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Advanced Information Systems Technology (AIST)

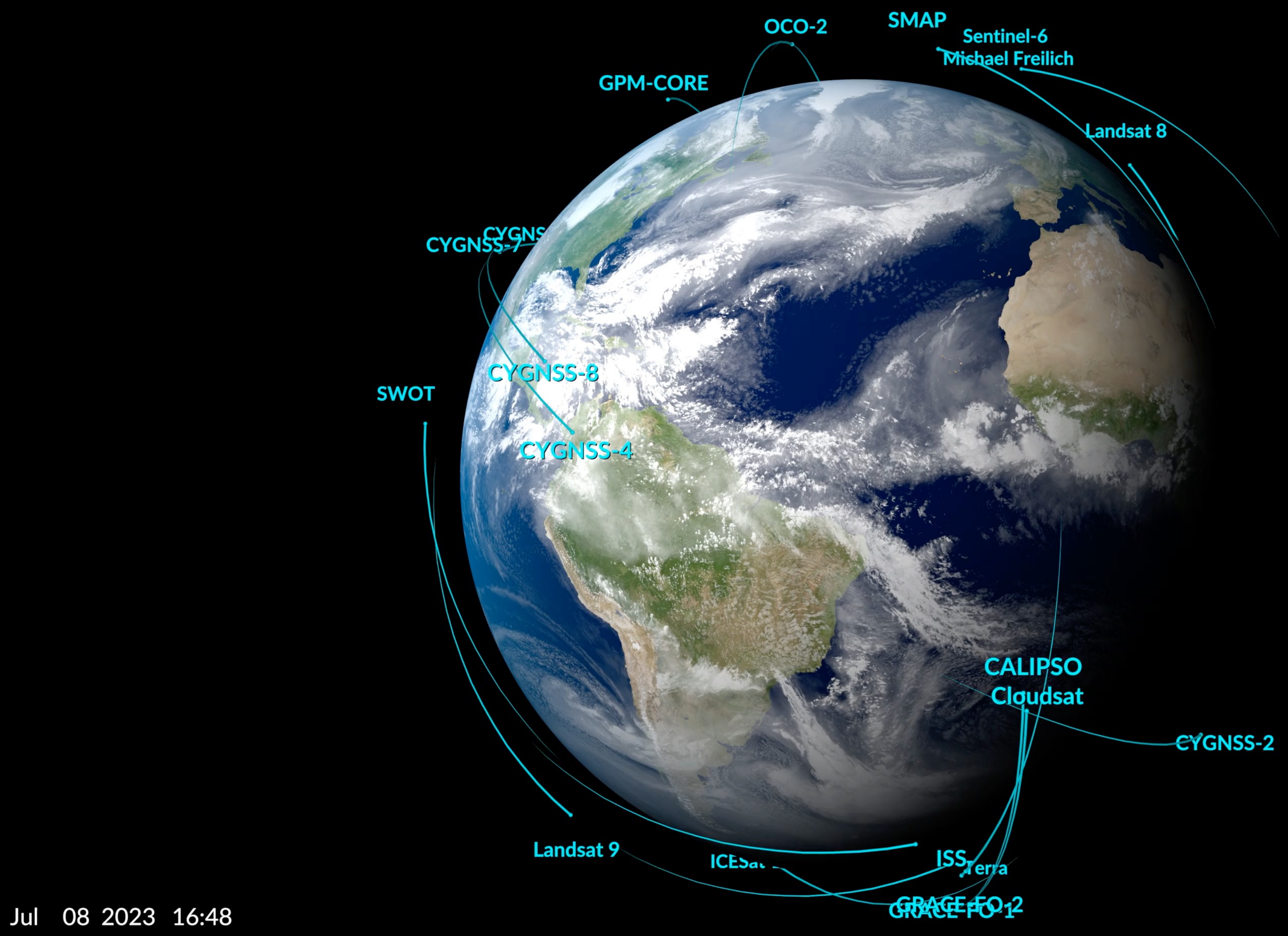
ESTO Earth Science Technology Office AIST

The Use of Multimodal Remote Sensing Data for NASA's Advanced Information Systems

Jacqueline Le Moigne

July 2023

Credit to: NASA's Scientific Visualization Studio
Designers: Kel Elkins and Greg Shirah



NASA Earth Fleet

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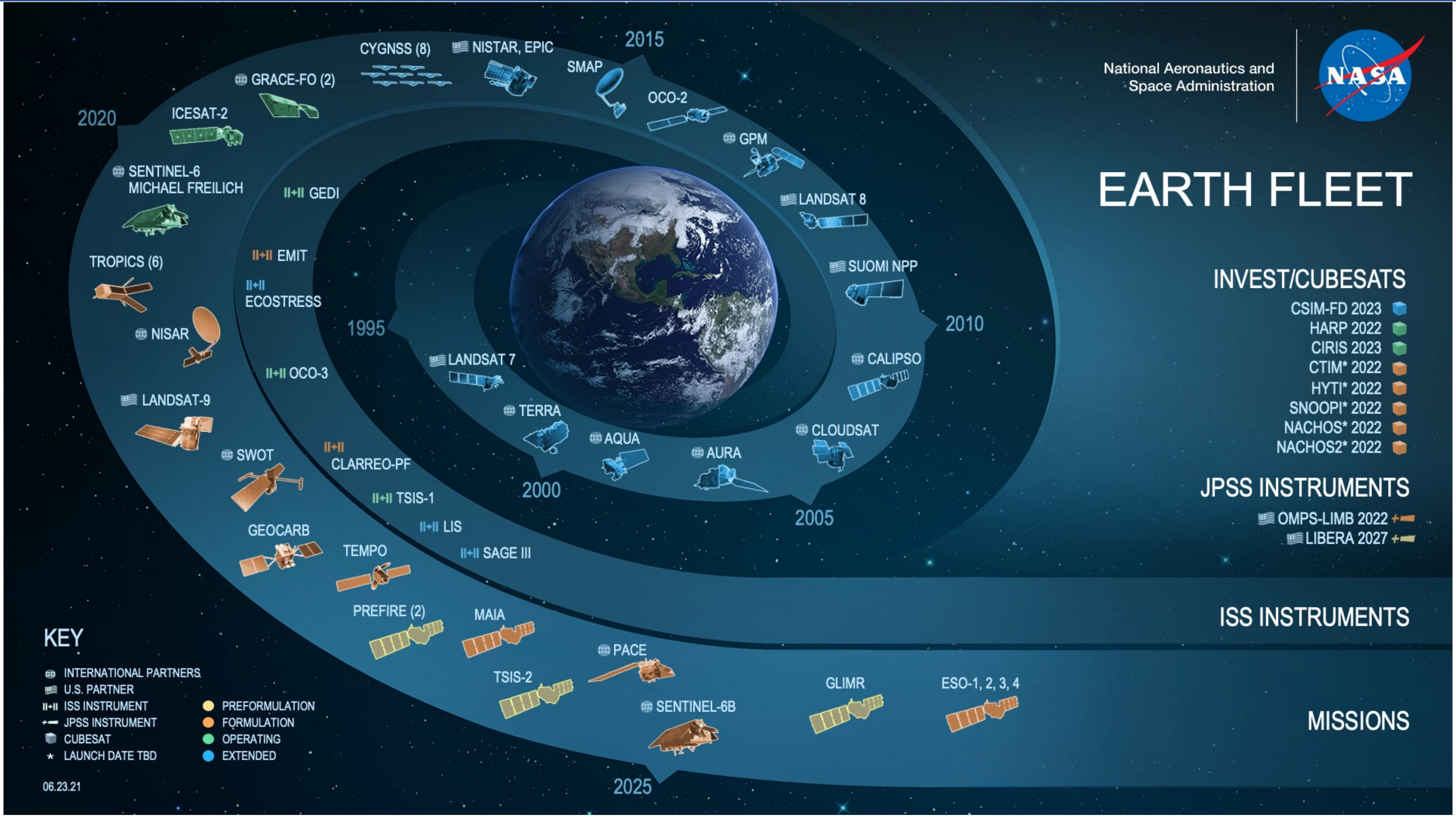

Earth System Observatory (ESO)
Interconnected Core Missions

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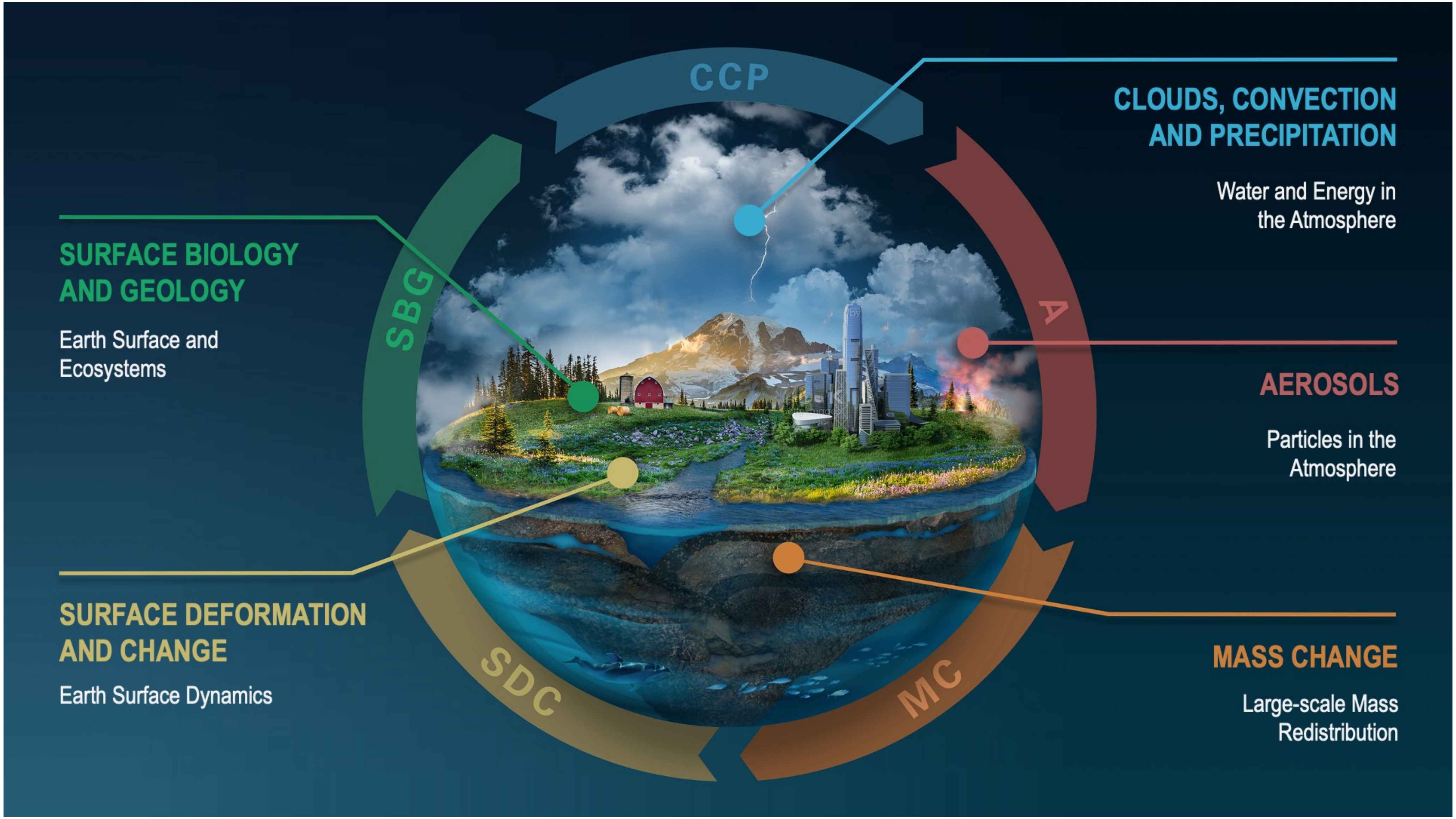

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Why Using various Spatial and Spectral Resolutions – *Example of Classification after Fusion*

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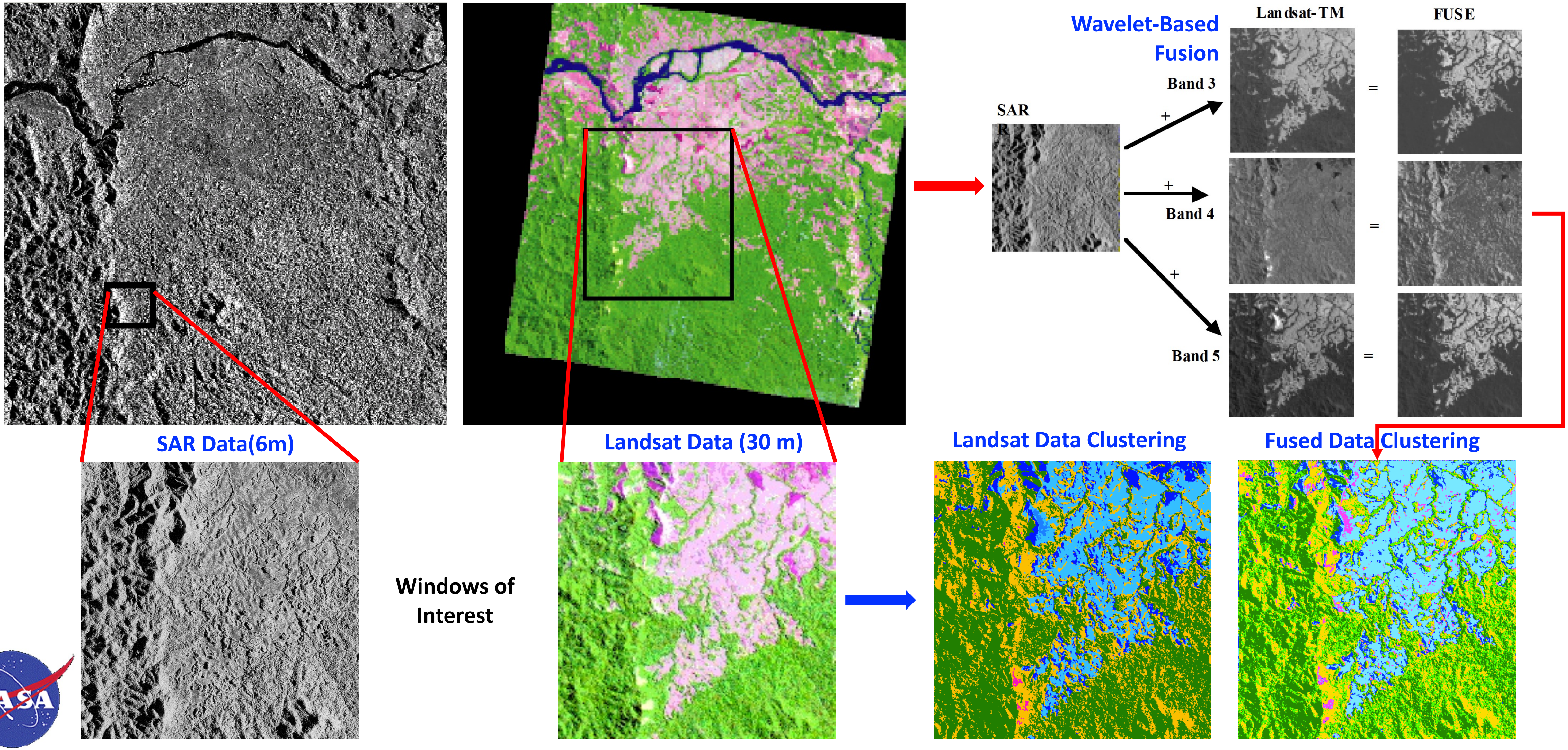

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Earth Science Technology Program Elements

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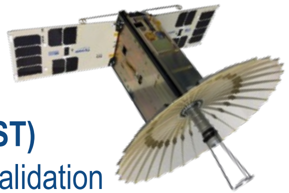
ESTO manages, on average, 130 active technology development projects. Over 830 projects have completed since 1998.

Advanced Technology Initiatives: ACT and InVEST

Advanced Component Technologies (ACT)
Critical components and subsystems for advanced instruments and observing systems

Solicitation planned in *FY24 & FY25*
Average award: $1.2M (2-3 years)

In-Space Validation of Earth Science Technologies (InVEST)
On-orbit technology validation and risk reduction for small instruments and instrument systems.



Solicitations planned in *FY23 & FY26*
Average award: $3-6M (3 years)

Instrument Incubator Program (IIP)

Innovative remote sensing instrument development from concept through breadboard and demonstration.
Average award IDD: $1.5M per year over 3 years. (instrument dev & demo)
Average award ICD: $750K over 1.5 years (Instrument concept demo)

Solicitations planned *in FY23 & FY26*
Average award: $4.5M (3 years)

Advanced Information Systems Technology (AIST)

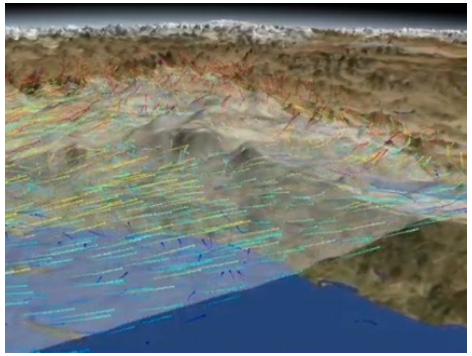
Innovative information systems for: new measurement collection through distributed sensing; Science missions ROI optimization; agile Science investigations; integrated information frameworks for mirroring Earth systems evolution and what-if scenarios.

Solicitations planned *in FY23 & FY26*
Average award: $1.2M (2 years)

Decadal Incubation

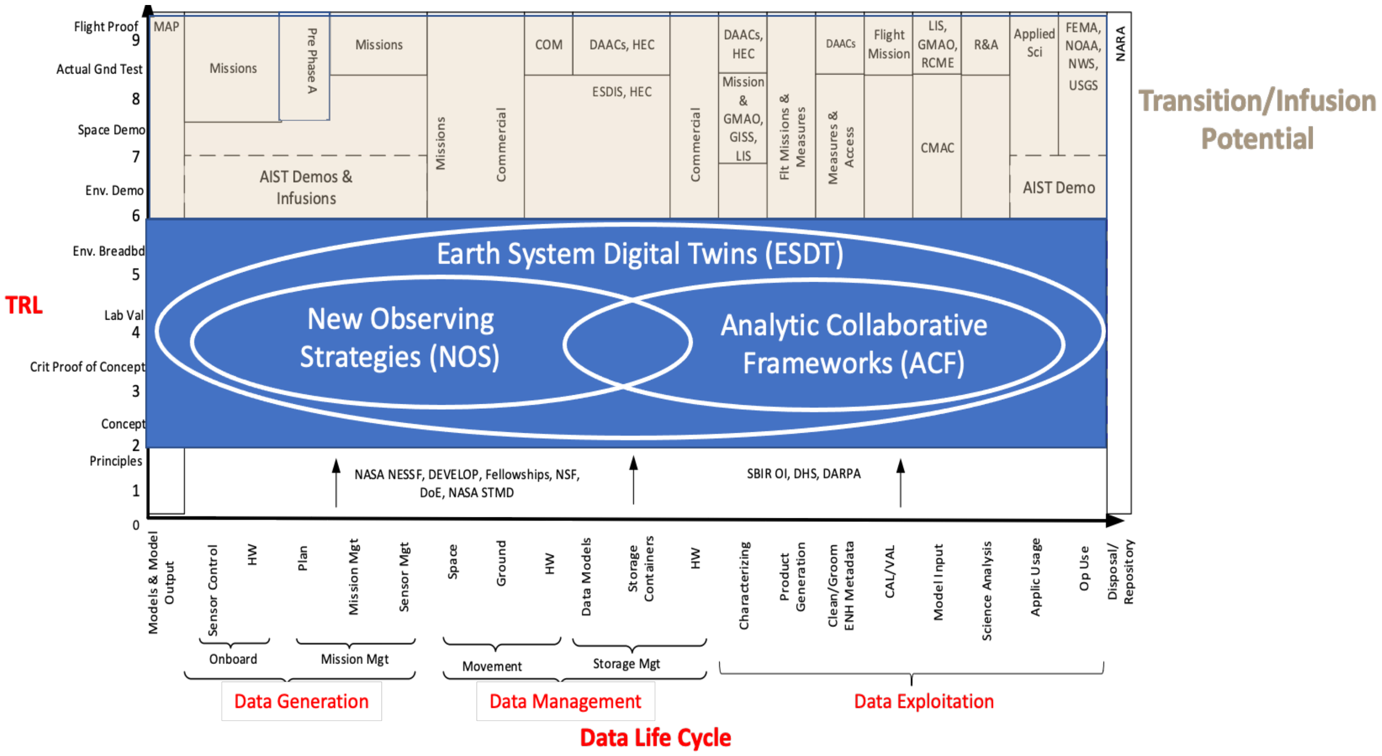
Maturation of observing systems, instrument technology, and measurement concepts for Planetary Boundary Layer and Surface Topography and Vegetation observables through technology development, modeling/system design, analysis activities, and small-scale pilot demonstrations

Solicitations planned *in FY24 and FY27*



NEW in FY22: **FireTech –** *Technology Development for Support of Wildfire Science, Management, and Disaster Mitigation*

AIST Program Scope



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

- "Starting with Science, Ending with Science"
- Extracting knowledge and information from Science data to make "Science decisions"

- **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/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

Novel Observing Strategies (NOS)

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

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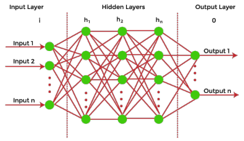
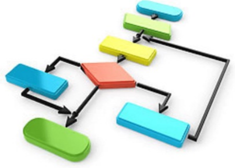
Resources

Data

Sensors & Platforms



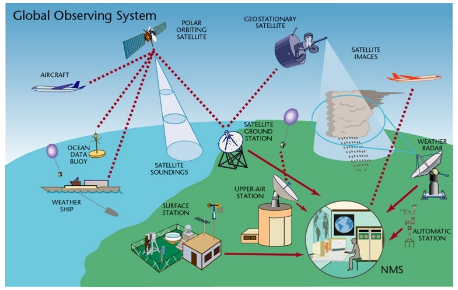
Models



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

Novel Observing Strategies (NOS)

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

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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?"

Optimize current & future Mission Portfolio and Mission Design

Drive Coordinated, Event-Driven Observations

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?"

From Archives to Analytic Frameworks

Focus on the Science User

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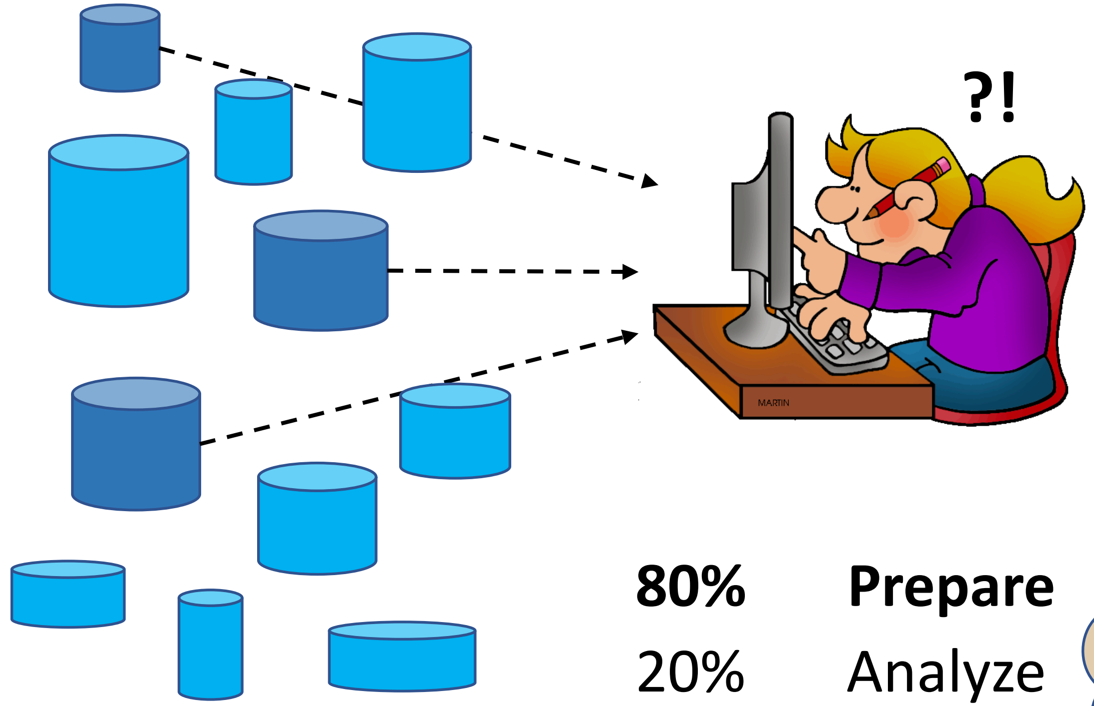
Allow flexibility/tailor configurations for Science investigators to choose among a large variety of datasets & tools

Data Archives

Focus on data capture, storage, and management

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



80% **Prepare**

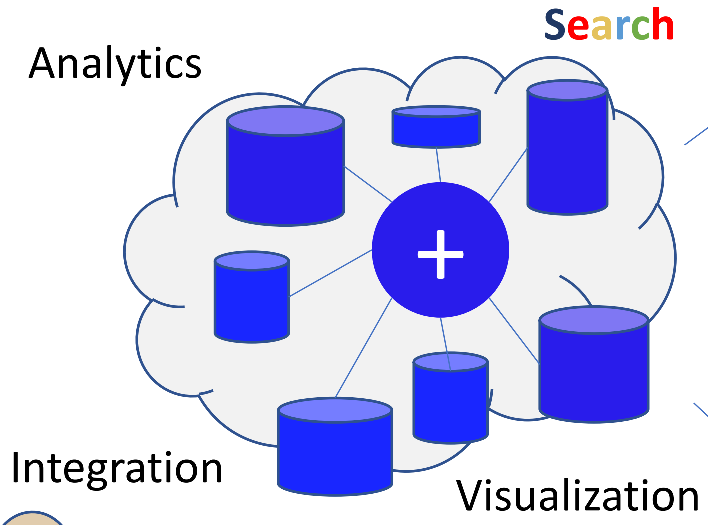
20% Analyze

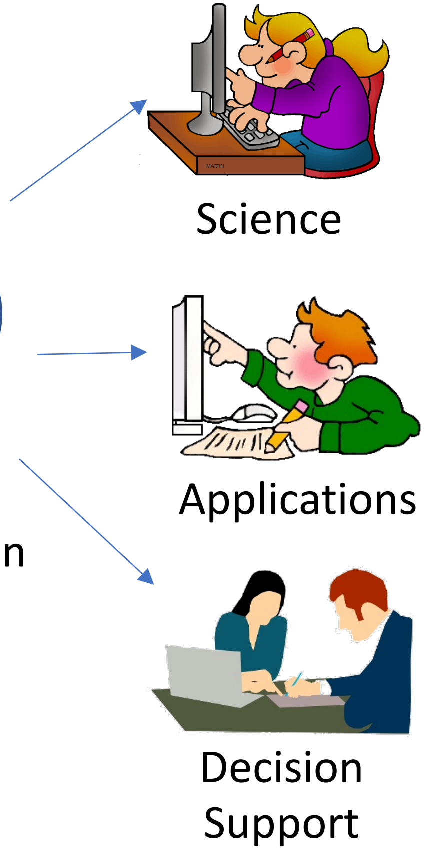
Reduce repetitive work in data access and pre-processing, e.g., develop reusable components

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

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Earth System Digital Twins (ESDT) build on the capabilities developed by NOS and ACF

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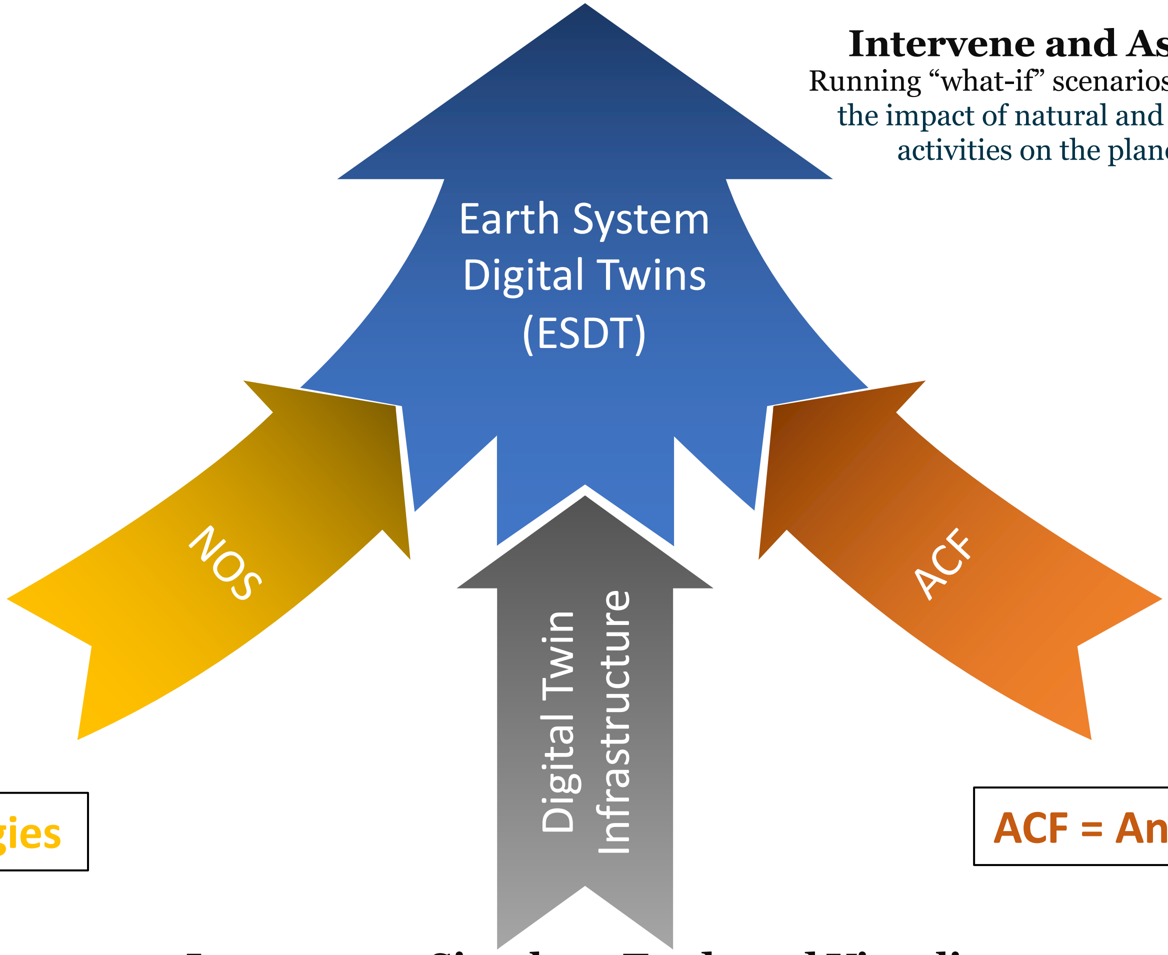
ESDT = Earth System Digital Twins

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

NOS = Novel Observing Strategies

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

ACF = Analytic Collaborative Frameworks

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

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Earth System Digital Twins Components

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. . .

Digital Replica . . . What now?

An integrated picture of the past and current states of Earth systems.

Forecasting . . . What next?

An integrated picture of how Earth systems will evolve in the future from the current state.

Impact Assessment . . . What if?

An integrated picture of how Earth systems could evolve under different hypothetical what-if scenarios.

- **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**

Multimodal Remote Sensing Data in AIST Systems

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- The use of multi-resolution and multimodal data is an integral part of all AIST systems.
- **For Novel Observing Strategies (NOS),** multimodal data is used to refine the information acquired by one sensor with a different sensor, e.g.:
  - Zooming on a specific location of interest by getting higher spatial resolution, or
  - Getting more information about an event by using a different spectral wavelength such as using infra-red instead of visible to observe wildfires.
  - It involves technologies such as onboard geo-registration, classification, feature extraction and sensor characterization.
- **When utilizing Analytic Collaborative Frameworks,** all these diverse data need to be mined, accessed and then accurately calibrated, geo-registered and fused before being analyzed or assimilated into models.
- **Earth System Digital Twins** will provide **digital replica** of Earth systems by continuously ingesting large numbers of multi-source/multimodal data (satellite, balloons, air, ground, buoys, or underwater) and even unstructured data from Internet of Things (IoT) sensors or from social media, just to name a few.
- ***For both NOS and ESDT,*** diverse observations need to be continuously targeted to optimize the required measurements.
- ***For both ACF and ESDT,*** technologies such as Machine Learning surrogate models, data fusion and assimilation as well as visualization need to be tailored to utilize those diverse data.

AIST-16/Chirayath (ARC) –

NeMO-Net - The Neural Multi-Modal Observation & Training Network for Global Coral Reef Assessment

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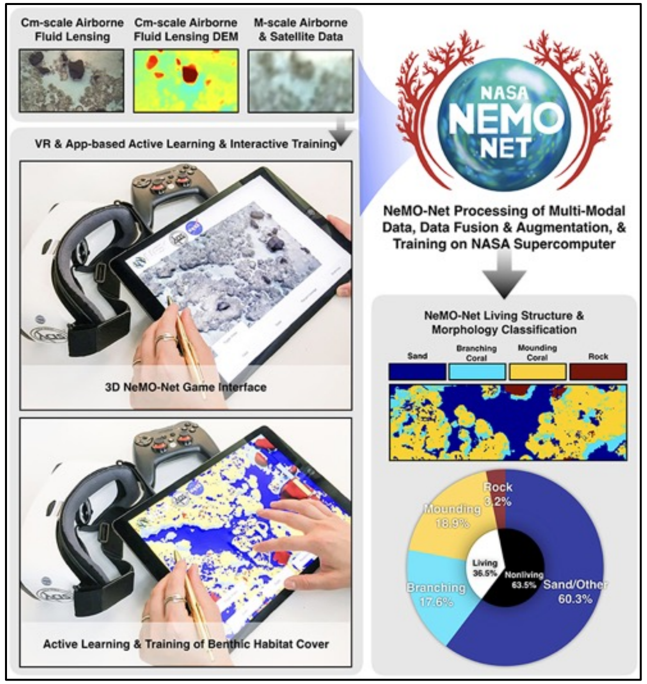
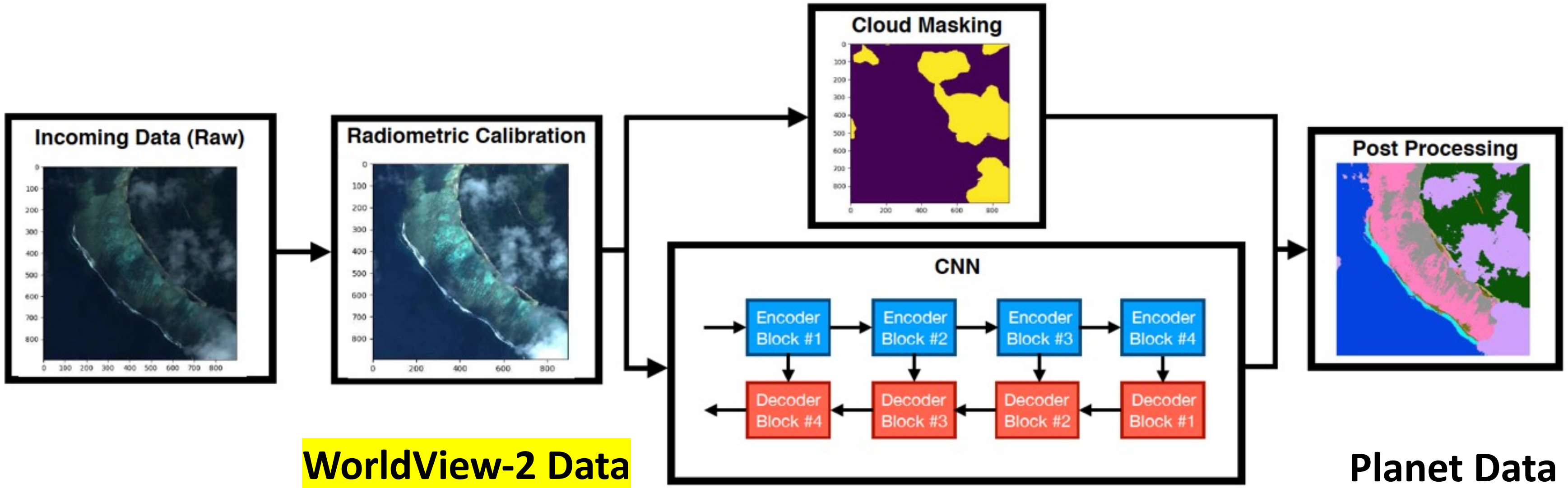
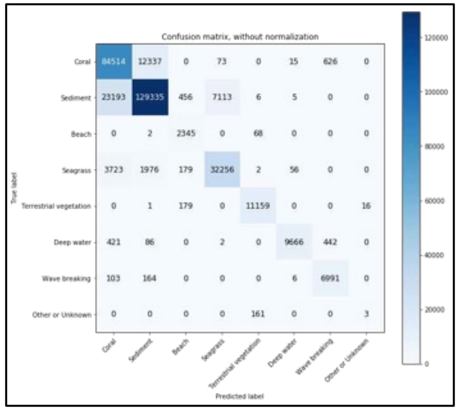
NeMO-Net deploys deep convolutional neural networks (CNNs) and active learning techniques to accurately assess the present and past dynamics of coral reef ecosystems through determination of precent living cover and morphology as well as mapping of spatial distribution. Ingests heterogeneous data from airborne and satellite imagery to demonstrate data fusion techniques to resolve temporal, spectral and spatial differences across datasets; and extends predictions over large temporal scales. The deep neural networks were trained using a citizen science app that allows people to label images. The algorithm was trained and tested on WorldView 2 imagery, and then used directly to successfully process Planet imagery.



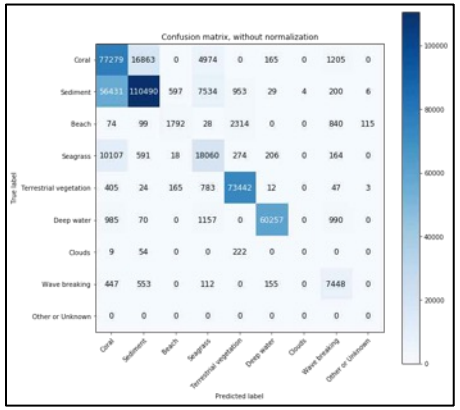


WorldView-2 Data



Total Accuracy: 84.3%
Accuracy amongst coral, sediment, seagrass classes: 83.6%

Planet Data



Total Accuracy: 76.0%
Accuracy amongst coral, sediment, seagrass classes: 68.1%

AIST-18/Duren (U. of Arizona & JPL) –
Multi-Scale Analytic Framework Supports Efficient Analysis of Methane Data

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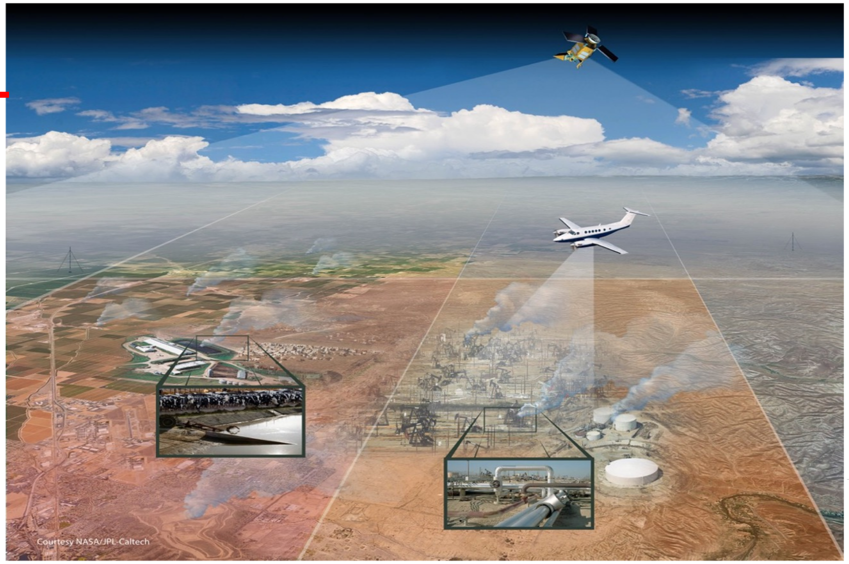
Develop and mature technologies to improve the understanding of methane as a major climate forcing agent through data discovery, efficient processing, analysis and use of methane data from multiple satellite and airborne observations, surface measurements and modeling systems from global to facility (point source) scales.

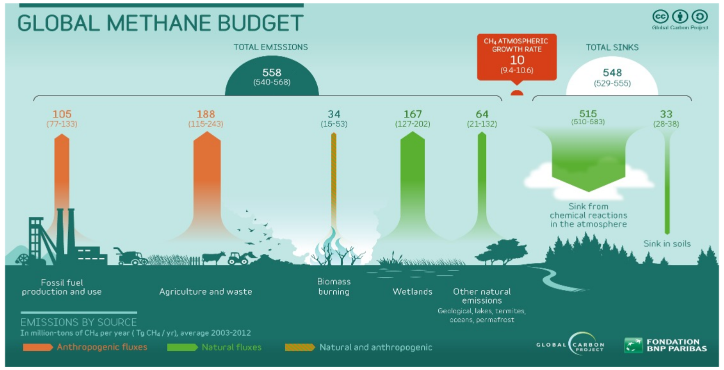
Data: (1) **Satellites**: Global mappers and point source mappers (e.g., Landsat, Planet, TROPOMI, OCO-2&3); (2) Regional and local surface **in-situ networks** (Towers); (3) **Airborne surveys**: local-regional net fluxes and point source mappers (e.g., AVIRIS) ; (4) **On-site and on-road surveys.**

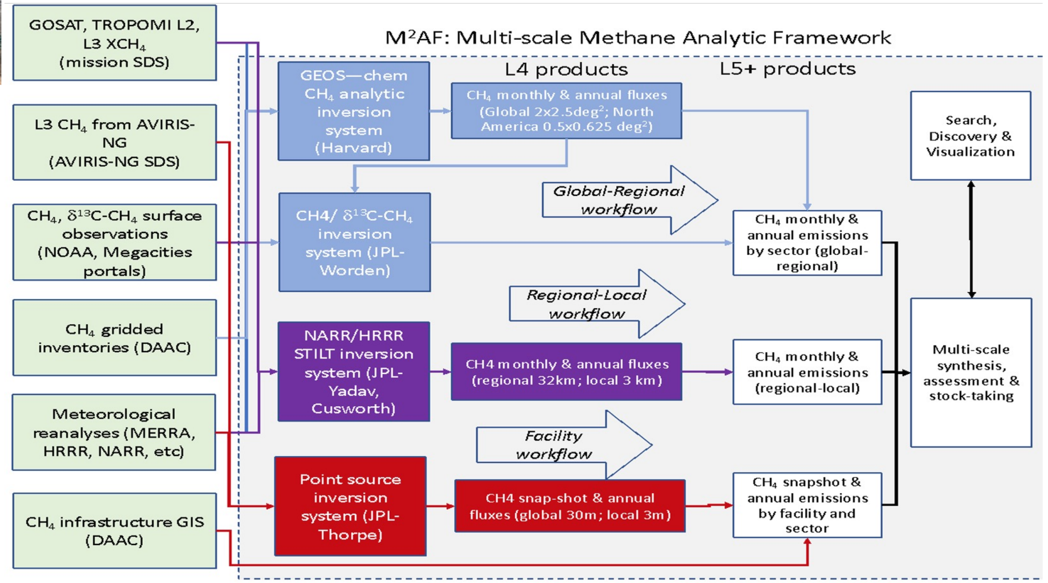


Objectives:

- Improve component workflows to reduce methane data product (Levels 4 and 5) latency and integrate common core functions
- Create new tools for on-demand analytics including fusion across multiple products and spatial scales
- Improved data search, discovery and visualization capabilities of Methane data

Methane is #2 anthropogenic climate forcing agent and ozone precursor.
There is large uncertainty (50% to unknown) across many scales.





AIST-18/Holm (City of Los Angeles) –
Predicting What We Breathe (PWWB)

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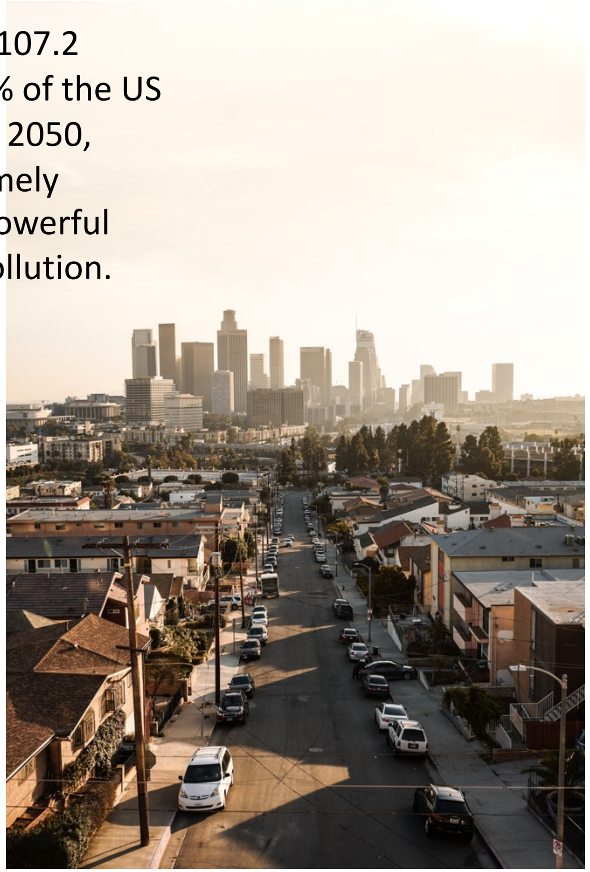
This project integrates ground-based, space-based data and machine learning to help cities predict air quality (AQ) and develop policies to mitigate air pollution. It will also improve the ability to forecast and mitigate air pollution events and may significantly reduce the negative environmental, economic and health impacts of these events in urban environments.

Air pollution is responsible for 4.5 million deaths and 107.2 million disability-adjusted-life-years globally. With 89% of the US population expected to live in urban environments by 2050, reducing air pollution-related loss of life will be extremely important. PWWB will provide policy makers with a powerful tool for reducing illnesses and deaths caused by air pollution.

- **New air quality initiative** led by the City of Los Angeles, in collaboration with OpenAQ (diverse fields including air quality research, data science, public health, city officials, and community activism.
- Using the **City of Los Angeles as a test case**
- Sister cities identified and recruited => air quality regime **similarities in cities around the world** being discovered
- Regional and international workshops to socialize the models, promote the open source, and gather requirements



PWWB website: https://airquality.lacity.org/

- Developed **5 predictive models** for analyzing air quality data based on ground-based sensors and satellite observations
- Provide predictions of PM2.5, NO2, CO, and O3
- **Ground-based air quality sensor data** from AQMIS and Port of LA datasets (arb.ca.gov)
- **Satellite observations** from NASA MODIS,ESA Sentinel-2; MERRA and MAIAC datasets; meteorological data including wind, temperature, humidity
- **Deep neural networks** based on the combination of **convolutional neural networks and recurrent neural networks** that discover both temporal and spatial patterns in the data

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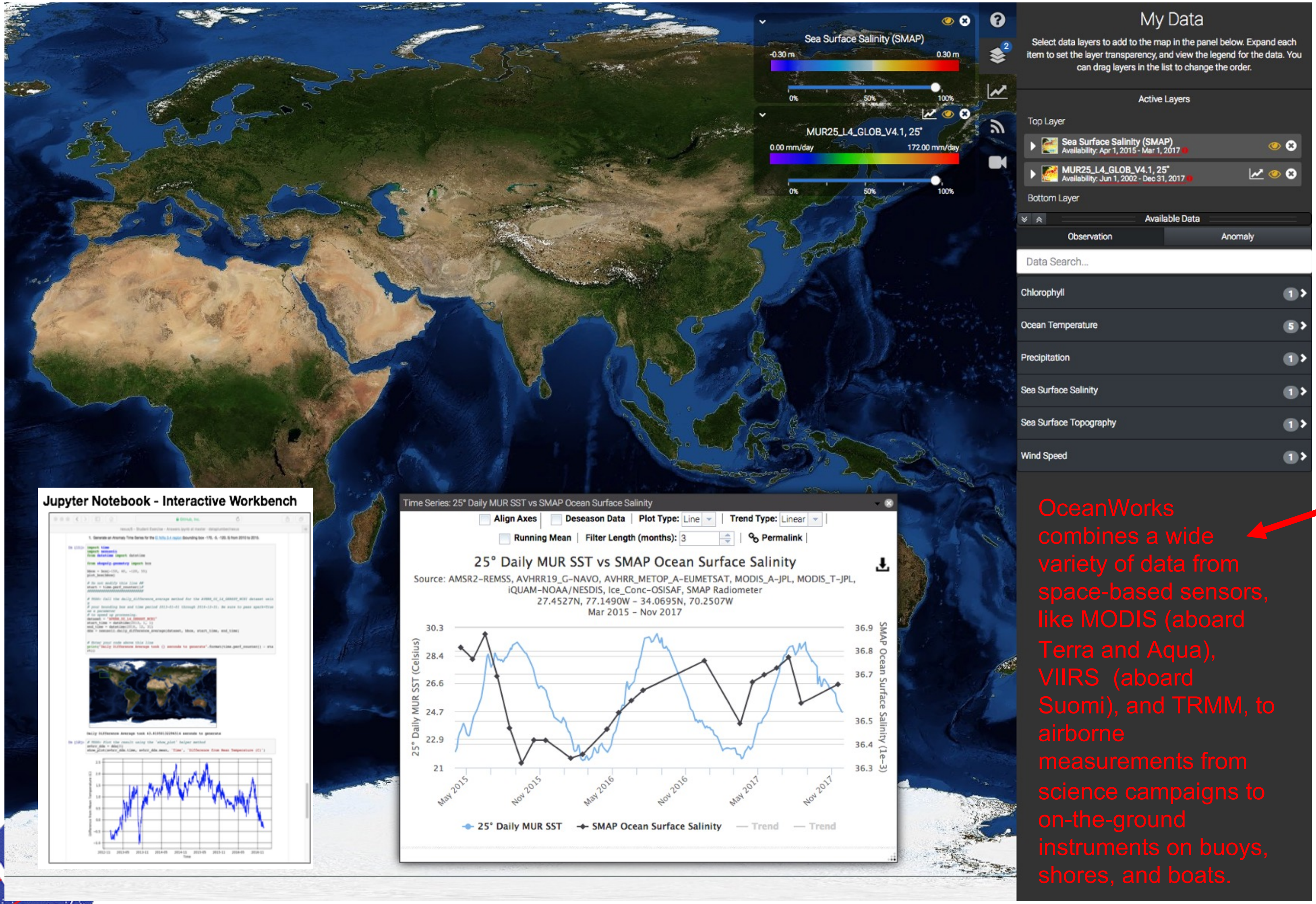
AIST-16/Huang (JPL)

OceanWorks – An Analytic Center Framework for Ocean Science



OceanWorks combines a wide variety of data from space-based sensors, like MODIS (aboard Terra and Aqua), VIIRS (aboard Suomi), and TRMM, to airborne measurements from science campaigns to on-the-ground instruments on buoys, shores, and boats.

Dozens of Ocean Data Sets
In the cloud, integrated, ready to go

Cloud-based analytics. Analyze years of data over multiple data sets in seconds… without downloading data.

Custom analytics Scientists can also run custom tools and algorithms

Integrated data. Match up in-situ and remote sensing data, despite differences in scale and resolution.

Search. Find relevant data sets

Visualization. Subsets, layers, animations. Integrates with ArcGIS and Jupyter Notebooks.

https://oceanworks.jpl.nasa.gov

AIST-21/Huang (NASA JPL, GSFC, LaRC with CNES) –
Integrated Digital Earth Analysis System (IDEAS)

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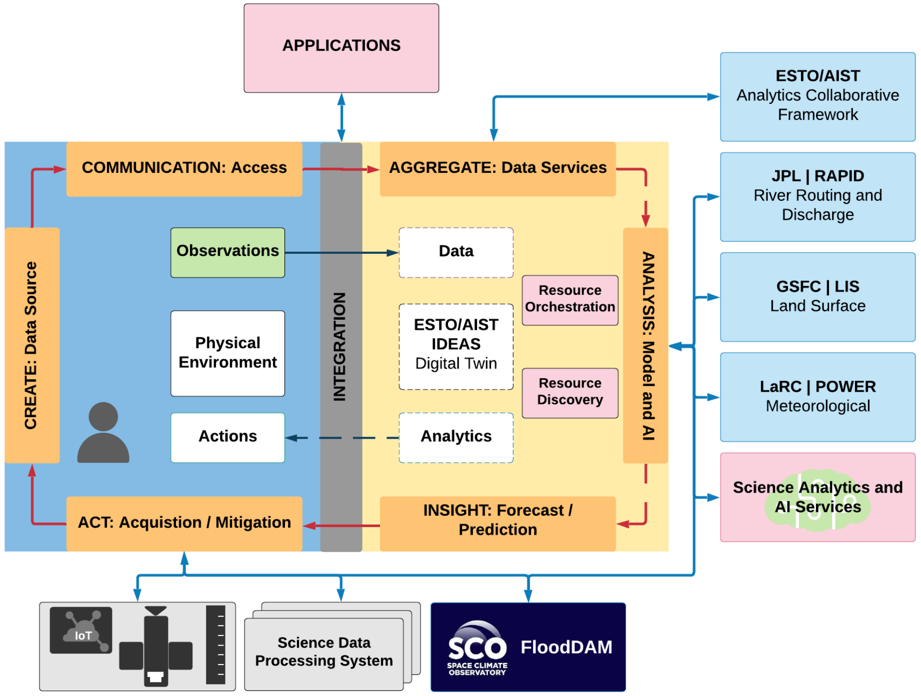
***IDEAS is a NASA ESTO/AIST Earth System Digital Twin** project that bridges the physical environment and its virtual representation by continuously assimilating new observations to improve forecast and prediction for integrated science and decision support.*



IDEAS – Digital Twin for Water Cycle and Flood Detection and Monitoring

- Using water cycle and flood analysis as the prototype application to integrate NASA, CNES, and Space Climate Observatory (SCO) data and science
- Remote Sensing Data:
  - GPM IMERG precipitation; SMAP soil moisture (saturation); MODIS snow/ice cover (timing of thaw both in south and north);
  - Sentinel-1 SAR (river ice detection; water extent); Landsat-8, Sentinel-2 A/B imagery (river ice and flood detection); and HLS (surface water extent/flooding)
  - SWOT river height, surface water extent (when available)
  - OPERA dynamic surface water extent (when available)
  - USGS in-situ stream gauge observations and VORTEX.IO in-situ micro-station observations
  - SEDAC socioeconomic data (crop, population, infrastructure impacts)
- Advanced numerical models and analysis
  - **JPL's RAPID**: Routing Application for Parallel computation of Discharge
  - **GSFC's LIS**: Land Information System
  - **LaRC's POWER**: Prediction of Worldwide Energy Resources
  - **CNES and SCO's FloodDAM:** Automated service to reliably detect, monitor and assess flood events globally
  - Integration with **NASA IPCC Sea Level Prediction** data for coastal flooding
  - Joint developed and trained flood detection and prediction machine learning algorithms
  - Promote and advance interoperable standards
- Improve the Machine Learning flood prediction model (Huang *et al.* 2020) from the JPL-CNES Joint Data Science pilot
- Scenario-based prediction for infrastructure and population impacts
- Ongoing formulation and planning with CNES and SCO's FloodDAM

NASA · Jet Propulsion Laboratory California Institute of Technology · Goddard Space Flight Center · Langley Research Center

Projects Final Reports and Quads
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