
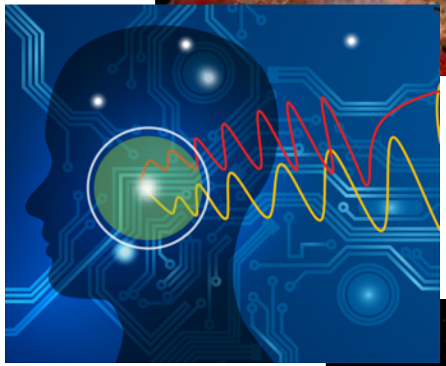
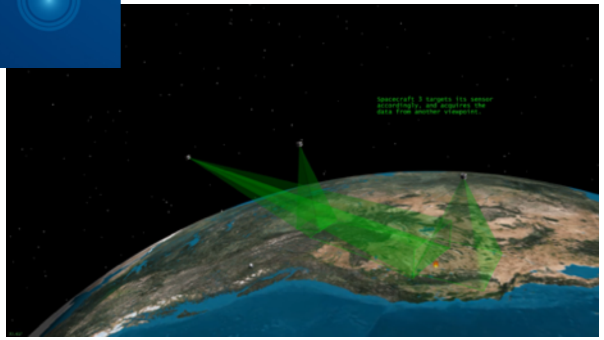

Novel Observing Strategies and Analysis Frameworks for Targeted Research Requirements

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ESTO, AIST Program

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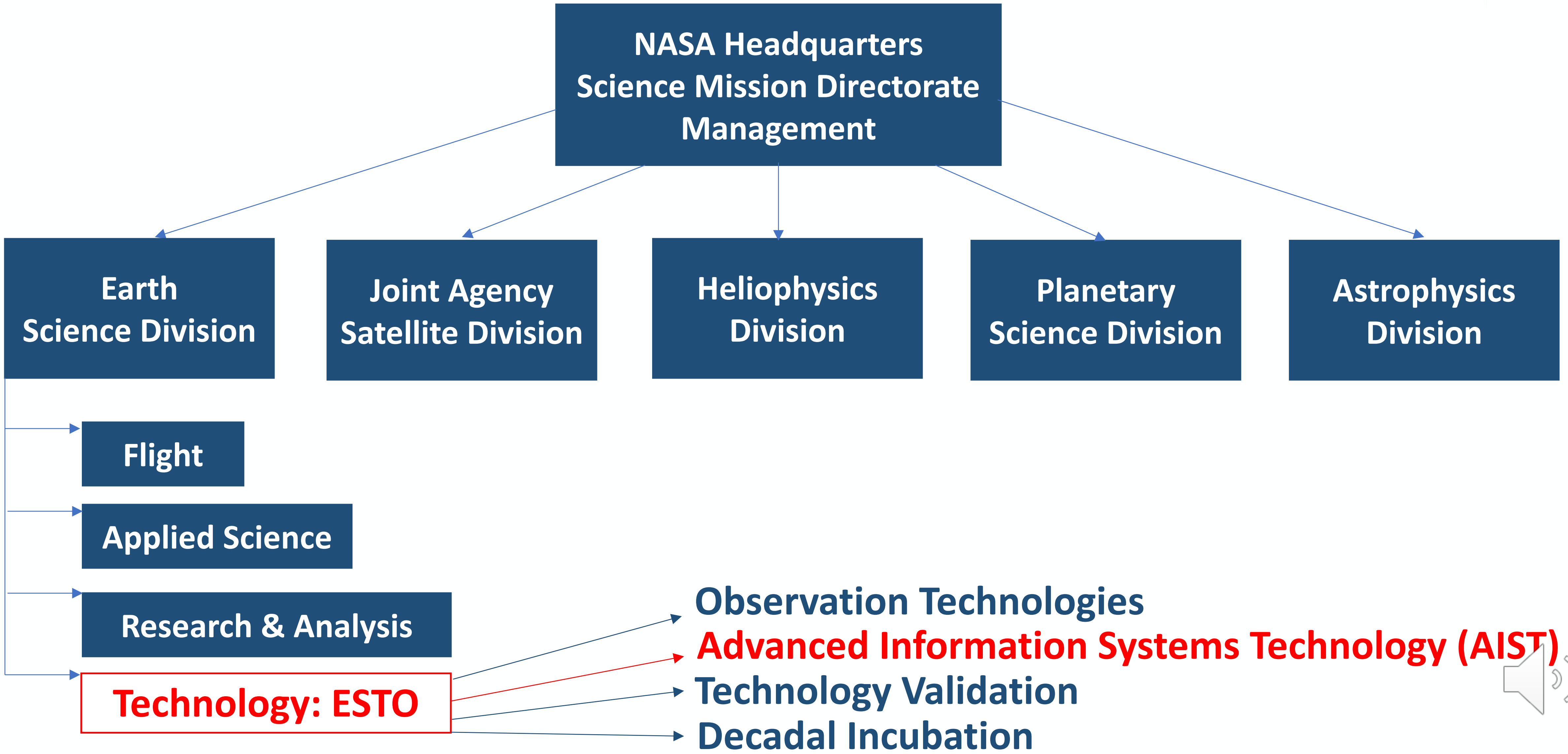
Earth Science Technology Office (ESTO)



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**

  Innovate in technologies that enable:

  - New and unique capabilities for new observing systems design and measurements collection through distributed sensing
  - Optimizing Science missions return on investment through flexible and dynamic information integration
  - Agile Science investigations through data analytics and artificial intelligence tools and algorithms

NOS and ACF for Science Data Intelligence

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

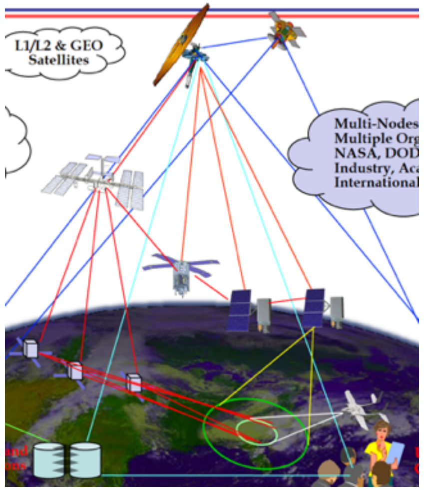
Assimilate Observations

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

New Observing Strategies (NOS)

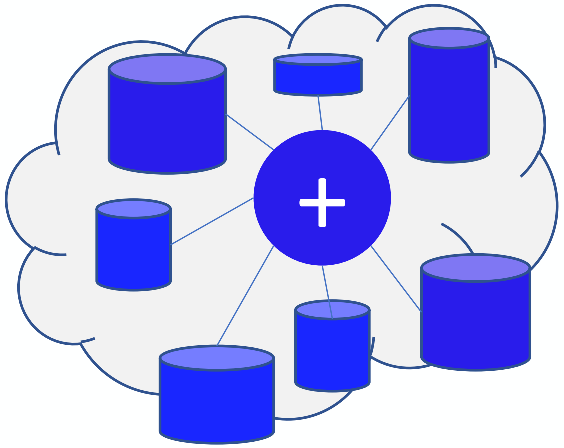
Acquire coordinated observations

Track dynamic and spatially distributed phenomena



Example: NOS Testbed Demonstration planned for Spring 2021 targeting Mid-West Floods with LIS Models as well as Space and ground observations

Analytic Collaborative Frameworks (ACF)



Assimilate many various data into models and analytic workflows.

What additional observations are needed?

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

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

New Observing Strategies (NOS)

NOS for Optimizing Measurements Design and Dynamically Capturing full Science Events

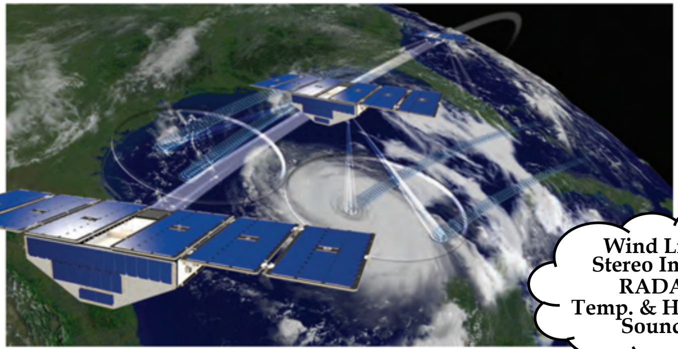
Distributed Spacecraft Missions (DSM):

A Distributed Spacecraft Mission (DSM) is a mission that involves multiple spacecraft to achieve one or more common goals.

Can provide:

- **Multi-perspective observation (angular, spatial, spectral, temporal)**, for fundamental physical understanding of dynamic phenomena
- **Multi-point measurements** for full observation coverage

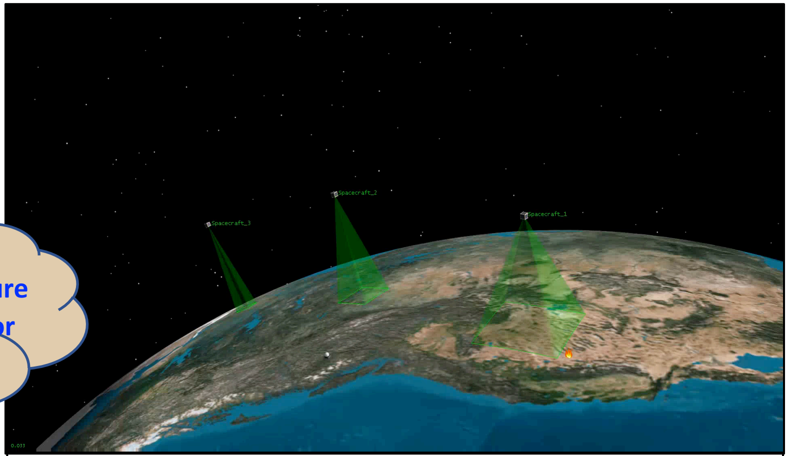
CYGNSS microsatellite observatories in orbit. Image credit: Southwest Research Institute



Using a constellation of eight small satellites enables frequent observations

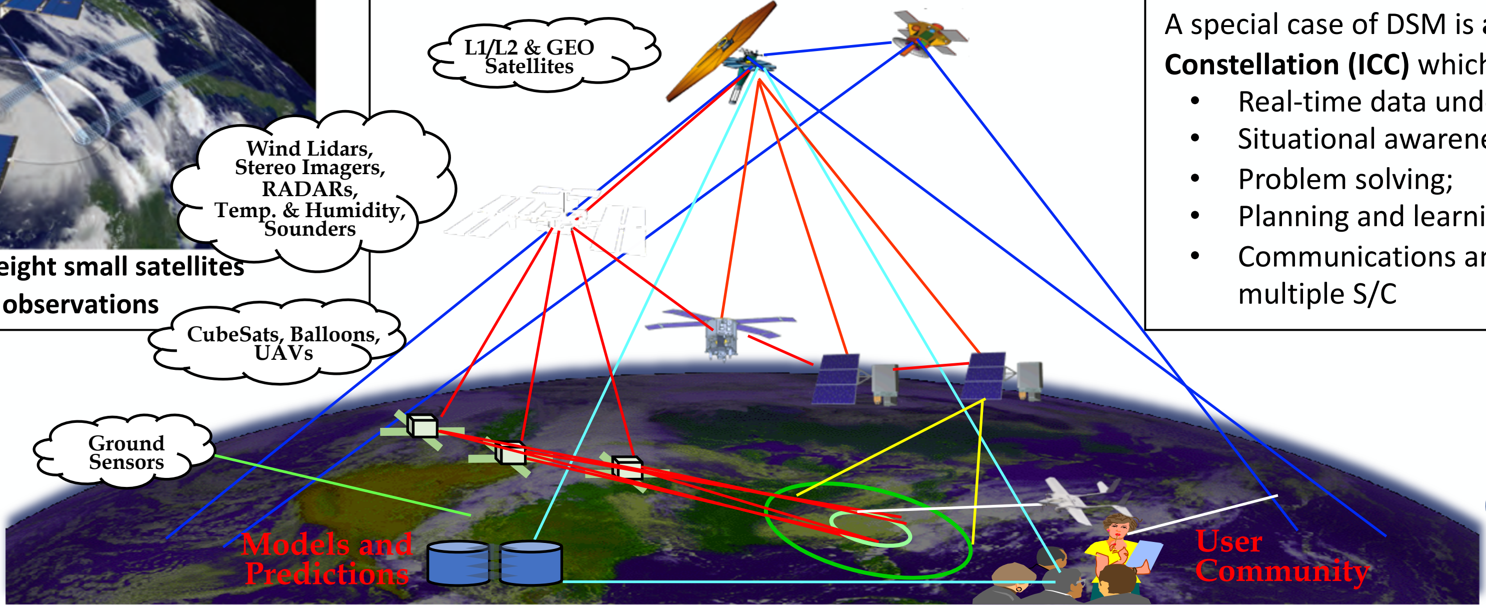
Multiple collaborative nodes from multiple organizations (NASA, OGAs, Industry, Academia, International) from multiple vantage points and in multiple dimensions (spatial, spectral, temporal, radiometric)

Provide complete picture of physical processes or natural phenomena



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 and learning from experience
- Communications and cooperation between multiple S/C



Increased understanding and predictability of dynamic events on Earth.

Actively acquire data in coordination with other sensors, models in response to measurement needs and/or science events

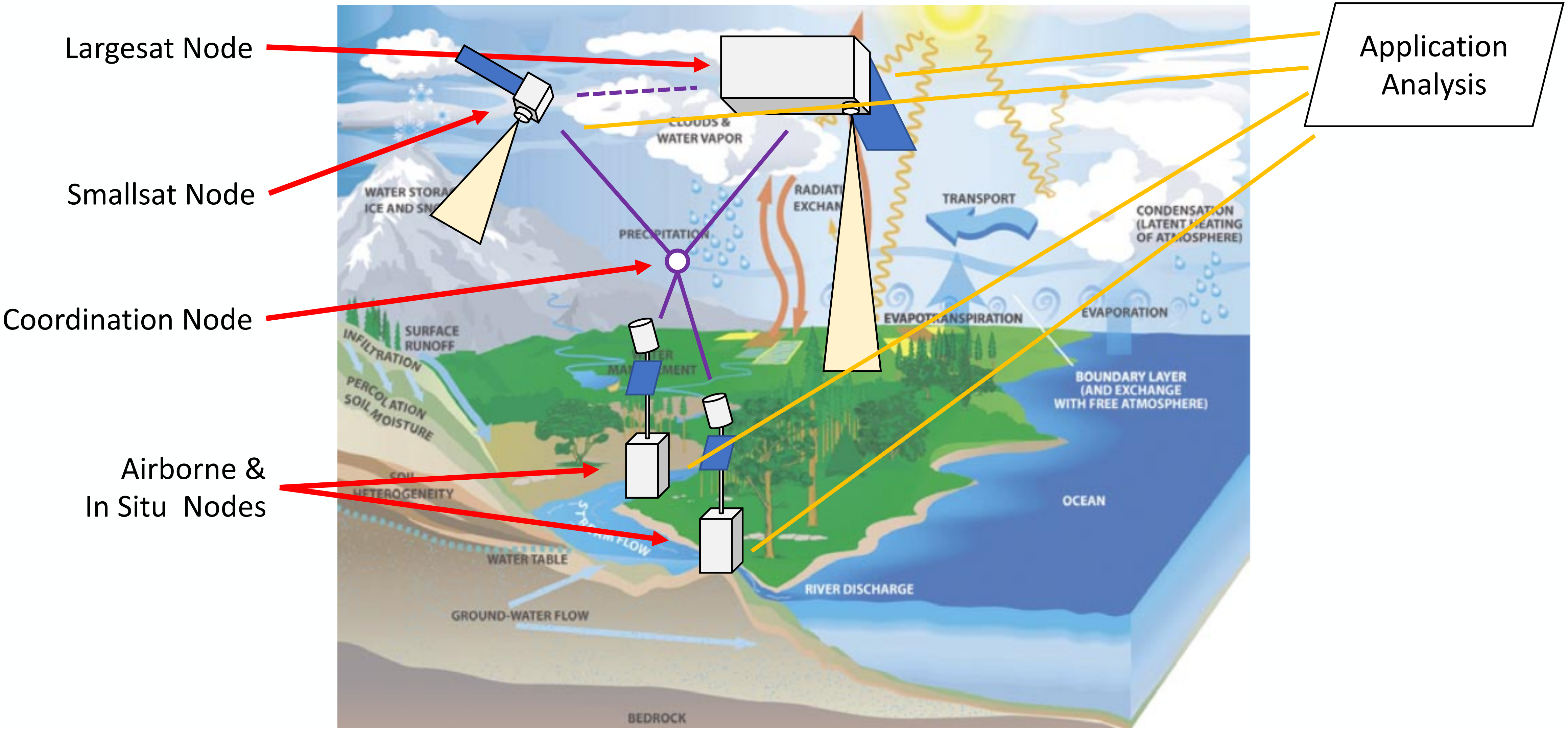
A SensorWeb is a distributed system of ***sensing nodes*** (space, air or ground) that are interconnected by a ***communications fabric*** and that functions as a single, highly coordinated, virtual instrument.

New Observing Strategies (NOS) Objectives

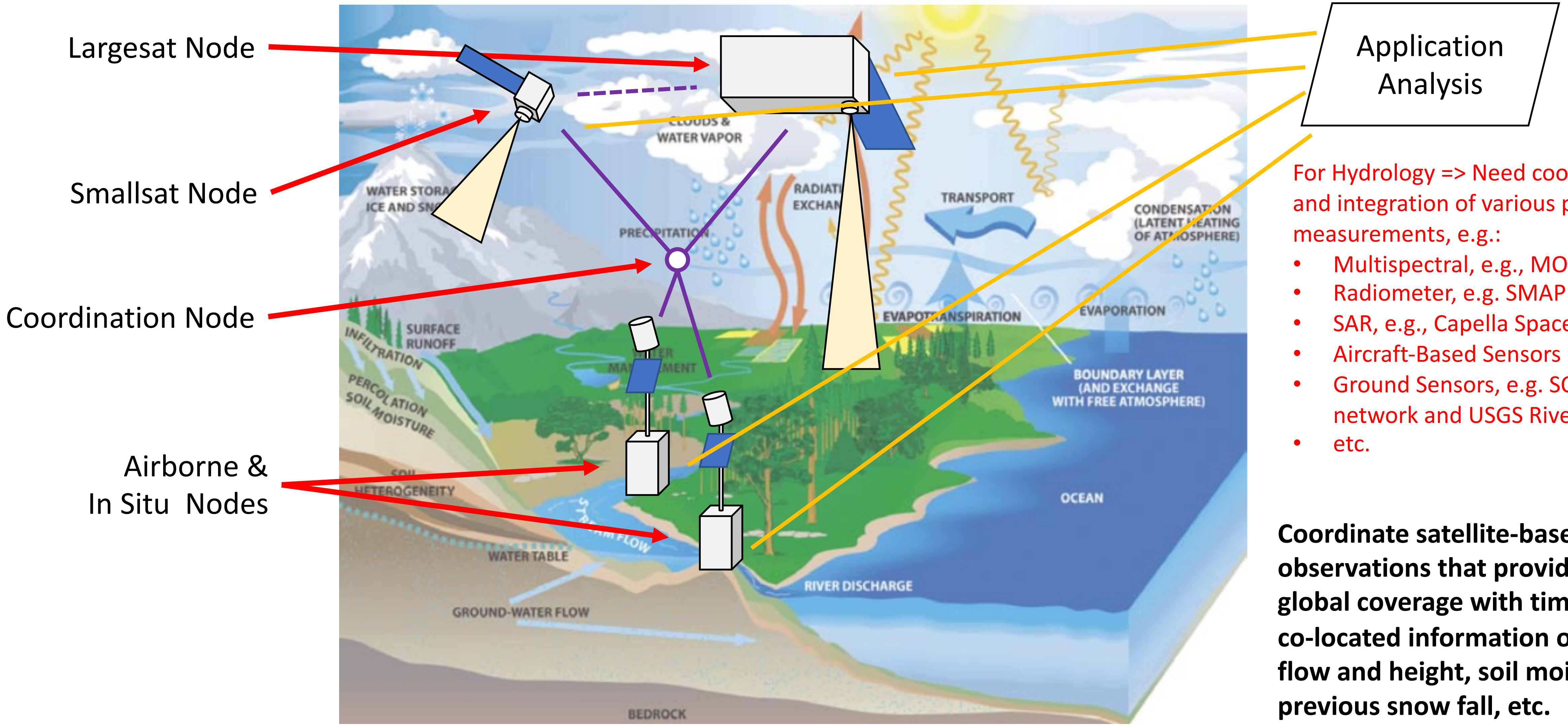
1. **Design and develop New and Future Concepts:**
   - In response to a need that comes from Decadal Survey or a Model or other science data analysis
   - Include **various size spacecraft** (CubeSats, SmallSats and Flagships)
   - Concepts will be **Systems of systems (or *Internet-of-Space*)** that include constellations, hosted payloads, ISS instruments, HAPS sensors, UAVs, ground sensors, and models (future: IoT sensors, social media & others)
   - Take into consideration other **various organizations** (OGAs, industry, academia, international) assets to optimize the development of new NASA assets
   - **Make trades** on number & type of sensors, spacecraft and orbits; resolutions (spatial, spectral, temporal, angular); 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** if connected in a feedback loop with a DTE or ACF system

2. **Respond to various science and applied science events of interest**
   - **Various overall observation timeframes**: from real-time to mid-term to long-term events
   - **Various area coverages**: from local to regional to global
   - **Dynamic** and in response to a specific event (science event or disaster or ...)
   - **Real-time SensorWeb response** by:
     - Analyzing which assets could observe the event at the required time, location, angle and resolutions.
     - Scheduling, re-targeting/re-pointing assets, as needed and as possible

NOS Concept


Largesat Node
Smallsat Node
Coordination Node
Airborne &
In Situ Nodes
Application
Analysis
WATER VAPOR
PRECIPITATION
TRANSPORT
EVAPOTRANSPIRATION
EVAPORATION
SURFACE
RUNOFF
INFILTRATION
PERCOLATION
SOIL MOISTURE
BOUNDARY LAYER
(AND EXCHANGE
WITH FREE ATMOSPHERE)
OCEAN
RIVER DISCHARGE
WATER TABLE
GROUND-WATER FLOW
BEDROCK

NOS Concept for Hydrology
=> Hydrology Nodes => Spring 2021 Concept Demonstration



For Hydrology => Need coordination and integration of various potential measurements, e.g.:

- Multispectral, e.g., MODIS
- Radiometer, e.g. SMAP
- SAR, e.g., Capella Space
- Aircraft-Based Sensors
- Ground Sensors, e.g. SOILSCAPE network and USGS River Gauges
- etc.

Coordinate satellite-based observations that provide global coverage with timely and co-located information on river flow and height, soil moisture, previous snow fall, etc.

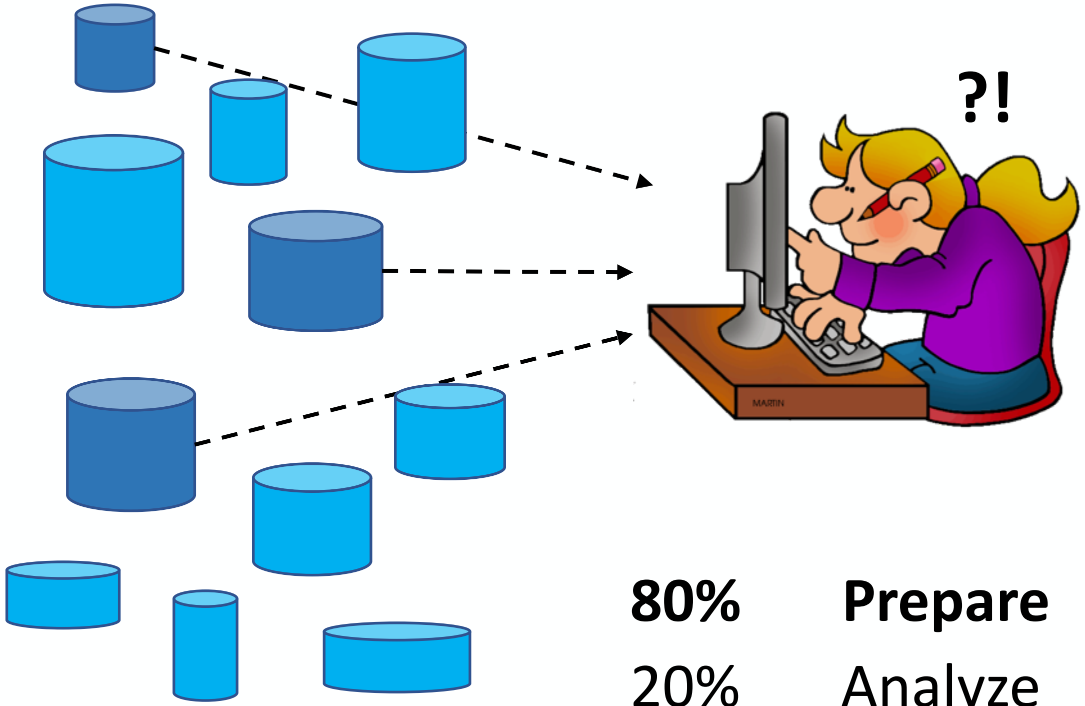
Analytic Collaborative Frameworks (ACF)

From Archives to Analytic Frameworks: *Focus on the Science User*

Data Archives

Focus on data capture, storage, and management

Each user has to find, download, integrate, and analyze



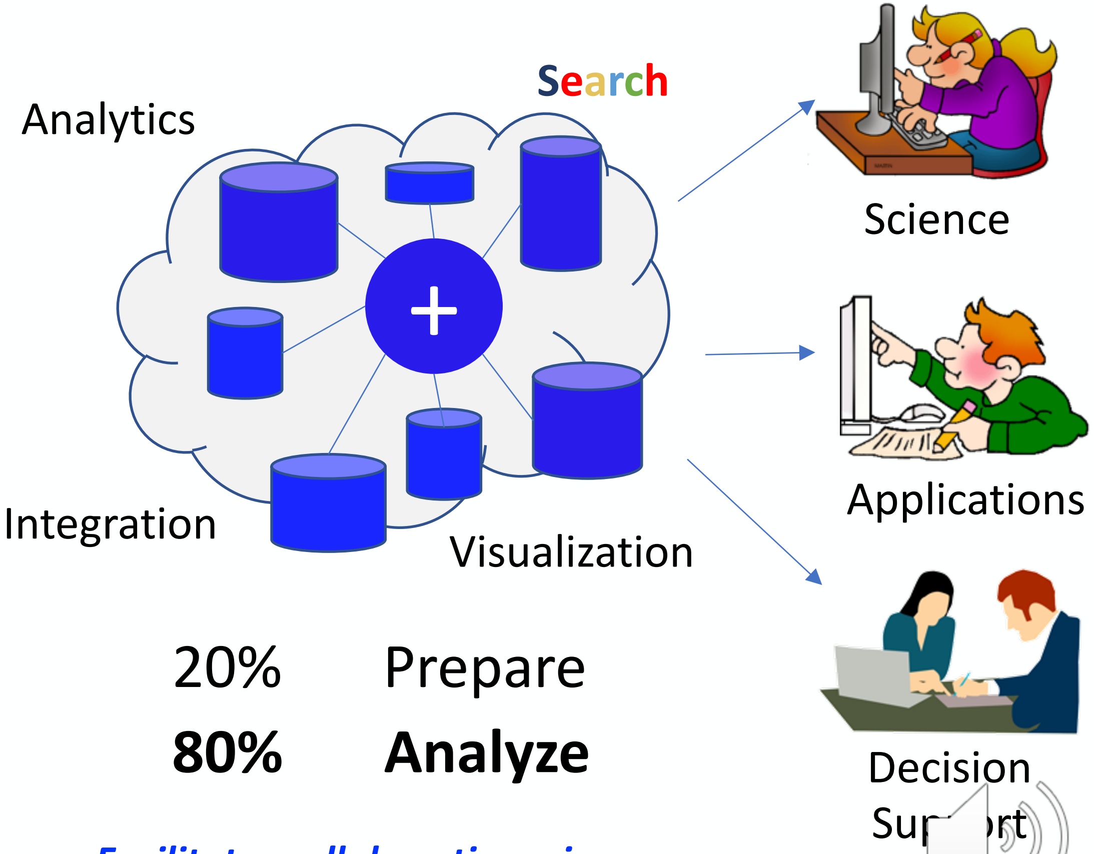
80% **Prepare**

20% Analyze

Analytic Frameworks

Focus on the science user

Integrated data analytics & tools tailored for a science discipline



20% Prepare

80% **Analyze**

Facilitates collaborative science across multiple missions and data sets

Analytic Collaborative Frameworks (ACF)

Focus is on the Science User

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

User

- Project Definition
- Plan for Investigation

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

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

Computational Infrastructure

- Computing
  - Capacity
  - Capability
- Storage
- Communications

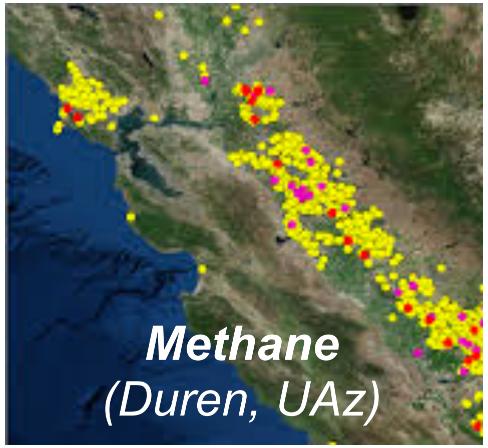
Storage

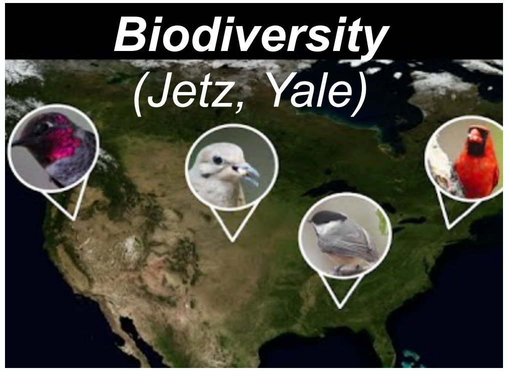
- Data Containers
- Thematic model
- Metadata/Ontology
- Resulting Products
- Published data
- Provenance

Computing

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

Analytic Collaborative Frameworks (ACF) support various Earth Science Disciplines





AIST Innovations –
A Few Examples

Technologies Currently Being Developed in AIST Projects

NOS CAPABILITIES:

- Observing Systems Simulation Experiments (OSSEs) (Gutmann, Posselt)
- NOS Framework (Grogan)
- Interactions between Modeling and Observation Nodes (Kumar, Crichton, David)
- Asset Coordination and Targeting (Frost)
- SensorWeb Operations Planning and Scheduling (Moghaddam, Nag, Chien)
- Autonomy (Carr, Moghaddam, Nag)
- On-Board Processing Systems (Carr)
- CubeSat/SmallSat Expertise (Carr)
- UAV Operations (Moghaddam)
- Sensor Calibration and Validation (Holm)
- Ground Stations as a Service (Nguyen)

AI CAPABILITIES:

- Machine Learning (Beck, Holm, Huffer, Uz, Nag)
- Deep Learning (Beck, Holm, Huffer, Uz)
- Data Services Discovery (Zhang)
- Uncertainty Quantification Methods (Ives)

ADVANCED ANALYTICS:

- Data Accessibility (Duren, Jetz, Coen)
- Data Fusion (Donnellan, Duren, Jetz, Uz, Coen, Foreman)
- Big Data Analytics (Hua, Ives, Swenson, Townsend)
- Data Mining (Donnellan)
- On-Demand Product Generation (Hua, Townsend)
- Data Operations Workflows (Zhang)
- Metadata, Provenance, Semantics, etc. (Huffer)

IMPROVED MODELING CAPABILITIES:

- Science Data Model Validation/Automation (Moisan)
- Software Architecture Frameworks (Posselt)
- Science Code Development and Reuse (Henze, Moisan)
- Modeling Systems (Martin, Foreman, Gutmann)
- Model Data Inter-Comparisons (Henze, Swenson)
- Custom Tools (Martin)
- Forecasting/Prediction (Jetz, Swenson, Townsend, Moisan)

COMPUTATIONAL ENVIRONMENTS:

- Cloud Computing (Beck)
- High-Performance and Edge Computing in Space (Chien)

AI in ESTO Advanced Information Systems Technology (AIST) Projects

AI for Observation Simulation Synthesis Experiments (OSSEs) and for Mission Design

- A Mission Planning Tool for Next Generation Remote Sensing of Snow (Forman/AIST-16)
- Trade-space Analysis Tool for Constellations Using Machine Learning (TAT-C ML) (Verville & Grogan/AIST-16)

AI for Time Series and for Science Models

- Advanced Phenology Information System (APIS) (Morisette/AIST-16)
- NASA Evolutionary Programming Analytic Center (NEPAC) (Moisan/AIST-18)
- Canopy Condition to Continental Scale Biodiversity Forecasts (Swenson/AIST-18)

AI for Quantum Computing

- Framework for Mining and Analysis of Petabyte-size Time-series on the NASA Earth Exchange (NEX) (Michaelis & Nemani/AIST-16)
- An Assessment of Hybrid Quantum Annealing Approaches for Inferring and Assimilating Satellite Surface Flux Data into Global Land Surface Models (Halem/AIST-16)

AI for Pattern and Information Extraction

- Computer-Aided Discovery and Algorithmic Synthesis for Spatio-Temporal Phenomena in InSAR (Pankratius/AIST-16)
- Autonomous Moisture Continuum Sensing Network (Entekhabi & Moghaddam/AIST-16)
- Supporting Shellfish Aquaculture in the Chesapeake Bay using AI for Water Quality (Schollaert-Uz/AIST-18)
- Mining Chained Modules in Analytics Cente Frameworks (Zhang/AIST-18)

AI for Image Processing and for Data Fusion

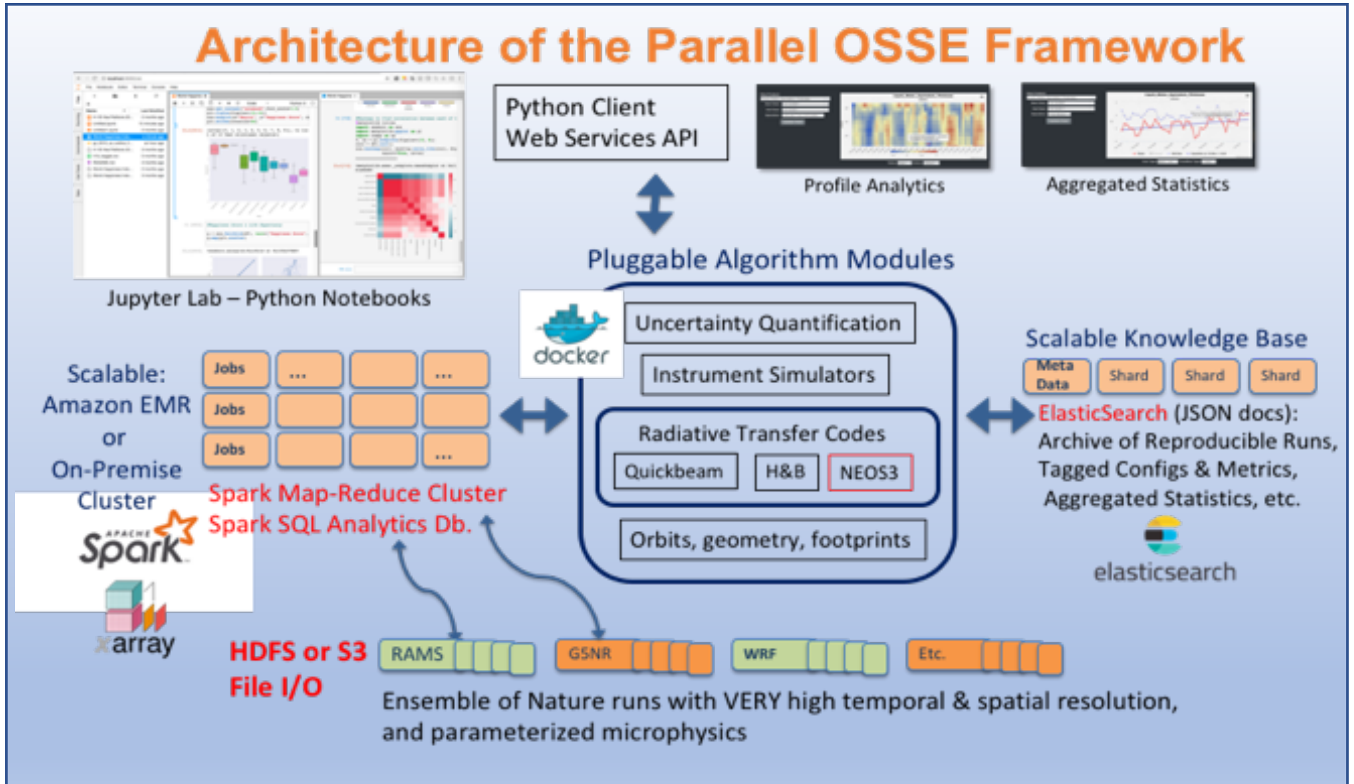
- Software Workflows and Tools for Integrating Remote Sensing and Organismal Occurrence Data Streams to Assess and Monitor Biodiversity Change (Jetz/AIST-16)
- NeMO-Net - The Neural Multi-Modal Observation & Training Network for Global Coral Reef Assessment (Chirayath/AIST-16)

AIST-18/Posselt (NASA JPL) –
Parallel Observing System Simulation Experiment (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.

Evaluate measurement contribution to mission science

- **Parallel OSSE system** uses distributed computing, data analytics, and Bayesian retrieval algorithms to rapidly and thoroughly evaluate information in a wide variety of prospective measurements



Includes: Interfaces to Nature Run databases; Pluggable instrument simulators and retrieval algorithms; Quantitative evaluation of science benefit vs SATM

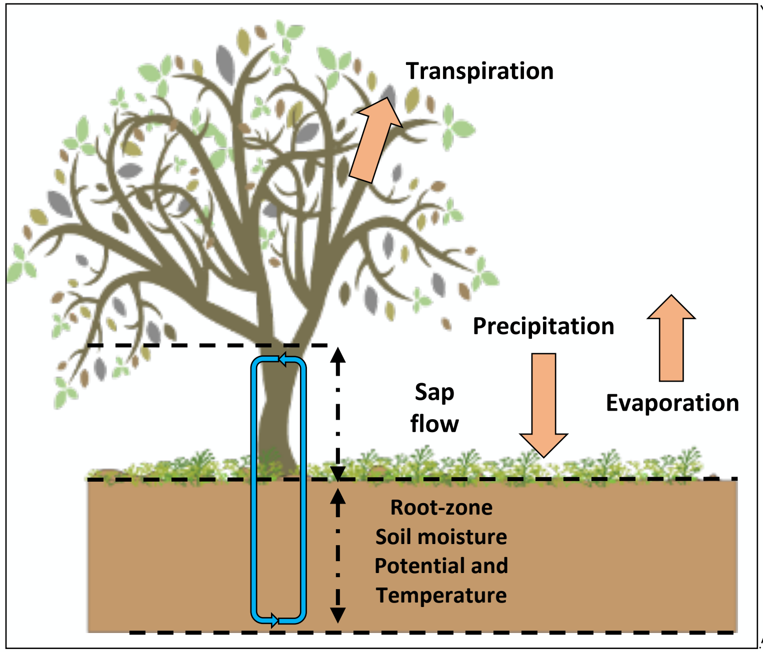
Technology already proven for evaluation of measurement goals for the ACCP DO study

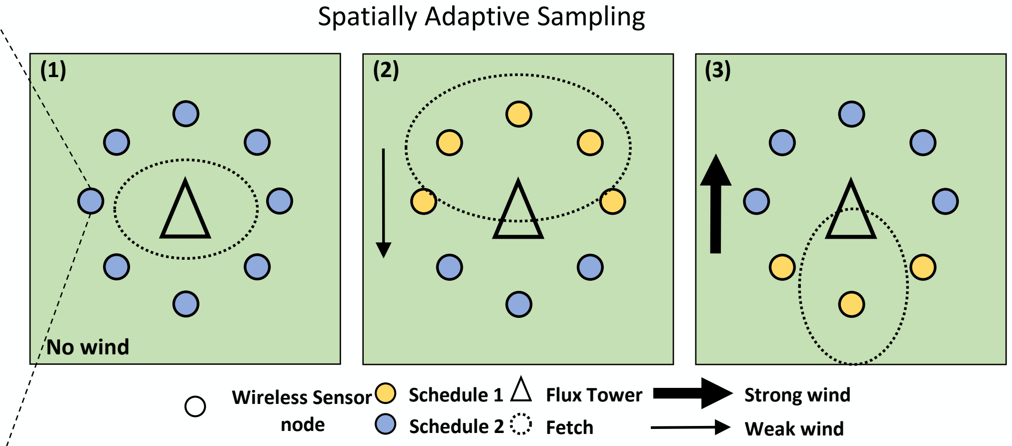
- Couple **instrument simulators** with a scalable parallel computing framework utilizing **Map-Reduce compute cluster**, a **scalable Knowledge Base**, a set of "pluggable" code modules, and **Python Live Notebooks**
- Produce **quantitative estimates of geophysical variable uncertainty** and information on mission architecture sufficiency
- Considered to address PBL observational goals

AIST-16&18/Entekhabi & Moghaddam (MIT & USC) –

Autonomous Moisture Continuum Sensing Network

Soil moisture is important for understanding hydrologic processes by monitoring the flow and distribution of water between land and atmosphere. A distributed, adaptive sensor network improves observations while reducing energy consumption to extend field deployment lifetimes .





Distributed wireless sensor network measures soil moisture, sap flow, and winds

Embedded Machine learning decides when and where to sample in order to optimize information gain and energy usage.

Evaluated **alternative adaptive sampling strategies** for performance (information) vs energy use.

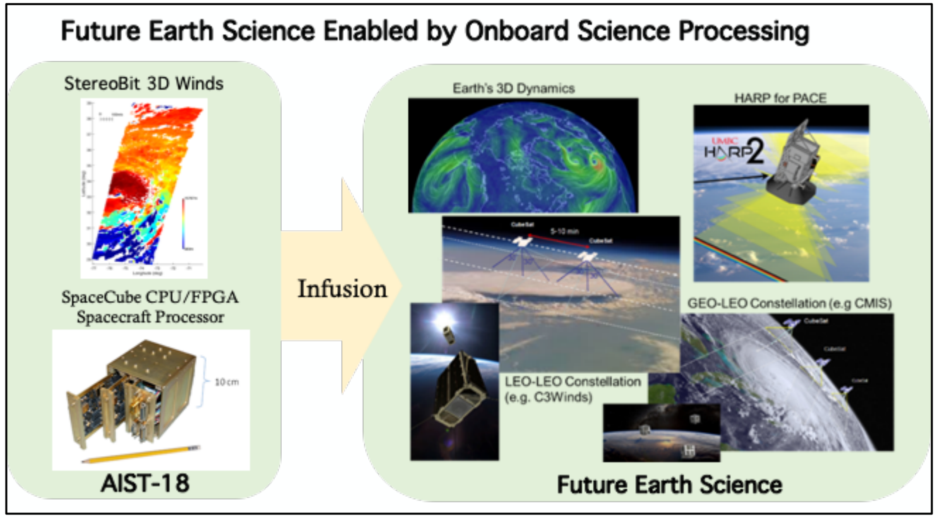
- ✓ Information Gain vs. Energy Consumption optimization → present as Pareto Fronts
- ✓ An autoregressive ML will have superior performance $\theta(t) = f\big(\theta(t-1)\big) + g\big(X(t)\big)$
- ✓ Simple Policies can achieve superior RMSE performance with less energy consumption

SoilSCAPE installation for CYGNSS Cal/Val

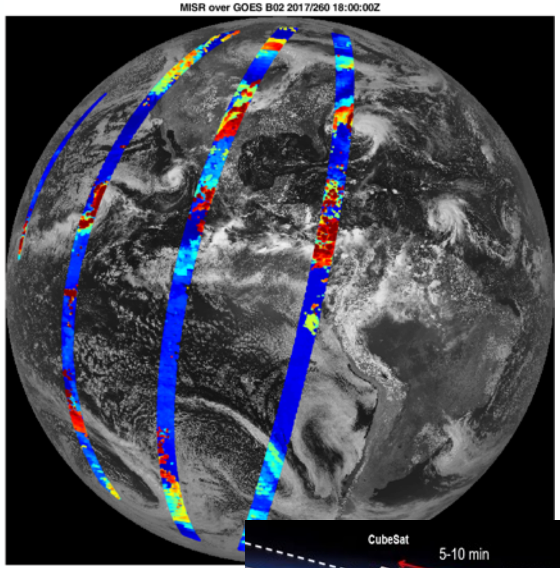
- **SoilSCAPE Plan → Satellites Cal/Val**
  - SMAP Cal/Val: Deployed 1 site at the Cary Institute of Ecosystem Studies (Millbrook, NY)
  - SoilSCAPE team (via. Co-I Moghaddam) collaborating with CYGNSS to provide *in situ* soil moisture for cal/val activities
  - Established a cal/val infrastructure for NiSAR

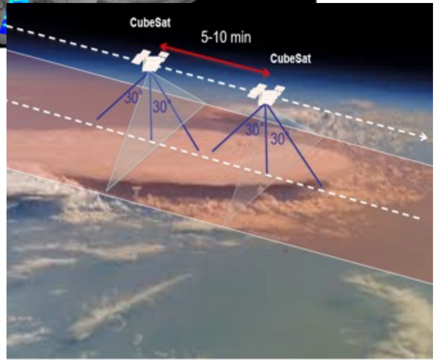
AIST-18/Carr (Carr Astronautics) –
StereoBit: Advanced Onboard Science Data Processing to Enable Future Earth Science

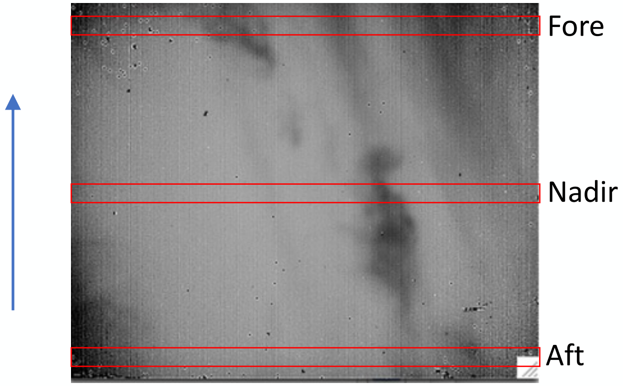
This investigation demonstrates higher-level onboard science data processing for more intelligent SmallSats and CubeSats to enable future Earth science missions and Earth observing constellations. Low-cost SmallSat architectures generally suffer from downlink bottlenecks and often result in lower data acquisitions per orbit. This project targets an objective relevant to the 2017-2027 Earth Sciences Decadal Survey - atmospheric dynamics with 3D stereo tracking of cloud moisture features using a Structure from Motion (SfM) technique called StereoBit that can be implemented onboard. This will lead to the development of a testbed to validate intelligent onboard systems.



SfM method from OpenCV implemented on SpaceCube 2.0 and flying on RRM3 using the Compact Thermal Imager (CTI)

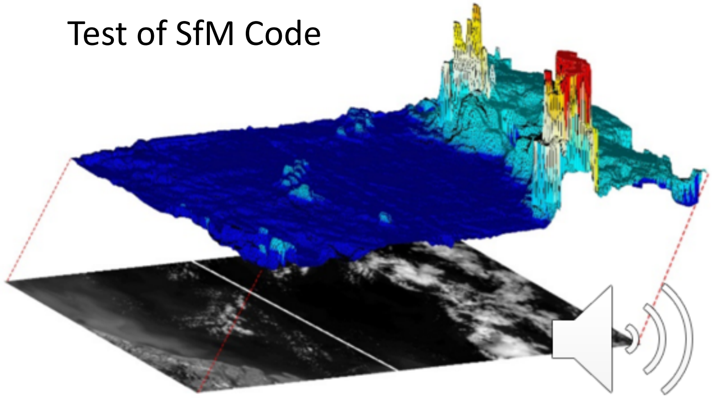






Early CTI Cloud Picture

Test of SfM Code



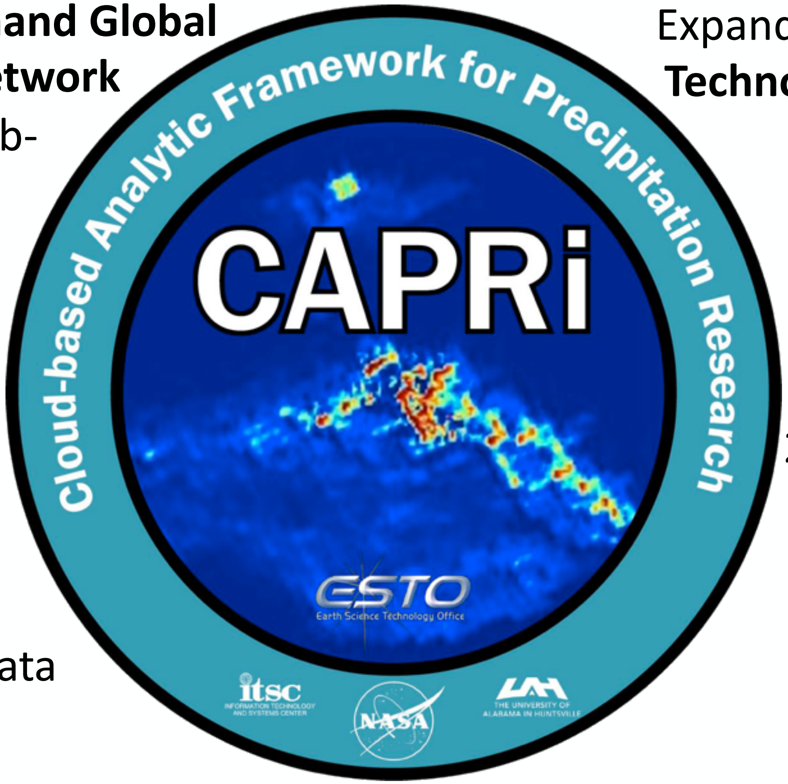
AIST-18/Beck (U. Alabama, Huntsville) –

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 uses coincident ground and space radar observations.

Provide users with tools for **on-demand Global Precipitation Mission Validation Network (GPM VN) data** querying, fusion, sub-setting, extraction, and analysis integrated with Deep Learning architectures

Develop **Super-Resolution** of remotely sensed images and develop **higher-resolution product** based on GPM Dual-frequency Precipitation Radar (DPR) gridded data prototype



Expand state of knowledge in **Cloud Technologies for precipitation data** by:

1. Providing new solutions for **real-time querying** of large data sets in a serverless environment;
2. Developing new methods for **generating Deep Learning Training data** on the fly; and
3. Providing an **easy-to-use user interface** for analysis and visualization of the data.

Future Integration of NOS and ACF

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

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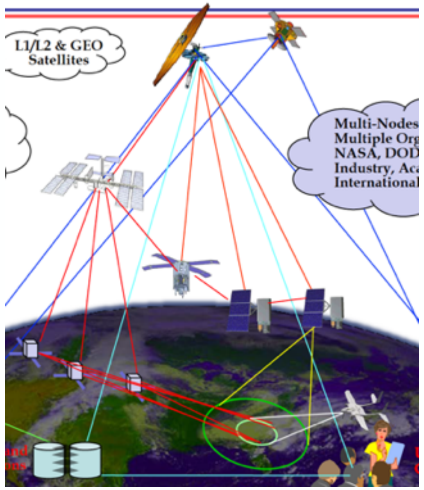

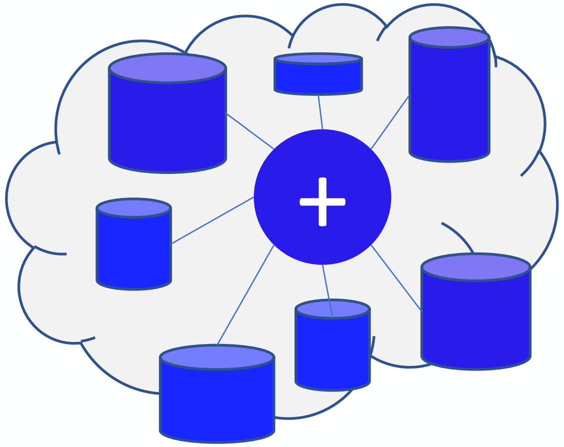

Assimilate many various data into models and analytic workflows.

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

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