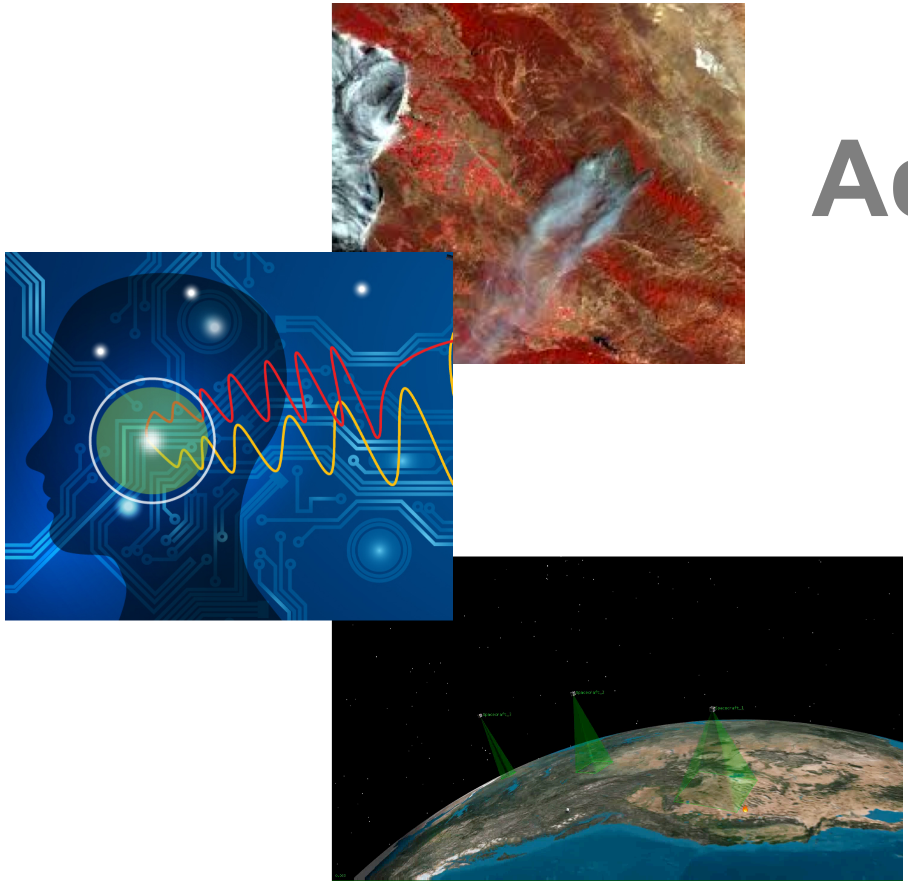


NASA Earth Science Technology Office (ESTO) Advanced Information Systems Technology (AIST) New Observing Strategies (NOS)

Jacqueline Le Moigne

2020 ESIP Winter Meeting

ESTO and AIST Goals

- **ESTO Goals**

  End-to-End Technology Development Approach

  - Identify technology needs based on Decadal Survey and annual requirements reviews
  - Develop technologies through competitive peer-reviewed solicitations
  - Assess the development strategy and maturity of funded technologies and leverage investments through internal NASA program synergy and partnerships with federal agencies, academia, and industry
  - Infuse maturing technologies into future missions and measurements

- **AIST Goals**

  Spearhead technologies that enable:

  - New and unique measurement collection capabilities through distributed sensing
  - Optimizing Science missions return on investment through flexible information integration
  - Agile Science investigations through data analytics and artificial intelligence tools and algorithms

AIST Thrusts: NOS and ACF

- **New 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 or relevant services

- **Analytic Center 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

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

DSM and Future Missions Environment

***Technology advances** have created an opportunity to make new measurements and to continue others less costly, e.g., **SmallSats** equipped with science-quality instruments and **Machine Learning** techniques permit handling large volumes of data.*

Hardware Technology Drivers:

- Instrument Miniaturization (Freeform Optics, Photonic Integrated Circuits, etc.)
- Novel Components (Metamaterials, etc.)
- Smaller Spacecraft (CubeSats and Nanosats)
- High Performance Space Processors

Software Technology Drivers:

- Big Data Analytics
- Artificial Intelligence
- Autonomous Decision Making
- Onboard Computing
- Intelligent & Collaborative Constellations and Sensor Webs

New Observation Strategies and New Missions Design:

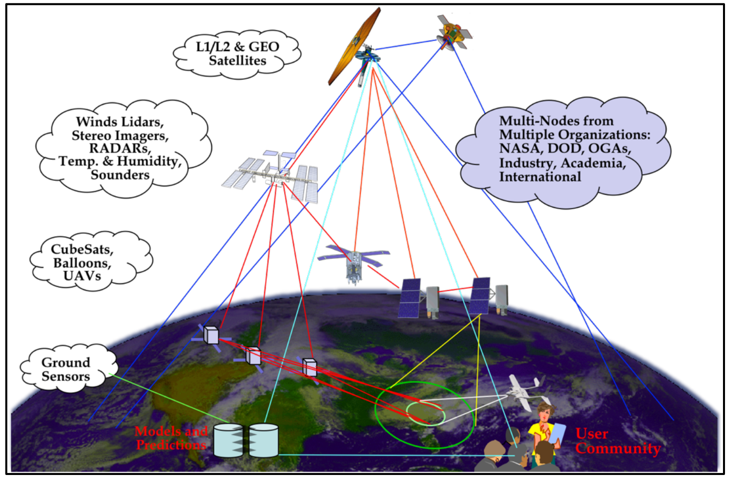
- **Utilizing Distributed Spacecraft Missions (DSM),** i.e., missions that involve multiple spacecraft to achieve one or more common goals.
- **Coordinating Space Measurements with Other Measurements (e.g., Aerial and In-Situ).**

New Observing Strategies (NOS)
=> *New Observing and Exploration Strategies*

New Observing Strategies (NOS):

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

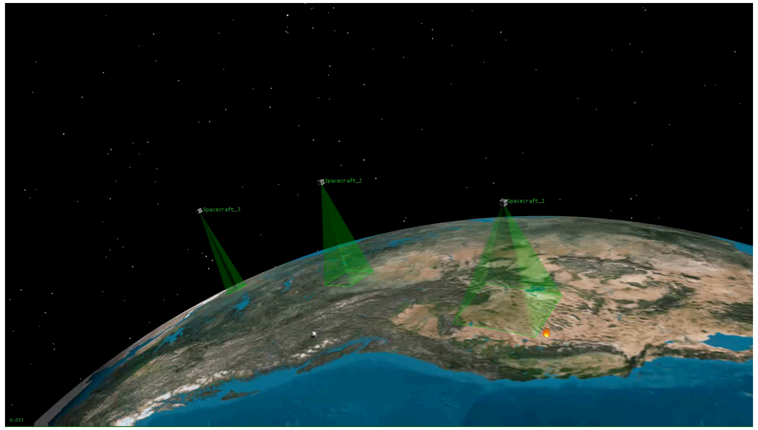
NOS Similar to SensorWeb Concept where each Node can be Individual Sensor or DSM



DSM can be a general Constellation, Formation Flying, Fractionated, etc.

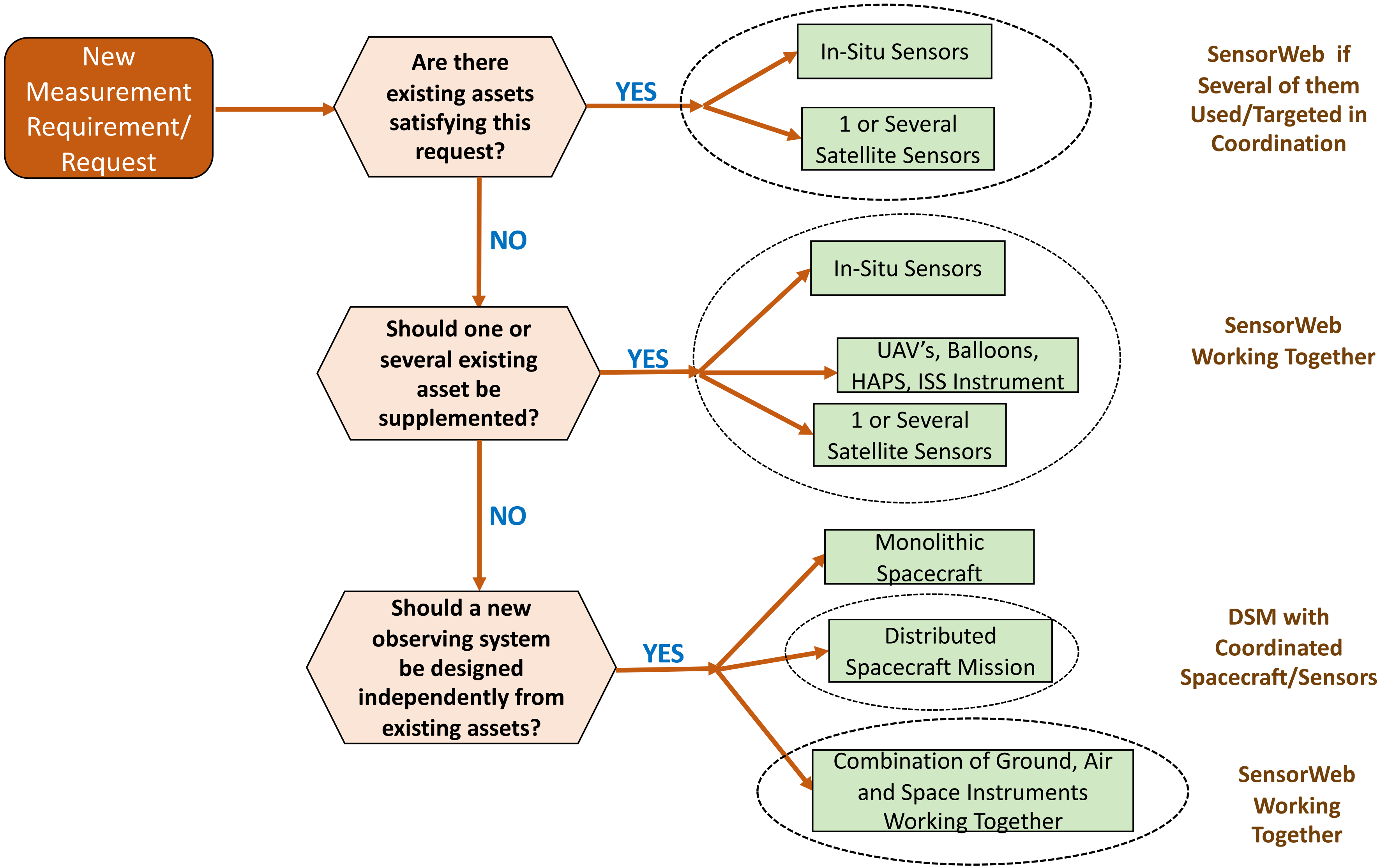
A special case of DSM is **an Intelligent and Collaborative Constellation (ICC)** which involves the combination of:

- Real-time data understanding
- Situational awareness
- Problem solving
- Planning andearning from experience
- Communications and cooperation between multiple S/C.



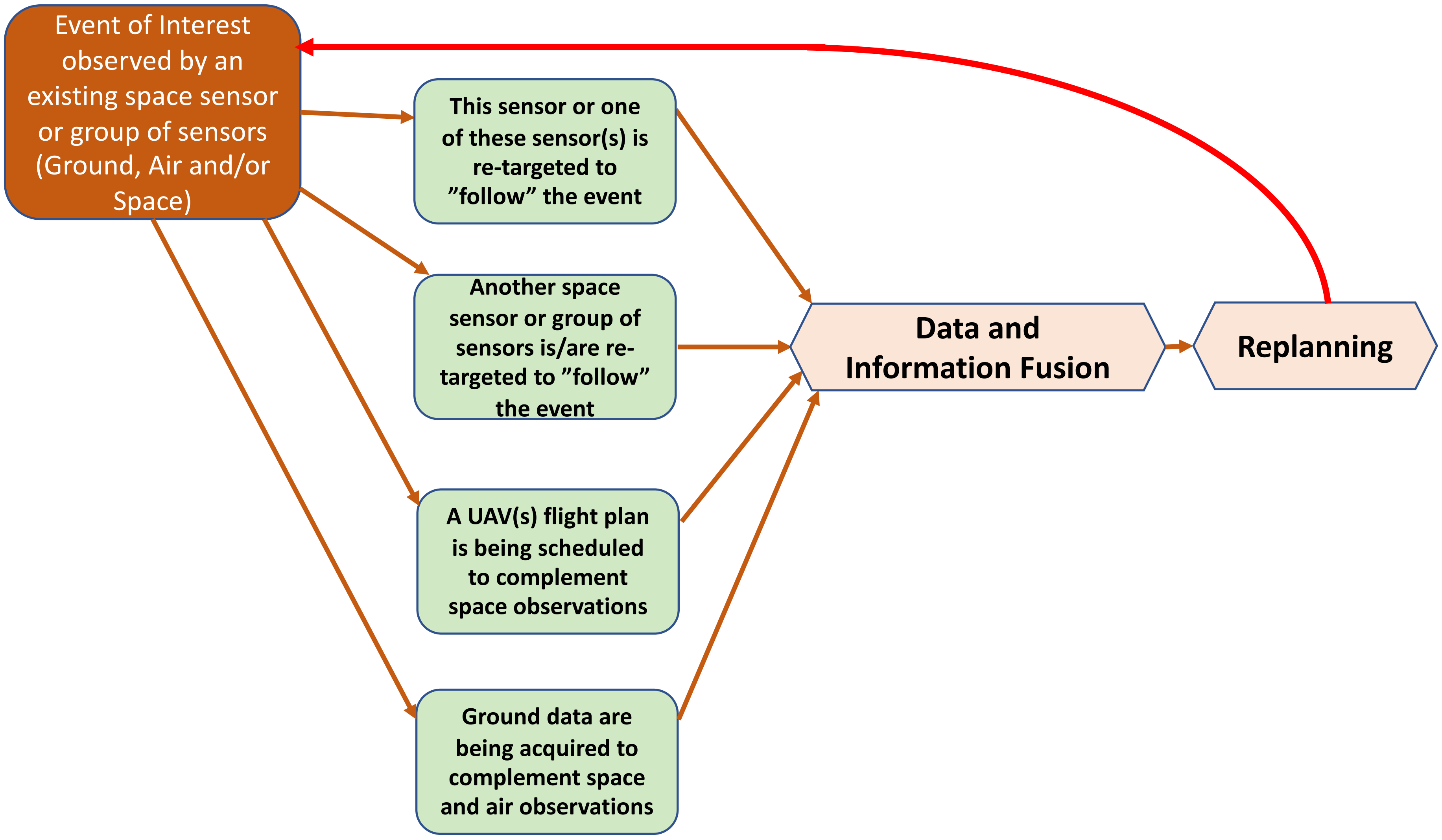
New Observing Strategies (NOS)

Measurement Acquisition ("Mission" Design or Model-Driven)



New Observing Strategies (NOS)

Observation Planning or Rapid Response to Event of Interest



Example of a Hydrology Use Case

Flood Monitoring with Space and Ground Sensors

1. A weather forecast or radar image indicates the potential for flood-inducing precipitation.

2. This triggers a network of ground-based sensors measuring changes in overland flow to begin telemetering data at high frequency.

3. When the ground sensors detect change in overland flow, they trigger a series of additional measurements:
   a. Space-based measurements, e.g., combination of space-based optical and radar, to determine surface water extent.
   b. In-situ measurements taken by either USGS technicians or future in-situ or UAS-mounted sensors, to measure high water level.
   c. A constellation of radar CubeSats is tasked to take targeted multi-angle measurements

Some Technologies Required for New Observing Strategies

- **Onboard Processing**
  - High Performance Spaceflight Computing
  - Radiation-Hardened vs. Radiation Mitigation by Software (e.g., SpaceCube)
  - Neuromorphic Computing
- **Enabling and Supporting Technologies**
  - Multi-Spacecraft Flight Software
  - Real-Time and Onboard Image Processing and Analysis
  - Sensor Protocols and Secure Access
  - Semantic Representation (Bridge) of Disparate Observation Data
  - Precision Attitude Control Systems
- **Collaborative Systems Technology**
  - Dynamical and Fast Sensor/Inter-Spacecraft Communications
  - Sensor Fleet Management; Automated Tools for Mission Planning, Risk Analysis and Value Assessment
- **Knowledge Management for Decision Making**
  - Onboard Machine Learning and AI Technologies
  - Data/Information Fusion and Decision Systems

New Observing Strategies Testbed

- Technologies to be deployed should be first integrated into a working ***breadboard*** where the components can be tested 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.

NOS Testbed Phased Execution

The NOS Testbed is built in such a way that it can be incrementally augmented and improved with additional sensors and capabilities. It will have multiple phases, e.g.:

- **Phase 1** with only multiple satellite-simulators, i.e., actual or simulated data from ground stations Level 0 data and/or software simulated satellite data
- **Phase 2** integrating in-situ sensors with satellite simulators
- **Phase 3** integrating in-situ sensors and satellite simulators with UAV's and balloons
- **Phase 4** integrating actual CubeSat(s) with the previous sensors
- **Phase 5** could include international collaborations and coordination.

NOS technologies and operation concepts would then be ready to transition and actually be infused into actual Science missions.

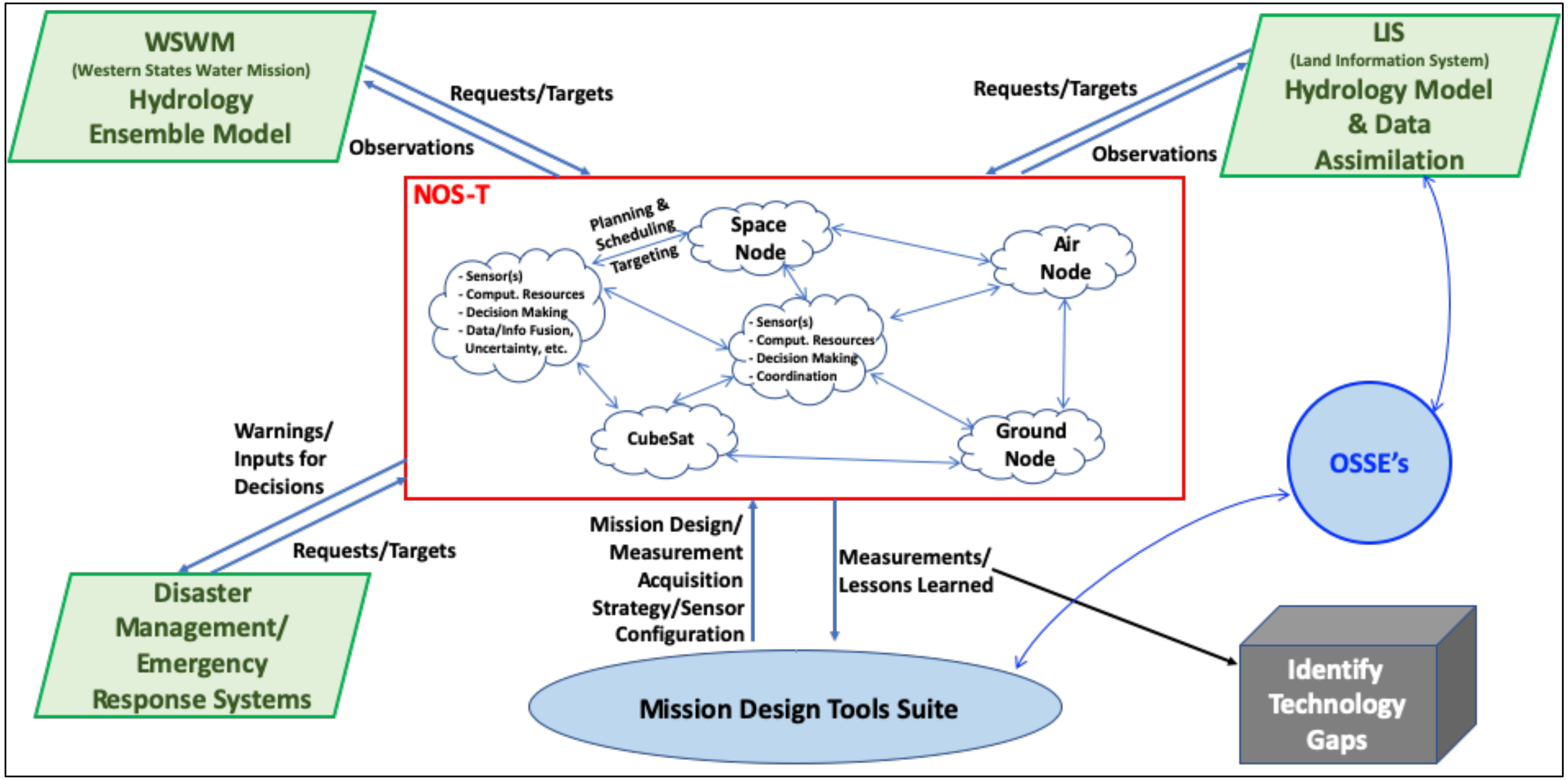
Experiment Lifecycle (for a given phase of the testbed):

1. Experiments will be proposed under various mechanisms
2. Experiments will be approved and reviewed by a governance board
3. Lessons learned will be used to:
   a. Identify technology gaps
   b. Improve testbed
   c. Define additional experiments
4. Experiments will be published appropriately

NOS-Testbed (NOS-T) Current Concept

NOS Testbed framework architecture being designed by the Systems Engineering Research Center (SERC) based on:

- **Use Cases**, esp. in Hydrology and in Air Quality
- **4 Pilot Projects:**
  - Land Information System (LIS) interactions with NOS-T (GSFC)
  - Tip-and-Cue of USGS River Gages (ARC)
  - Planning and Scheduling (JPL)
  - Western States Water Mission(WSWM) interactions with NOS-T (JPL)



AIST18 Awards – NOS Clusters

• NOS-T Relevant

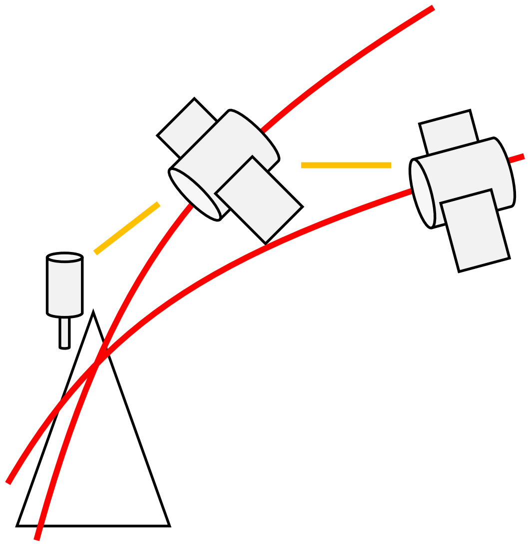
Award #	PI's Name	Organization	Title	Synopsis
AIST-18-0055	Coen	Univ. Corp for Atmospheric Research (UCAR)	Creation of a Wildland Fire Analysis: Products to enable Earth Science	Integrate multi-source data from various sensors and constellationsfrom both public and private sectors for wildfire prediction and modelling.
AIST-18-0077	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".
AIST-18-0082	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).
AIST-18-0042	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.

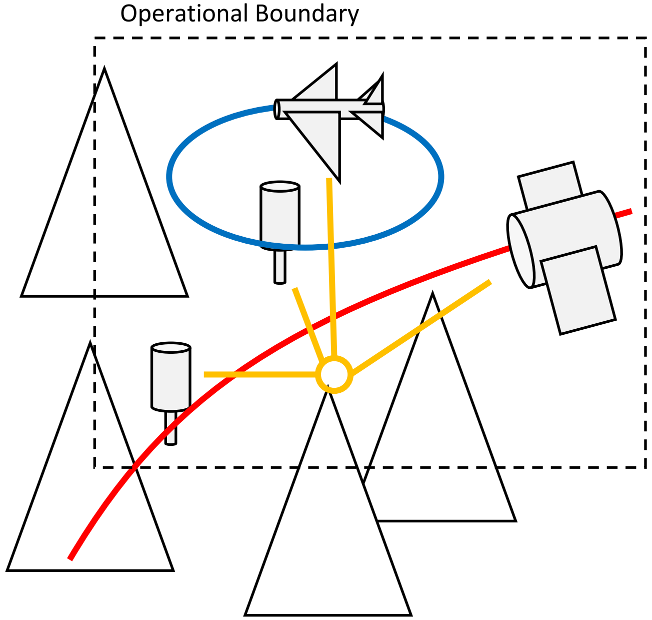
• OSSEs (Observing System Simulation Experiments)

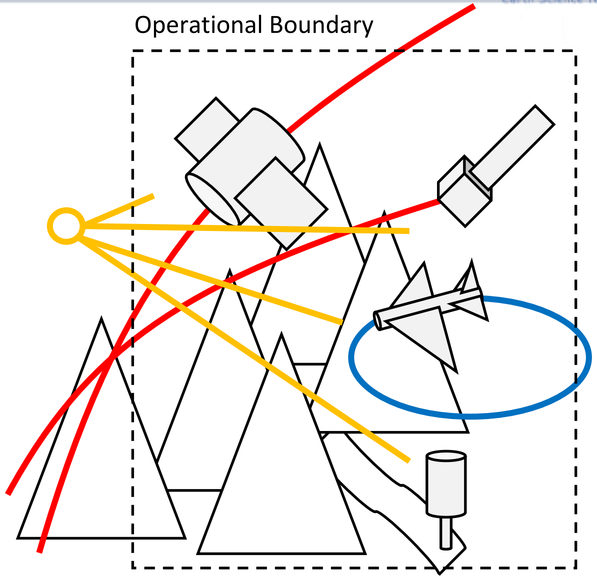
Award #	PI's Name	Organization	Title	Synopsis
AIST-18-0009	Posselt	NASA JPL	Parallel OSSE Toolkit	Fast-turnaround, scalable OSSE Toolkit to support both rapid and thorough exploration of the trade space of possible instrument configurations, with full assessment of the science fidelity, using cluster computing.
AIST-18-0041	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.
AIST-18-0042	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.

NOS-T Architecture

* **Graphics courtesy of SERC/P. Grogan**







Tactical mission
Minutes-hours
Point event/phenomenon

Detect emergent event
Deploy observation assets

- Responsiveness
- Interaction
- Dynamics
- Adaptation

Operational mission
Hours-days
Spatial phenomenon

Deploy observation assets
Digest information sources

- Resource allocation
- Coordination
- Data assimilation
- Prediction/forecasting

Strategic mission
Months-years
Spatial-temporal phenomenon

Design observation system
Digest information sources

- Platform selection
- Coordination
- Data assimilation
- State estimation (belief)

NOS – Future Directions

- Develop Various **Use Cases and Design Reference Missions** Corresponding to Candidate Science and Application Needs
- Identify **Technology Needs and Gaps**, as well as State-of-the-Art Capabilities, and develop an **NOS Technology Roadmap**
- **Validate Novel Technologies** in the ESTO Testbed then in Tech Demo Missions (e.g., SMD/InVEST, STMD/SST)
- **Transition and Infuse** NOS Technologies in Future NASA Missions and Projects:
    - Integration with Science and Forecast Models
    - Augmentation of Spaceborne Missions with Ground and Airborne Sensors
    - Definition of ISS Experiments or CubeSat Constellations

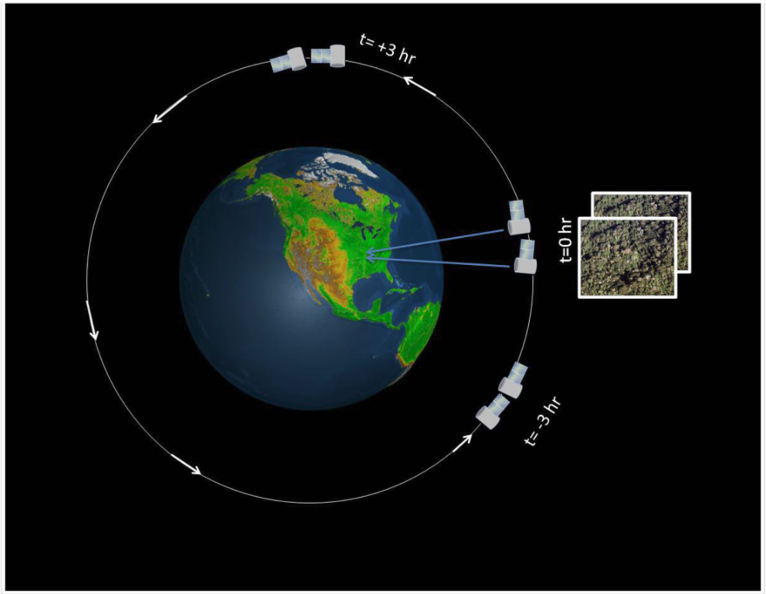
CREATE AN "INTERNET OF SPACE"

Any Questions?

Distributed Spacecraft Missions (DSM)
New Observing Strategies (NOS) for Earth Science

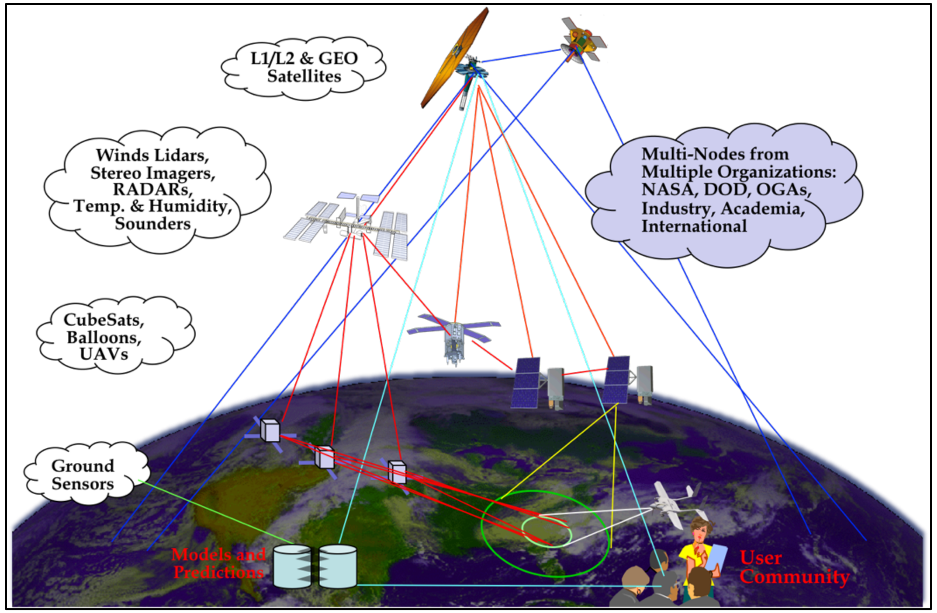
In Earth Science

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



Example: SAFE (Structure and Function of Ecosystems): First diurnal high-spatial resolution measurements of plant functional properties, i.e., of structure and functioning of vegetation provide the complete picture of plant productivity and stress. (POC: Jon Ranson/GSFC)

A SensorWeb is a distributed system of *sensing nodes* (space, air or ground) that are interconnected by a *communications fabric* and that functions as a single, highly coordinated, virtual instrument. It semi- or - autonomously detects and dynamically reacts to events, measurements, and other information from constituent sensing nodes and from external nodes by modifying its observing state so as to *optimize mission information return.* (e.g., EO-1 SensorWeb 3G). (Ref: Talabac et al, 2003)



NOS for Candidate Science Needs

- **Hydrology**
  - River flow and Flooding
  - Snow fall in 3D
  - Aquifer degradation
- **Precipitation**
  - Extreme precipitation events
- **Cryosphere**
  - Glaciers changes
  - Sea Ice changes
- **Urban Air Quality Events**
  - At a resolution (vertical and horizontal)
- **Biodiversity**
  - Migrations
  - Invasive species
  - Transient spring phenomena
- **Solid Earth and Interior**
  - Landslides
  - Plate movement
  - Volcanic activity
  - Interior magma movement
- **Disaster Management**
  - Floods
  - Earthquakes
  - Volcanic Eruptions

Technologies Needed for NOS

Some Examples of Capabilities Needed Onboard:

- Recognizing science events of interest
- Exchanging data inter-spacecraft
- Analyzing data for optimal science return
- Reconfiguring the spacecraft based on coordinated observations