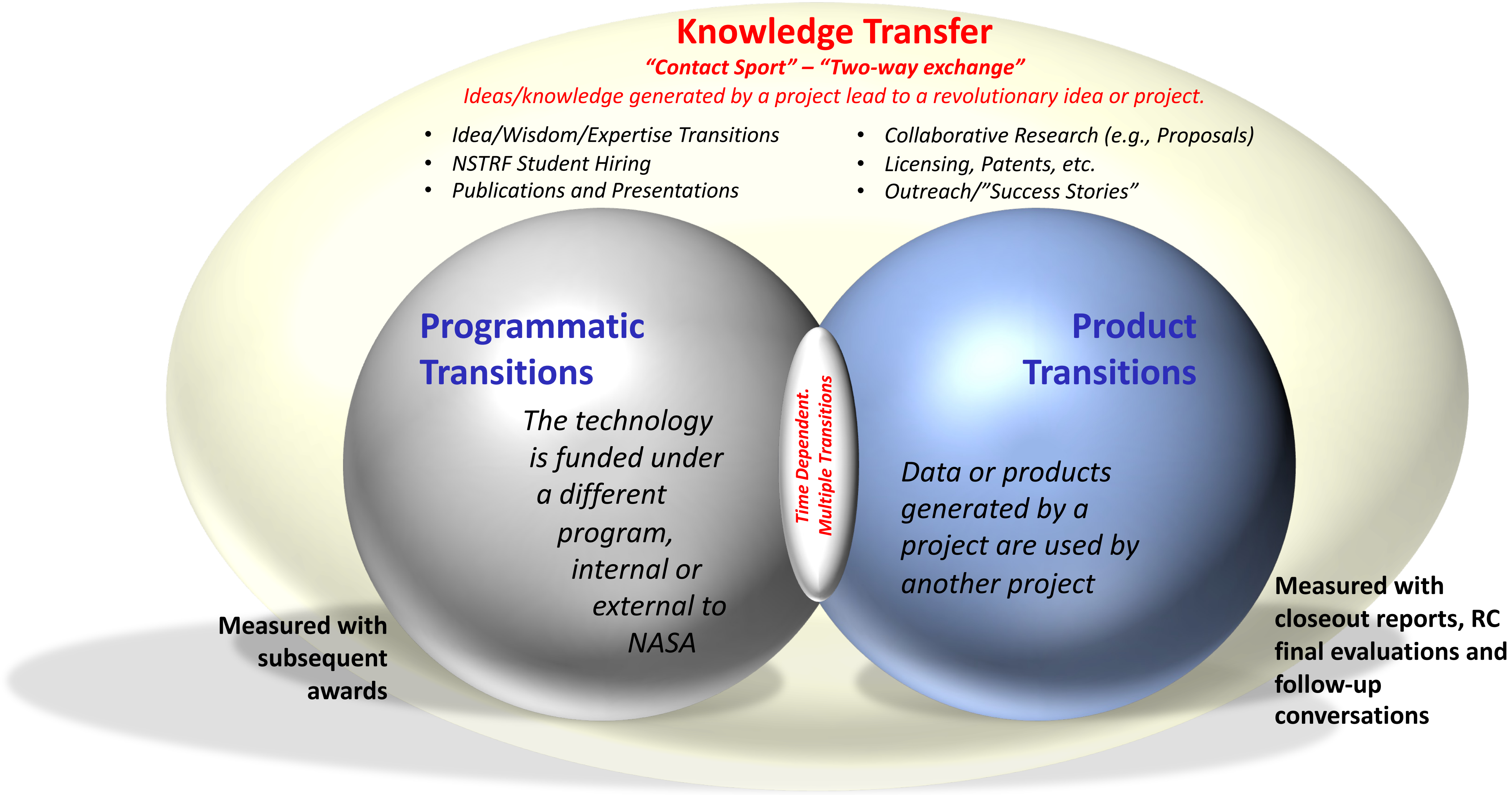
- **EST in Quantum Computing**

PI's Name	Organization	Title	Synopsis
Alexandre Guillaume	NASA Jet Propulsion Laboratory (JPL)	Stochastic parameterization of an atmospheric model assisted by quantum annealing	Will create a quantum computing framework to characterize a stochastic parameterization of the boundary layer clouds constrained by remote sensing data. Will use similarity of both, stochastic parameterization and quantum hardware, to the regular lattice known as Ising model, to leverage the quantum computing efficiency. (1) Implement Restricted Boltzmann Machine (RBM) using D-Wave quantum annealer; (2) Use this ML method to determine the parameters of a stochastic parameterization of the stratocumulus cloud area fraction (CAF) when it is coupled to the dynamics of large-scale moisture.
Shon Grabbe	NASA Ames Research Center	A Path Towards Quantum-Computing-Assisted Earth Science Data Acquisition Tasking and Processing	Will build on the NASA Quantum Artificial Intelligence Laboratory (QuAIL) team's expertise in quantum and classical optimization to coordinate and dynamically task a constellation of space-based and air-based assets in an agile fashion to respond to changes driven by extreme events. It will identify triggers in Earth science datasets that lead to missing, noisy, or sparse datasets and develop quantum-assisted and classical approaches to optimize the allocation of Earth science observational assets to dynamically respond to these historically derived triggers.

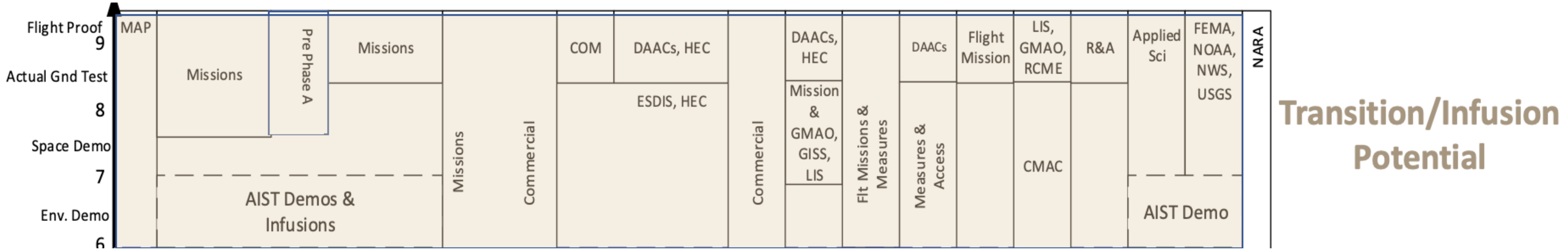
AIST Transitions

Infusion or Transition => Measuring Impact

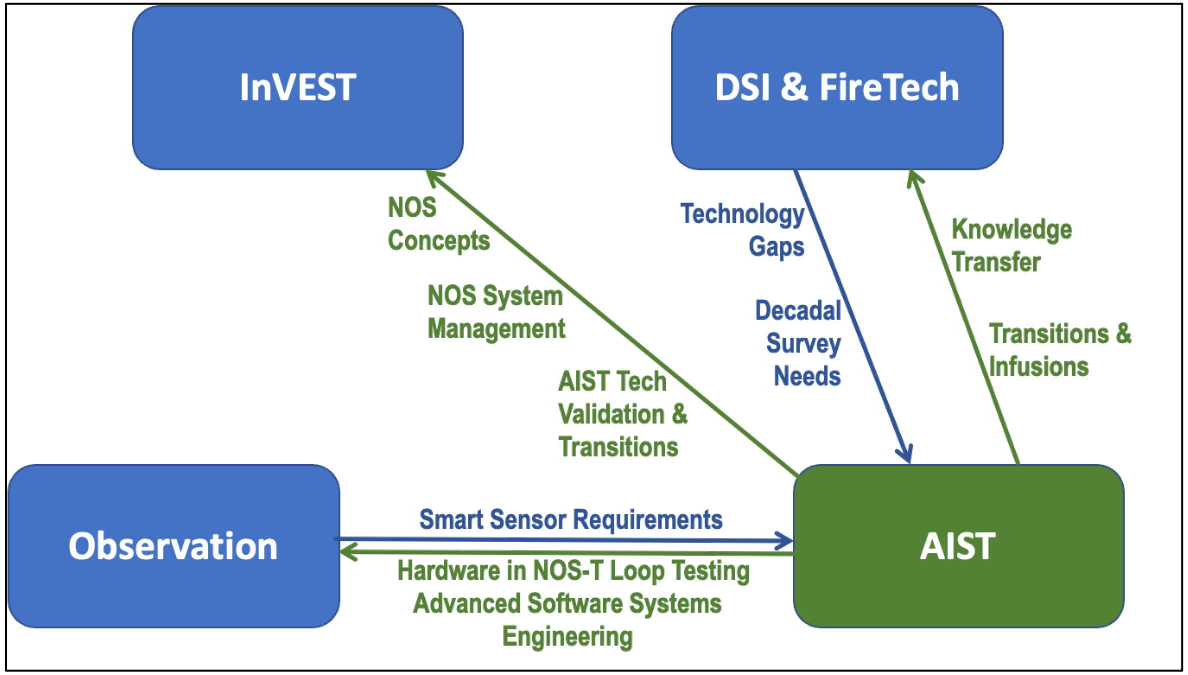
A "transition" occurs when a technology *continues* to evolve and/or to be developed, *but with some change* (could be programmatic, technical or application-related)



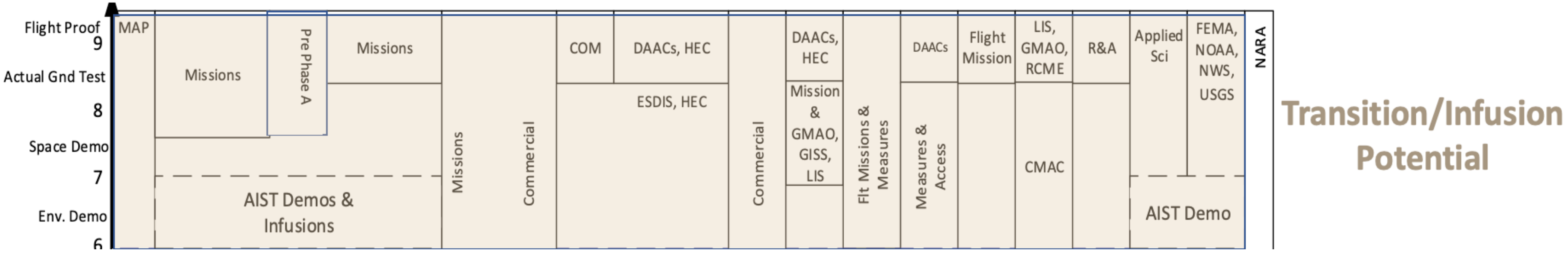
AIST Potential Transitions/Infusions



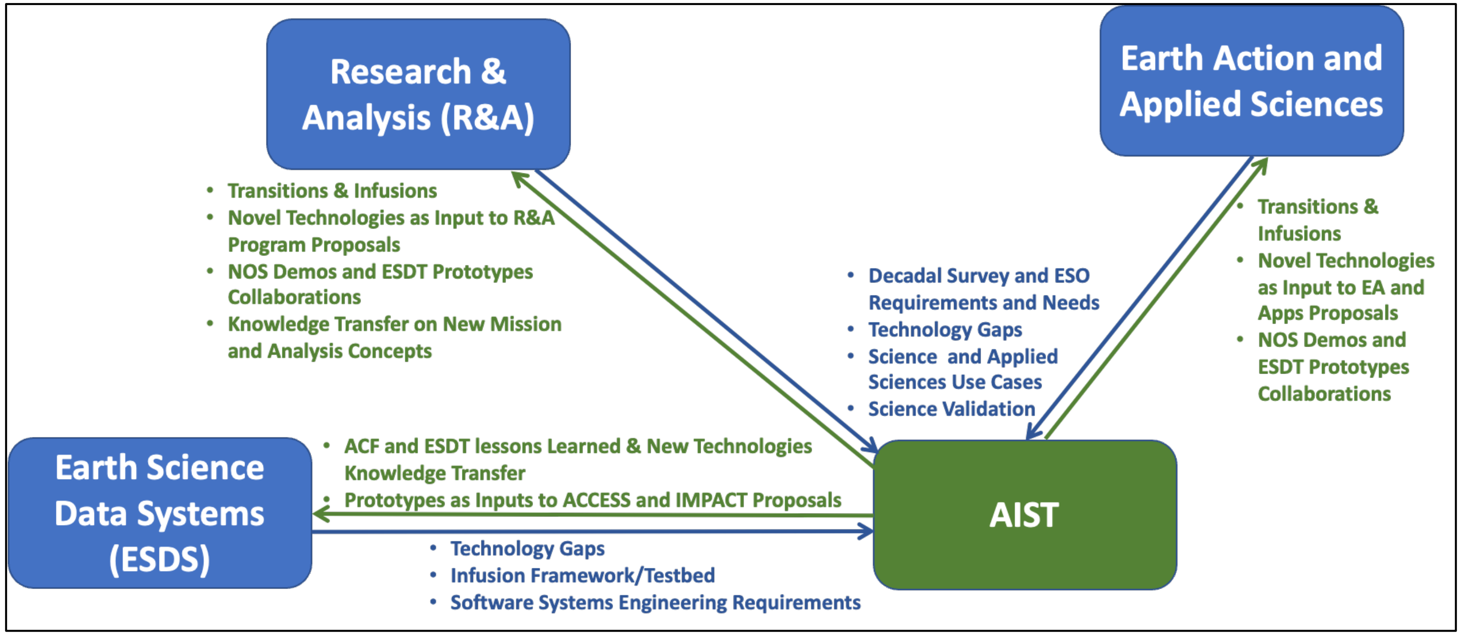
Within ESTO



AIST Potential Transitions/Infusions



Within ESD



Projects Final Reports and Quads
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