NASA Novel Observing Strategies for Earth Observations

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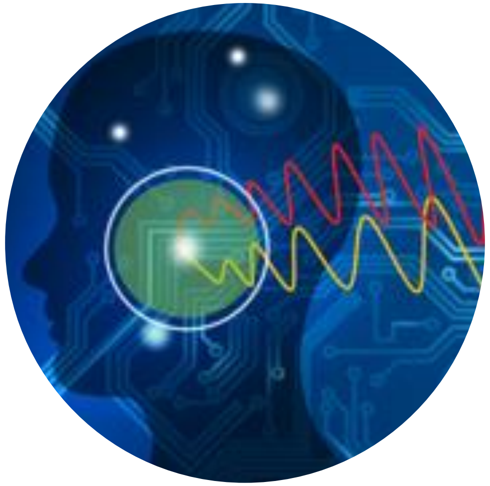
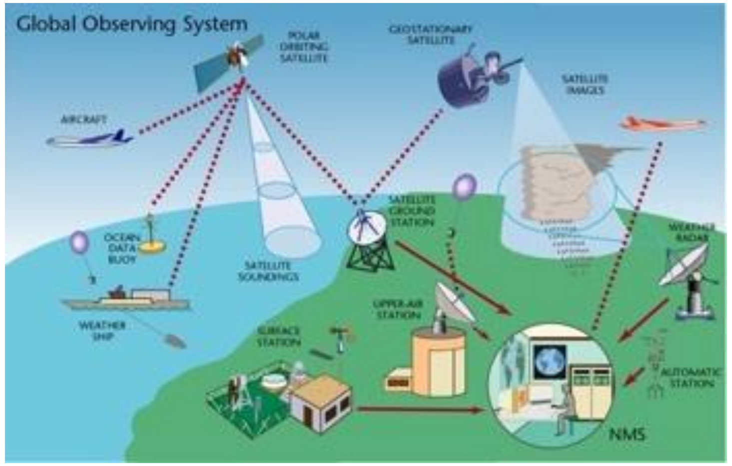
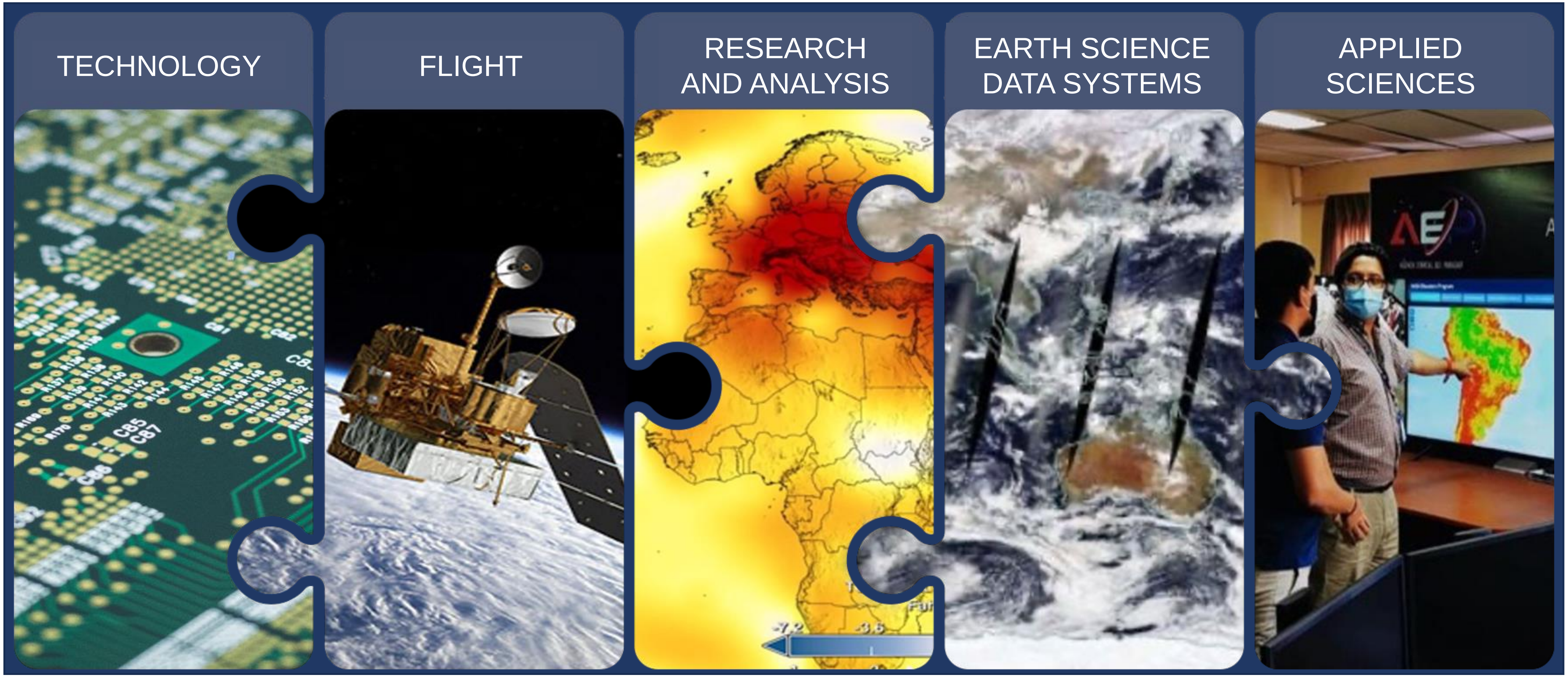




Louis Nguyen
Jacqueline Le Moigne

Dec 2024

Earth Science at NASA



Earth Science Technology Office

Earth Science Technology Office (ESTO) *Program Elements*

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Advanced Technology Initiatives

Advanced Component Technologies (ACT) :
Critical components and subsystems for advanced instruments and observing systems. Average award: $400k per year over 2-3 years.

FireSense Technology :
New observation and predication capabilities for understanding and managing wildfires.

In-Space Validation of Earth Science Technologies (InVEST) :
On-orbit technology validation and risk reduction for small instruments and instrument systems. Average award: $3M per year over 3 years.

Instrument Incubator Program (IIP)

Innovative remote sensing instrument developments from breadboard and demonstration through maturation to TRLs 4-6.

- *Instrument Development and Demonstration (IDD)* average award: $1.5M per year over 3 years.
- *Instrument Technology Maturation (ITM)* average award: $2.5M over 2 years, starting with IIP-23

Quantum Gravity Gradiometer (QGG): A pathfinder demonstration to collect more precise measurements of Earth's gravitational field.

Intelligent Systems Technologies (IST)

Innovative information systems for: new measurement collection through distributed sensing; Science missions ROI optimization; agile Science investigations; integrated information frameworks for mirroring Earth systems evolution and what-if scenarios.

- *Demonstrations & Prototypes (D&P)* average award: $1,300K per year over 3 years
- *Advanced & Emerging Technology (AET)* average award: $650k per year over 2 years.
- *Early-Stage Technology (EST)* average award: $600k total over 1.5 years

Decadal Survey Incubation (DSI)

Maturation of observing systems, instrument technologies, and measurement concepts for Planetary Boundary Layer (PBL) and Surface Topography and Vegetation (STV).

- Average tech award: $500k per year for 3 years.
- Average science award: $200k per year for 3 years.
- Average OSSE award: $200k per year (STV) / $500k per year (PBL) for 2 years.

Sustainable Land Imaging-Technology (SLI-T)

Development of engineering prototypes and component/instrument demonstrations that will reduce the risk, cost, size, volume, mass, and development time of the next generation of Landsat instruments.

- *Advanced Technology Demonstration (ATD)* average award: $2M per year over 4 years.
- *Technology Investment (TI)* average award: $500k per year over 3 years.

Earth Science Technology Office (ESTO)

Intelligent Systems Technologies (IST)

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Current & Future Earth Science Missions

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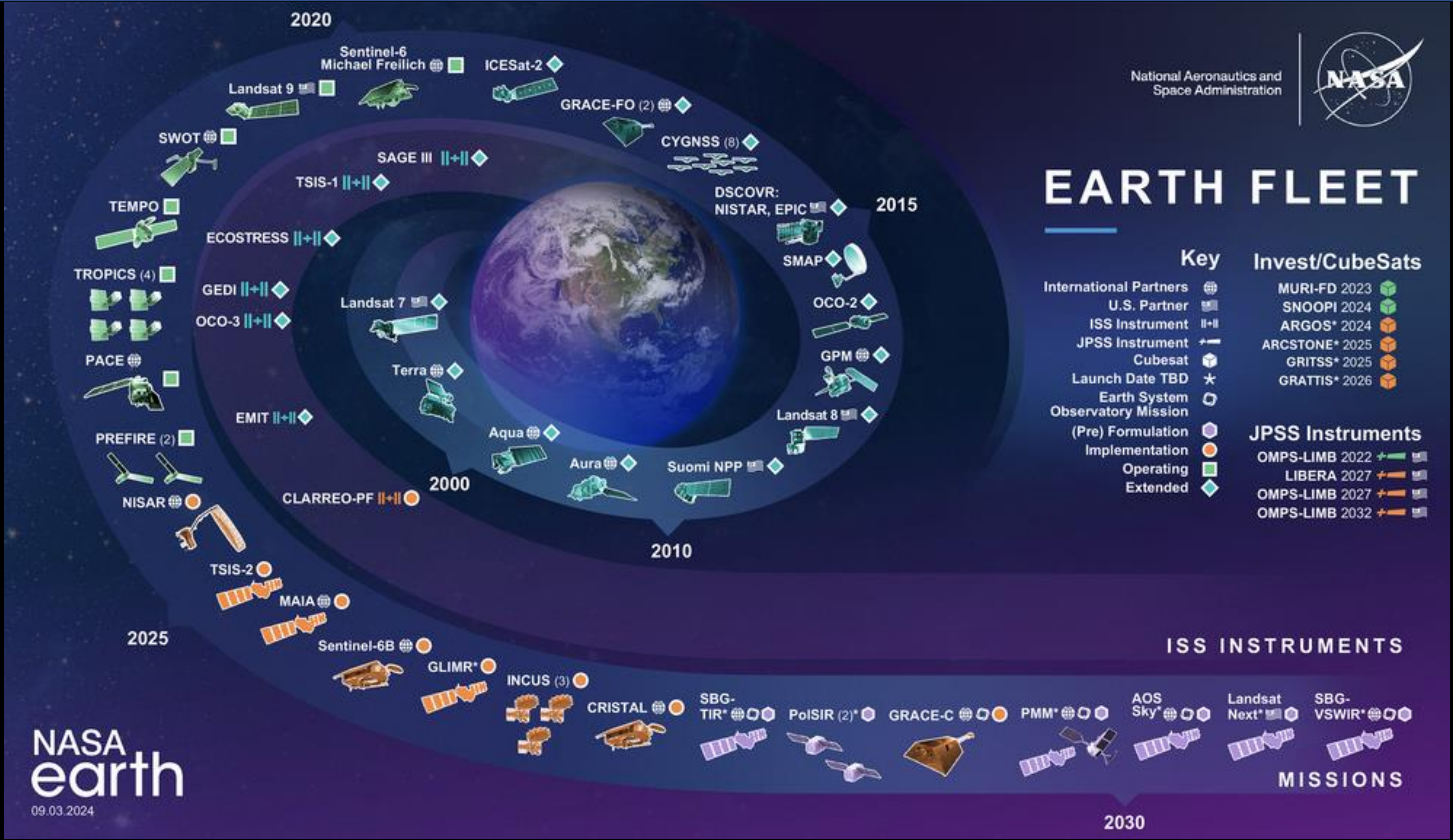

Novel Observing Strategies (NOS) for Earth Science

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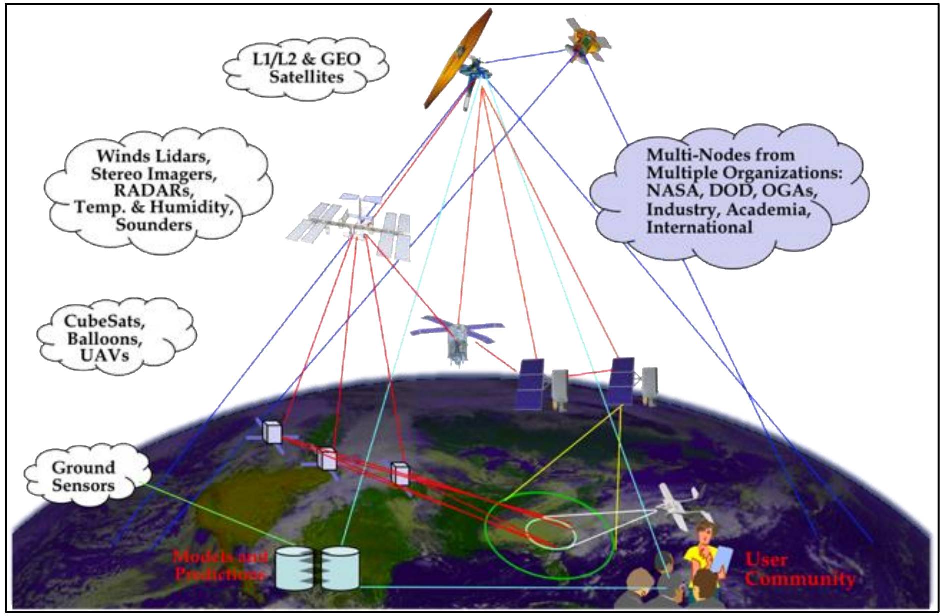
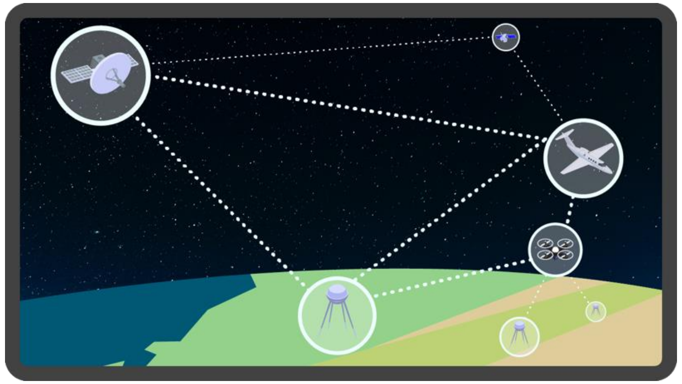
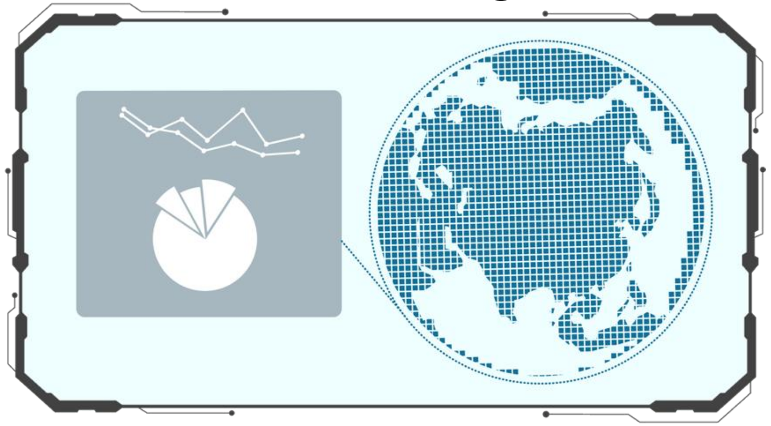
2005 SensorWeb Concept



Drive Coordinated, Event-Driven Observations



Optimize current & future Mission Portfolio and Mission Design



NOS VISION:

- Provide a dynamic and more complete picture of physical processes or natural phenomena
- Leverage multiple collaborative sensor nodes producing measurements integrated from multiple vantage points and in multiple dimensions (spatial, spectral, temporal, radiometric)

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

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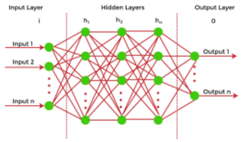
NOS: Generalized SensorWeb Concept where each Node can be Individual Sensor, a Constellation of Sensors, a Model, some Data Record, IoT Sensors, Social Media, etc.

Resources

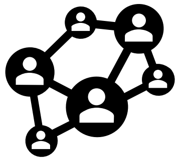
Data

Sensors & Platforms



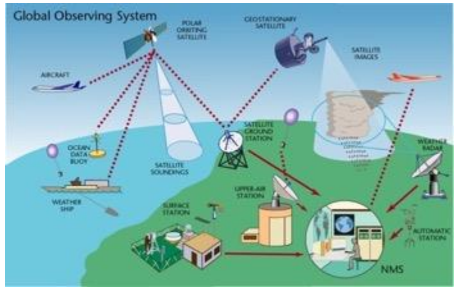
Models

Algorithms



IoT & Social Media

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



Observation Strategy

NOS Application Cases

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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 mid-term Air Quality or long-term Climate models*	*Select observing strategy to optimize all measurements that will improve long-term 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)

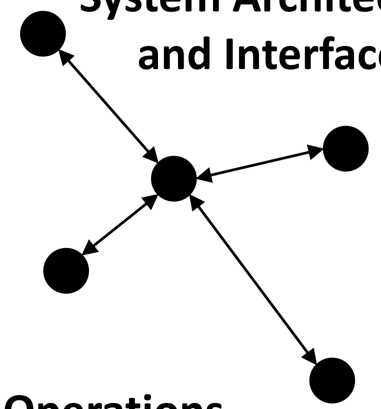
Novel Observing Strategies Testbed/Framework

- 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”

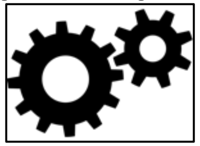
Testbed Main Goals:

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.

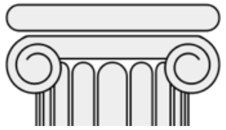
System Architecture and Interfaces



Concept of Operations



Governance Model



NOS-T framework objective:

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

Novel Observing Strategies (NOS)
AIST Projects and Activities

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- **19 NOS projects funded since 2018 in the following areas:**
  - Observing System Simulation Experiments (OSSEs) and Mission Design
  - Smart Sensors and Onboard Intelligence
  - UAS Integration and NOS Prototypes
  - NOS Architecture Infrastructure and Cybersecurity
- **NOS-Testbed Activities:**
  - 10 technology projects funded
  - 3 demonstrations conducted between 2019 and 2022
  - Future demonstrations planned
  - Future integration of NOS and ESDT

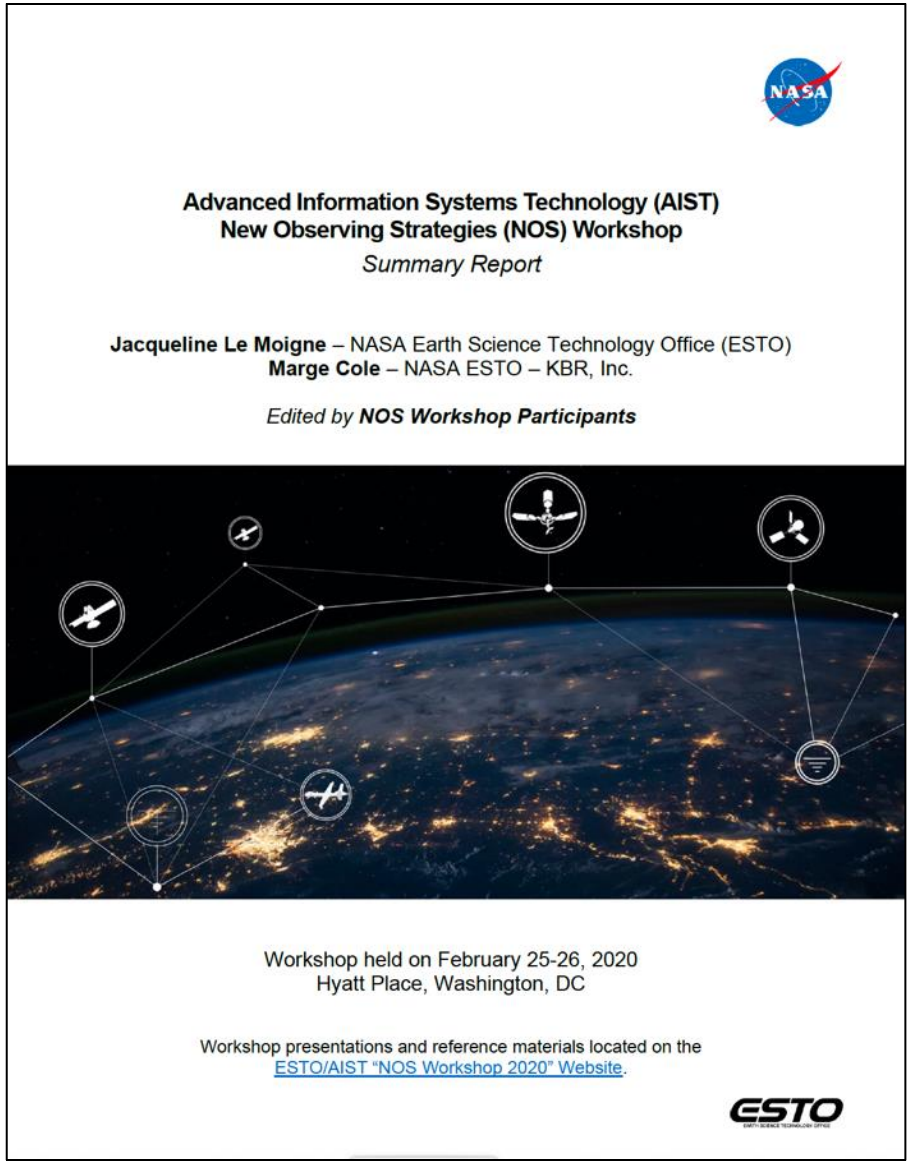
NOS-T Historical Flood Demonstration → NOS-T Live Flood Demonstration (If/When Live Event Happens) → NOS + NOS-T Live (NOS-L) Live Science Demonstration → **AIST-23: AET and D&P – NOS Activities related to Future Measurements and iESO Activities**

Early Spring 2021:
- NOS-T Node Coordination
- Simulated Trigger Generation
- Integration of *Historical* Data **On Demand**
- Ground Station as a Service (GSaaS) *Simulation* Demonstration

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

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

NOS References



Advanced Information Systems Technology (AIST)
New Observing Strategies (NOS) Workshop
Summary Report

Jacqueline Le Moigne – NASA Earth Science Technology Office (ESTO)
Marge Cole – NASA ESTO – KBR, Inc.

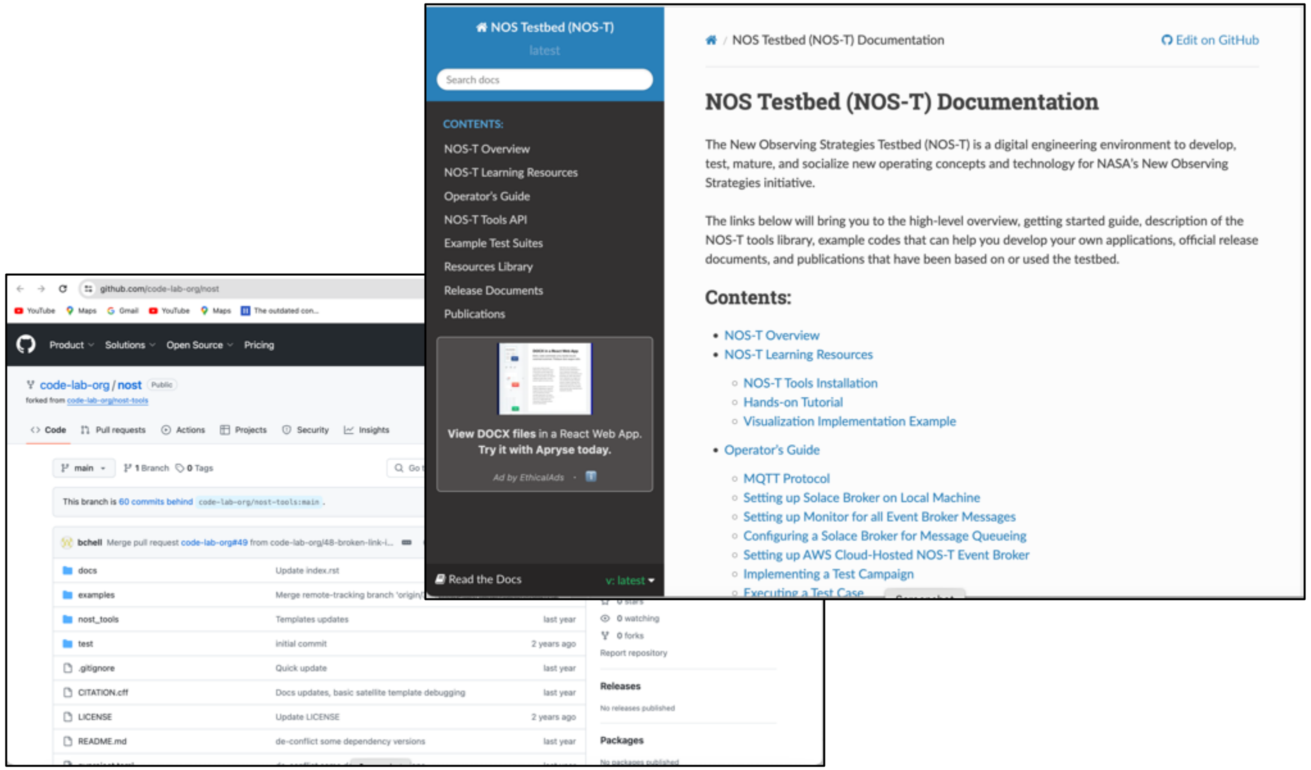
Edited by ***NOS Workshop Participants***

Workshop held on February 25-26, 2020
Hyatt Place, Washington, DC

Workshop presentations and reference materials located on the ESTO/AIST "NOS Workshop 2020" Website.

NOS Workshop Report available on AIST Website: https://esto.nasa.gov/wp-content/uploads/2021/02/AIST-NOS-Workshop-Report.pdf

NOS-Testbed Architecture Framework Documentation and Open-Source Software available at: https://nost.readthedocs.io/en/latest/ and https://github.com/code-lab-org/nost



IoT4EO Related Projects

Funded by ESTO Program

GSON: Ground Station Observation Network
AIST-QRS-20 Nguyen (NASA LaRC)

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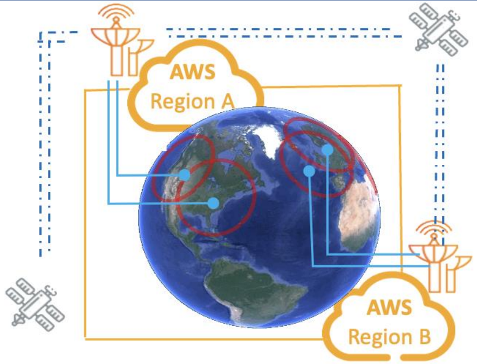
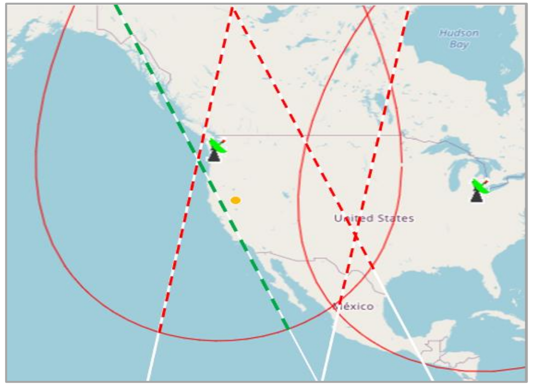


*GSON is a proof-of-concept demonstration that uses smart tasking (planner and scheduler) of **Amazon Ground Station as a Service (GSaaS)** to deliver low latency LEO data*

Amazon Ground Station as a Service

- Provides global network of GS
- On-boarding and Scheduling
- Command, control, and Downlink
- Antenna supports X- & S- Band
- Pay as you go service model

GSON smart tasking of GSaaS for reserving high volume satellite downlinks

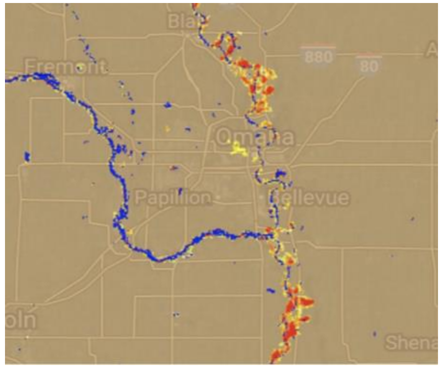


GSON Participates in NASA AIST New Observing Strategies Testbed (NOS-T) Flood Demonstration

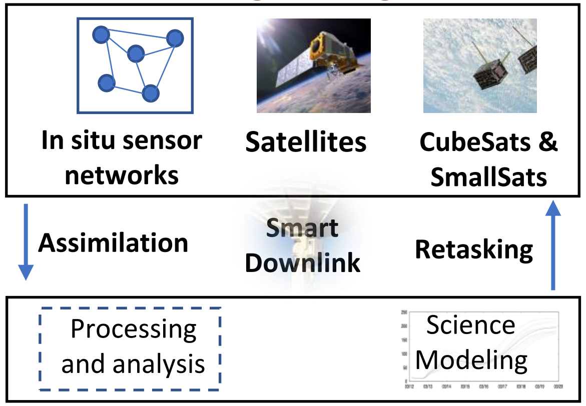
(Smith, et al., 2022, IGARSS 2022)

- Overflow of stream gauge sensors triggers GSON smart tasking
- Automated planning, scheduling and job orchestration (reception & processing workflows)
- GSON delivers low latency VIIRS flood products to NOS-T forecast node in under ~25min

VIIRS Flood Detection



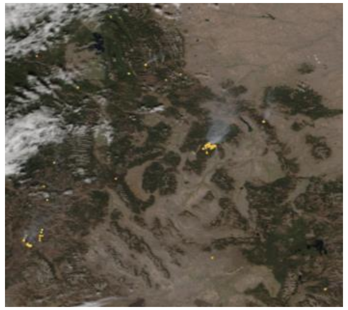
New Observing Strategies Testbed



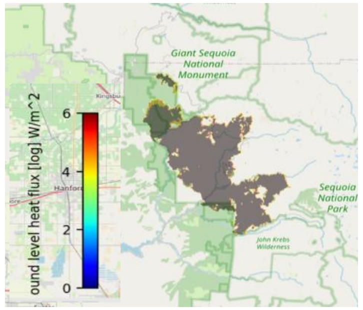
GSON Delivers Low Latency VIIRS Active Fires for WRF-SFIRE Forecasting Demonstration

- Monitors area of interest and delivers VIIRS Active Fires <12min (reduced from 3+ hrs)
- WRF-SFIRE model ingests the low latency VIIRS active fire product to initialize fire perimeter
- Forecast initialized with low latency matches the observations best (*Hilburn, et al., 2022*)

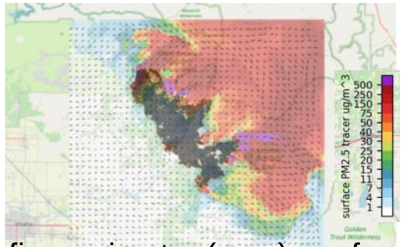
VIIRS Active Fires



Initial Fire Perimeter



WRF-SFIRE 24hr Forecast



fire perimeter (gray), surface smoke (colors), and wind

3D-CHESS: Decentralized, Distributed, Dynamic, and Sensor Systems | AIST-21 Selva (Texas A&M Univ)

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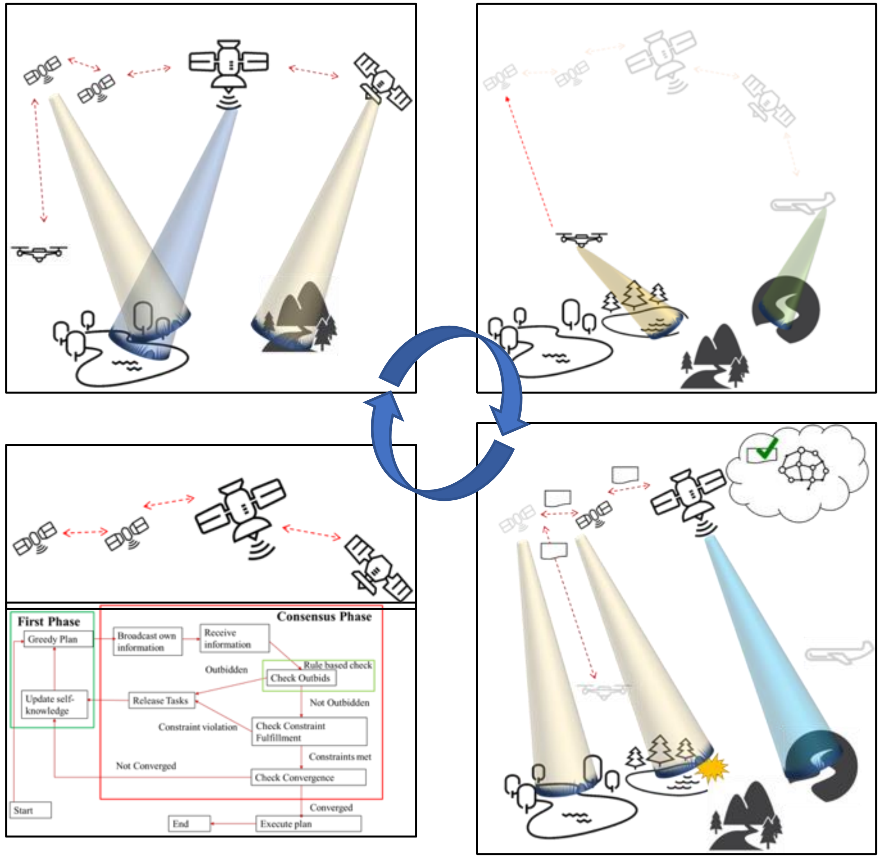
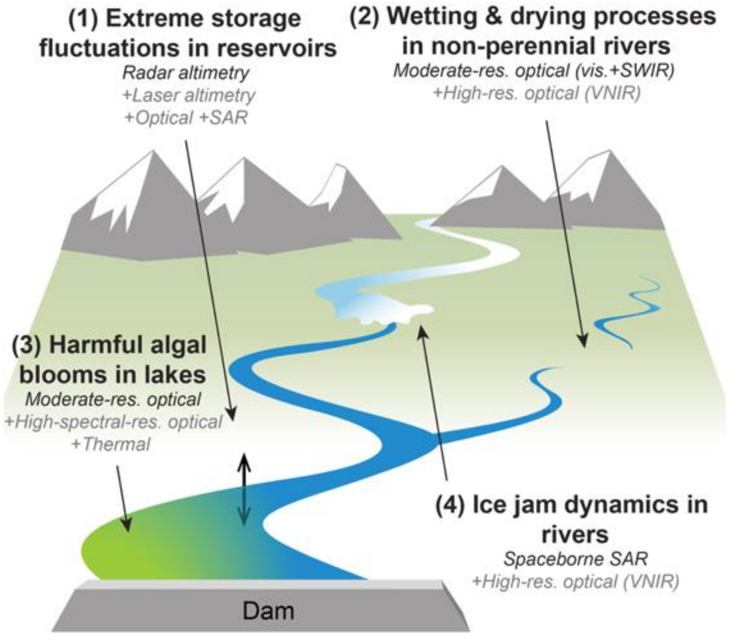
Proof of concept for a context-aware Earth observing sensor web of interconnected space, air and ground nodes.

#1 – Default Missions **#2 – Event Detected**



#4 – Decentralized Planning **#3 – Instrument Capability Reasoning**

1. **Default Missions – Data Processing**
   Each node conducts its nominal mission, following a default plan.
2. **Event Detected – Task Request Sent**
   One node detects (or predicts) an event of interest at a certain location. It sends a Task Request to the network.
3. **Instrument Capability Reasoning**
   Nodes receive the task request and use contextual information from their knowledge base and the reasoning algorithm to autonomously determine if they can perform this task.
4. **Decentralized Planning**
   Nodes enter a decentralized planning phase to coordinate The tasks. Nodes use a science-driven utility function to determine if they should perform the task at the cost of temporarily abandoning their current mission. Engineering costs (e.g., energy) are also considered. Once converged, the nodes update their plans.
5. **Updated Plans – Iterate**



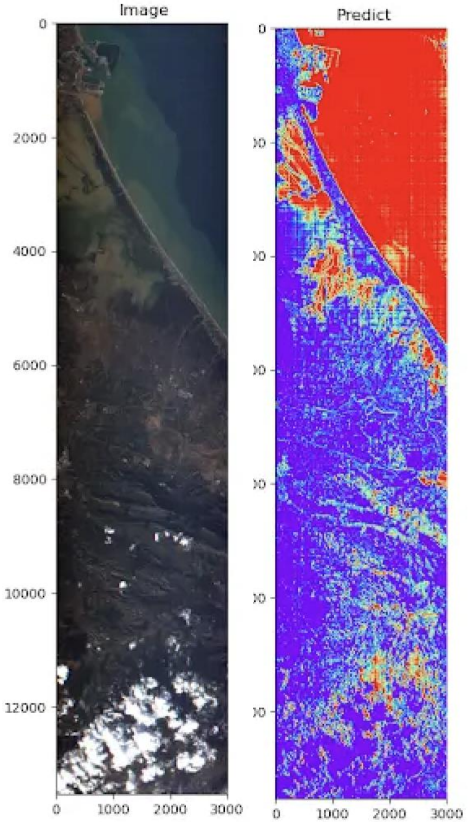
Technology feasibility and value will be demonstrated in a multi-sensor in-land hydrologic and ecological monitoring system with 4 inter-dependent objectives.

Dynamic Targeting
AIST-21 Chien (Jet Propulsion Laboratory)

ESTO Earth Science Technology Office IST

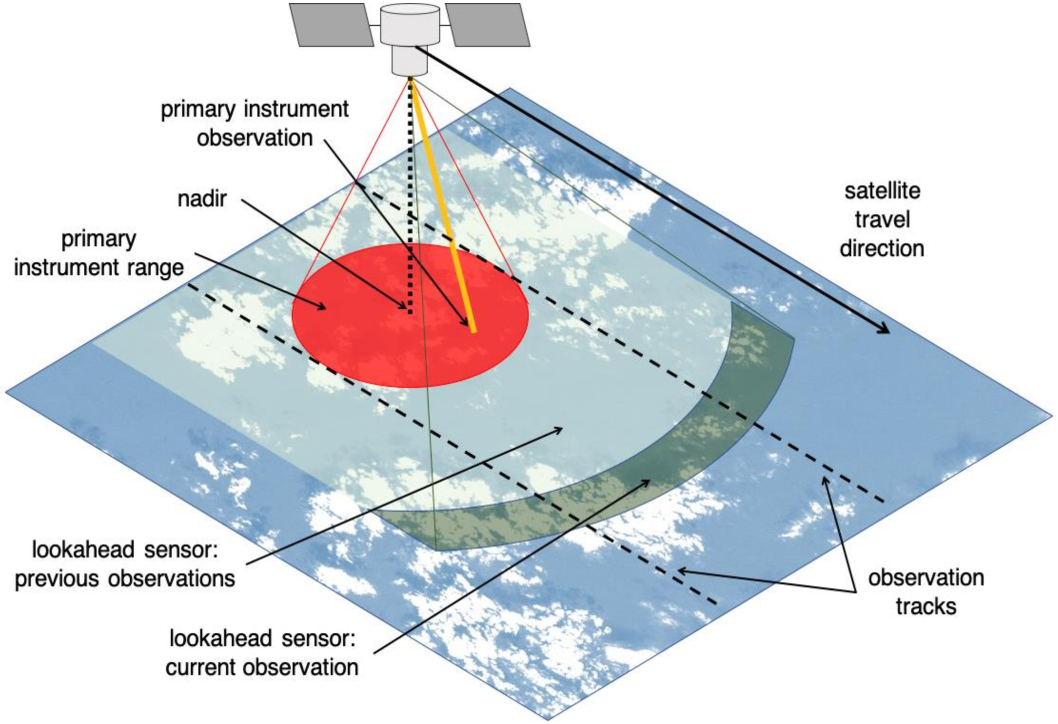
Flight of networked assets in space as well as within asset triggers.

Onboard Deep Learning, Spectral analysis, and Cross tasking



Surface water extent (red) map derived onboard CogniSAT-6 via CNN inference near Valencia, Spain
02 November 2024.

A summary message including number of flooded pixels was downlinked via ISL shortly after acquisition and analysis
(see also at ubotica.com/news)
Partners: Ubotica, Open Cosmos



Self tasking Flight on Cognisat-6 in 2025.

Dynamic Targeting Flight Opportunities:

- Fall 2024: Cognisat-6 (Ubotica/Open Cosmos), ION SCV 004 (D-Orbit), YAM-6 (Loft)
- 2025 plans to add additional spacecraft

POC: Steve Chien, JPL steve.a.chien@jpl.nasa.gov   ai.jpl.nasa.gov

D-SHIELD: Distributed Spacecraft with Heuristic Intelligence to Enable Logistical Decisions | AIST-18 Nag (NASA ARC)

ESTO Earth Science Technology Office
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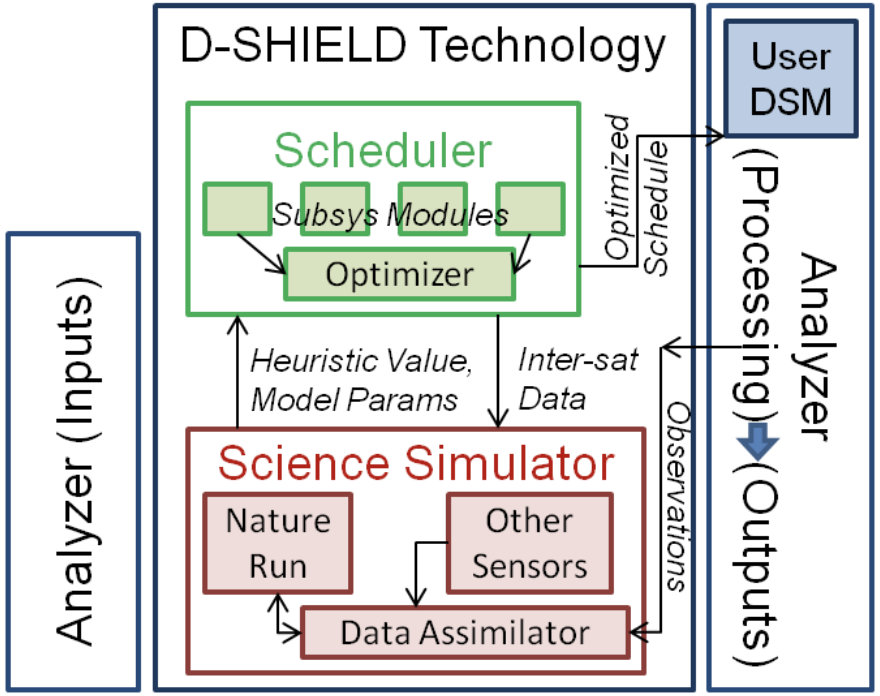
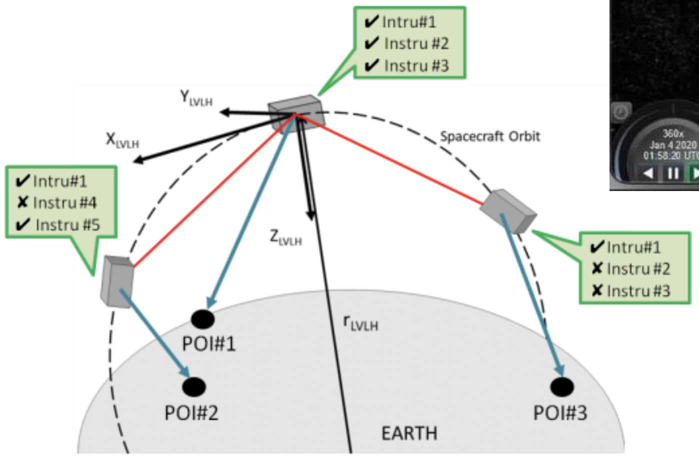
D-SHIELD is an operations design tool that will, for a given distributed space mission (DSM) architecture, plan re-orienting and operations of heterogeneous payloads, accounting for power/payload constraints while maximizing science value. It uses an iterative science observable simulator based on Observing System Simulation Experiments (OSSEs) adapted for real time planning and rapid mission design. This project contributes to the New Observing Strategy (NOS) thrust area by developing an AI-based planning and scheduling-based DSM operations tool.



D-SHIELD system diagram including data flows.



Cartoon of 3-satellite constellation with multiple instruments and D-SHIELD coordinated decisions

DSM technology gaps: need inter-satellite links to exchange data. IoT4EO service needed.

Nag (ARC/BAERI)

Observing Earth's Changing Surface Topography & Vegetation Structure (NASA's STV Incubator Study Team, 2021)

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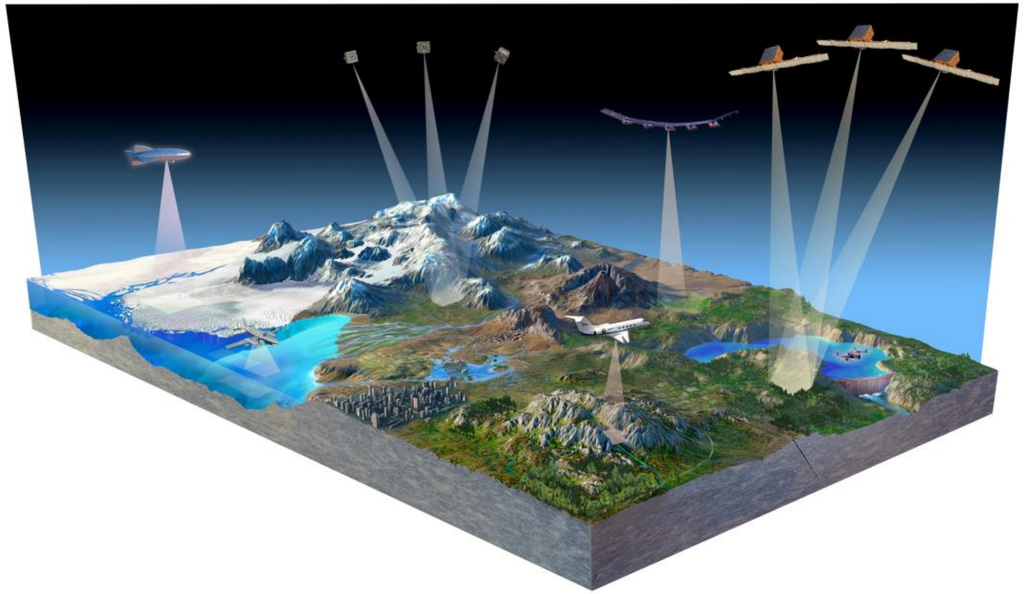
Developing high-res global observations of surface topography and vegetation structure. These observations aim to enhance understanding of Earth's changing surface and its impact on natural and human systems.

STV missions for continuous global monitoring will utilize a new observing strategies that employ flexible, multi-platform system combining spaceborne constellation of STV instruments and suborbital sensors focusing on taking global 3D topographic and vegetation observations from lidar, radar, and stereophotogrammetry.



Key Objectives:

- **Science and Applications Goals:**
  - Understanding solid Earth processes (e.g., tectonics, landslides, earthquakes)
  - Mapping vegetation structure for carbon cycle dynamics and ecosystem; monitoring cryosphere changes (glaciers, ice sheets)
  - Observing hydrological processes (rivers, wetlands, water reservoirs
  - Assessing coastal processes (erosion, storm surges, bathymetry).
- **Technology Development**
  - Advancing sensors like Lidar, radar, and stereophotogrammetry.
  - Establishing multi-platform observation systems (spaceborne and airborne).
- **Roadmap and Gaps:** Long term (7-10 years, 2028-2031)
  - Design, implement, and deliver a full spaceborne constellation of STV mission for continuous global monitoring of topographic and vegetation observations
  - Develop smart tasking systems using **sensor web** (identified as more challenging with higher benefits) for rapid response to natural disasters.
  - Real-Time processing and low-latency data delivery: large volumes of data will require edge computing and on-board satellite processing. The use of commercial downlink, station ground, and satellite-to-satellite, in-space communication networks are needed.

Source Credit: https://smd-cms.nasa.gov/wp-content/uploads/2023/06/STV_Study_Report_20210622.pdf

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