

**National Aeronautics and Space  
Administration**

**Jet Propulsion Laboratory**  
California Institute of Technology  
Pasadena, California

# **Professional Open-Source Framework for Earth System Digital Twins and Applications**

**Thomas Huang**

Group Supervisor – Instrument Software and Science Data Systems section  
Strategic Lead - Interactive Data Analytics

NASA Jet Propulsion Laboratory  
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4800 Oak Grove Drive, Pasadena, CA 91109-8099, U.S.A.

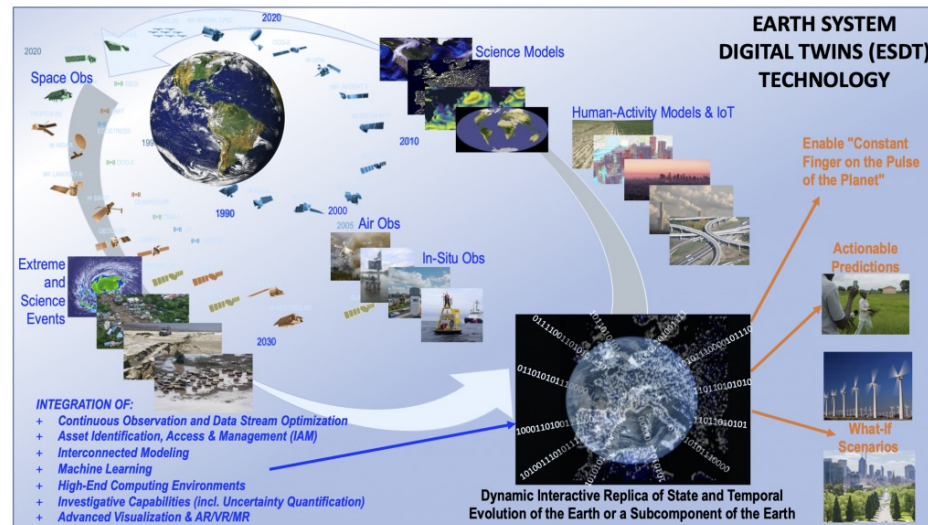


It is about  
**Streamline, Long-time Records, Agility**, and the **What-Ifs**



# Earth System Digital Twins

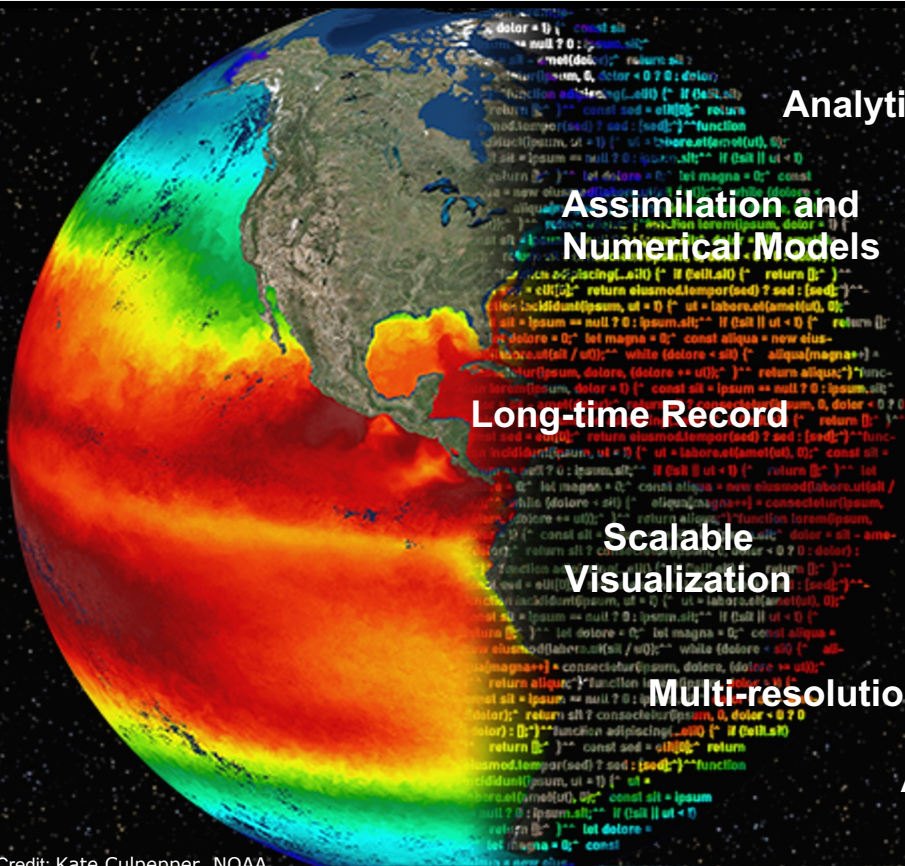
- An **Earth System Digital Twin (ESDT)** – an interactive and integrated multidomain, multiscale, digital replica of the state and temporal evolution of Earth systems
- It dynamically integrates
  - Relevant Earth system models and simulations
  - Other relevant models (e.g., related to world's infrastructure)
  - 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/>

# ESDT requires



Analytic Collaborative Framework

Assimilation and  
Numerical Models

New Observing Strategies

Artificial Intelligence

Extensible  
Framework

Long-time Record

Scalable  
Visualization

Real-time

Multi-computing

Federated

Multi-resolution

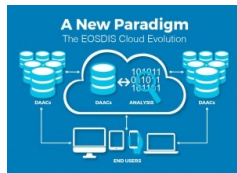
Multivariate  
Access and Analysis

Image Credit: Kate Culpepper, NOAA

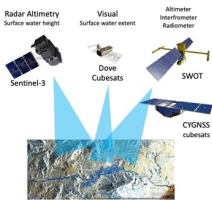
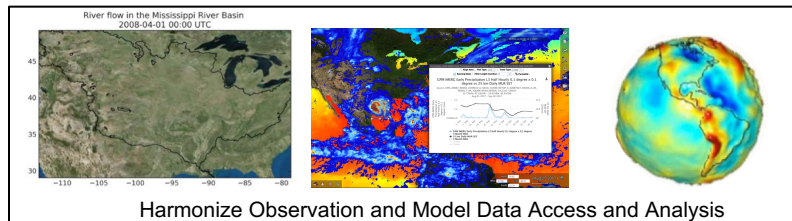




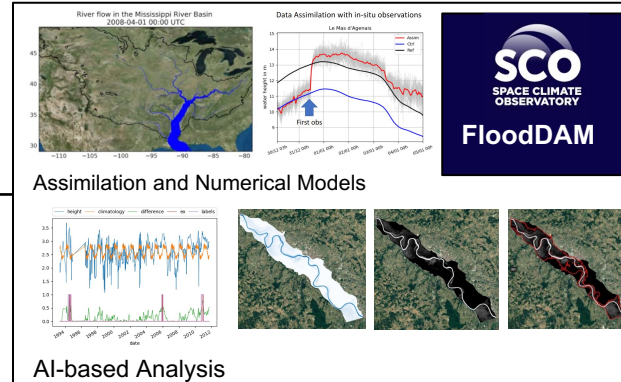
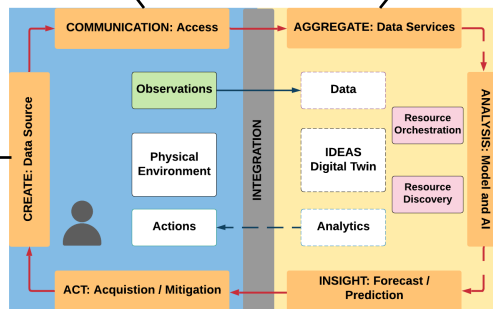
# NASA AIST Integrate Digital Earth Analysis System (IDEAS) Professional Open-Source Earth System Digital Twins Framework



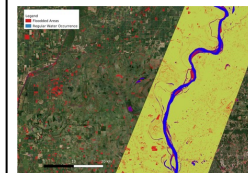
Automate Access to Many Repositories and Services



Acquire Observation and Analysis



Decision Support and Science Planning



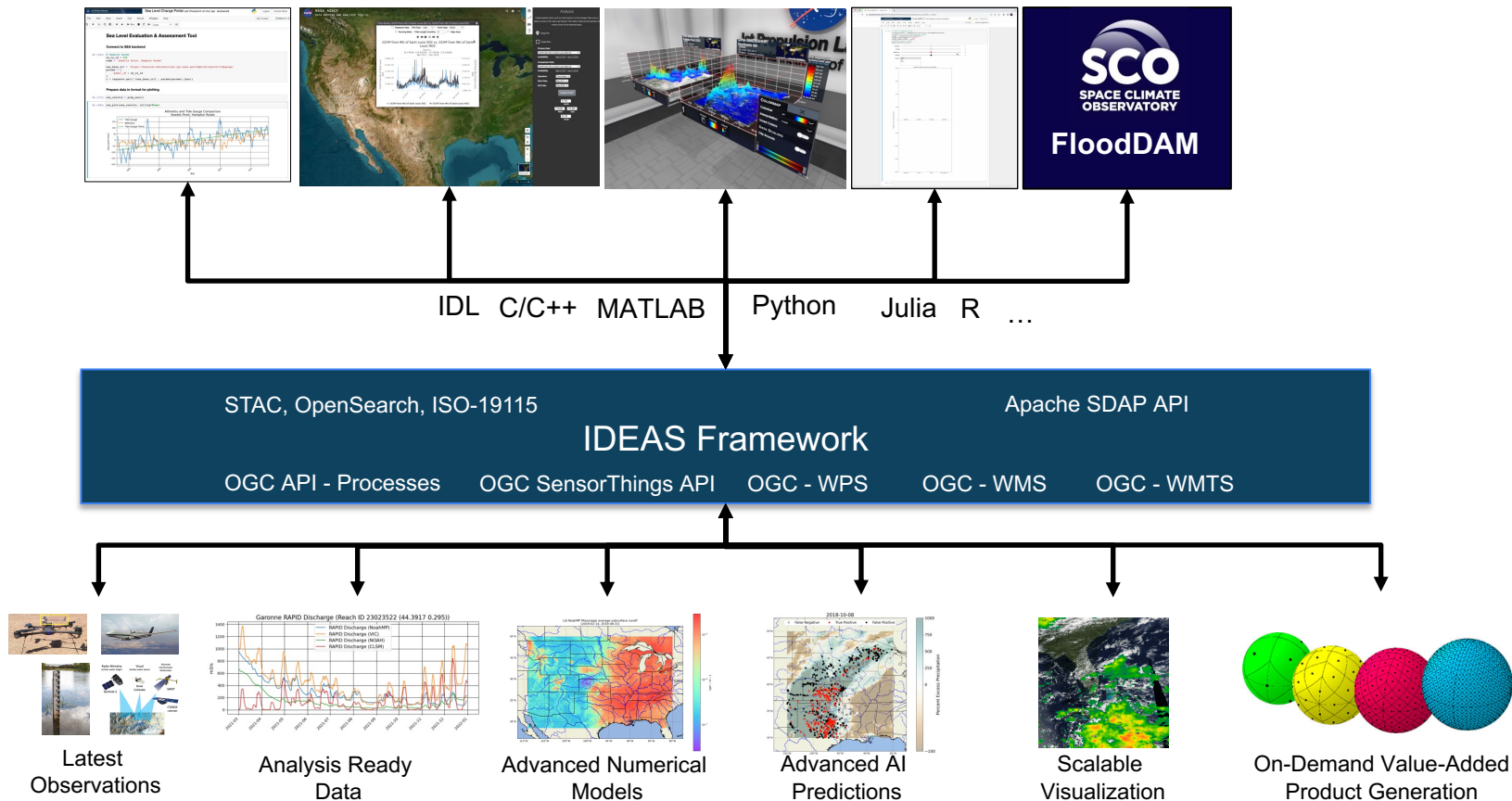
Forecast and Prediction



- Facilitate access, integration, and understanding of disparate datasets
- Streamline data assimilation for models and analysis
- Enable dynamic integration of new observation and analysis
- Establish interoperable ML models and data services



# Professional Open-Source Digital Twins Framework





# 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, Megan Bull (intern), 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

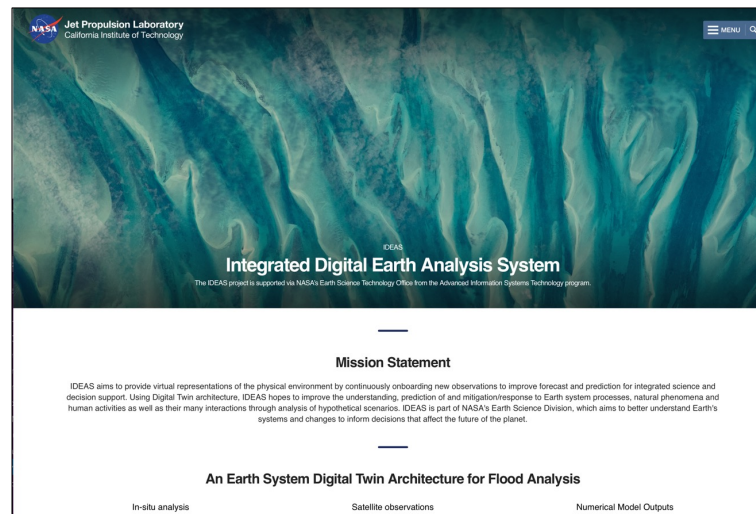
**CNES:** Simon Baillarin, Lerre Benjamin, Frederic Bretar Gwendoline Blanchet, Peter Kettig, Raquel Rodriguez Suquet, and Lonjou Vincent

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

**Collecte Localisation 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



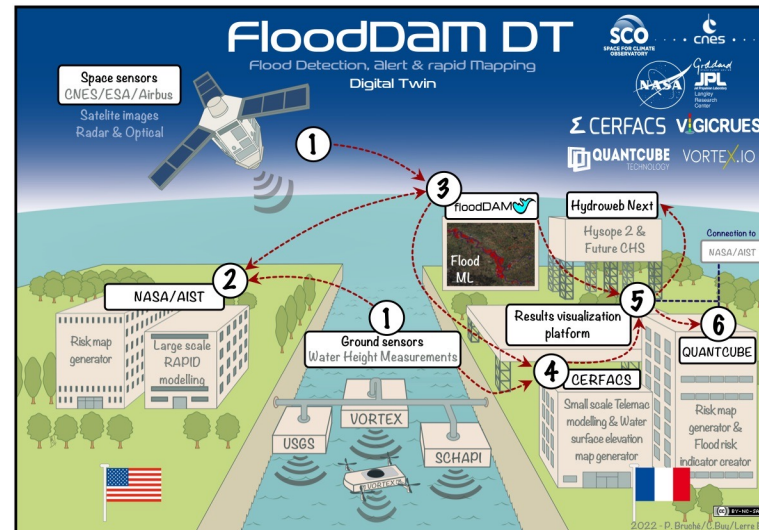
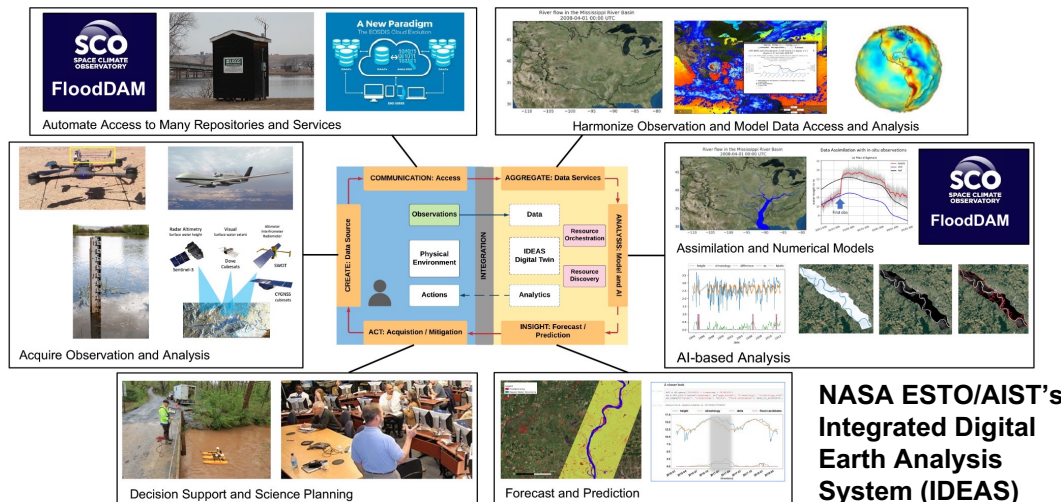
<https://ideas-digitaltwin.jpl.nasa.gov/ideas/>

## What are the environmental and infrastructural impacts of floods?





# NASA – CNES: Federated Digital Twins



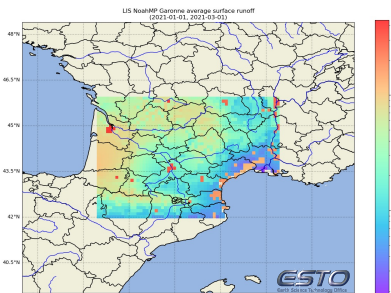
- Establish federated digital twins solution between the **NASA ESTO/AIST's Integrated Digital Earth Analysis System (IDEAS)** (Huang/JPL) and the **Space for Climate Observatory (SCO) FloodDAM-DT** (Rodriguez-Suquel/CNES)
- NASA AIST IDEAS is an open-source Earth System Digital Twins (ESDT) framework
- The collaboration focuses on establishing DT-powered flood alert systems, analysis, and risk maps on local and global scales

## PARTNERS:

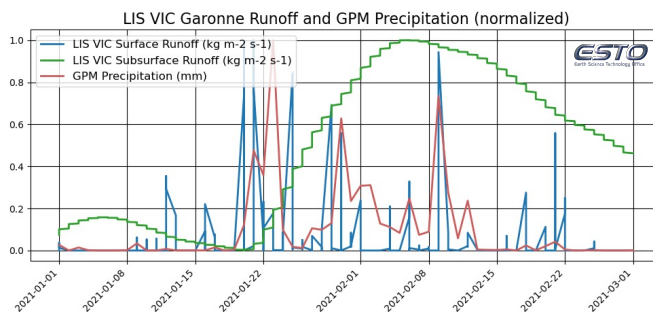


# Bringing Observations and Models Together

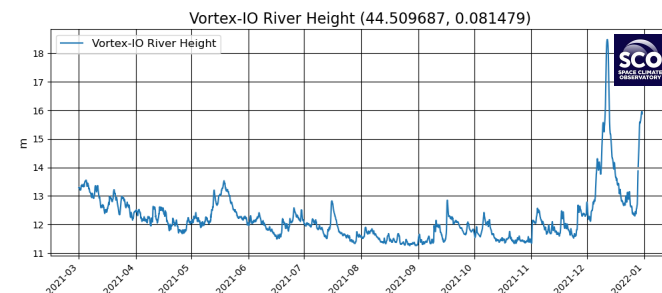
## 2021-03 through 2021-12 in Garonne



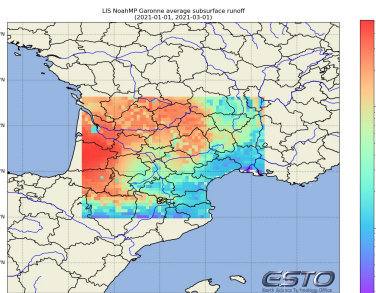
NoahMP Average Surface Runoff



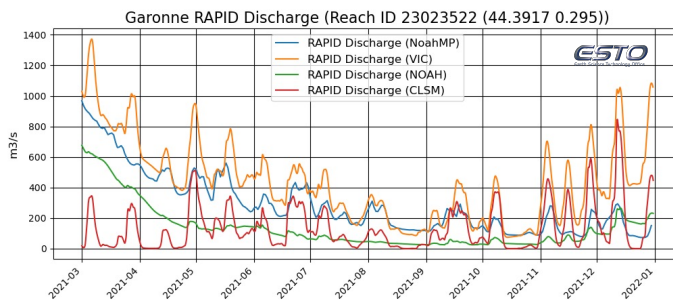
VIC Runoff and GPM Precipitation (normalized)



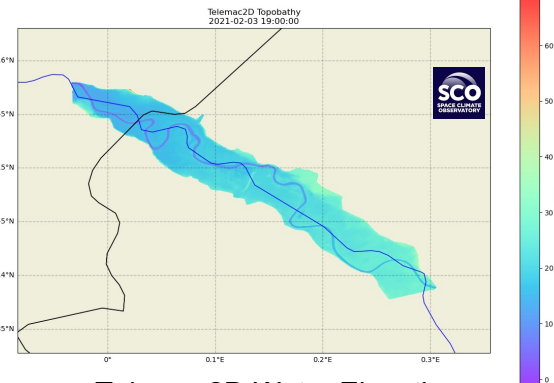
Vortex.io River Height



NoahMP Average Subsurface Runoff



RAPID Discharge from different Land Surface Models



Telemac2D Water Elevation

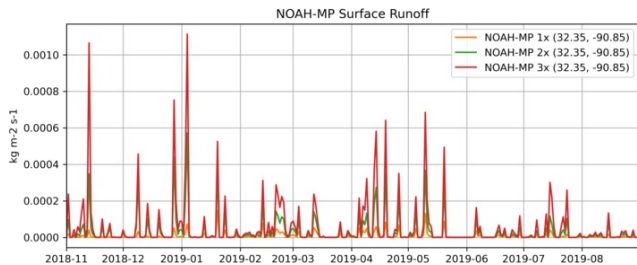




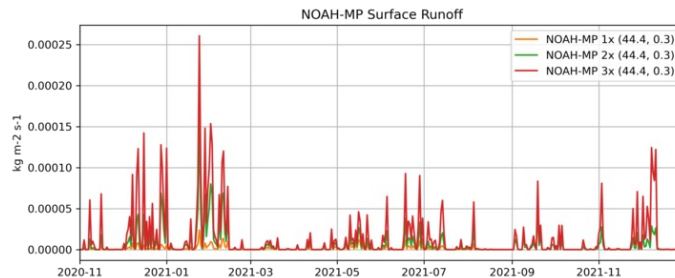
# What-If: 1x 2x 3x Precipitation

## Surface Runoff

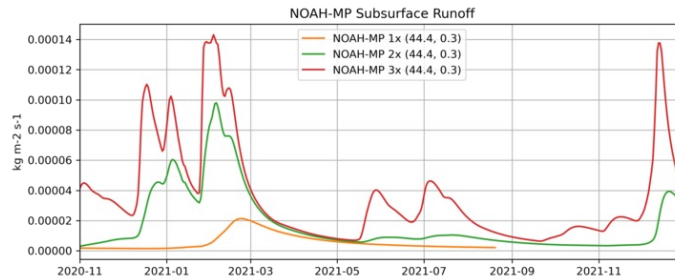
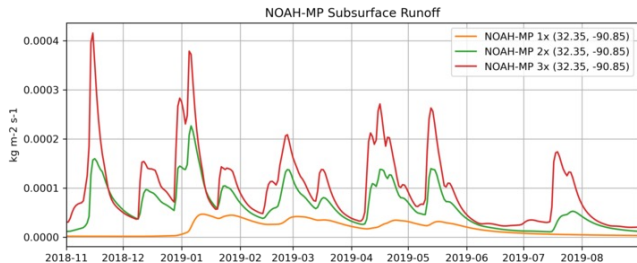
### Mississippi River



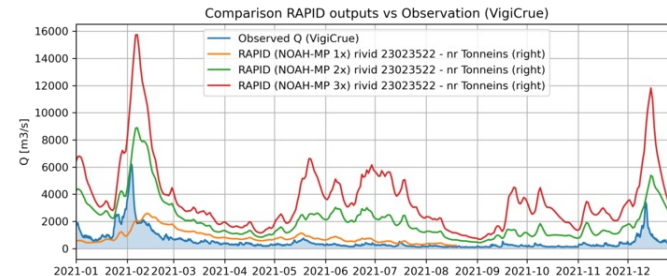
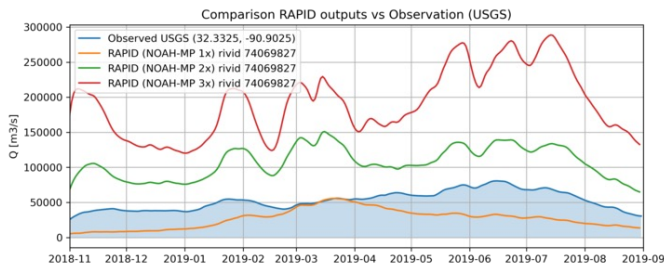
### Garonne River



## Subsurface Runoff

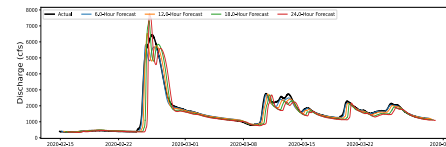
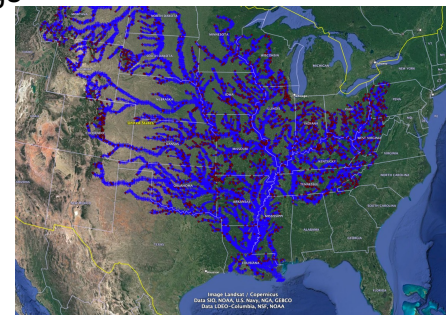
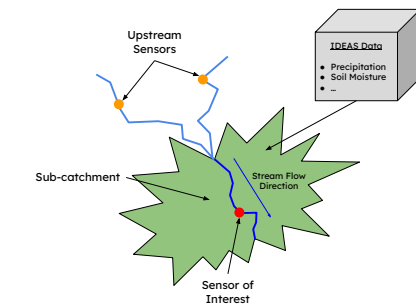


## River Discharge



- **Precipitation-Only Approach:** use GPM data and ML model to predict daily peaks in discharge
- Random Forest model trained on 2,195 gages over 2 years, totaling 2.2 M examples, from midwestern US

- **Incorporating Stream Network:** use MERIT basin/reach database to model propagation of flow during flooding events
- Long Short-Term Memory (LSTM) neural network trained to forecast 6-24 hours into the future for each sensor given upstream readings



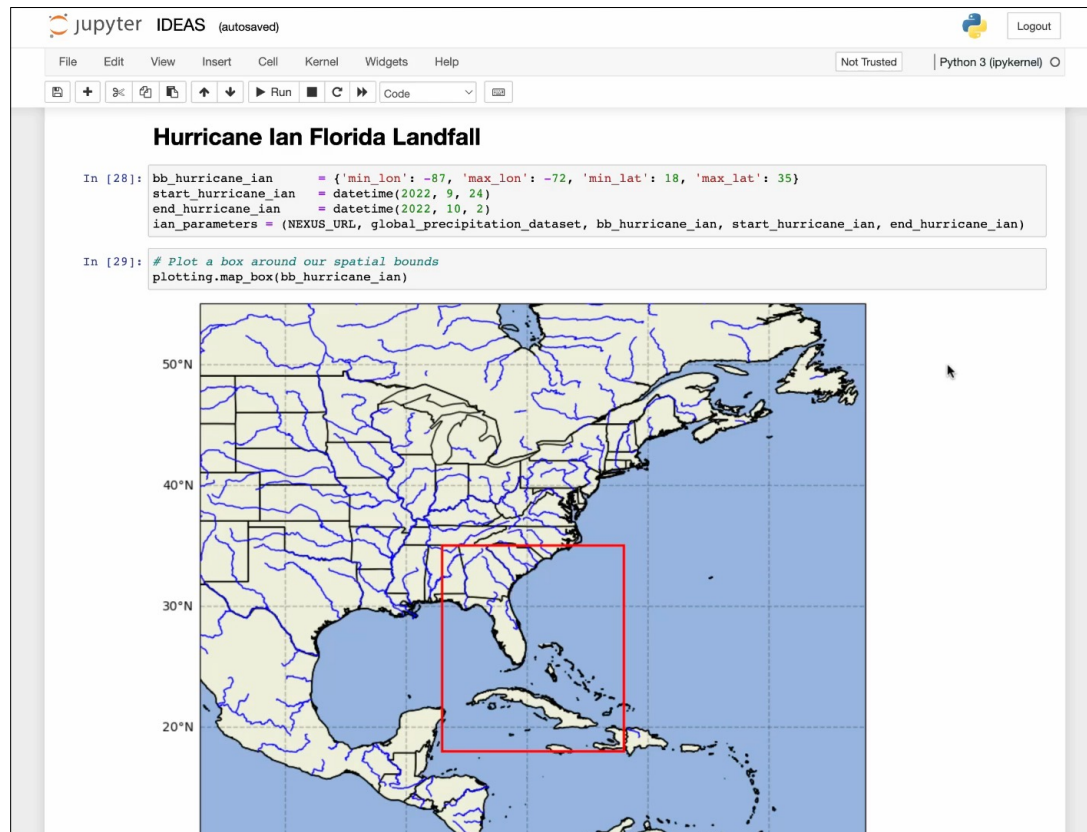
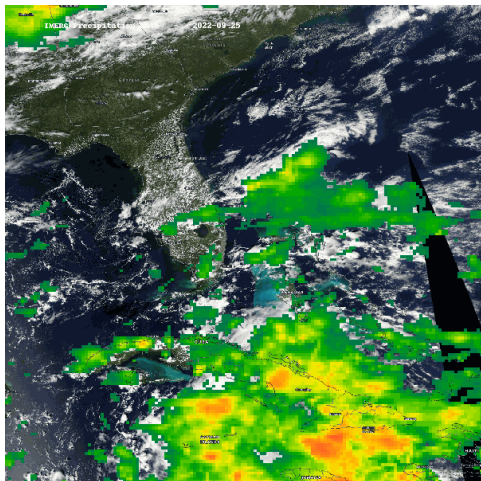


# IDEAS-Powered Flood Notebook

[https://github.com/EarthDigitalTwin/IDEAS-notebooks/blob/main/Flood\\_Demo.ipynb](https://github.com/EarthDigitalTwin/IDEAS-notebooks/blob/main/Flood_Demo.ipynb)

Demonstrates the latest IDEAS API and capabilities

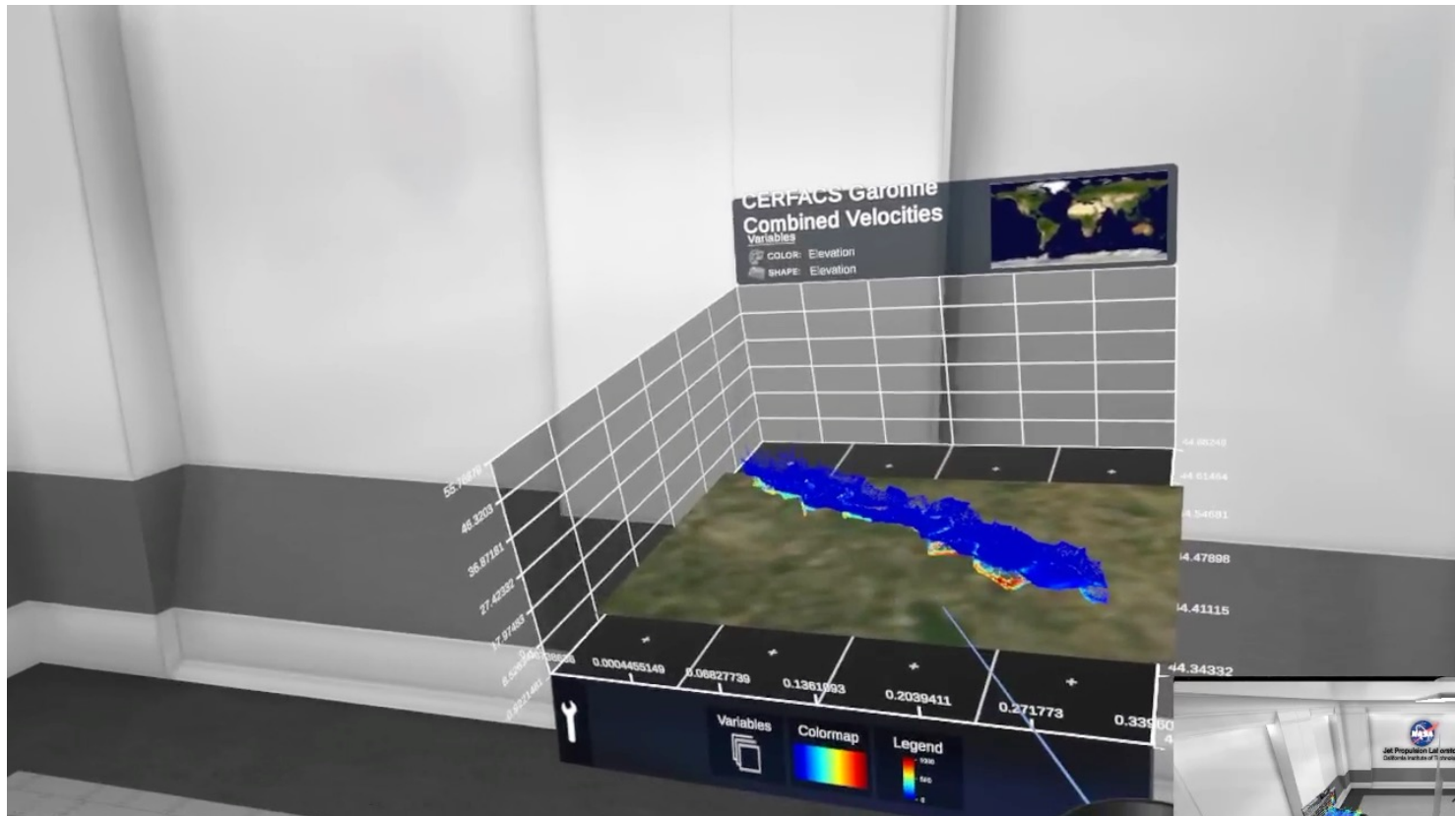
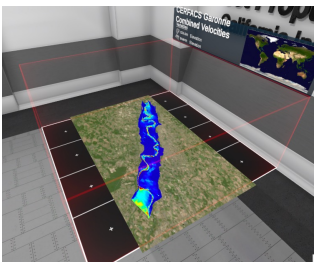
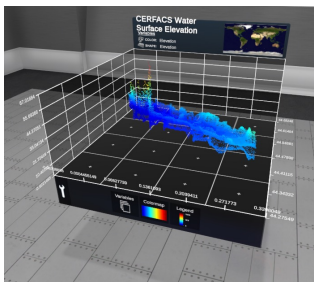
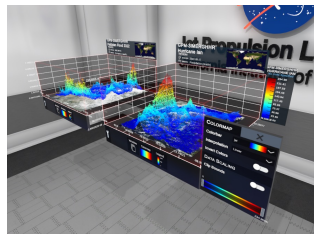
- STAC – Data search and metadata
- Data access – satellite, in-situ, and models
- Interactive, harmonized data analytic capabilities
- Visualizations – Tile WMS and on-demand animation generation





# Immersive Flood Prediction and Analysis

Powered by IDEAS







# IDEAS for Wildland Fire, Air Quality, and Health Impact

Partnership with NASA's MAIA Mission, National Institute of Environmental Health Sciences, and  
City of Los Angeles

**NASA JPL:** Thomas Huang, Nga Chung, David Diner, Gary Doran, Sina Hasheminassab, Sarah Hallam (intern), 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

**National Institute of Environmental Health Sciences:** Aubrey Miler, Ann Liu, Richard Kwok

**Howard University:** Joseph Wilkins and Jonathan Barnes

**Washington University:** Randall Martin

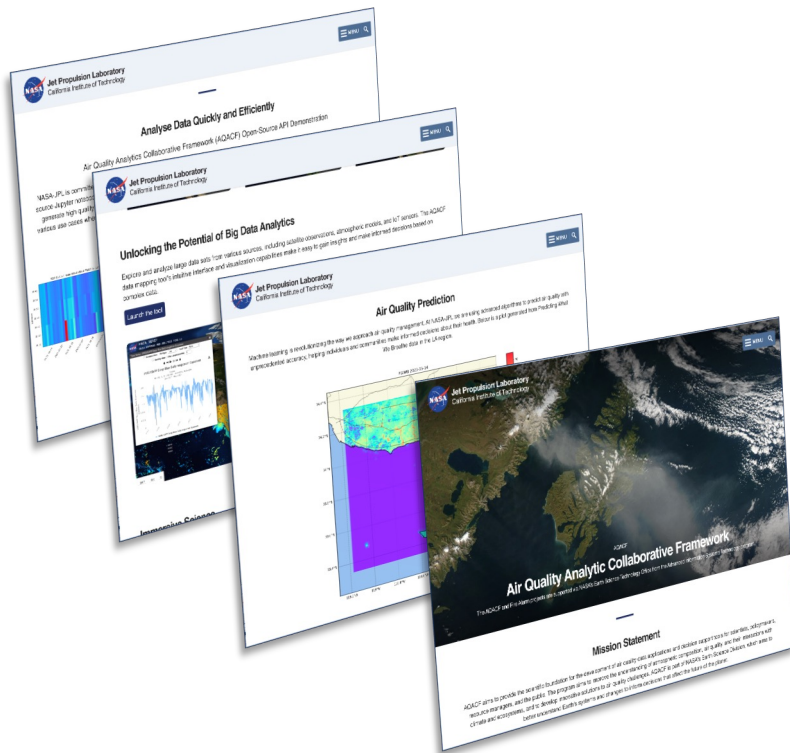
**University of Colorado:** Daven Henze

What are the environmental and health impacts of wildfires?





# Information System and Data Platform for Air Quality



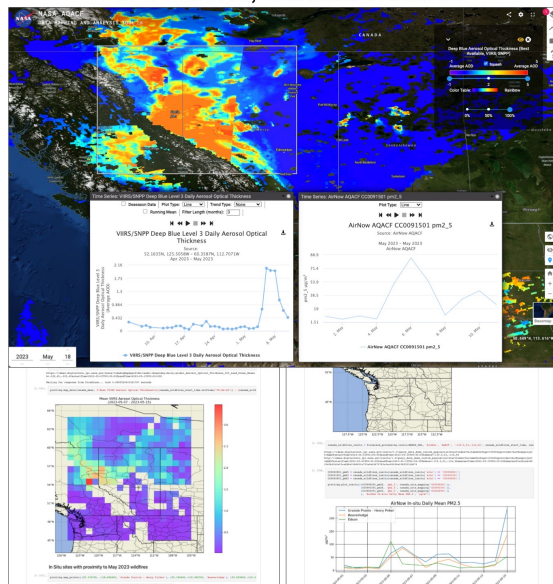
<https://ideas-digitaltwin.jpl.nasa.gov/aqacf/>

- Professional Open-Source Air Quality Platform
  - Harmonize data management, analysis, and visualization
    - Satellite
    - Model
    - In-Situ
  - Automate onboarding latest observation and model data
  - ML-base Air Quality Prediction
  - Production-Quality Applications
    - Web-based AQ Data Analysis Tool
    - AQ Notebook for API tutorial and receipts
    - VR-powered Immersive Science
- AIST Fire Alarm introduces
  - Earth System Digital Twins architecture
  - Scenario-based analysis
  - Expand support for wildfire, air quality, and health impact (partner with NIH and Howard University)
  - Expand support for Greenhouse Gas support (satellite and in-situ)
  - ML-driven dynamic instrument tasking (partner with MAIA mission)
  - ML-driven data and analysis integration

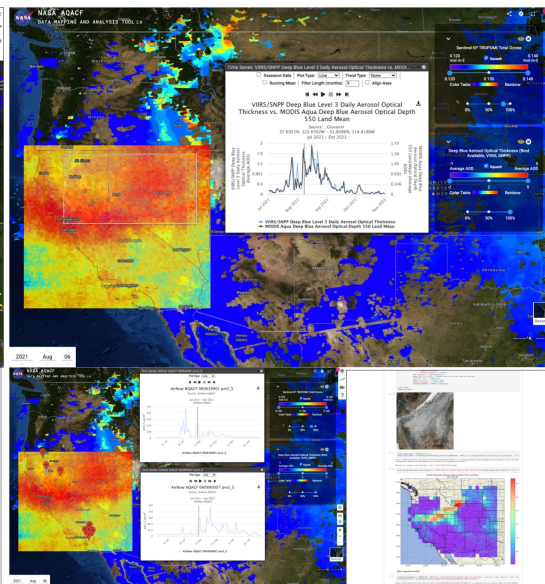


# Wildland Fire Air Quality and Health Impact Digital Twin

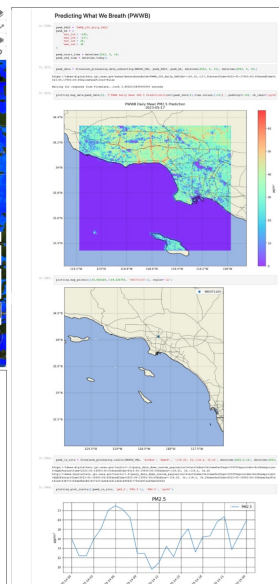
2023 Alberta, Canada Wildfires



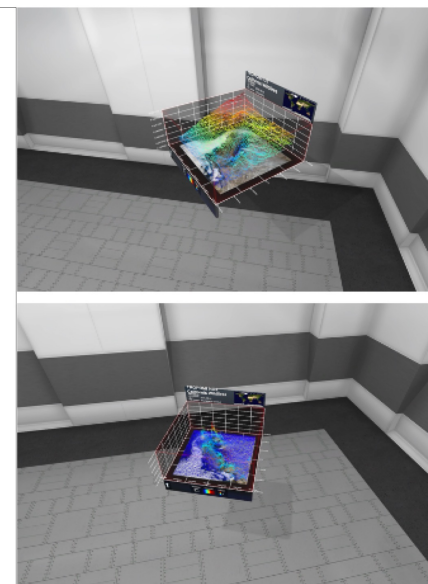
2021 Dixie Fire



Real-time  
AQ Prediction



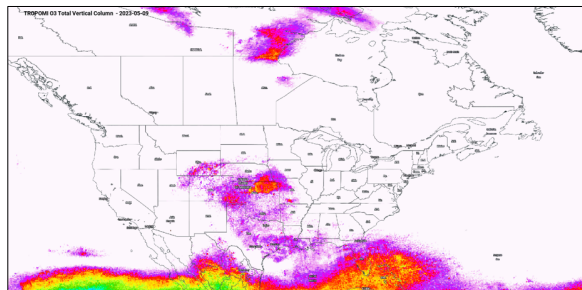
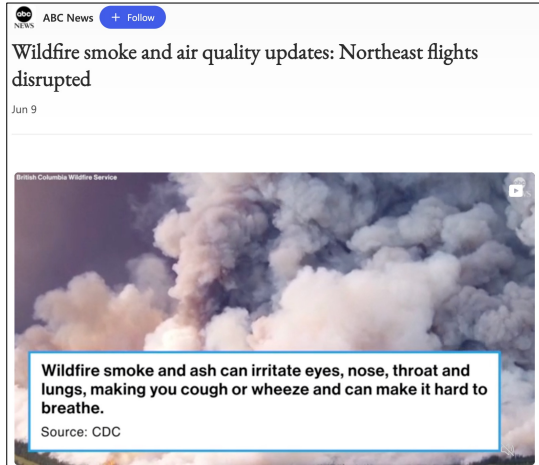
Immersive Science



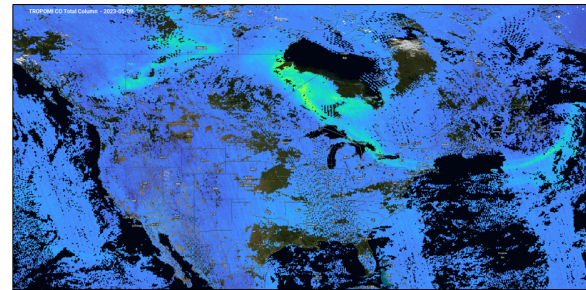
Interactive Data Analysis Tool  
Notebook for exploratory science  
Real-time AQ prediction for LA  
Immersive Science



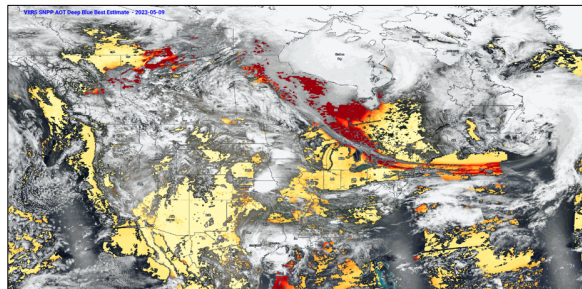
# Visualize Canadian Wildfire Smoke



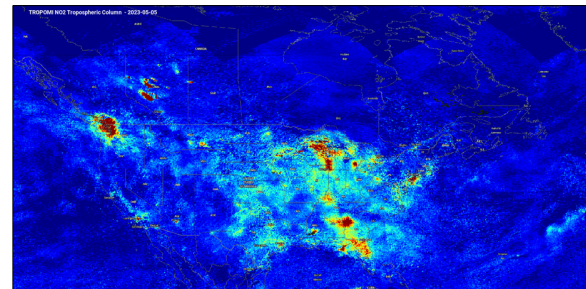
TROPOMI O3 Total Vertical Column  
2023-05-09 – 2023-06-08



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



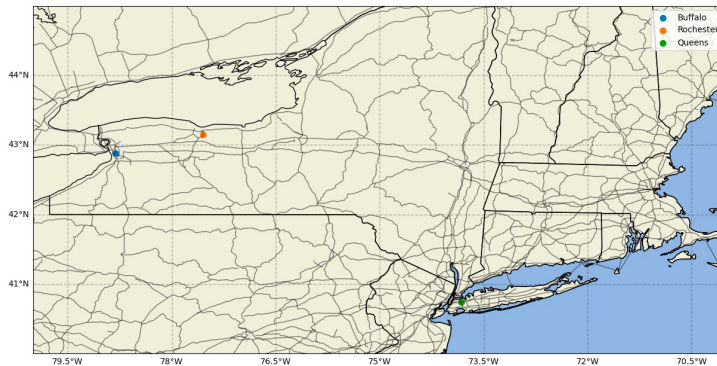
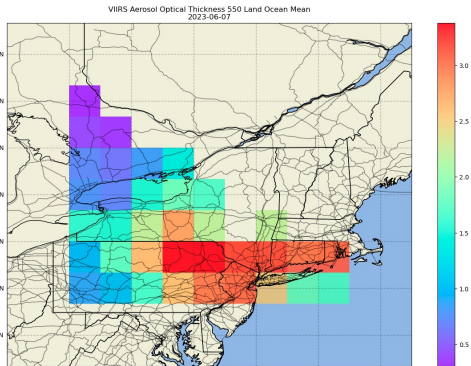
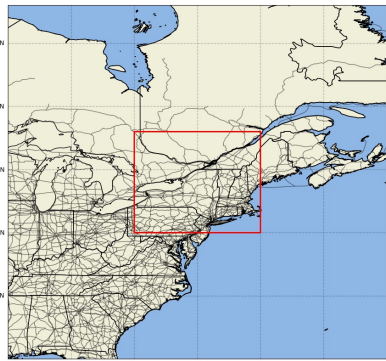
VIIRS SNPP Aerosol Optical Thickness  
Deep Blue Best Estimate  
2023-05-10 – 2023-06-09



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

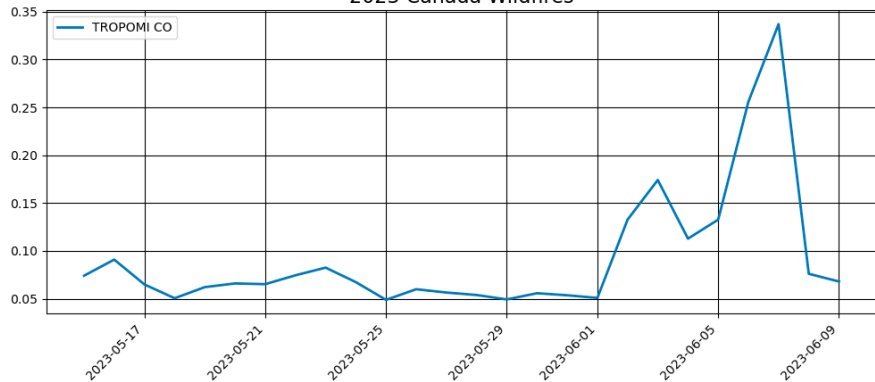


# Analyze Canadian Wildfire Smoke



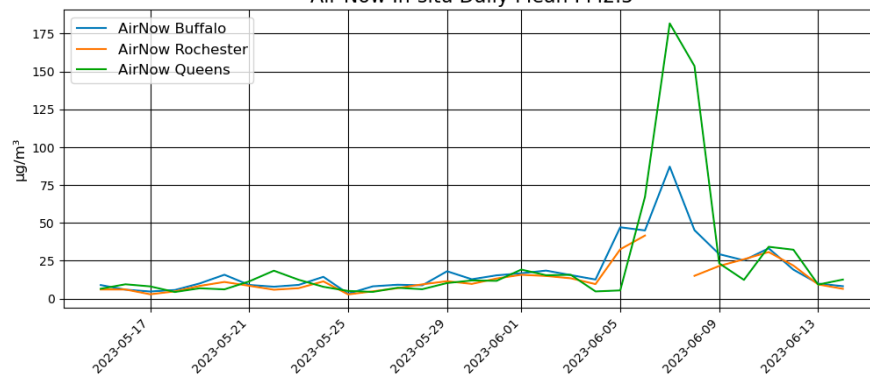
VIIRS Aerosol Optical Thickness  
2023-06-07

2023 Canada Wildfires



TROPOMI CO 2023-05-15 – 2023-06-09

Air Now In-situ Daily Mean PM<sub>2.5</sub>



AirNow Buffalo, Rochester, and Queens PM<sub>2.5</sub> – 2023-05-15 – 2023-06-14



# Analyze In-situ Data

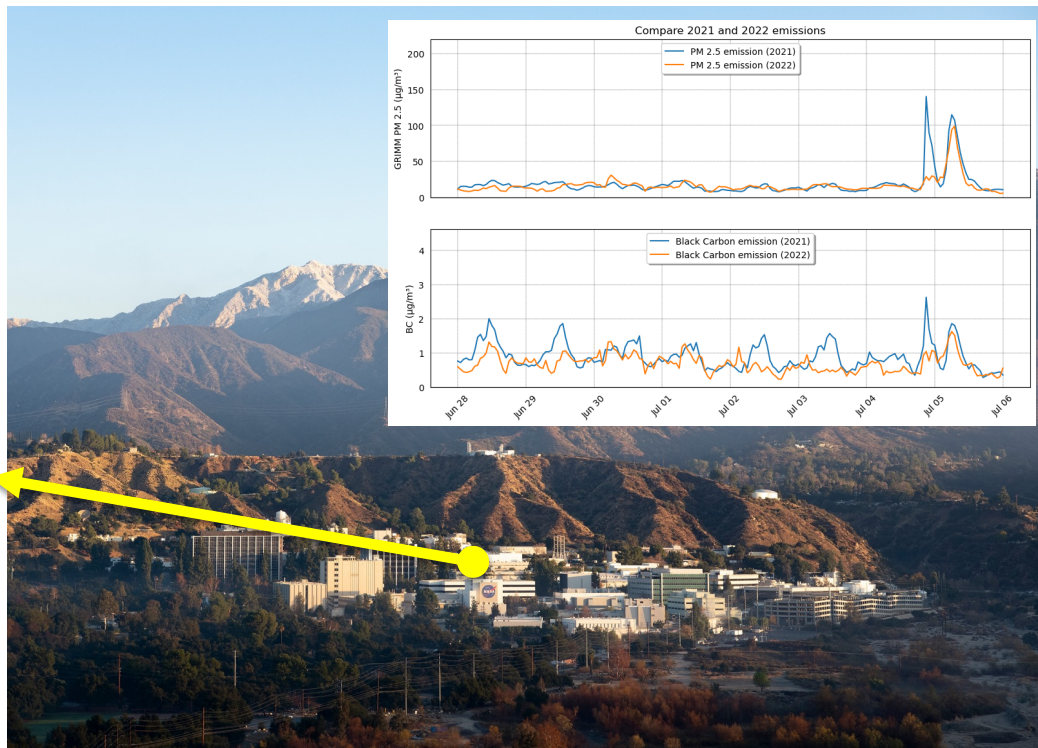
Example: PM<sub>2.5</sub> and Black Carbon from July 4<sup>th</sup> Fireworks



Source: San Gabriel Valley Tribune

Dynamic retrieval of in-situ  
measurements

PM<sub>10</sub>, PM<sub>2.5</sub>, BC, CO, NO<sub>2</sub>,  
O<sub>3</sub>, AOD, etc.

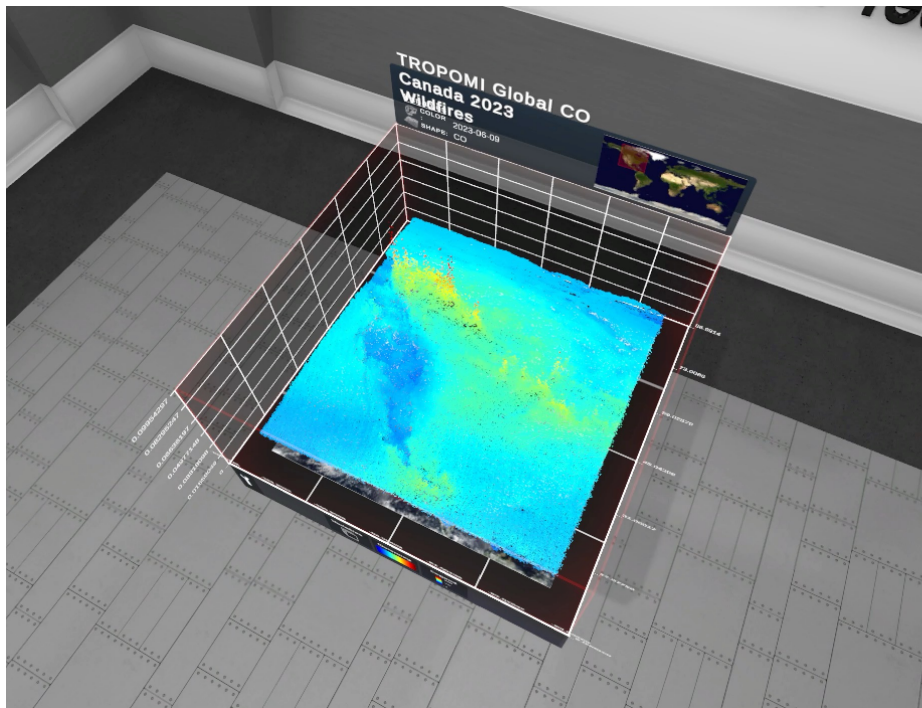


NASA Jet Propulsion Laboratory (JPL), Pasadena, CA

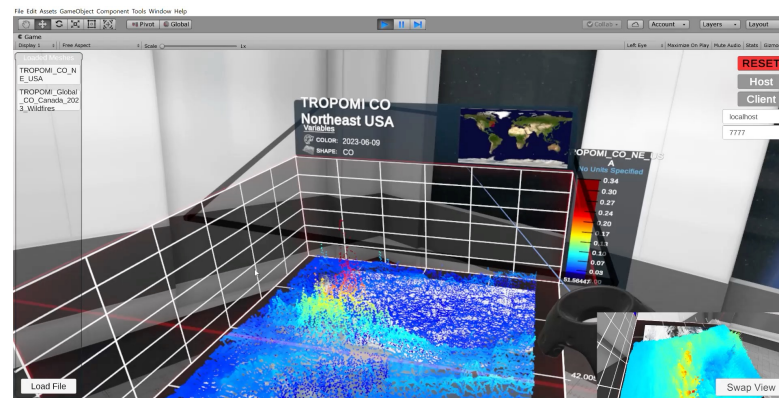




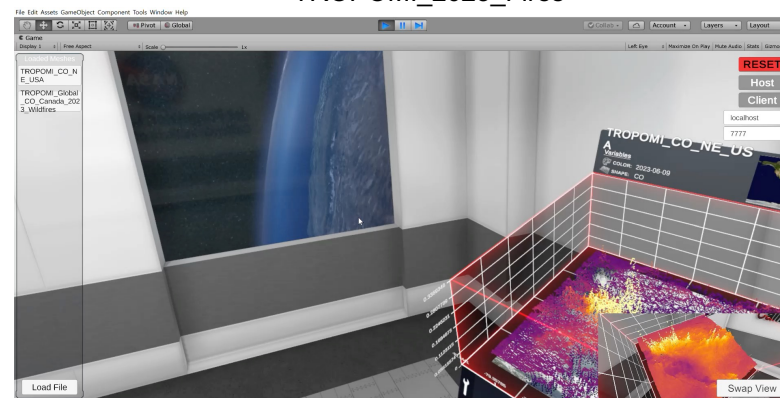
# Immersive Air Quality, and Health Impact Analysis Powered by IDEAS



TROPOMI CO Canada Wildfires



TROPOMI\_2023\_Fires



TROPOMI\_2023\_Inferno

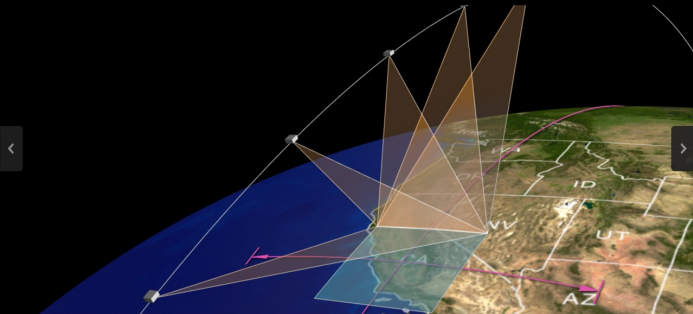


# Multi-Angle Imager for Aerosols (MAIA)

<https://maia.jpl.nasa.gov>

NASA Jet Propulsion Laboratory California Institute of Technology | MAIA

Home Science Objectives MAIA and Your Health Investigation Resources



**New NASA Instrument to Study Air Pollution**

scroll for more

The Multi-Angle Imager for Aerosols (MAIA) represents the first time NASA has partnered with epidemiologists and health organizations on a satellite mission to study human health and improve lives.

**What is MAIA?**

The Multi-Angle Imager for Aerosols (MAIA) investigation will seek to understand how different types of air pollution affect human health.

SCIENCE OBJECTIVES

**MAIA and Your Health**

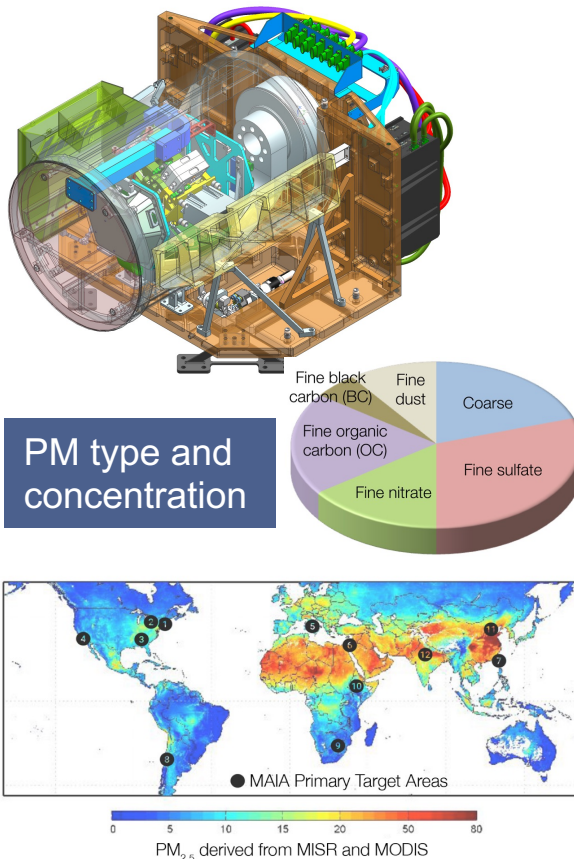
Air pollution can cause serious health problems such as heart disease, lung disease, and stroke. Find out more about what is known.

AEROSOLS AND HEALTH

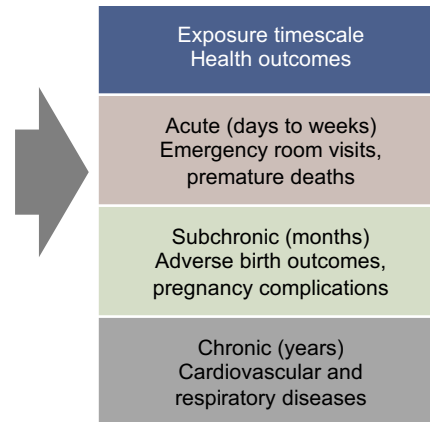
**The MAIA Investigation**

A state-of-the-art satellite instrument producing data that will be used in health studies to examine the health effects of various types of air pollution.

MISSION



DT-Driven instrument  
re-tasking





# 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



**NASA HEALTH AND AIR QUALITY  
APPLIED SCIENCES TEAM**



# Conclusion – Digital Twins is about Bridges

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

We can create Digital Twin islands

**BUT**

Let's also build Bridges

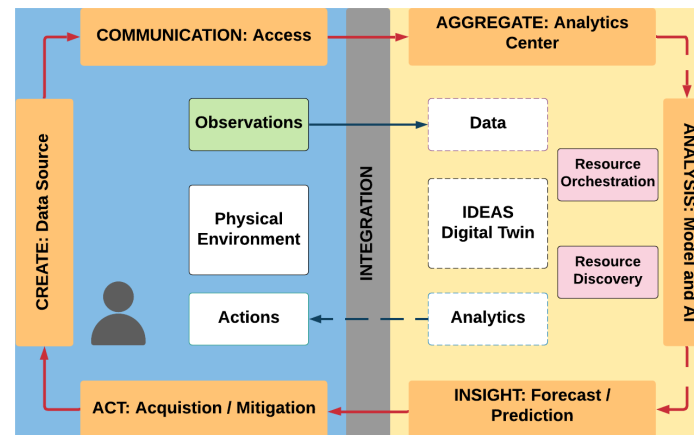
Let's bring together our best information assets

Let's make them interoperable

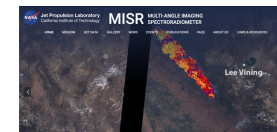
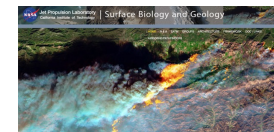
The Earth System is an interconnected system of systems

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

got ideas?



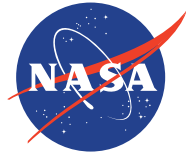
**NASA ESTO/AIST's Integrated Digital Earth Analysis System (IDEAS)** – an Earth System Digital Twin framework. Framework for pre-fire, during fire, and post fire analysis



## Thomas Huang

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NASA Jet Propulsion Laboratory  
California Institute of Technology



**DARE MIGHTY THINGS  
TOGETHER!**