

Integrated Digital Earth Analysis System (IDEAS)

An Open-Source Framework for Earth System Digital Twins

Clearance: CL#23-6057

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Committee on
Earth Observation Satellites

Thomas Huang

NASA Jet Propulsion Laboratory

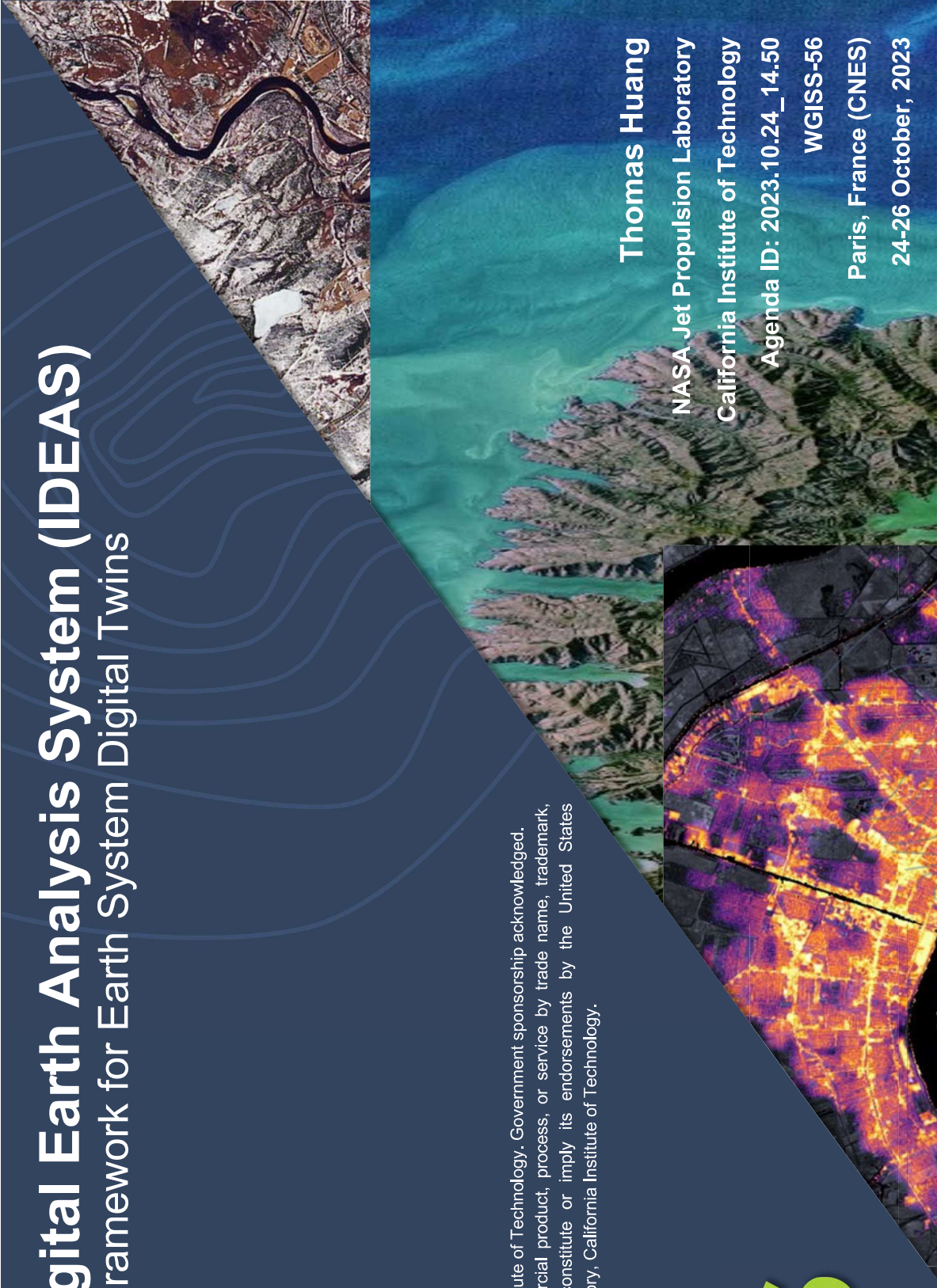
California Institute of Technology

Agenda ID: 2023.10.24_14.50

WGISS-56

Paris, France (CNES)

24-26 October, 2023

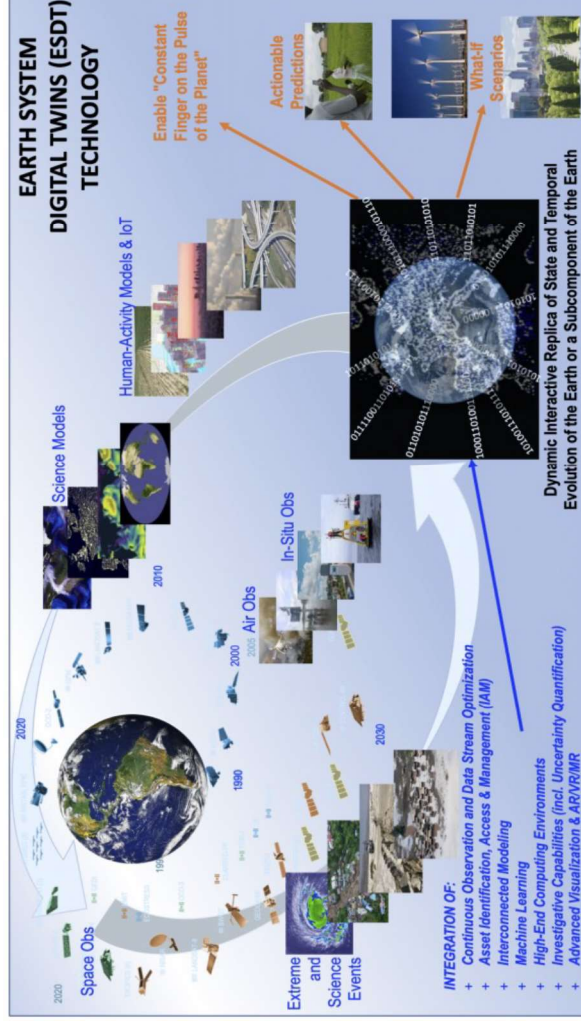


It is about
Past, Present, Future

Earth System Digital Twins



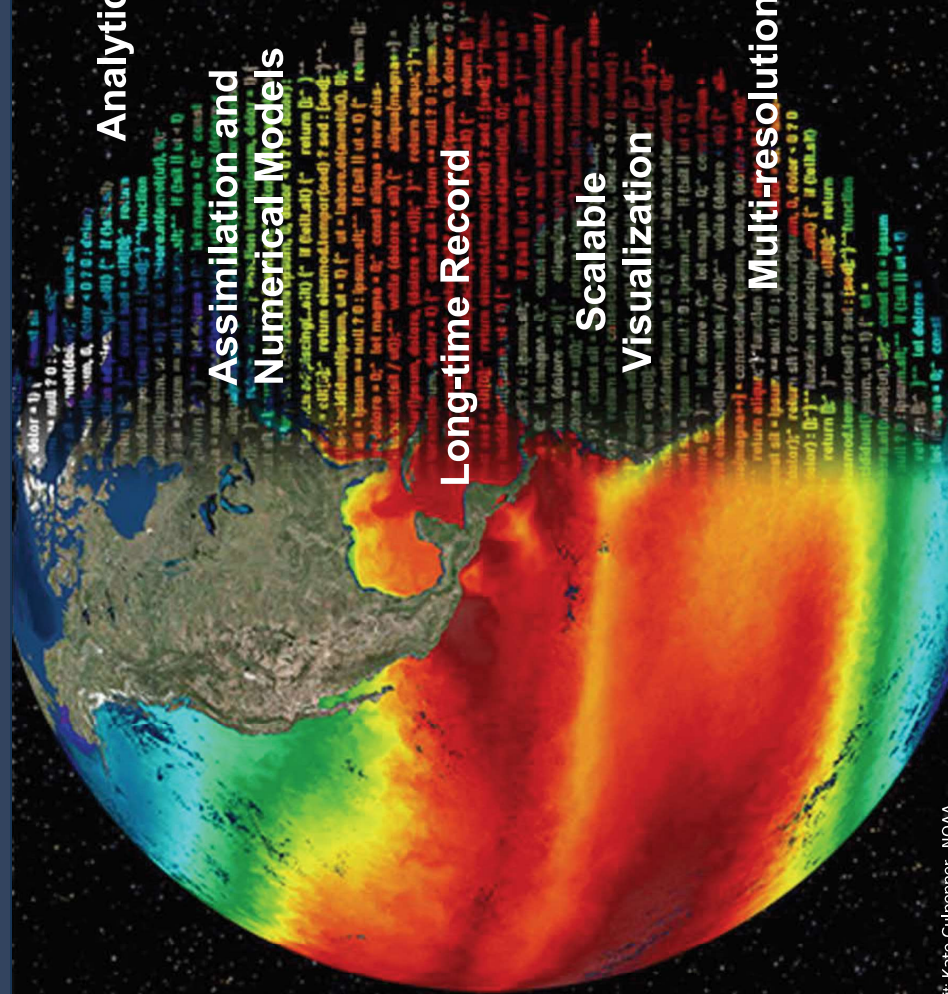
- An **Earth System Digital Twin (ESDT)** – an interactive and integrated multidomain, multiscale, digital replica of the state and temporal evolution of Earth systems
- It dynamically integrates
 - Relevant Earth system models and simulations
 - Other relevant models (e.g., related to world's infrastructure)
 - Continuous and timely (including near real-time and direct readout) observations (e.g., space, air, ground, over/underwater, Internet of Things (IoT), socioeconomic)
 - Long-time records
 - Analytics and artificial intelligence tools
- Enable users to run hypothetical scenarios to improve the understanding, prediction of and mitigation/response to Earth system processes, natural phenomena and human activities as well as their many interactions



An integrated information system that, for example, enables continuous assessment of impact from naturally occurring and/or human activities or physical and natural environments

Source: <https://esto.nasa.gov/aist/>

Earth System Digital Twin Framework



Analytic Collaborative Framework

Standards New Observing Strategies

Assimilation and Numerical Models

Extensible Framework

Artificial Intelligence

Long-time Record

Real-time

Scalable

Visualization

Multi-computing

Federated

Multi-resolution

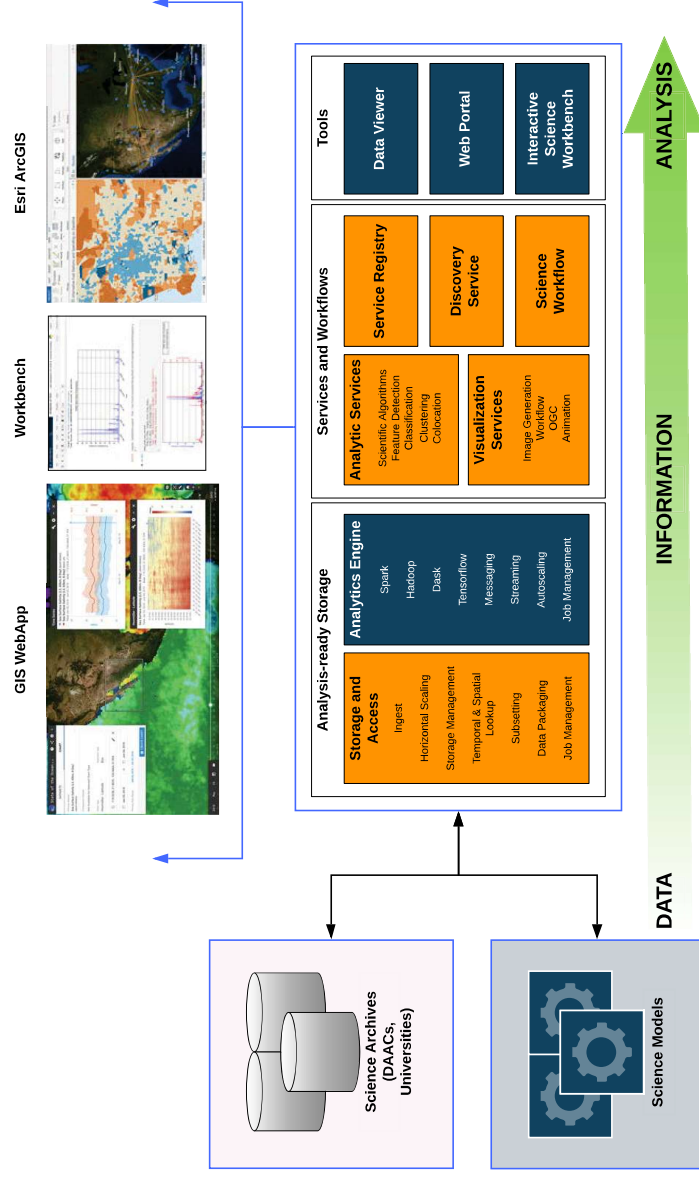
Multivariate

Access and Analysis

Image Credit: Kate Culpepper, NOAA

Analytic Collaborative Framework

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



- ❖ An **Analytic Collaborative Framework (ACF)** to provide an environment for conducting a science investigation
 - Enables the confluence of resources for that investigation
 - Tailored to the individual study area (physical ocean, sea level, etc.)
- ❖ Harmonizes data, tools and computational resources to permit the research community to focus on the investigation
- ❖ Scale computational and data infrastructures
- ❖ Shift towards integrated data analytics
- ❖ Algorithms for identifying and extracting interesting features and patterns
- ❖ Customers and Stakeholders
 - Scientists from various disciplines
 - Data archive centers
 - Policy makers

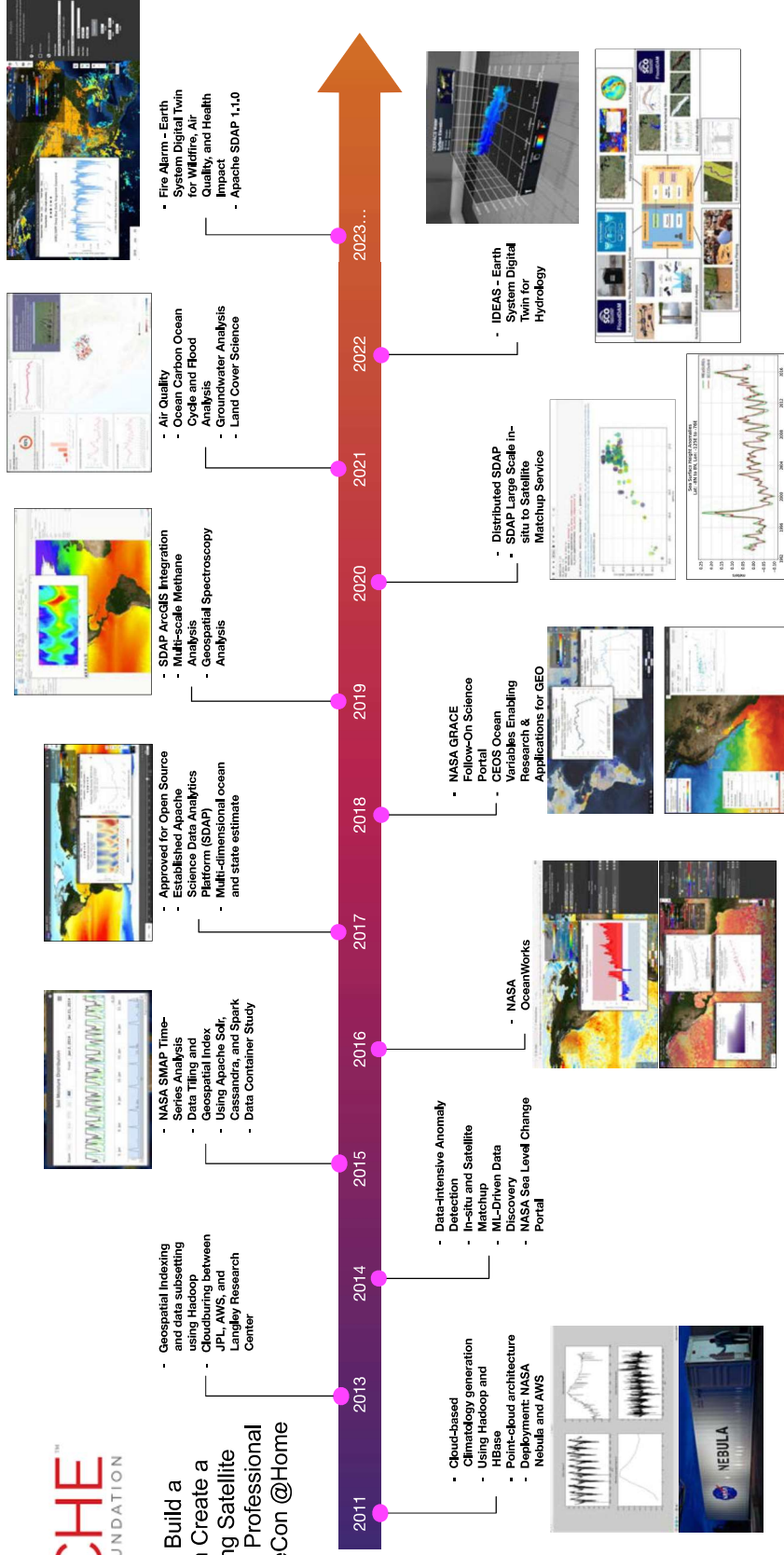
High-level System Architecture

Professional Open-Source Analytic Collaborative Framework

<https://sdap.apache.org>



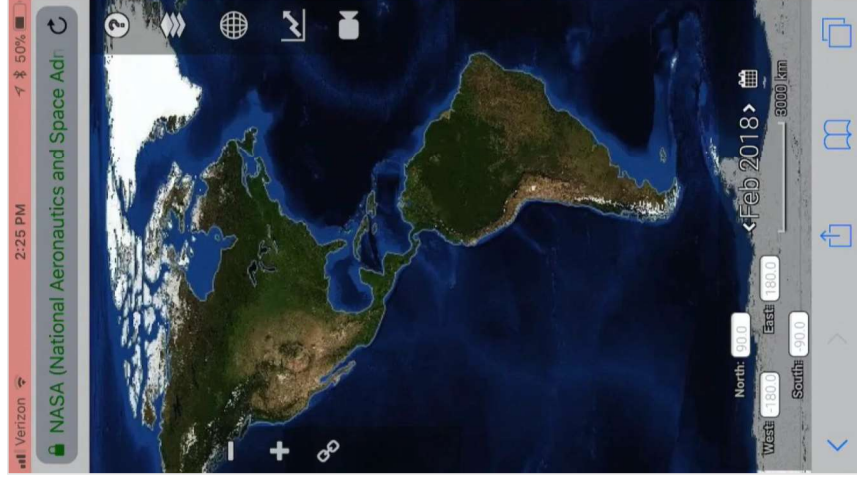
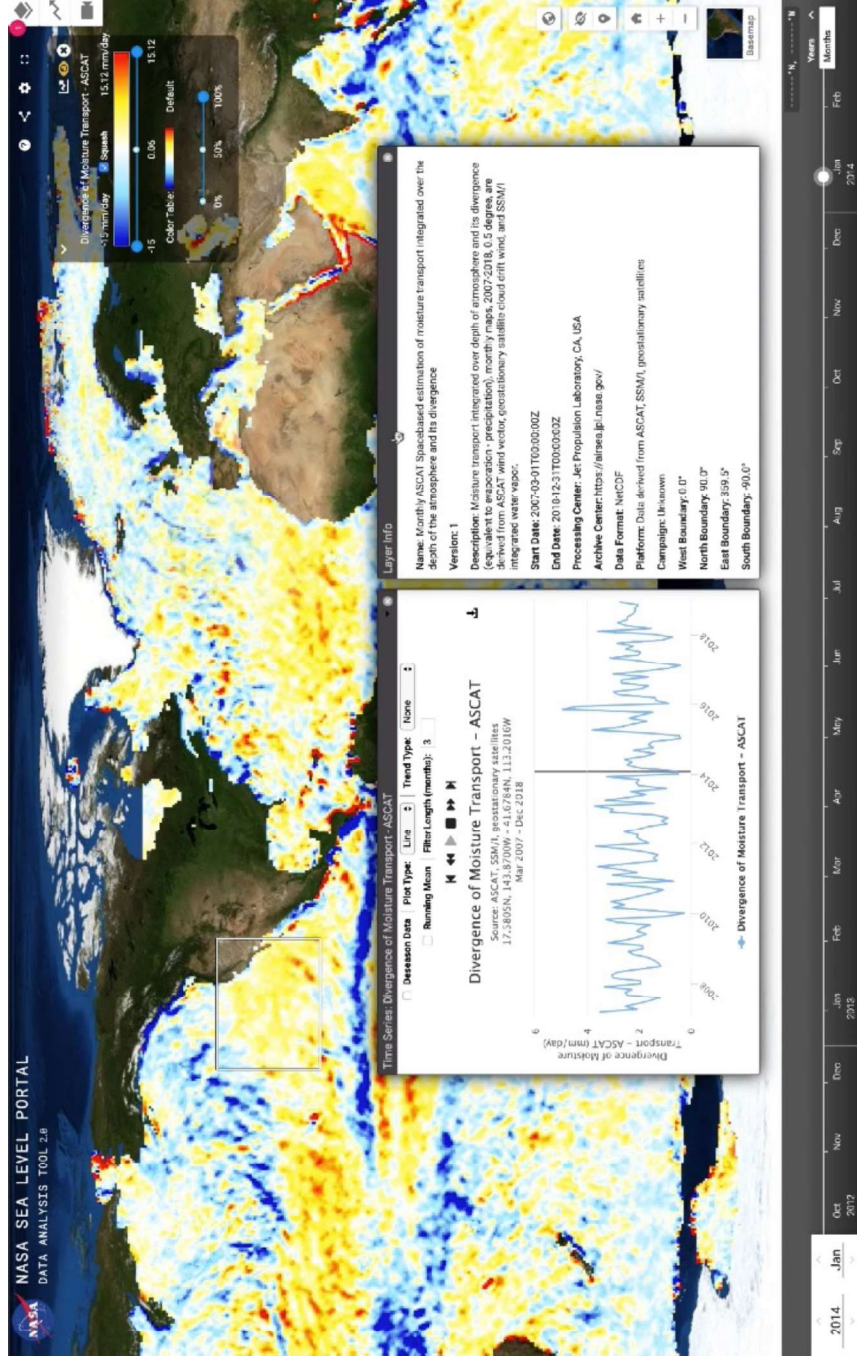
T. Huang, 2020: "Why Build a Castle When You Can Create a Community - Advancing Satellite Data Analysis through Professional Open Source" ApacheCon @Home 2020 Keynote



Evolution of Apache Science Data Analytics Platform (SDAP)

Sea Level Rise

<https://sealevel.nasa.gov>



Interactive Sea Level Analysis

Visualization of In-situ and Remotely-Sensed Groundwater Observations (VIRGO)

<https://www.jpl.nasa.gov/media/virgo>



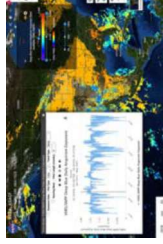
VIRGO visualizes data from a variety of sources

- in-situ wells and GPS stations as well as remotely-sensed gravity and InSAR (interferometric synthetic aperture radar) data
- to enable groundwater trends to be assessed.

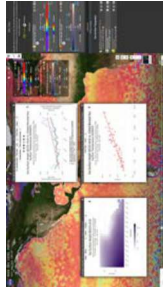
By bringing together both satellite and in-situ data, VIRGO offers deeper context to NASA's data and makes it possible to do complimentary analysis and comparison.



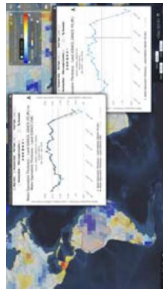
Federation of Science Analytic Platforms



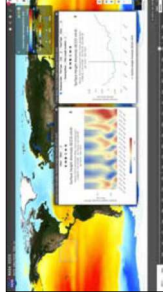
AQ Analysis Tool



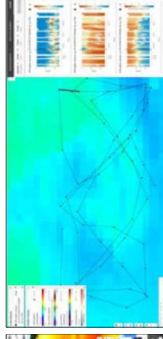
Sea Level Analysis Tool



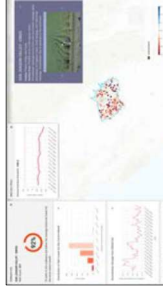
GRACE-FO Analysis Tool



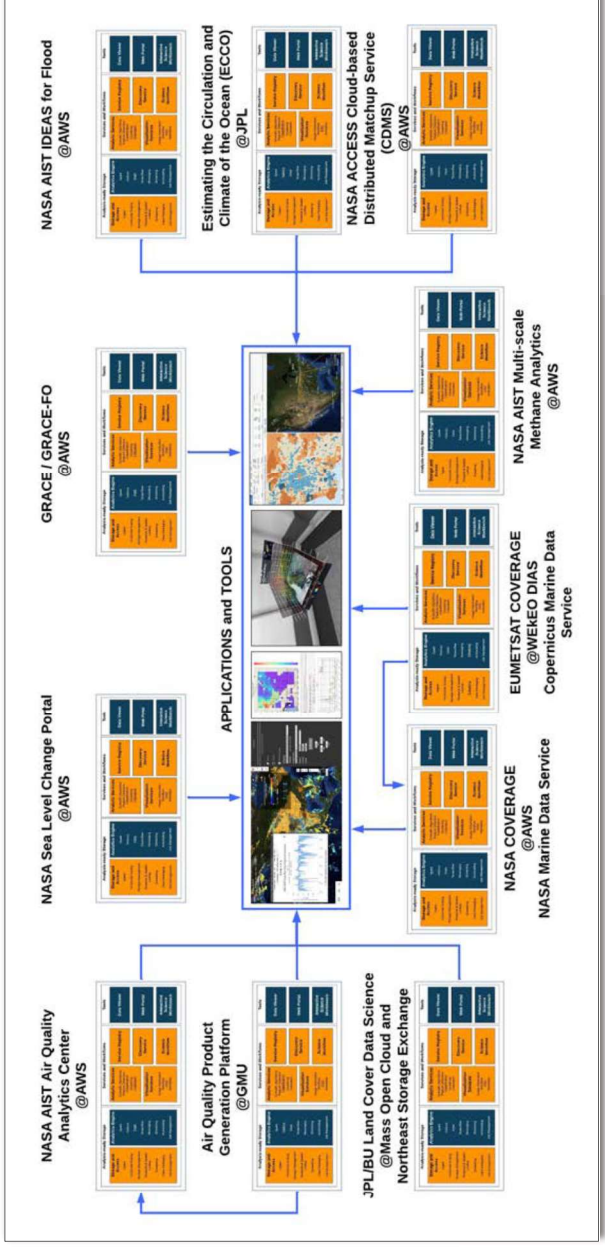
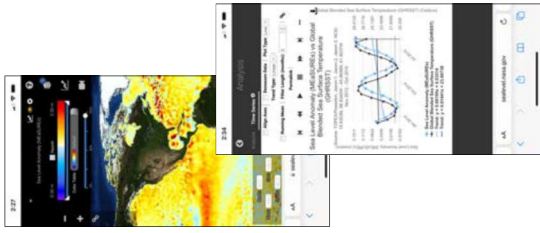
ECCO Analysis Tool



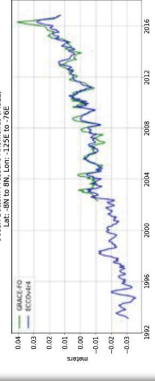
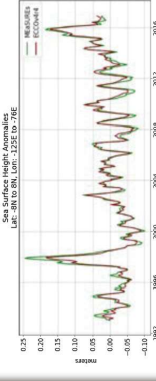
CEOS COVERAGE Analysis Tool



VIRGO Groundwater Tool



E. Tropical Pacific SSH: ECCO vs. NASA MEAsURES Satellite Product



Verify ECCO OBP vs. NASA/JPL GRACE-FO Product

Professional Open-Source | Eliminate Data Replication | Access to Operational ACFs | Distributed Multi-Computing Solution

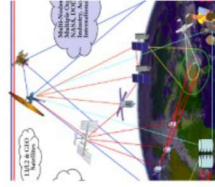
Actionable Science – New Observing Strategies



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

Assimilate Observations

New Observing Strategies (NOS)

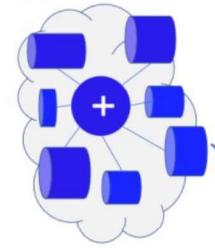


Acquire coordinated observations

Track dynamic and spatially distributed phenomena

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

Analytic Collaborative Frameworks (ACF)

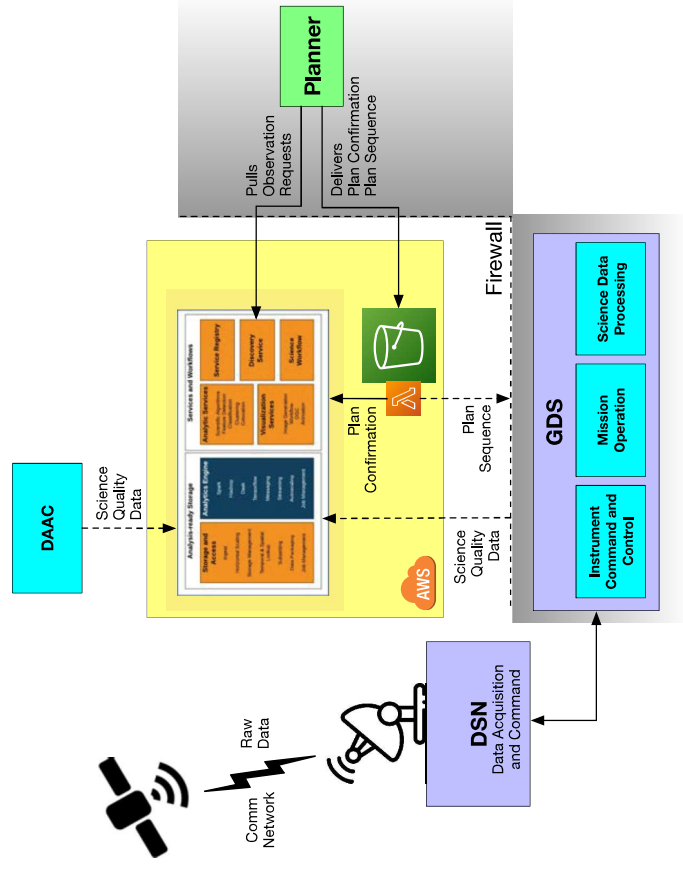


Assimilate many various data into models and analytic workflows.

What additional observations are needed?

Observation Requests

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

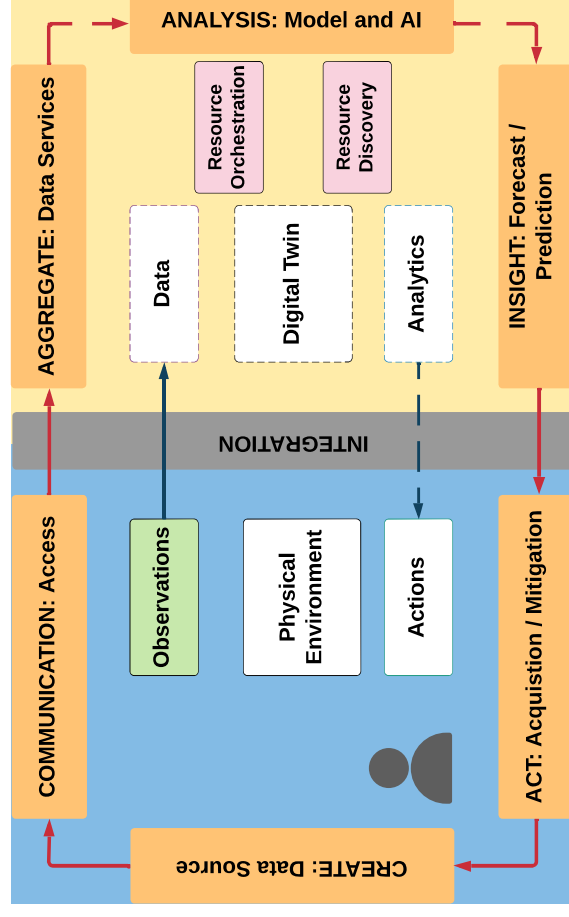


- Science-Driven architecture for Acquiring new observations and Dynamic data assimilation
- Develop trend analysis, anomaly detection and event dispatch

Earth System Digital Twin: Key Components

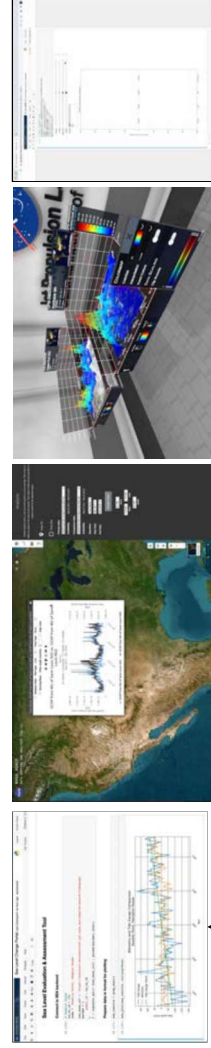


- **Data and Services Assets:** Supports Extract, Transform, and Load (ETL) workflow for metadata harvesting, error detection and correction, re-gridding/reprojecting, Analysis Ready Data (ARD) transformation
- **New Observation and Analysis:** Smarter method to automate onboarding relevant data
- **Integrated Multiphysics, Multi-scale, Probabilistic Models:** Automates inclusion of the latest measurements and supports scenario-based model execution
- **AI and Advanced Analytics:** enables dynamic data acquisition, long-term prediction, data classification, process orchestration and management, etc.

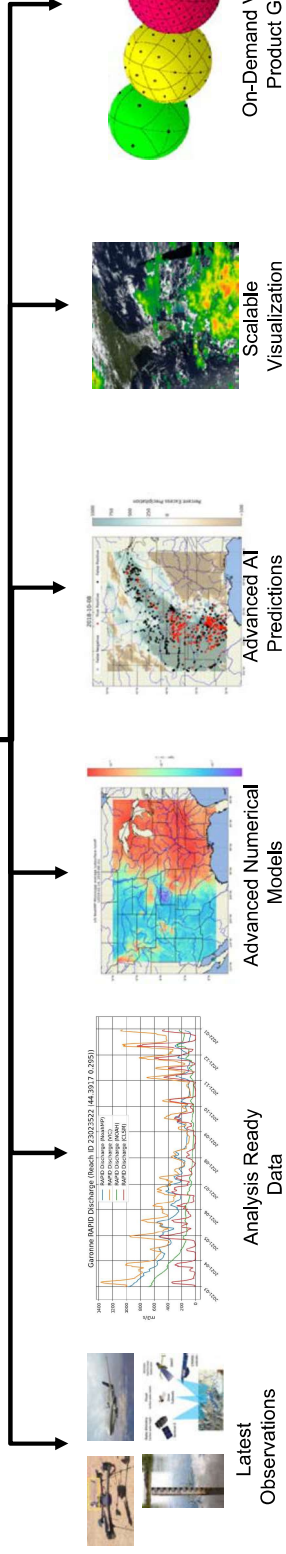


Bridges the Physical Environment and its Virtual Representation

Professional Open-Source Digital Twins Framework



IDL C/C++ MATLAB Python Julia R ...



IDEAS for Hydrology, Flood Prediction, and Analysis

Partnership between NASA and the CNES-led Space for Climate Observatory (SCO)'s FloodDAM-DT effort

NASA JPL: Thomas Huang, Cedric David, Gary Doran, Jason Kang, Grace Llewellyn, Kevin Marlis, Stepheny Perez, Wai (William) Phyo, Catalina M. Oaida, and Joe T. Roberts

NASA GSFC: Sujay V. Kumar and Nishan Biswas

NASA LaRC: Paul Stackhouse, David Borges, Madison P. Broddle, and Bradley MacPherson

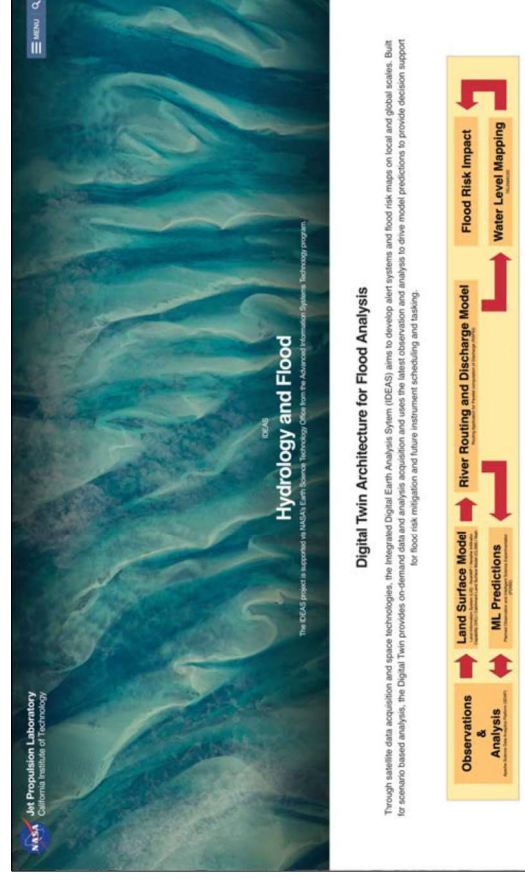
CNES: Simon Baillarin, Lerre Benjamin, Frederic Bretar Gwendoline Blanchet, Peter Kettig, Raquel Rodriguez Suquet, and Lonjou Vincent

CERFACS: Sophie Ricci, Thanh-Huy Nguyen, and Andrea Piacentini

Collecte Localization Satellites (CLS): Christophe Fatras, Sylvain Brunato, and Eric Guzzonato

QuanCube: Alice Froidevaux, Antoine Guiot, Thanh-Long Huynh, and Romane Raynal

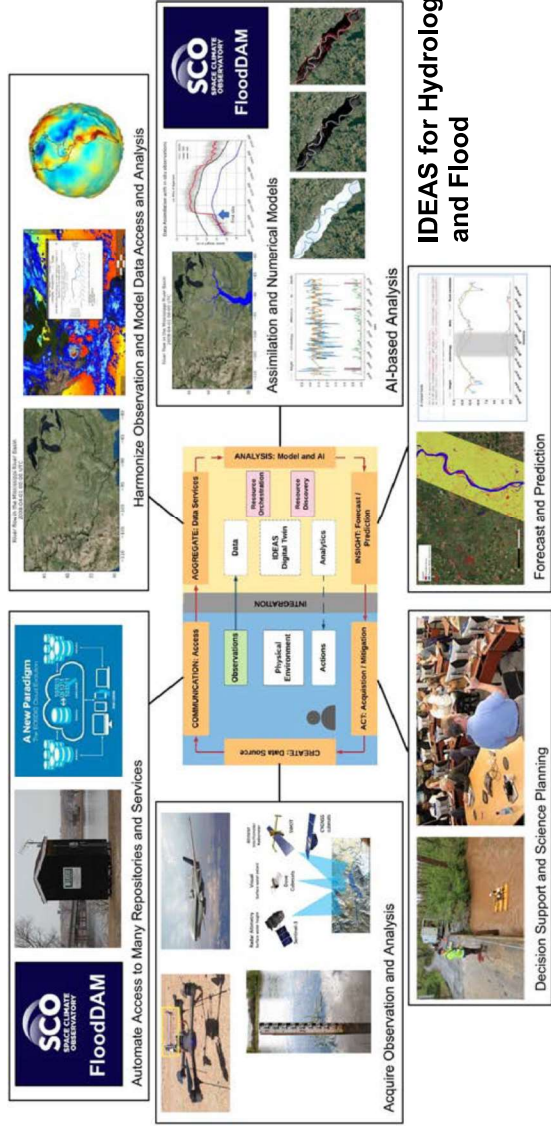
Vortex.io: Guillaume Valladeau and Jean-Christophe Poisson



<https://ideas-digitaltwin.jpl.nasa.gov/hydrology/>

What are the environmental and infrastructural impacts of floods?

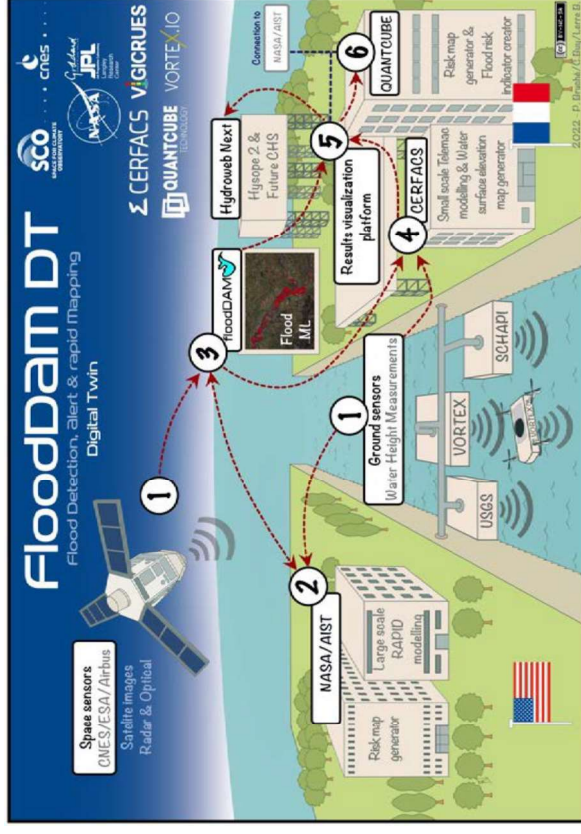
NASA – CNES: Federated Digital Twins



IDEAS for Hydrology and Flood

Establish federated digital twins solution between the **NASA ESTO/AIST's Integrated Digital Earth Analysis System (IDEAS)** (Huang/JPL) and the **Space for Climate Observatory (SCO FloodDAM-DT)** (Rodriguez-Suque/CNES)

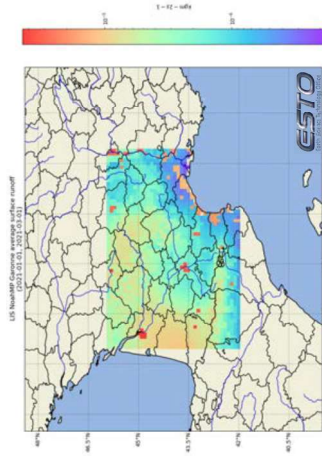
NASA AIST IDEAS is an open-source Earth System Digital Twins (ESDT) framework
 The collaboration focuses on establishing DT-powered flood alert systems, analysis, and risk maps on local and global scales



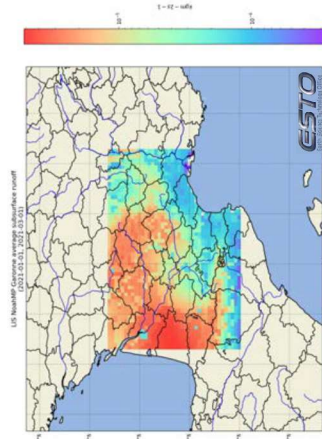
PARTNERS:



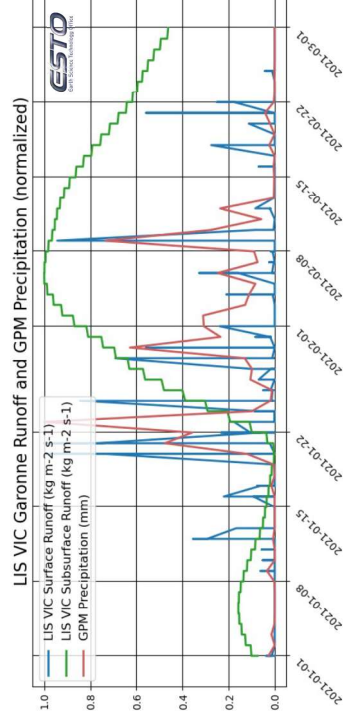
Bringing Observations and Models Together 2021-03 through 2021-12 in Garonne



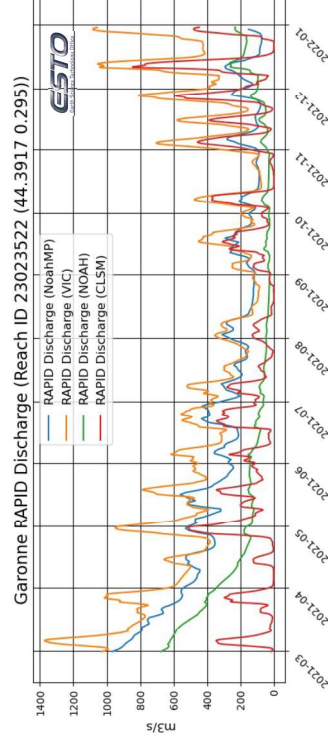
NoahMP Average Surface Runoff



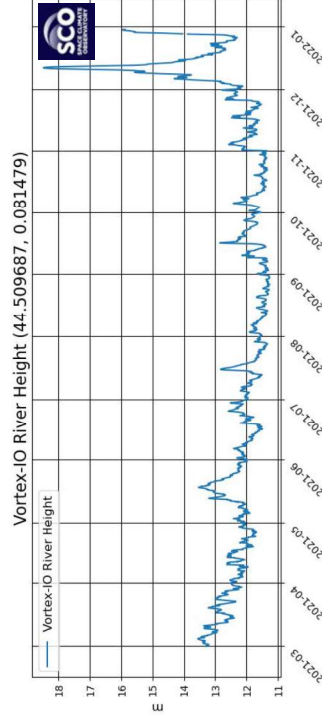
NoahMP Average Subsurface Runoff



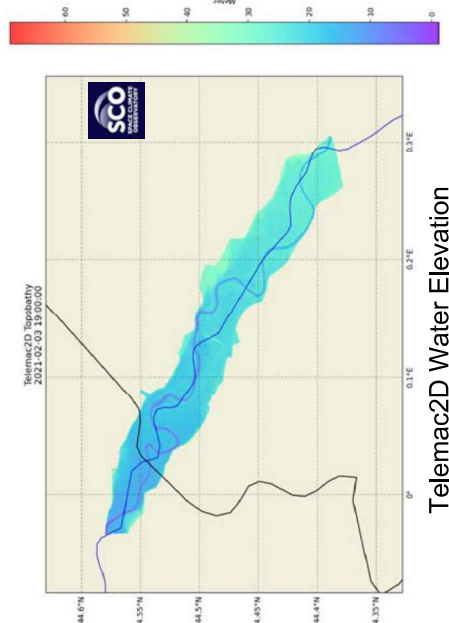
VIC Runoff and GPM Precipitation (normalized)



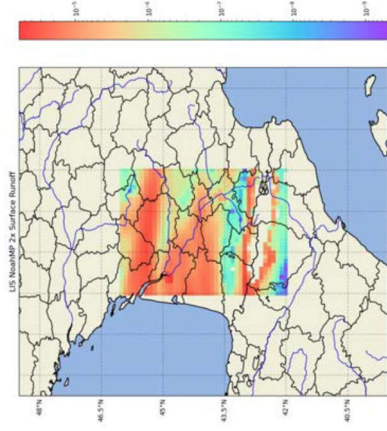
RAPID Discharge from different Land Surface Models



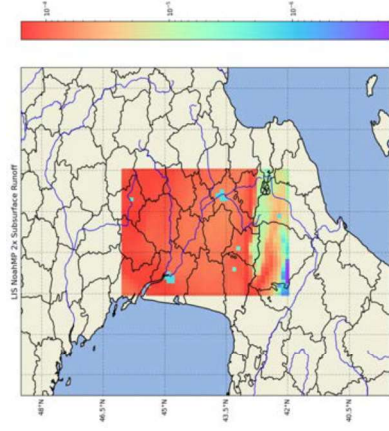
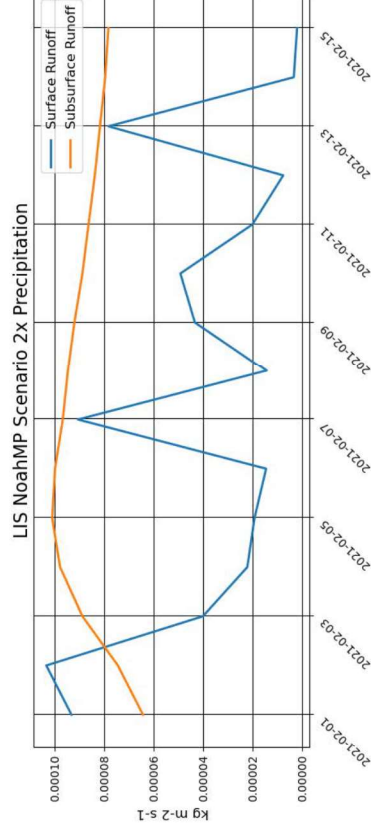
Vortex-IO River Height



What-If Garonne: 2x Precipitation

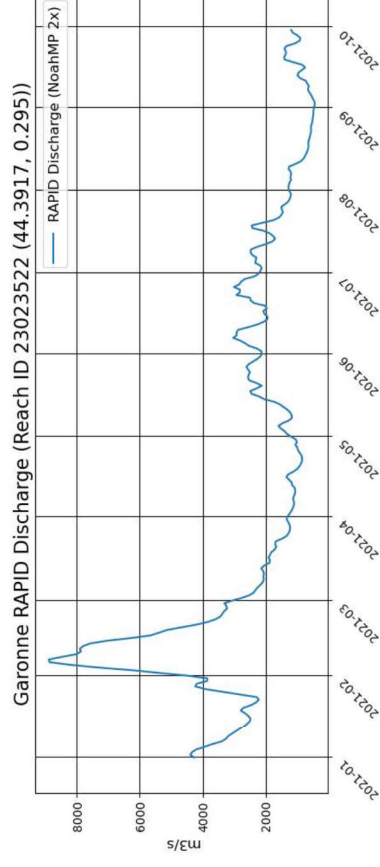


NoahMP – Surface Runoff



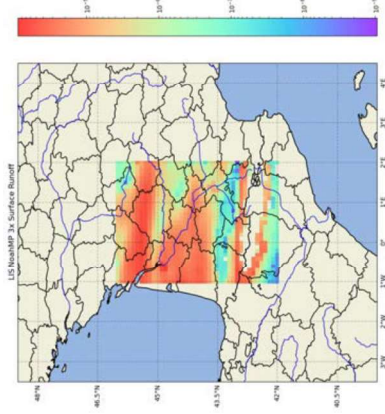
NoahMP – Subsurface Runoff

NoahMP Surface and Subsurface Runoffs

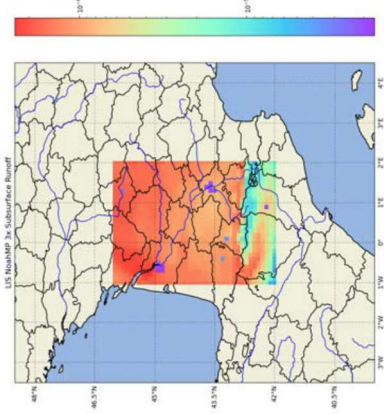
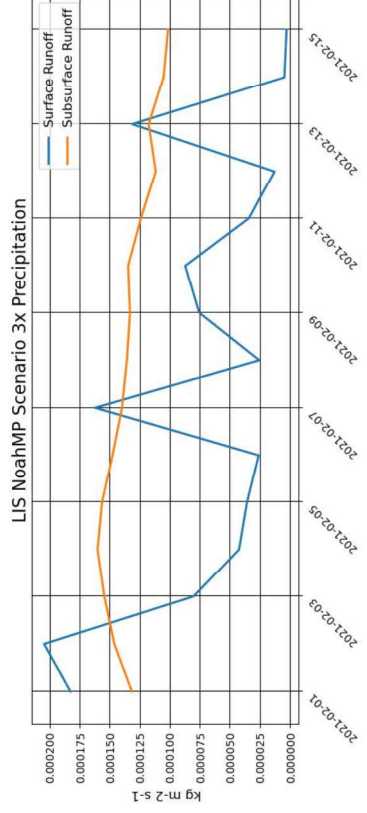


RAPID Discharge

What-If Garonne: 3x Precipitation

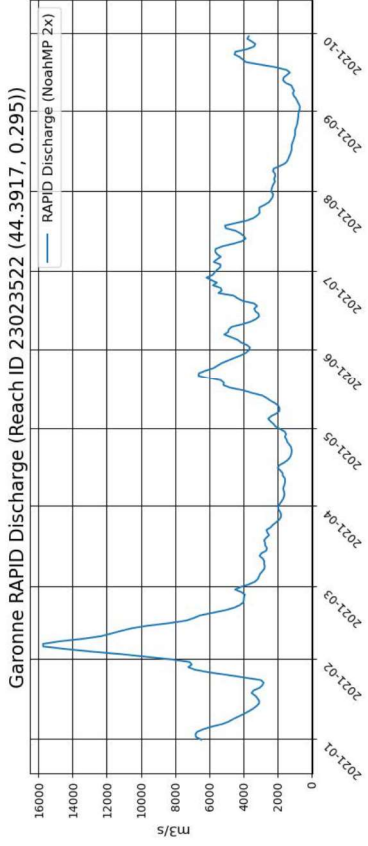


NoahMP – Surface Runoff



NoahMP – Subsurface Runoff

NoahMP Surface and Subsurface Runoffs

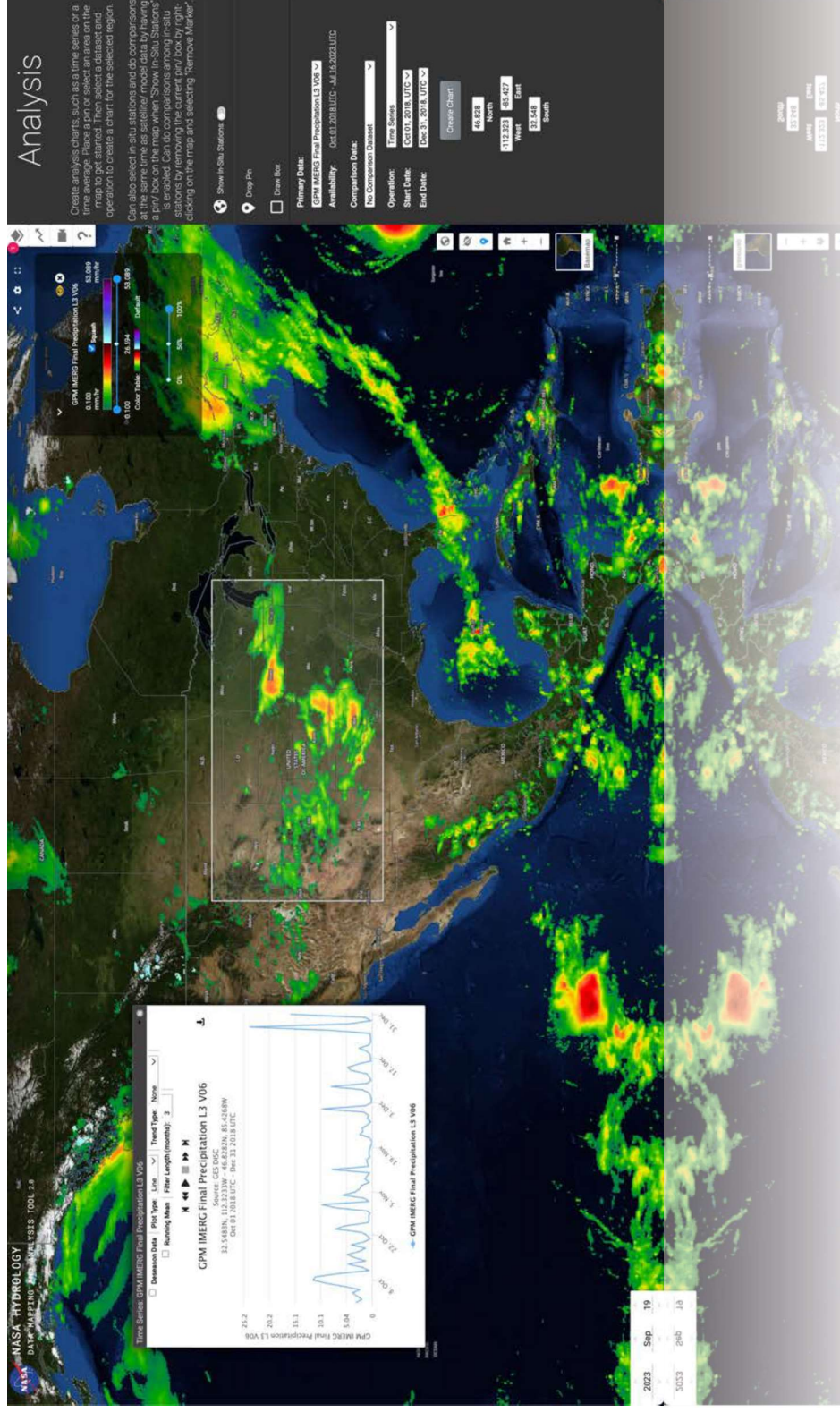


RAPID Discharge

Hydrology Data Analysis Tool



- Interactive visualization of all satellite, model, and in-situ measurements
- Compare model outputs with actuals
- Interactive matchup between satellite to satellite, and in-situ to satellite

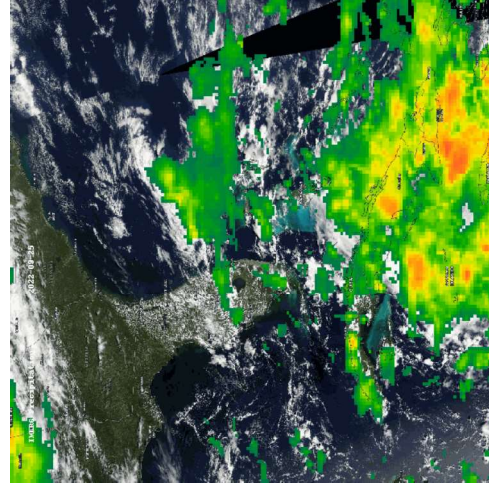


IDEAS-Powered Flood Notebook

https://github.com/EarthDigitalTwin/IDEAS-notebooks/blob/main/Flood_Demo.ipynb



- Demonstrates the latest IDEAS API and capabilities
- STAC – Data search and metadata
- Data access – satellite, in-situ, and models
- Interactive, harmonized data analytic capabilities
- Visualizations – Tile WMS and on-demand animation generation



Jupyter IDEAS (autosaved) | Python 3 (ipykernel) | Not Trusted | Logout

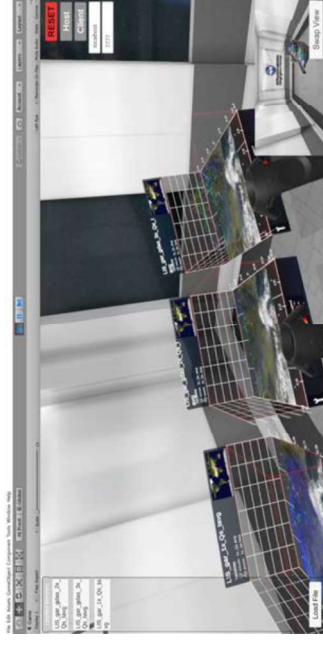
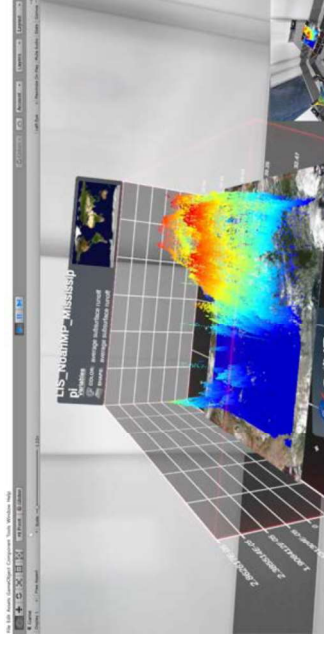
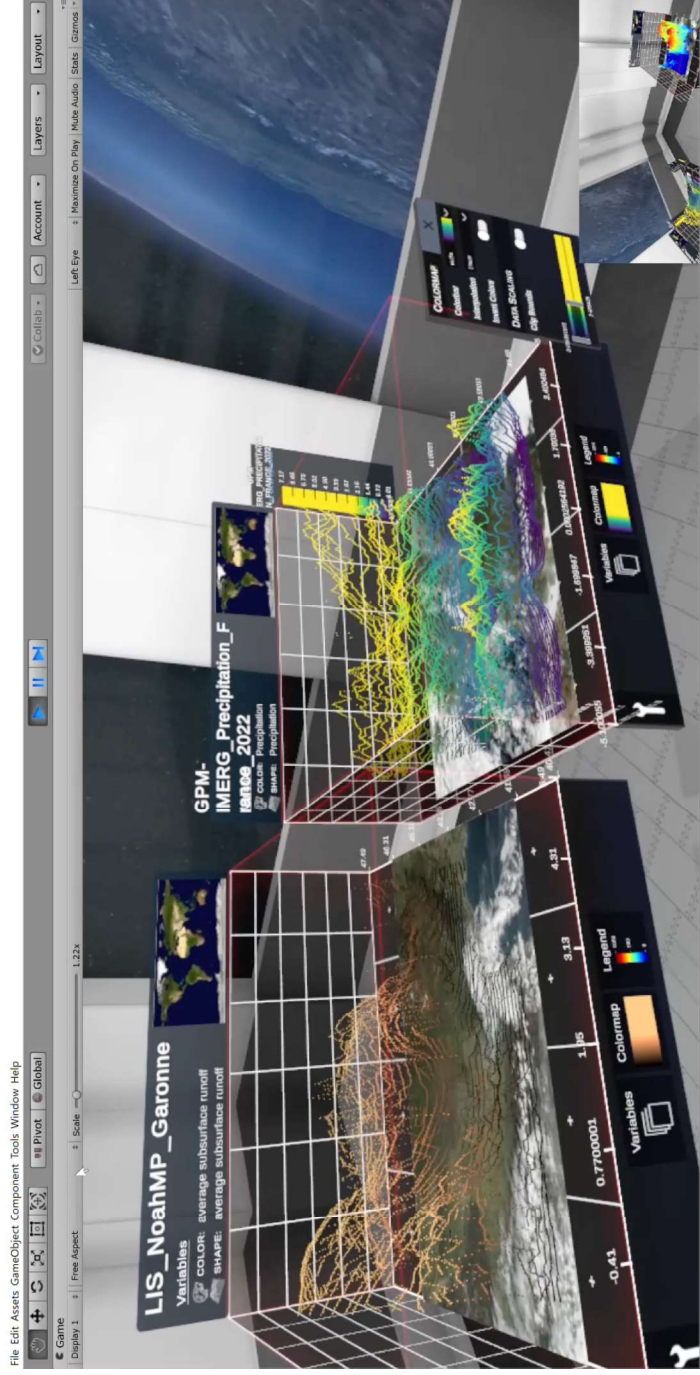
Hurricane Ian Florida Landfall

```
In [28]: bb_hurricane_ian = {'min_lon': -87, 'max_lon': -72, 'min_lat': 18, 'max_lat': 35}
start_hurricane_ian = datetime(2022, 9, 24)
end_hurricane_ian = datetime(2022, 10, 2)
ian_parameters = (REXUS_00r, global_precipitation_dataset, bb_hurricane_ian, start_hurricane_ian, end_hurricane_ian)

In [29]: # Plot a box around our spatial bounds
plotting.map_box(bb_hurricane_ian)
```

The map shows the United States with a red bounding box around the Florida region, indicating the area of interest for the hurricane landfall analysis.

Immersive Flood Prediction and Analysis



IDEAS for Wildfire, Air Quality, GHG, and Health Impact

Partnership with NASA's MAIA Mission, and City of Los Angeles

NASA JPL: Thomas Huang, Nga Chung, David Diner, Gary Doran, Sina Hasheminassab, Jason Kang, Olga Kalashnikova, Kyo Lee, Grace Llewellyn, Thomas Loubrieu, Kevin Marlis, Jessica Neu, Joe T. Roberts, and David Schimel

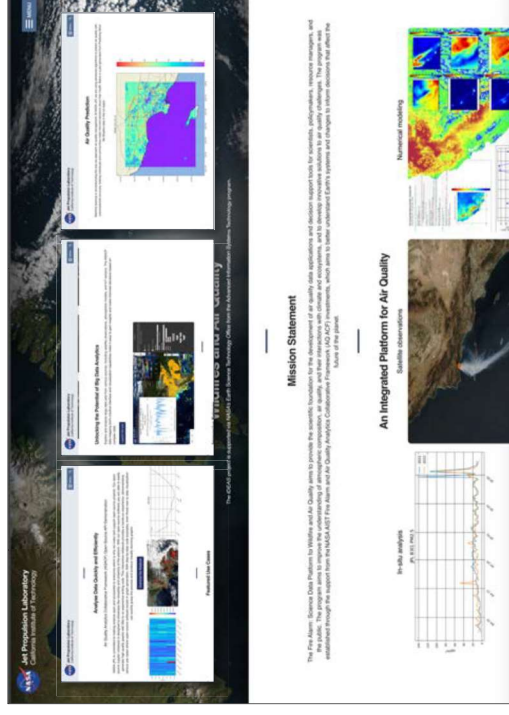
City of Los Angeles: Jeanne Holm, and Dawn Comer

CSU Los Angeles: Mohammad Pourhomayoun, and Pratyush Muthukumar

Howard University: Joseph Wilkins and Jonathan Barnes

Washington University: Randall Martin

University of Colorado: Daven Henze

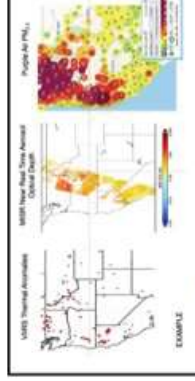


<https://ideas-digitaltwin.jpl.nasa.gov/airquality/>

What are the environmental and health impacts of wildfires?



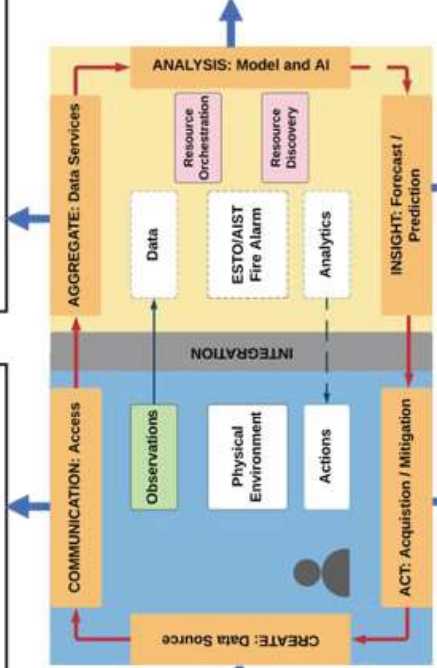
Automate access to fire data repositories for the each fire event of interest



Harmonize datasets to track pre-fire, active fire, and post fire impacts for the event of interest



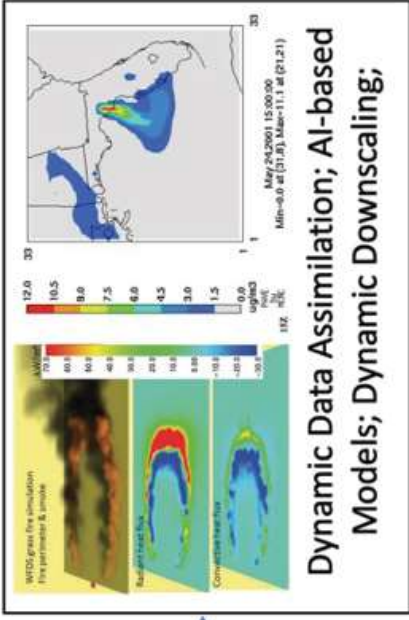
Acquire Observations



Decision Support and Science

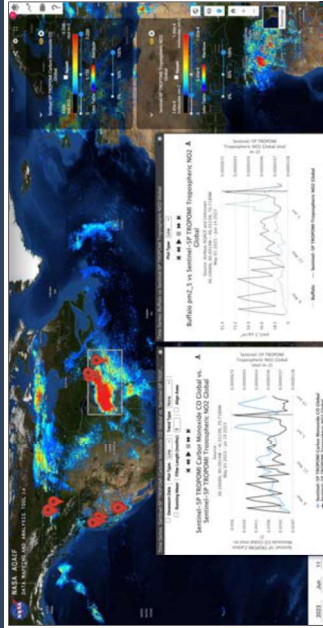


Forecast and Prediction

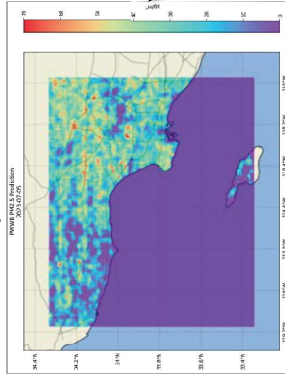


Dynamic Data Assimilation; AI-based Models; Dynamic Downscaling;

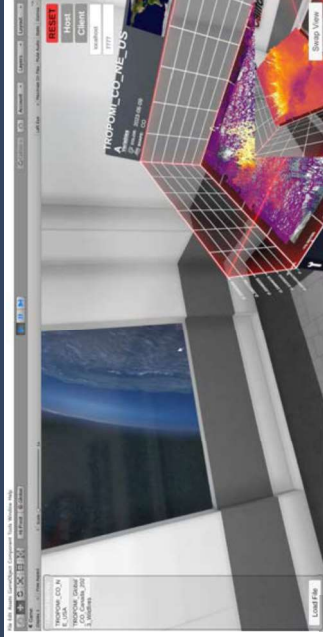
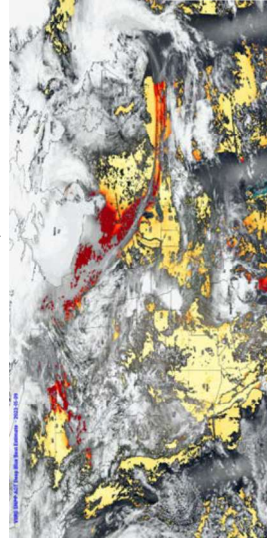
NASA's Open-Source ESDT Platform for Air Quality



Web-based Data Analysis Tool



Real-time AQ Prediction



Immersive Science

Mission Statement

The Air Quality Collaborative Framework (AQCF) is a multi-agency effort to advance the state-of-the-art in air quality science and technology. The program will support the development of a next-generation air quality system that integrates data from a wide range of sources, including satellite, ground-based, and model data, to provide a comprehensive view of air quality and its impacts on human health and the environment.

An Integrated Platform for Air Quality

Surface measurements

National models

<https://ideas-digitaltwin.jpl.nasa.gov/airquality/>

Air Quality Analytics Collaborative Framework (AQCF) API Demonstration

The Air Quality Analytics Collaborative Framework (AQCF) is a multi-agency effort to advance the state-of-the-art in air quality science and technology. The program will support the development of a next-generation air quality system that integrates data from a wide range of sources, including satellite, ground-based, and model data, to provide a comprehensive view of air quality and its impacts on human health and the environment.

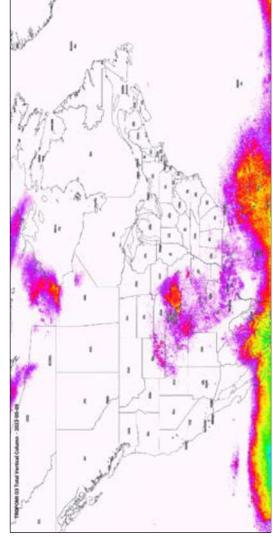
Libraries and Functions

The Air Quality Analytics Collaborative Framework (AQCF) is a multi-agency effort to advance the state-of-the-art in air quality science and technology. The program will support the development of a next-generation air quality system that integrates data from a wide range of sources, including satellite, ground-based, and model data, to provide a comprehensive view of air quality and its impacts on human health and the environment.

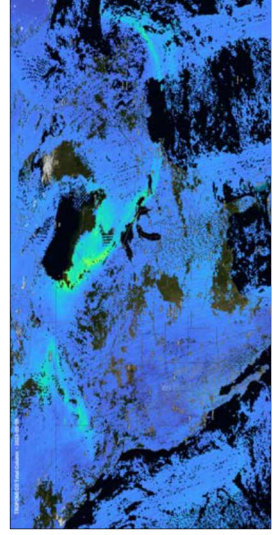
Science Workbench

- Built on a decade of NASA's big data investment
- Professionally Open-Source through the Apache Software Foundation
- One AQ information platform for access, visualize, and analyze measurements from
 - Satellite
 - Model
 - In-situ
 - ML Predictions

Visualize and Analyze Smoke from the Canadian Wildfire



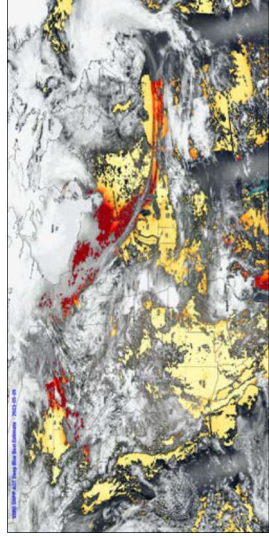
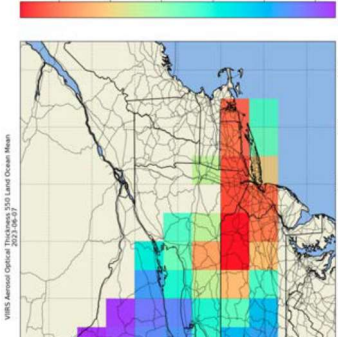
TROPOMI O3 Total Vertical Column
2023-05-09 – 2023-06-08



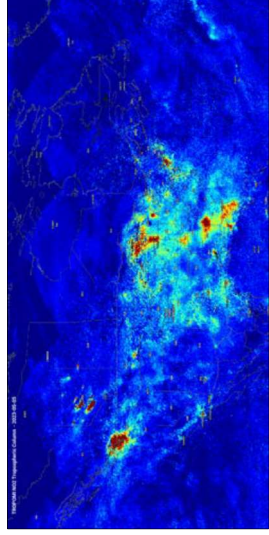
TROPOMI CO total column
2023-05-10 – 2023-06-09



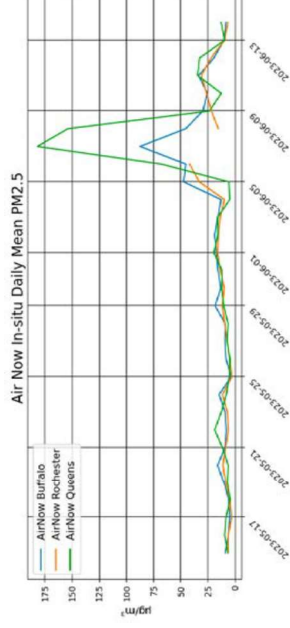
VIIRS Aerosol Optical Thickness
2023-06-07



VIIRS SNPP Aerosol Optical Thickness
Deep Blue Best Estimate
2023-05-10 – 2023-06-09

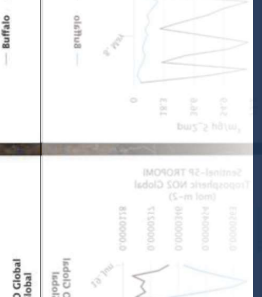
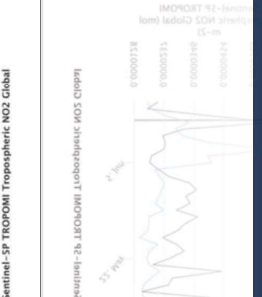
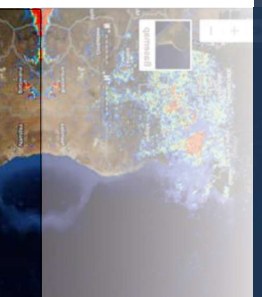
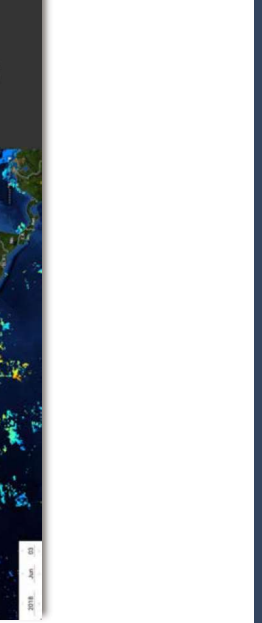
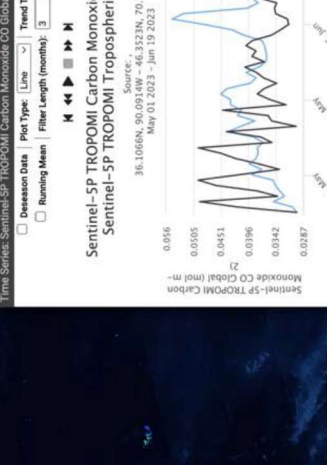
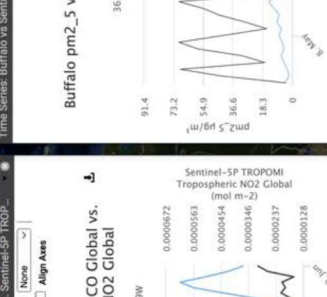
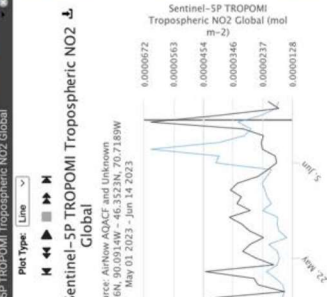
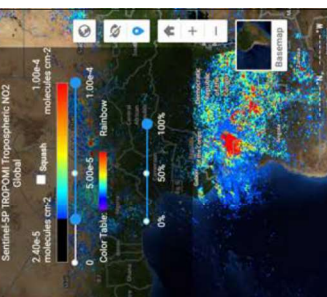
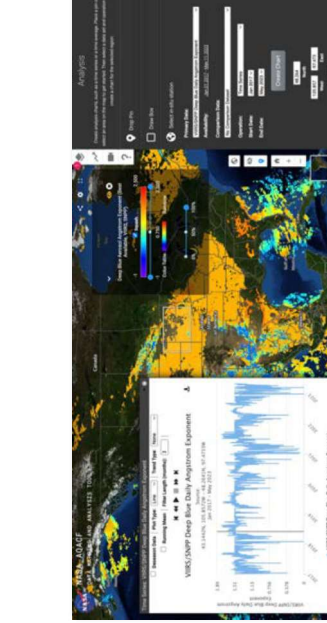
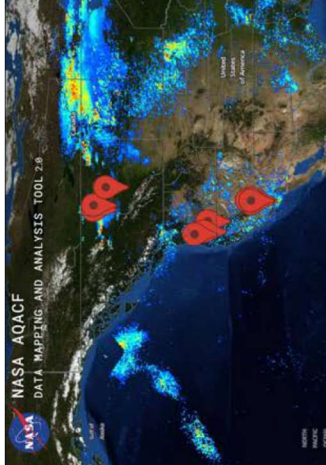
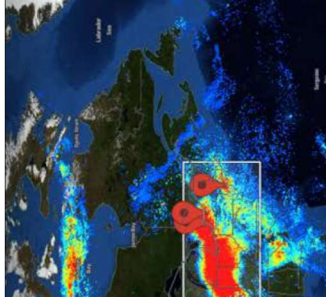
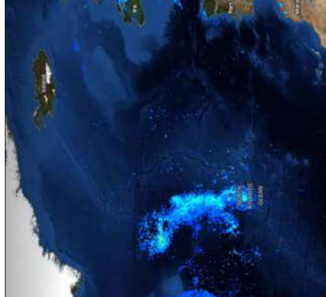
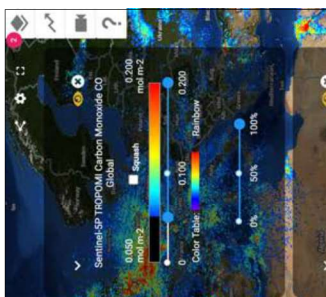
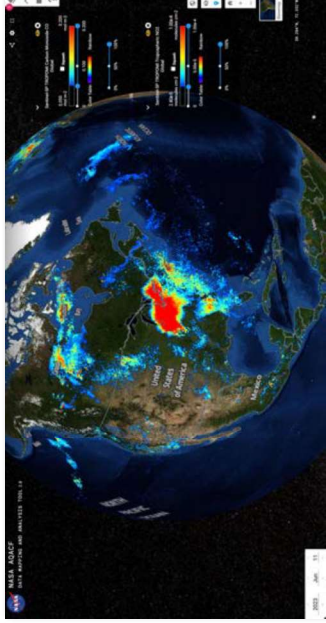


TROPOMI NO2 Tropospheric Column
2023-05-06 – 2023-06-05

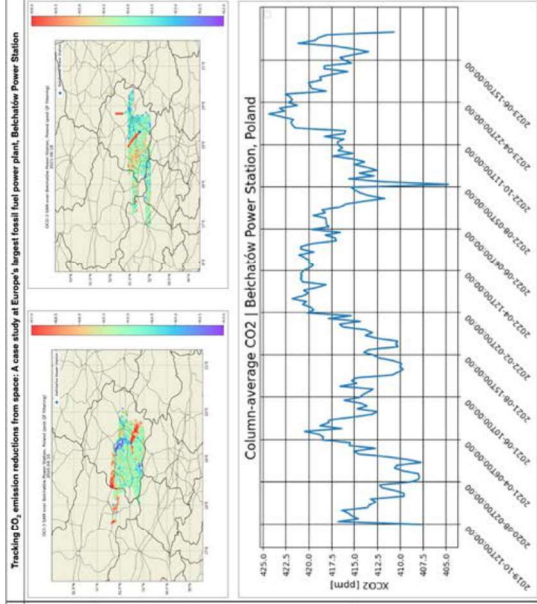
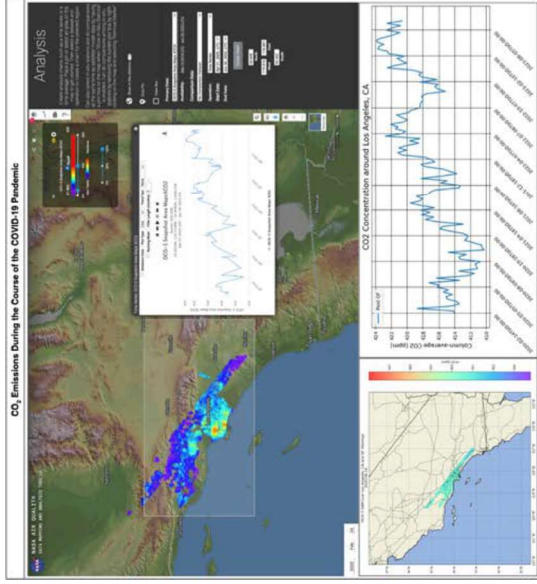


AirNow Buffalo, Rochester, and Queens PM_{2.5} –
2023-05-15 – 2023-06-14

Web-base AQ Data Analysis Tool

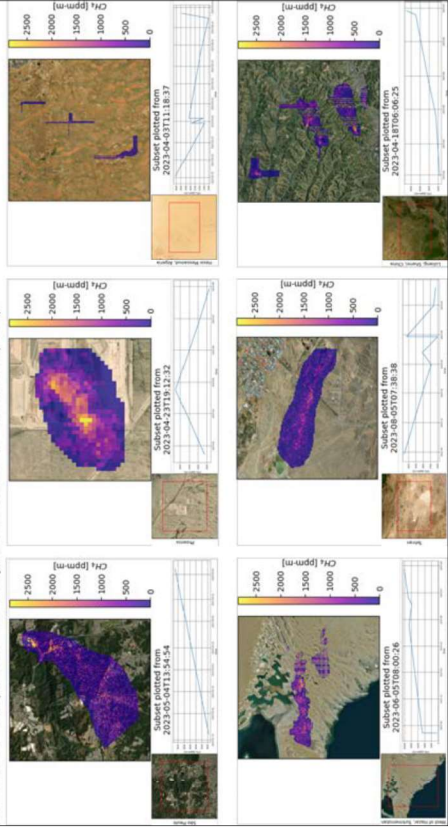


Greenhouse Gas (GHG)



Working with NASA EMIT Mission's Methane (CH₄) Plume Data on the AIST Fire Alarm - an Integrated Air Quality Information Platform

Powered by the Apache Science Data Analytic Platform (SDAP)
A Professional Open-Source Analytic Collaborative Framework (ACF)



Multi-Angle Imager for Aerosols (MAIA)

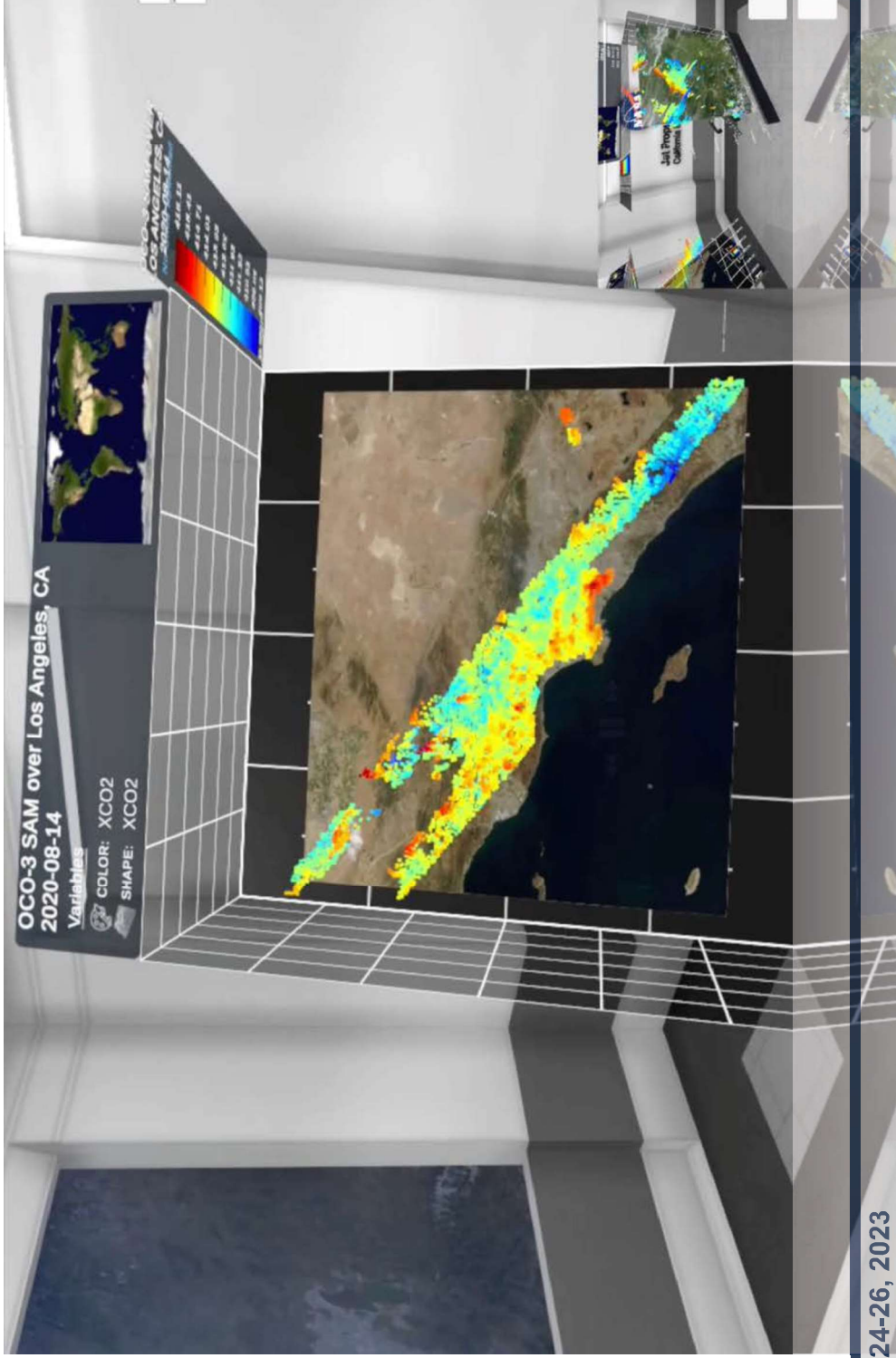


- MAIA is a partnership between NASA and the Italian Space Agency (ASI)
- The mission's primary objective is to link exposure to different types of airborne particulate matter (PM) with human health
- PM mapping and epidemiological studies will take place in selected metropolitan areas around the world
- Satellite launch is planned for 2025



Image Credit: ASI

Greenhouse Gas (XCO2 in LA and Wuhan)



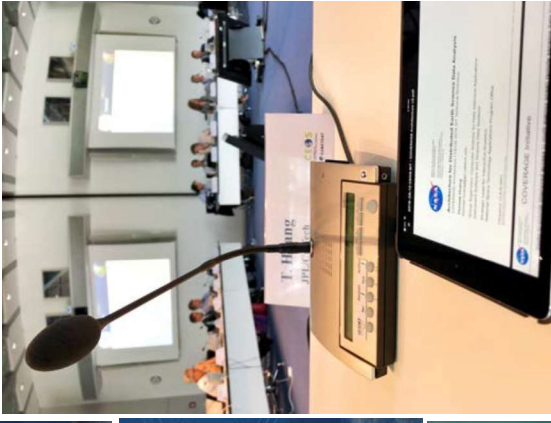
Open-Source Science and Community Collaboration



- Partnership with Apache Software Foundation
- Define and refine standards by working with OGC, GEO, NIH, CNES, EU, and ESA
- Evolve the technology through community contributions
- Open-Source Science
 - Technology demonstrations. Share recipes and lessons learned
 - Inclusive and Diverse Project Management Committee (PMC)
- Host webinars, hands-on cloud analytics workshops and hackathons




KEYNOTE by Thomas Huang,
Technical Group Supervisor and
Strategic Lead for Interactive Analytics
at NASA Jet Propulsion Laboratory



NASA HEALTH AND AIR QUALITY
APPLIED SCIENCES TEAM

Conclusion – Digital Twin is about Building Bridges

If you want to go far, go together.



Climate Understanding is about **Knowledge Sharing** and **Technology Reusing** and promote **Collaboration**

The Earth System is too complex and too expensive to be accurately represented by a single digital twin

We can create different types of Earth System Digital Twins

BUT

Let's also build Bridges

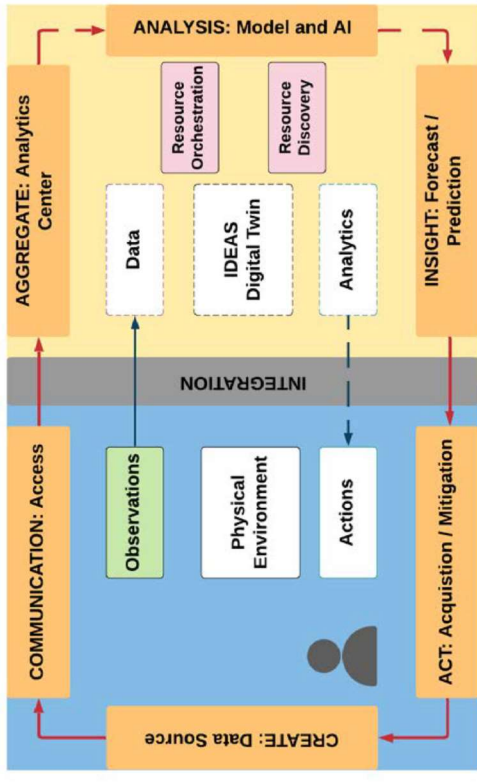
Let's bring together our best information assets

Let's make them interoperable

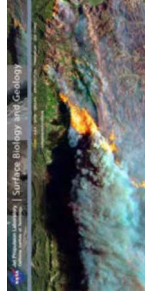
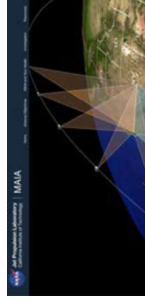
The Earth System is an interconnected system of systems

Reusable software framework, open-source, and standards are the Bridges

got ideas?

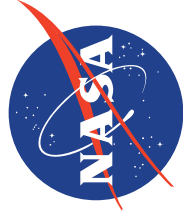


NASA ESTO/AIST's Integrated Digital Earth Analysis System (IDEAS) – an Earth System Digital Twin framework. Framework for pre-fire, during fire, and post fire analysis





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Caltech

JPL

**DARE MIGHTY THINGS
TOGETHER!**

<https://ideas-digitaltwin.jpl.nasa.gov>