**National Aeronautics and Space Administration**

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

# Open-Source Framework for Earth System Digital Twins

**Thomas Huang**

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Strategic Lead - Interactive Data Analytics

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**National Aeronautics and Space Administration**

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# AIST Distributed Oceanographic Matchup Service Team Meeting
# June 2016
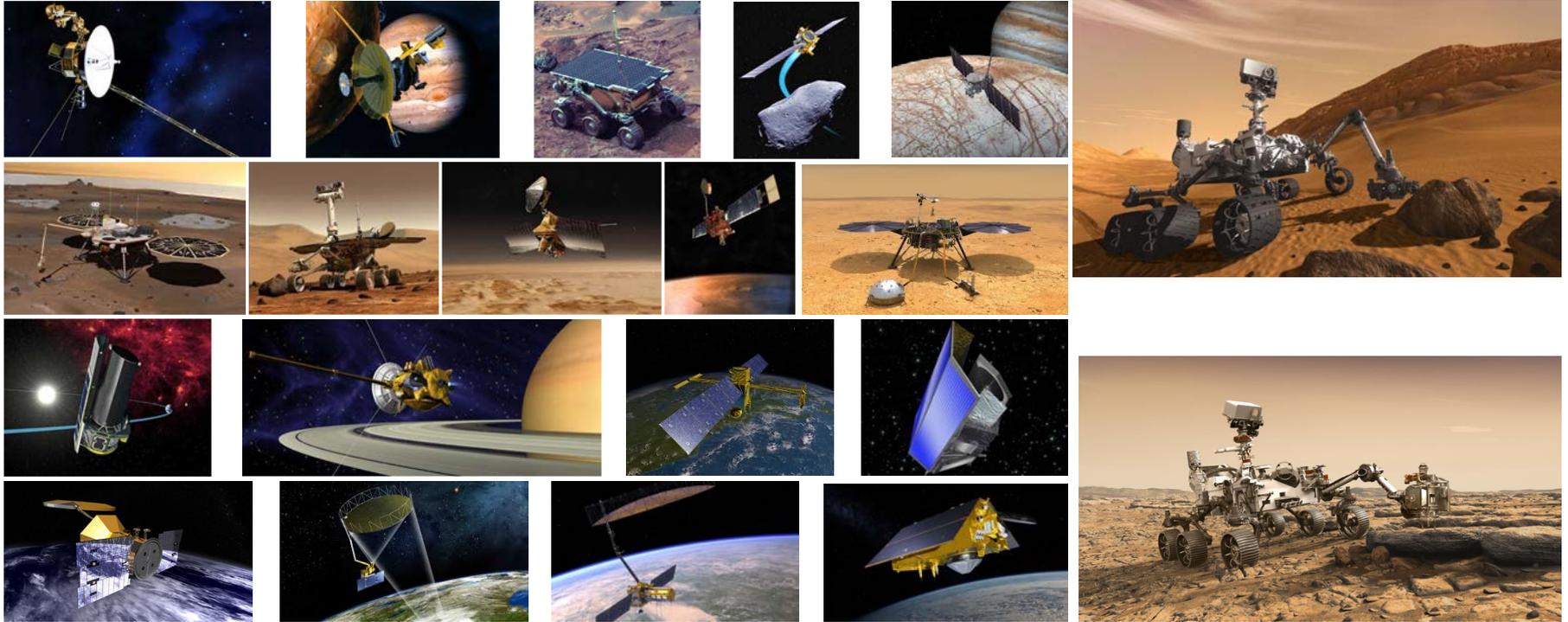
Product Generation | Data Management | Data Access | Data Distribution | Instrument Operation Technology

# If you want to go far, go together.

## How it started



- Thomas Huang for patches to Krb5Keytab functionality, Krb 1.2.* API support, and help in other areas

Kerberos Module for Apache

### Credits

Daniel Kouril is current maintainer of the module.

Thanks to:
- Daniel Henninger for bringing the module to SourceForge and maintaining it.
- Ben Fried for the original extensions to the NCSA web server, which were the basis for this module.
- James Robinson first did kerberos authentication via the Basic Auth mechanism. Then, as he puts it, promptly stole the code from the NCSA web server to do the mutual ticket authentication.
- Bobby Pham for aiding in the V5 testing.
- Jim Barlow for the code clean-up patch.
- Von Welch for the V5 bug-fixes, the KRB5_SAVE_CREDENTIALS feature, and the KRB5_VERIFY_TICKET feature.
- Nitin Dahyabhai for the Hesiod group patch.
- Mark Mentovai for the compiler warning and HTTP protocol correction patch.
- David MacKenzie for the instance directives and Stronghold compatibility fixes.
- Gary Rosenblum for the ticket file expiration suggestions, help, and testing.
- Earl Fogel for KrbAuthAuthoritative support.
- Thomas Huang for patches to Krb5Keytab functionality, Krb 1.2.* API support, and help in other areas
- Ryan Linn and Steve Grau for their suggestions/assistance getting the dso compile instructions up.
- Christopher P. Lindsey for enhancements in ccache handling.
- Oskar Liljeblad
- Jari Ahonen

https://modauthkerb.sourceforge.net

```
/*
 * $Id: mod_auth_kerb.c,v 4.11 2002/04/09 19:27:06 daniel Exp $
 */

#ifdef KRB5_DEFAULT_KEYTAB
        keytab_name = KRB5_DEFAULT_KEYTAB;
#else   /** added to consider the .htaccess configuration.  - T.Huang **/
        if (sec->krb5_keytab) {
            keytab_name = sec->krb5_keytab;
        }
#ifdef KRB_V5_KEYTAB
        else {
            keytab_name = KRB_V5_KEYTAB;
        }
#endif /* KRB_V5_KEYTAB */
#endif /* KRB5_DEFAULT_KEYTAB */
```

## How it's going  To date, Authored and Contributed to Open Sourcing of 30+ JPL Software Technologies

**** APPROVED ****

The EDGE code is approv
You may upload
the code at anytime to an open source repository.

**** APPROVED ****

The DMAS code is approved
may upload the code at anytim

**** APPROVED ****

The HORIZON code is approve
upload the code at anytime to a

**** APPROVED ****

The software known as NEXUS: Deep Data Platform (NTR-50157) has been approved for release as open source. You are authorized to upload the software to open source repository when you are ready to do so.

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# Open – The Key to Climate Understanding

It is about

# **Knowledge Sharing** and **Technology Reusing**
## and promote **Collaboration**

# Analytic Collaborative Framework

https://esto.nasa.gov/aist

GIS WebApp     Workbench     Esri ArcGIS
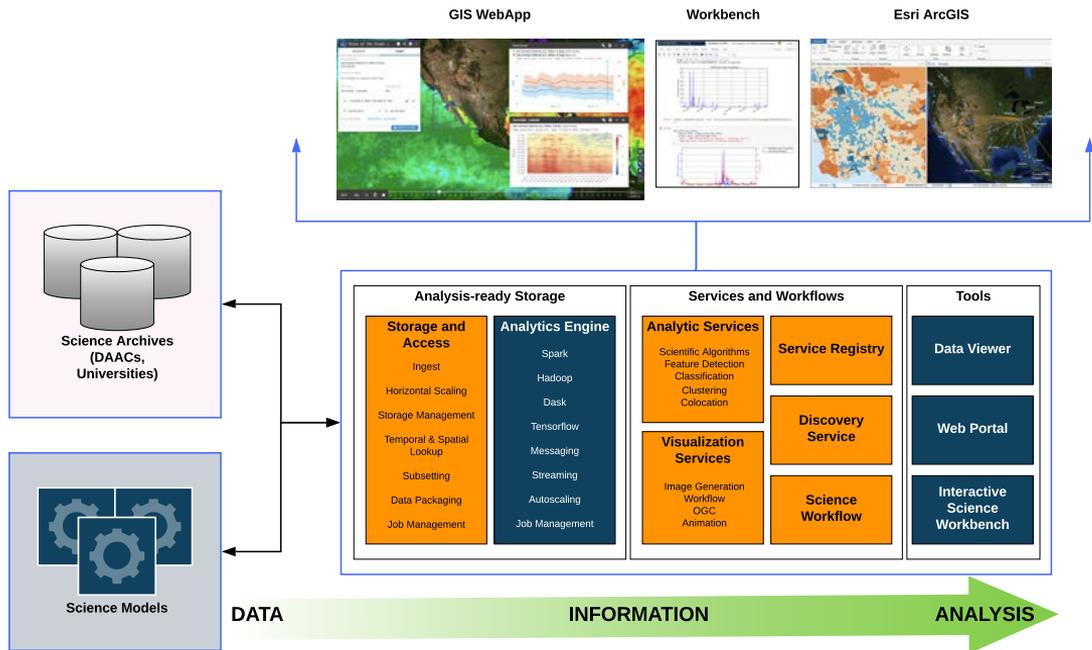


**High-level System Architecture**

- 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

Science Archives (DAACs, Universities)

Science Models

**Analysis-ready Storage**

**Storage and Access**
Ingest
Horizontal Scaling
Storage Management
Temporal & Spatial Lookup
Subsetting
Data Packaging
Job Management

**Analytics Engine**
Spark
Hadoop
Dask
Tensorflow
Messaging
Streaming
Autoscaling
Job Management

**Services and Workflows**

**Analytic Services**
Scientific Algorithms
Feature Detection
Classification
Clustering
Colocation

**Visualization Services**
Image Generation
Workflow
OGC
Animation

**Service Registry**

**Discovery Service**

**Science Workflow**

**Tools**

**Data Viewer**

**Web Portal**

**Interactive Science Workbench**

DATA      INFORMATION      ANALYSIS

# Reusable Professional Open-Source Technology for Earth Science
https://sdap.apache.org



THE **APACHE** SOFTWARE FOUNDATION

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

**2013**
- Geospatial Indexing and data subsetting using Hadoop
- Cloudburing between JPL, AWS, and Langley Research Center

**2015**
- NASA SMAP Time-Series Analysis
- Data Tiling and Geospatial Index
- Using Apache Solr, Cassandra, and Spark
- Data Container Study

**2017**
- Approved for Open Source
- Established Apache Science Data Analytics Platform (SDAP)
- Multi-dimensional ocean and state estimate
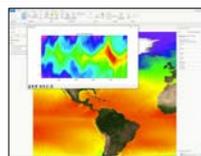
**2019**
- SDAP ArcGIS Integration
- Multi-scale Methane Analysis
- Geospatial Spectroscopy Analysis

**2021**
- Air Quality
- Ocean Carbon Ocean Cycle and Flood Analysis
- Groundwater Analysis
- Land Cover Science
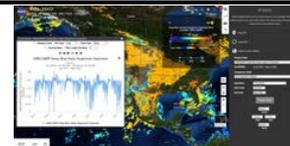
**2023...**
- Fire Alarm - Earth System Digital Twin for Wildfire, Air Quality, and Health Impact
- Apache SDAP 1.1.0

Timeline: 2011 — 2013 — 2014 — 2015 — 2016 — 2017 — 2018 — 2019 — 2020 — 2021 — 2022 — 2023...

**2011**
- Cloud-based Climatology generation
- Using Hadoop and HBase
- Point-cloud architecture
- Deployment: NASA Nebula and AWS
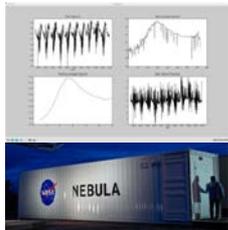
**2014**
- Data-intensive Anomaly Detection
- In-situ and Satellite Matchup
- ML-Driven Data Discovery
- NASA Sea Level Change Portal

**2016**
- NASA OceanWorks
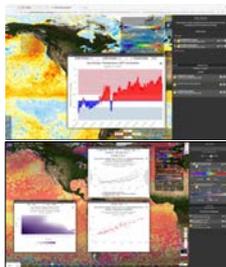
**2018**
- NASA GRACE Follow-On Science Portal
- CEOS Ocean Variables Enabling Research & Applications for GEO
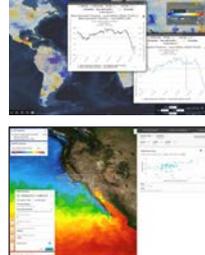
**2020**
- Distributed SDAP
- SDAP Large Scale in-situ to Satellite Matchup Service
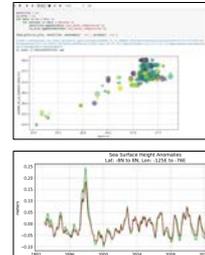
**2022**
- IDEAS - Earth System Digital Twin for Hydrology
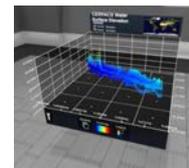
## Evolution of Apache Science Data Analytics Platform (SDAP)

# Ocean Sciences





*Houston Police SWAT officer Daryl Hudeck carries Catherine Pham and her 13-month-old son Aiden after rescuing them from their home surrounded by floodwaters from Tropical Storm Harvey Sunday, 27 August 2017, in Houston. (AP Photo/David J. Phillip)*



*Interstate 69 is covered by floodwaters from Tropical Storm Harvey, Aug. 29, 2017, in Humble, Texas. (AP Photo/David J. Phillip)*

Hurricane Harvey – Aug. 17 - Sept. 2, 2017

# Sea Level Rise

https://sealevel.nasa.gov
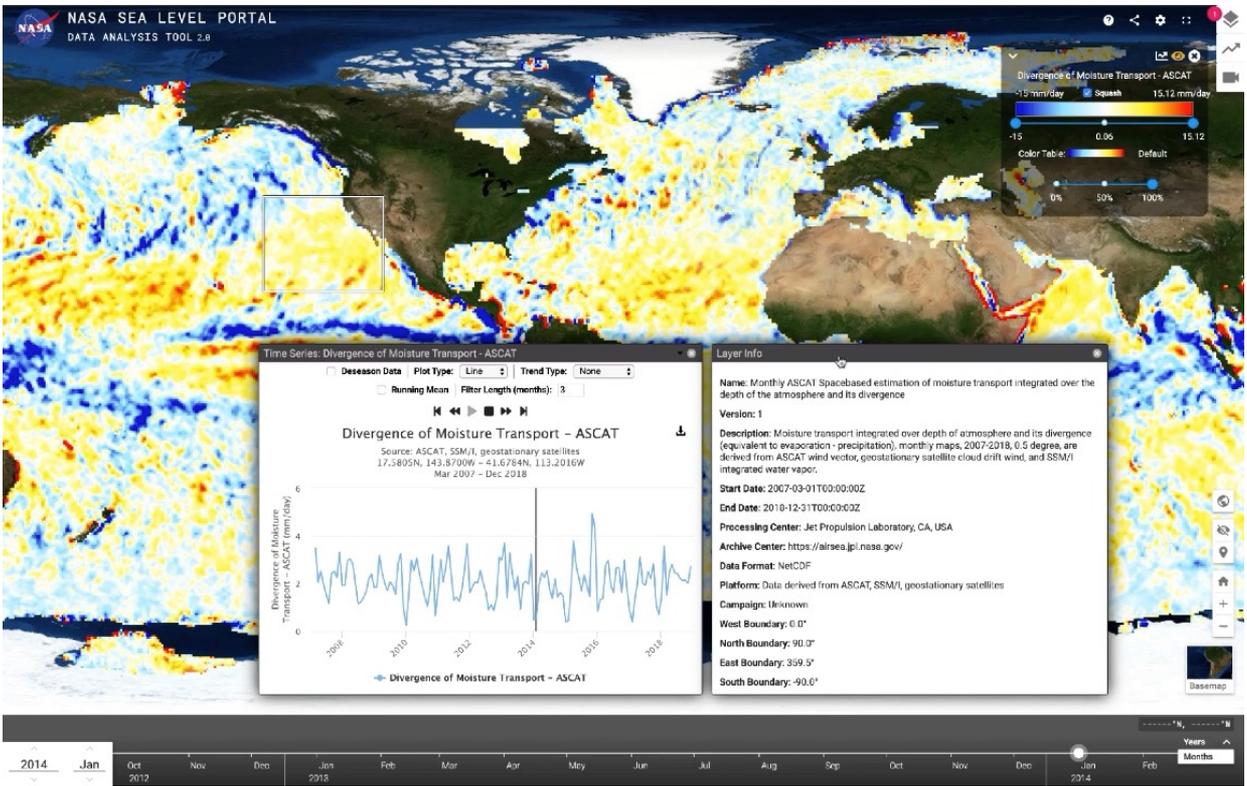


Interactive Sea Level Analysis

# Scalable Data Management, Access, and Analysis in Production

- Amdahl's Law taught us adding more machines may not necessarily improve the latency of the execution
- The keys
  - Sustainable, Repeatable and Affordable architecture
  - Maximize parallelization
  - Minimize data movement
- NASA's IPCC Sea Level Projection Tool served over 135k global users in under 24hr







Users ▾ vs. New Users ▾ ⊗    Hourly | Day | Week | Month

- Users  - New Users

**Wednesday, August 11, 2021 08:00**
- Users: **9,927**
- New Users: **9,573**

Aug 11    Aug 12    Aug 13    Aug 14    Aug 15
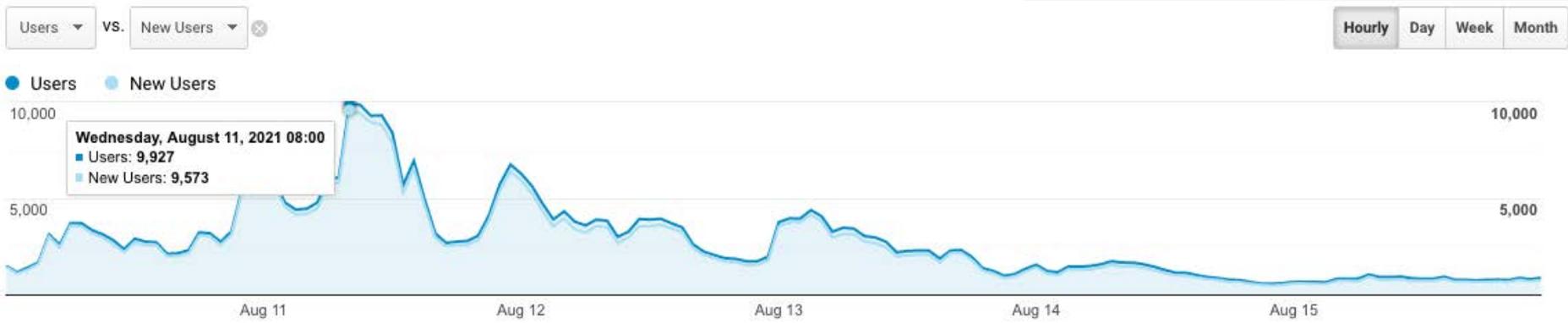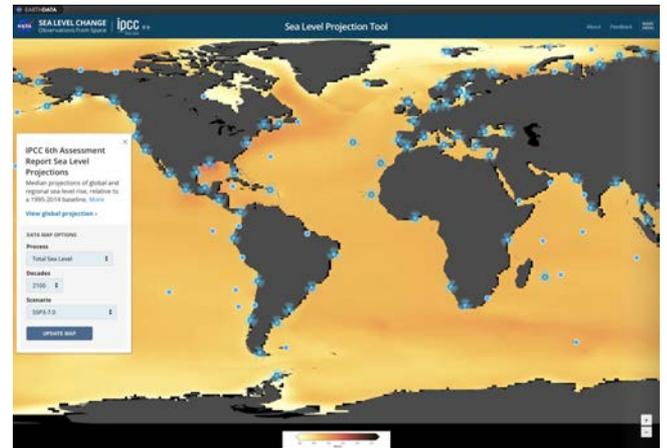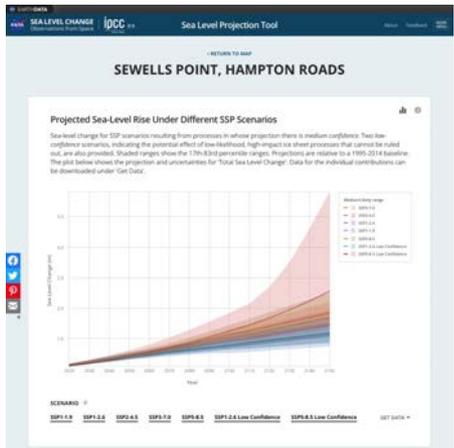
# Visualization of In-situ and Remotely-Sensed Groundwater Observations (VIRGO)

ESTO
Earth Science Technology Office

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.

2023-07-10 Digital Twins Discussion
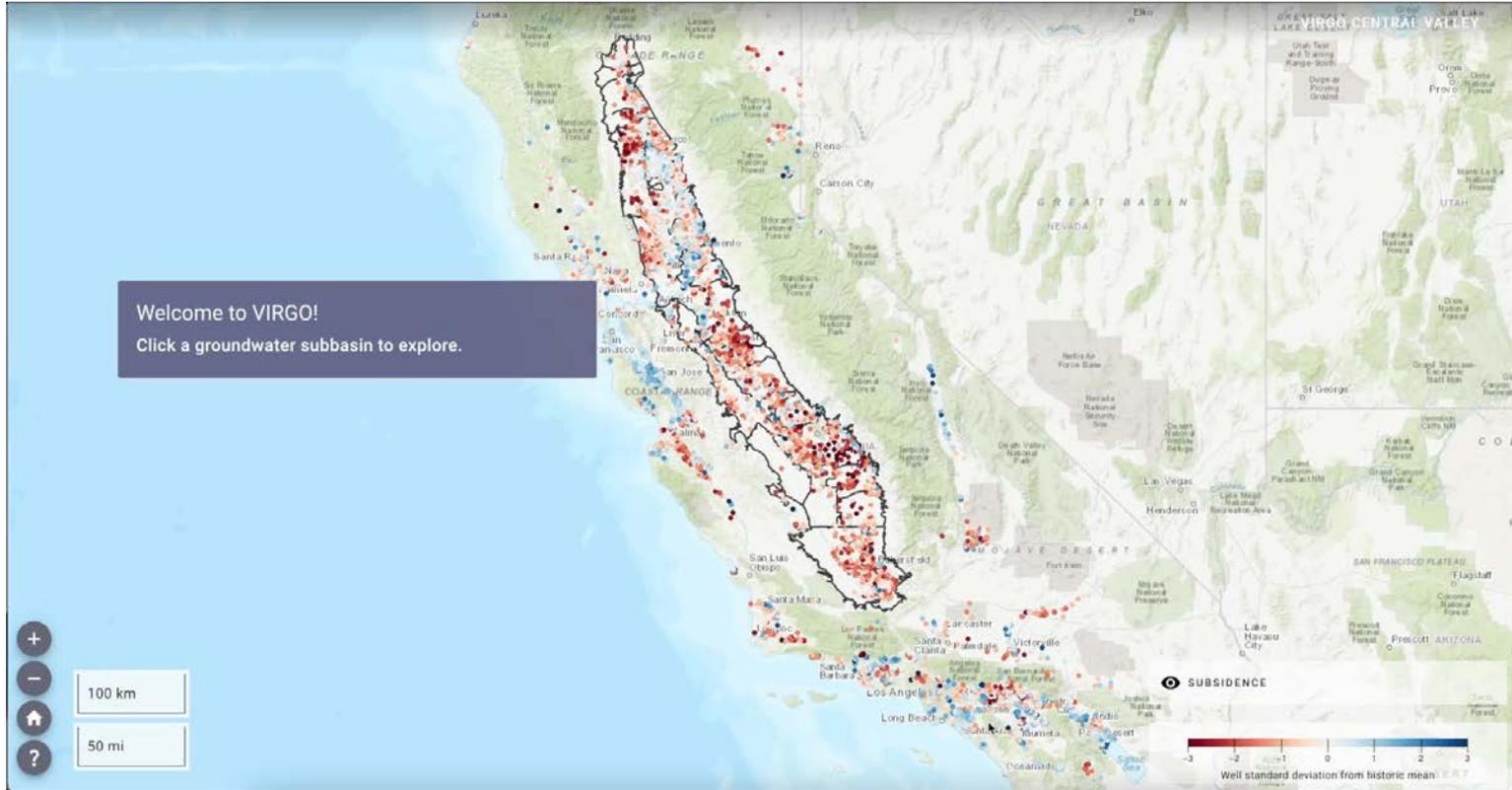
# Federation of Science Analytic Platforms
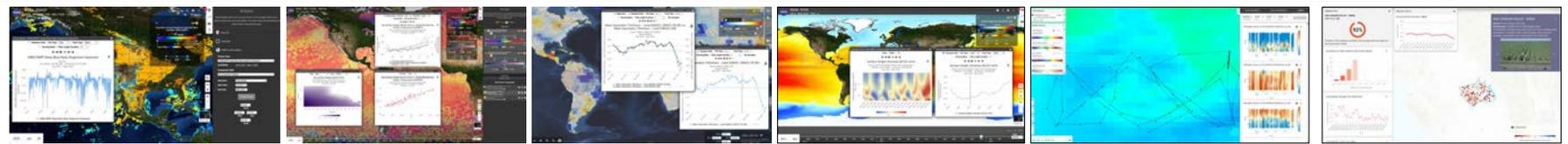


| AQ Analysis Tool | Sea Level Analysis Tool | GRACE-FO Analysis Tool | ECCO Analysis Tool | CEOS COVERAGE Analysis Tool | VIRGO Groundwater Tool |
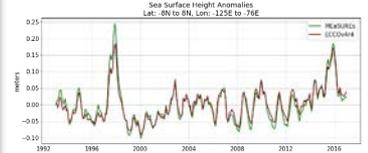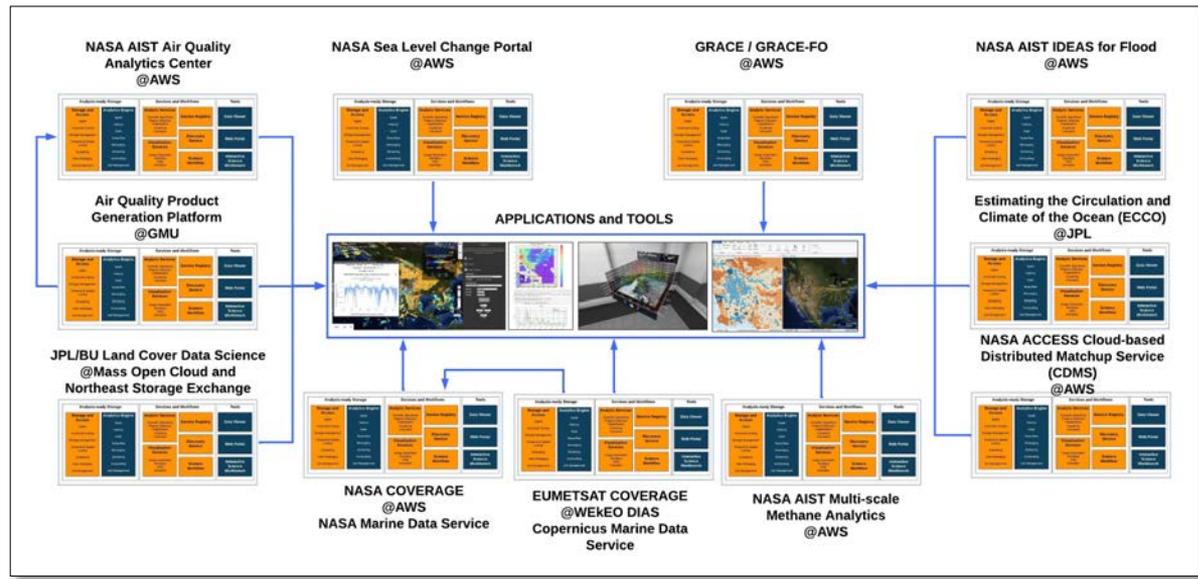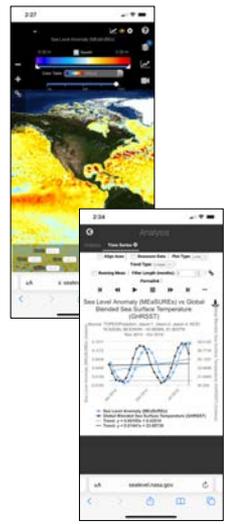


E. Tropical Pacific SSH: ECCO vs. NASA MEaSUREs Satellite Product
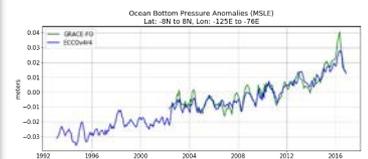
Verify ECCO OBP vs. NASA/JPL GRACE-FO Product

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

# Actionable Prediction – New Observing Strategies
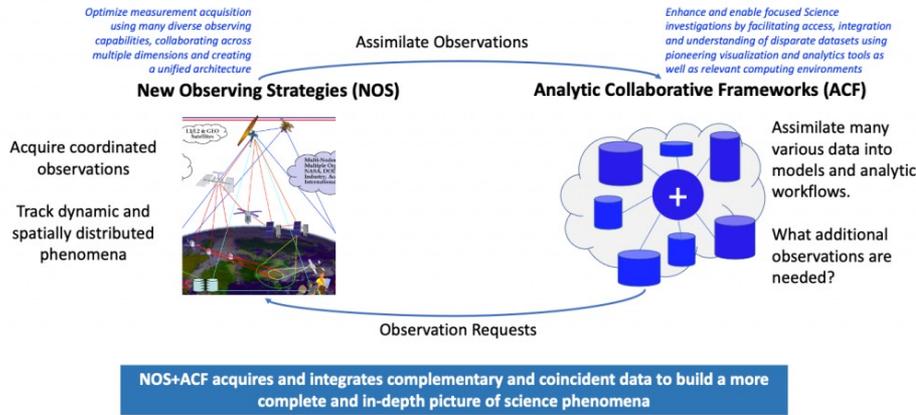


Science-Driven architecture for Acquiring new observations and Dynamic data assimilation

Develop trend analysis, anomaly detection and event dispatch

Support the formalization of NOS Testbed (NOS-T) messaging specification and architecture
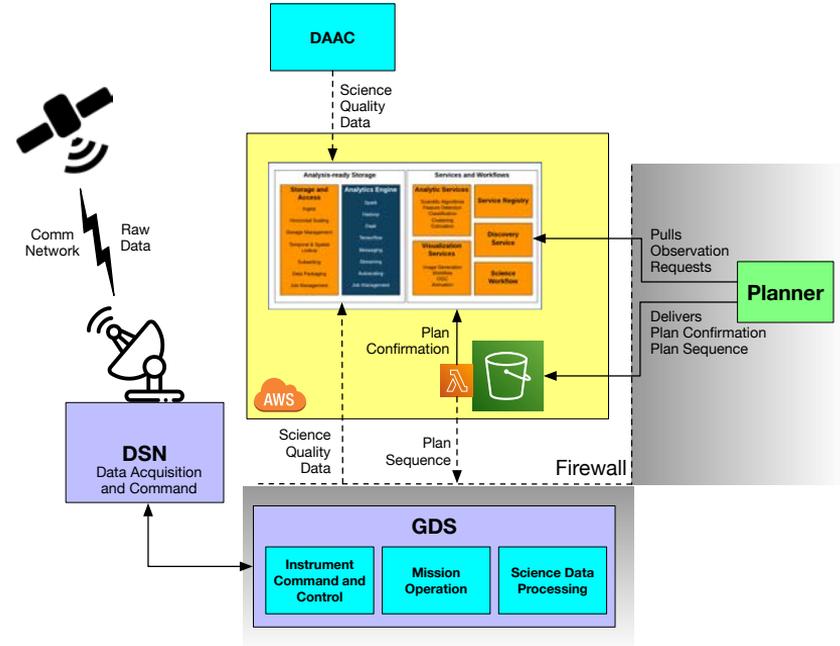
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Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

# Earth System Digital Twins

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
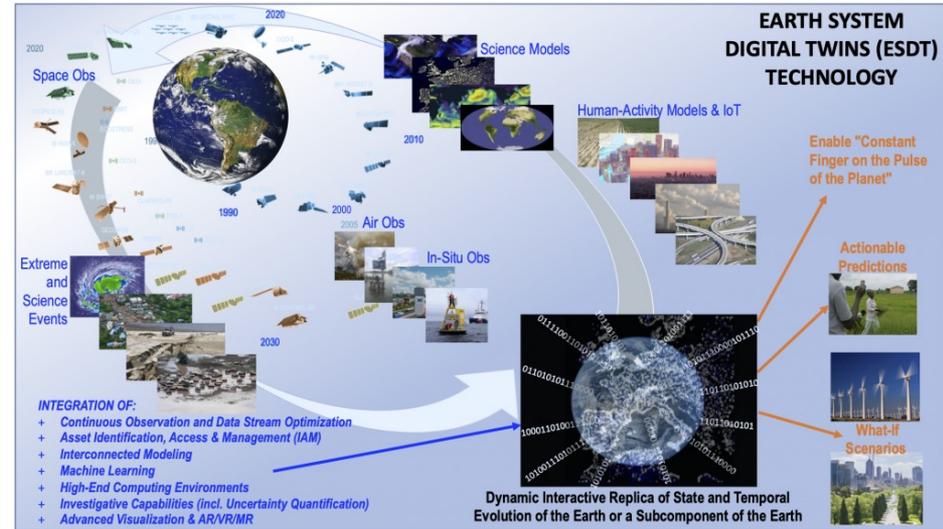


An integrated information system that, for example, enables continuous assessment of impact from naturally occurring and/or human activities or physical and natural environments

Source: https://esto.nasa.gov/aist/
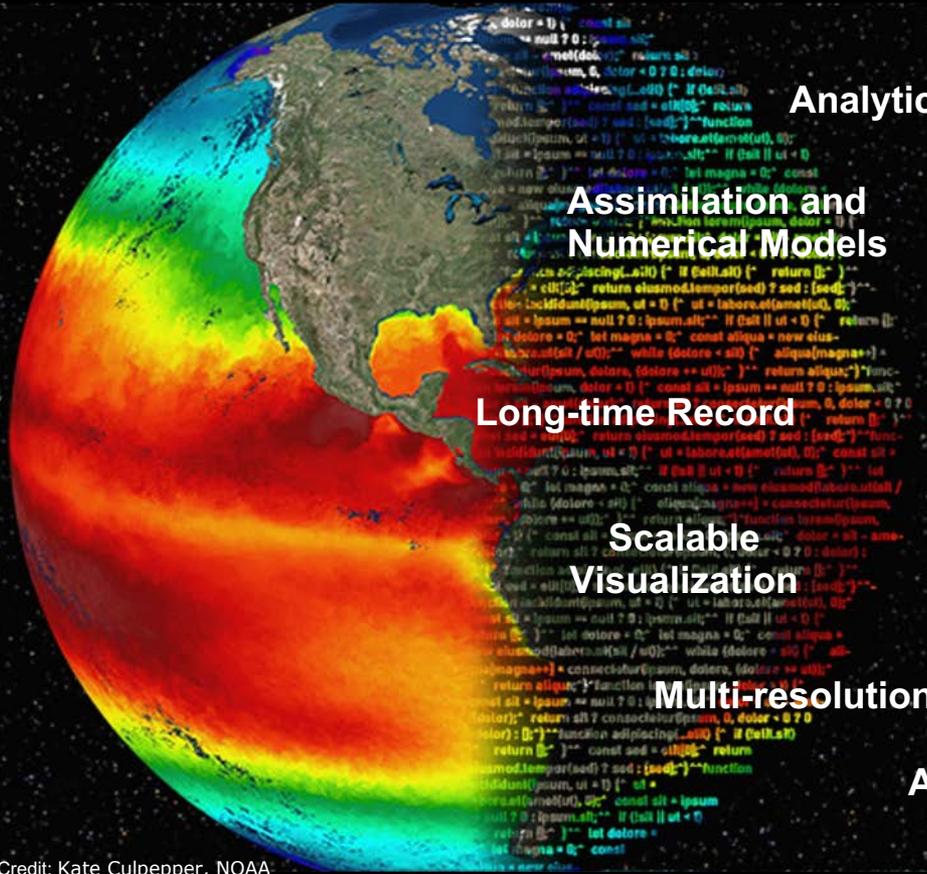
Analytic Collaborative Framework

New Observing Strategies

Assimilation and Numerical Models

Artificial Intelligence

Long-time Record

**Extensible Framework**

Real-time

Scalable Visualization

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
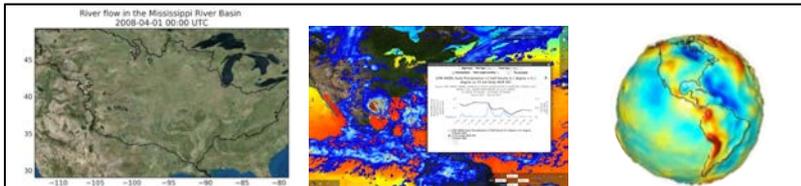
Harmonize Observation and Model Data Access and Analysis
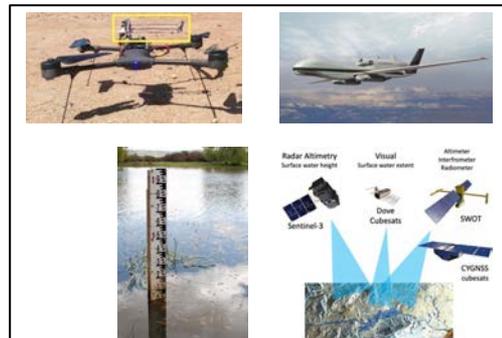
Acquire Observation and Analysis

Assimilation and Numerical Models

AI-based 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

THE APACHE SOFTWARE FOUNDATION
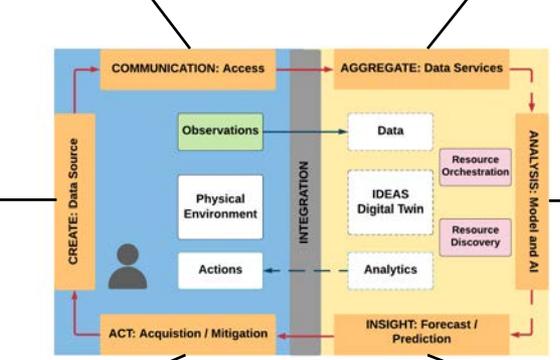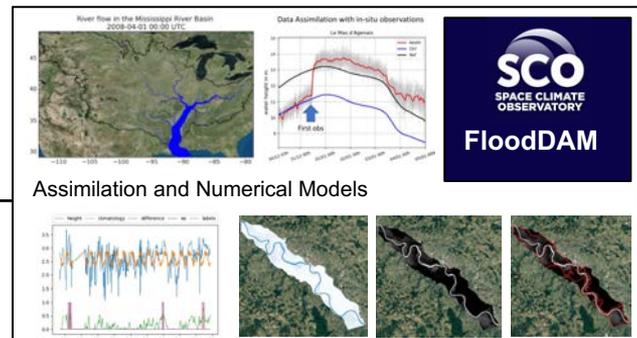
FloodDAM — SCO SPACE CLIMATE OBSERVATORY
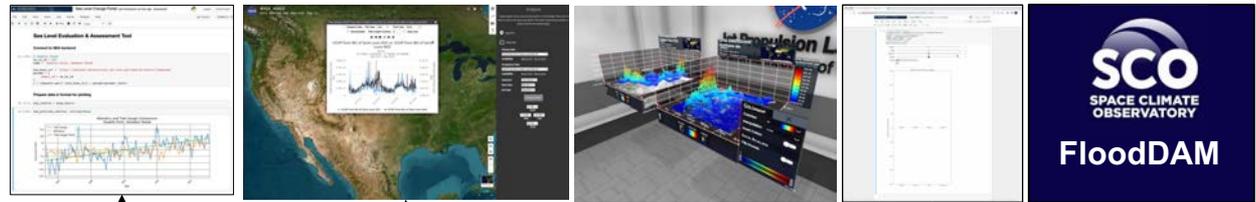
IDL   C/C++   MATLAB   Python   Julia   R   …

**IDEAS Framework**

STAC, OpenSearch, ISO-19115

Apache SDAP API

OGC API - Processes    OGC SensorThings API    OGC - WPS    OGC - WMS    OGC - WMTS

Latest Observations

Analysis Ready Data

Advanced Numerical Models

Advanced AI Predictions

Scalable Visualization

On-Demand Value-Added Product Generation
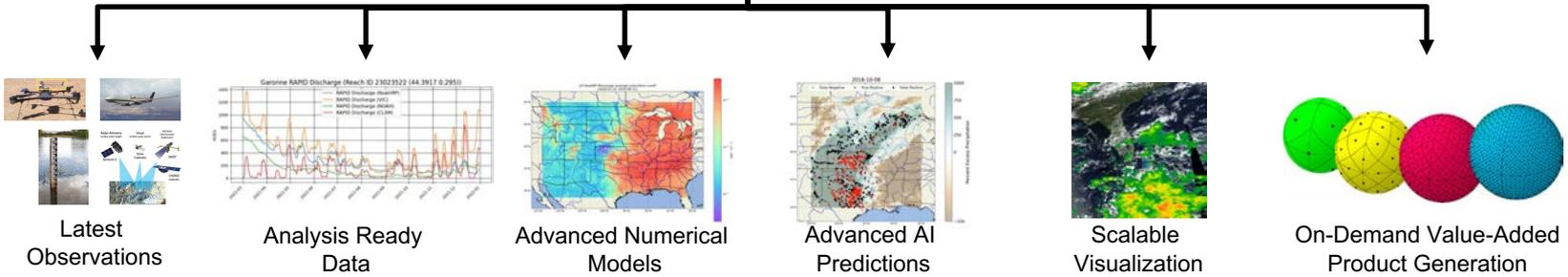
# IDEAS for
# Hydrology, Flood Prediction, and Analysis

## 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 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



Integrated Digital Earth Analysis System

https://ideas-digitaltwin.jpl.nasa.gov/floods/
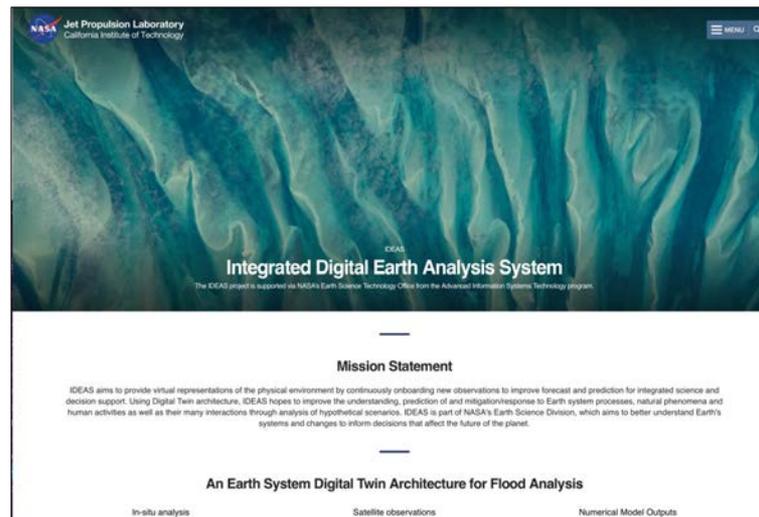
What are the environmental and infrastructural impacts of floods?

# NASA – CNES: Federated Digital Twins



**NASA ESTO/AIST's Integrated Digital Earth Analysis System (IDEAS)**
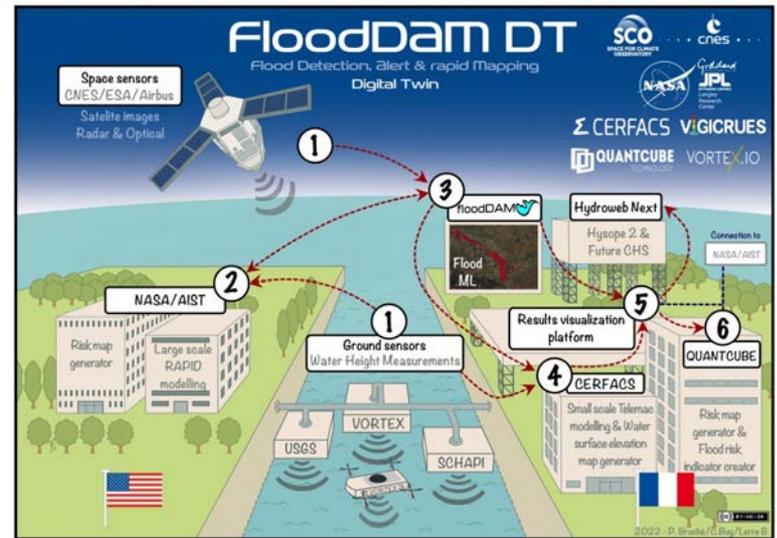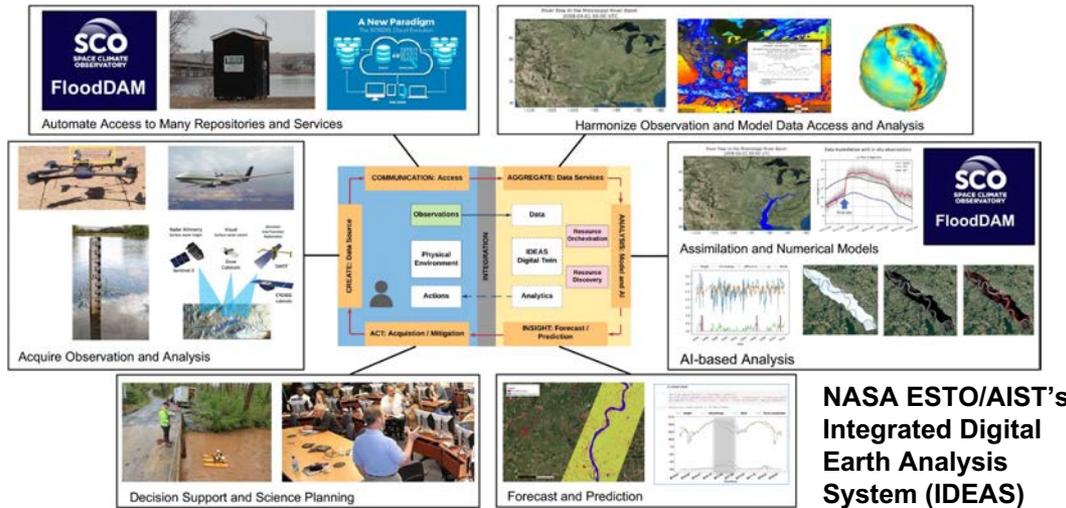


- Establish federated digital twins solution between the **NASA ESTO/AIST's Integrated Digital Earth Analysis System (IDEAS)** (Huang/JPL) and the **Space for Climate Observatory (SCO) FloodDAM-DT** (Rodriguez-Suquel/CNES)

- 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
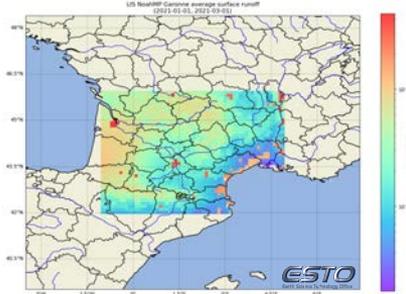


NoahMP Average Surface Runoff
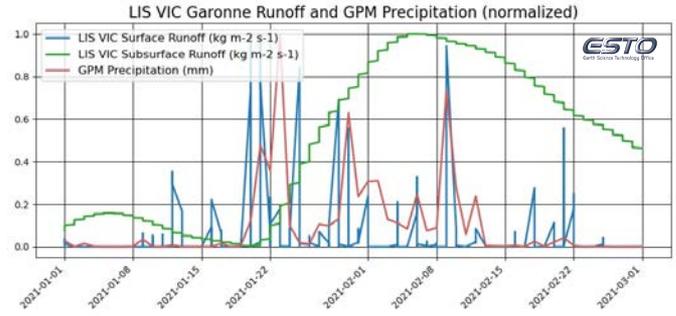


VIC Runoff and GPM Precipitation (normalized)
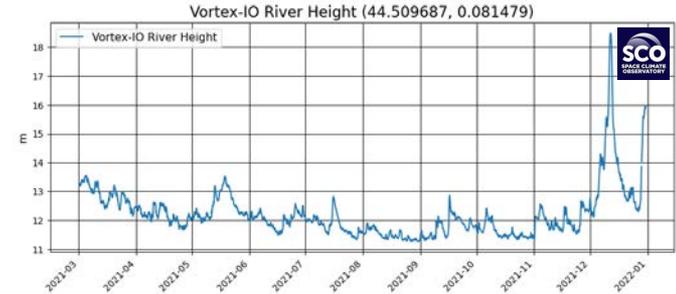


Vortex.Io River Height
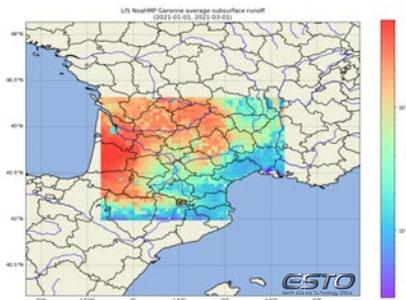


NoahMP Average Subsurface Runoff
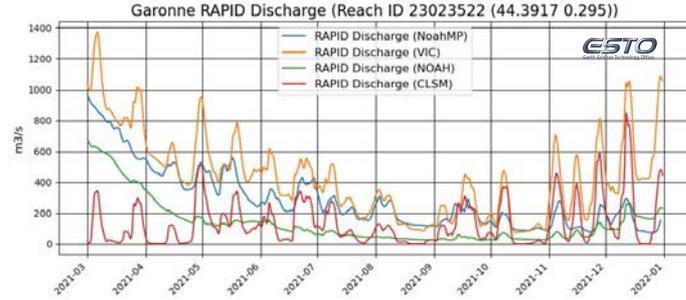


RAPID Discharge from different Land Surface Models
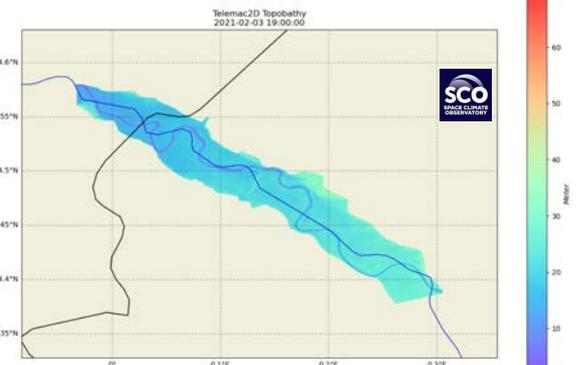


Telemac2D Water Elevation

# **What-If Garonne:** Nominal Precipitation



NoahMP – Surface Runoff



NoahMP Surface and Subsurface Runoffs



NoahMP – Subsurface Runoff



RAPID Discharge

# **What-If Garonne:** 2x Precipitation
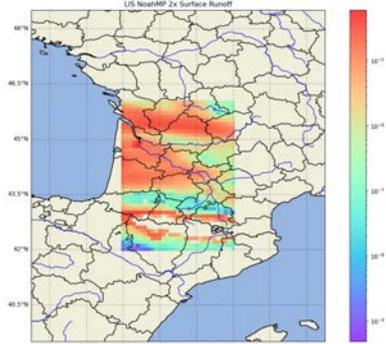


NoahMP – Surface Runoff
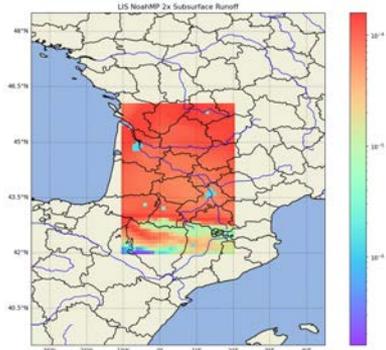


NoahMP – Subsurface Runoff
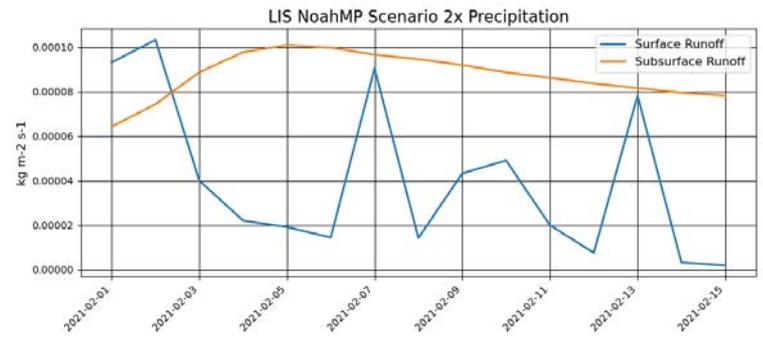


NoahMP Surface and Subsurface Runoffs
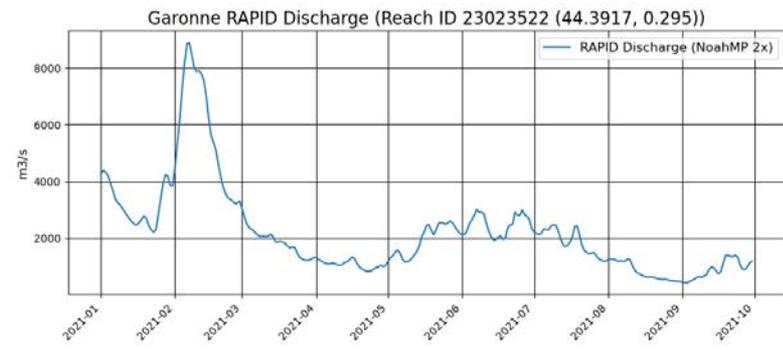


RAPID Discharge

# What-If Garonne: 3x Precipitation



NoahMP – Surface Runoff



NoahMP Surface and Subsurface Runoffs



NoahMP – Subsurface Runoff
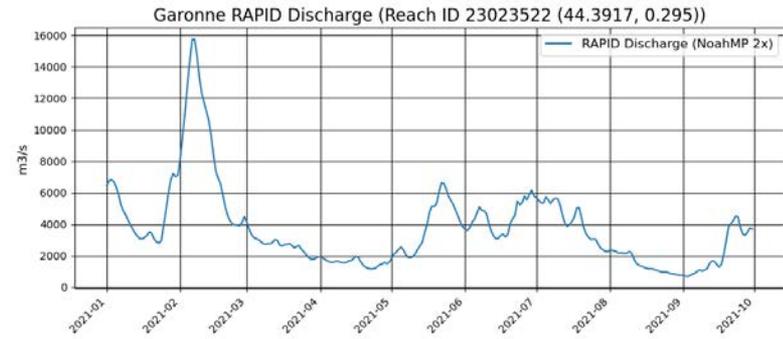


RAPID Discharge

# ML-Driven In-Situ Data Acquisition

Minimize storage and computation need for pre-staging different in-situ sensor data. Use real-time ML to predict which stream gauges will be most useful for analysis

- **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
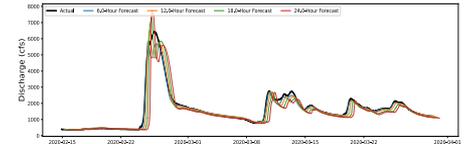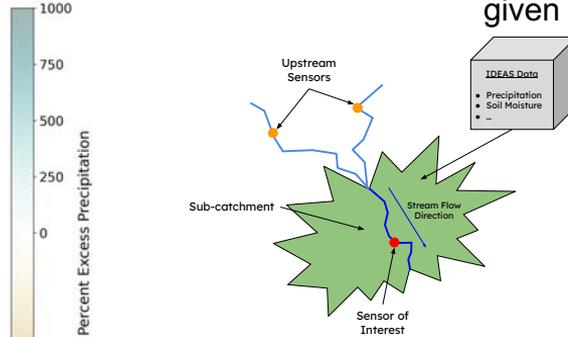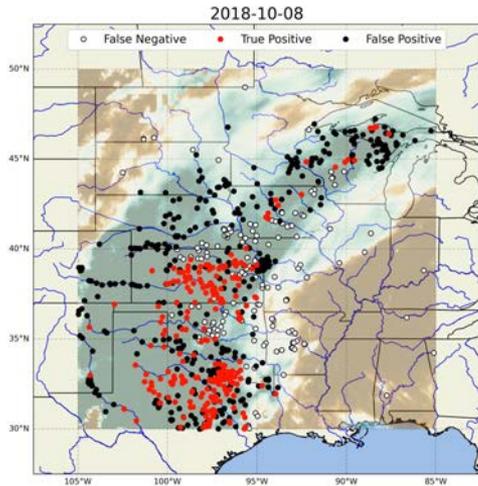
# Matchup Service

- Collaborated with NASA ACCESS Cloud-Based Data Matchup Service (CDMS) project to integrate matchup capability with Flood data holdings.
- Notebook demo: https://github.com/access-cdms/cdms-notebooks/blob/master/CDMS-AQ-Match-Up-Demo.ipynb

```
{
  "primary": "GPM-3IMERGHHR-06-daily-global-precipitationCal_transposed",
  "matchup": "LIS_miss_1x_Qs_tavg",
  "startTime": 1551398400,
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  "bbox": "-97.500,27.799,-82.500,38.500",
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  "radiusTolerance": 18750.0,
  "platforms": "74069827"
}
```

Difference plot between GPM Precipitation and LIS Surface Runoff

Plot of precipitationCal

Plot of surface_runoff_amount

# 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
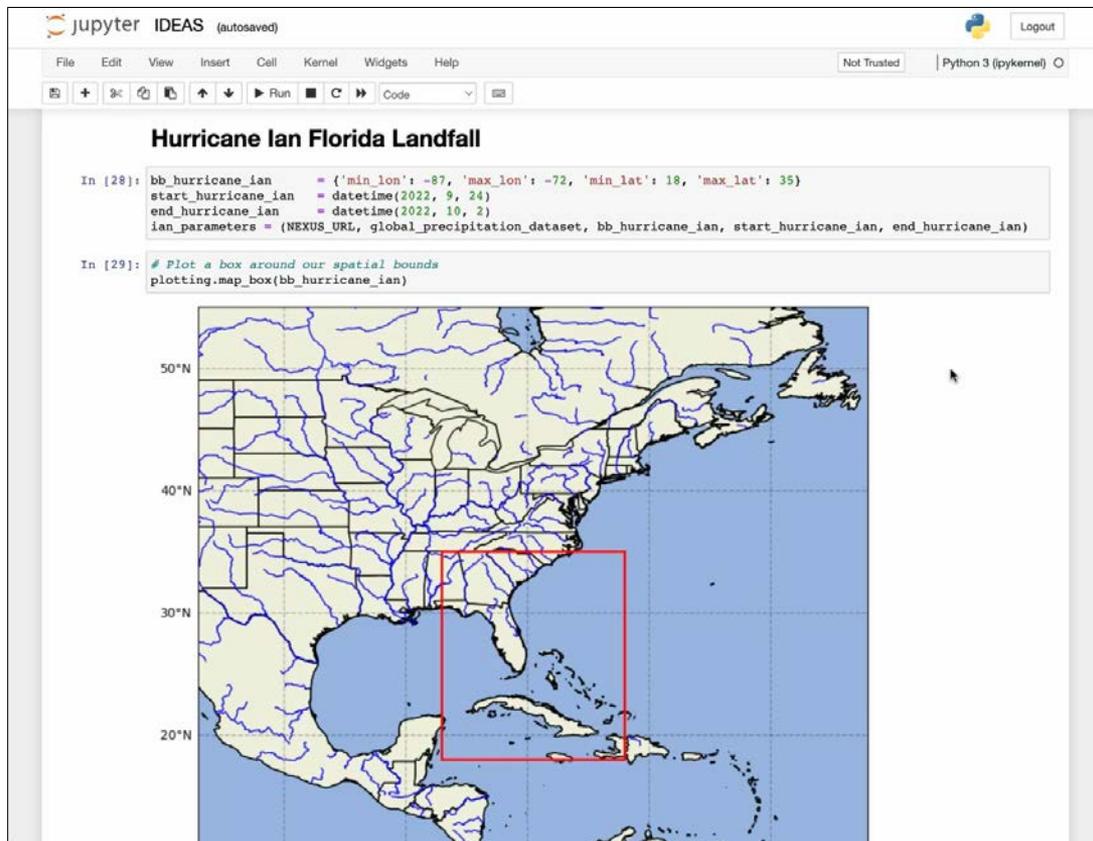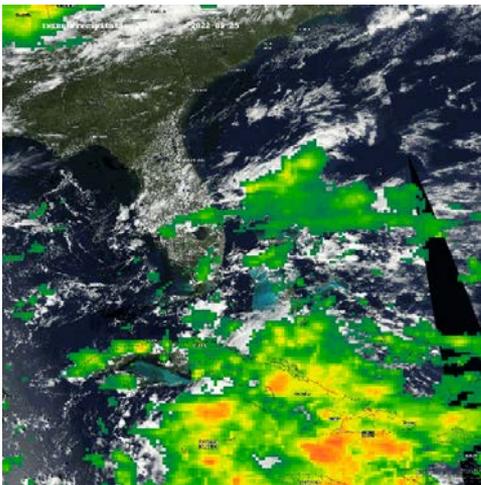
# Immersive Flood Prediction and Analysis
Powered by IDEAS
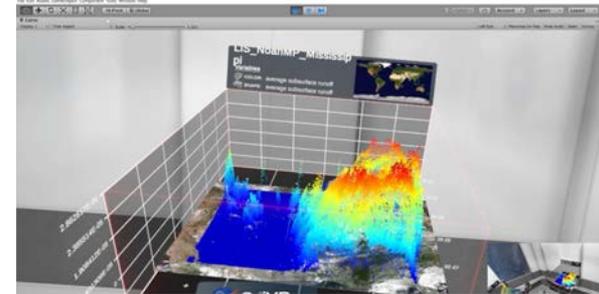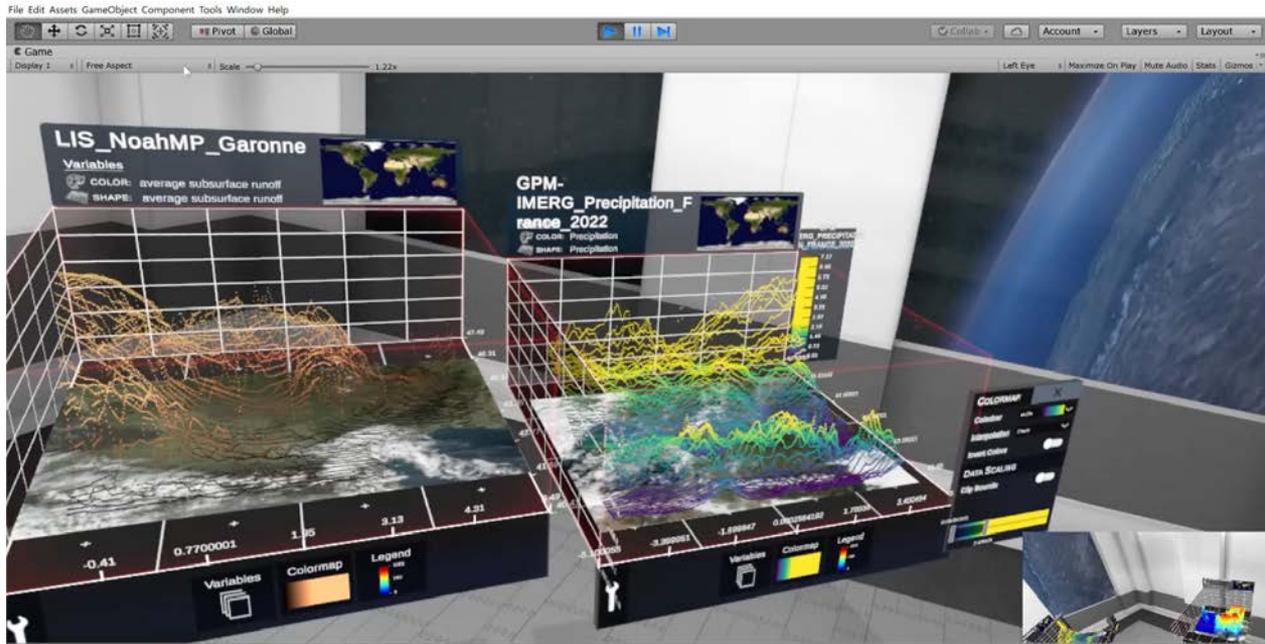
# "South Korea floods kill 40, including 13 trapped in highway tunnel" - CBS News



"Climate change is happening... deal with it"

"This kind of extreme weather event will become commonplace — we must accept climate change is happening, and deal with it," President Yoon Suk Yeol said during an emergency response meeting Monday.

The idea that extreme weather linked to climate change "is an anomaly and can't be helped needs to be completely overhauled", he said, calling for "extraordinary determination" to improve the country's preparedness and response.



IMERGE Precipitation



SMAP Soil Moisture

https://www.msn.com/en-us/weather/topstories/south-korea-floods-kill-40-including-13-trapped-in-highway-tunnel/ar-AA1dYeua
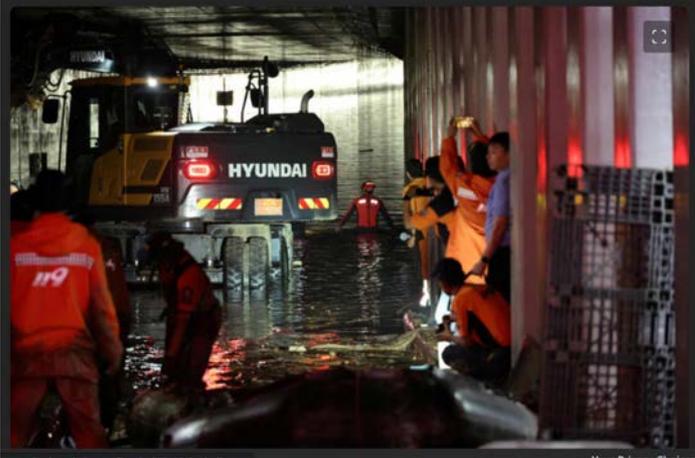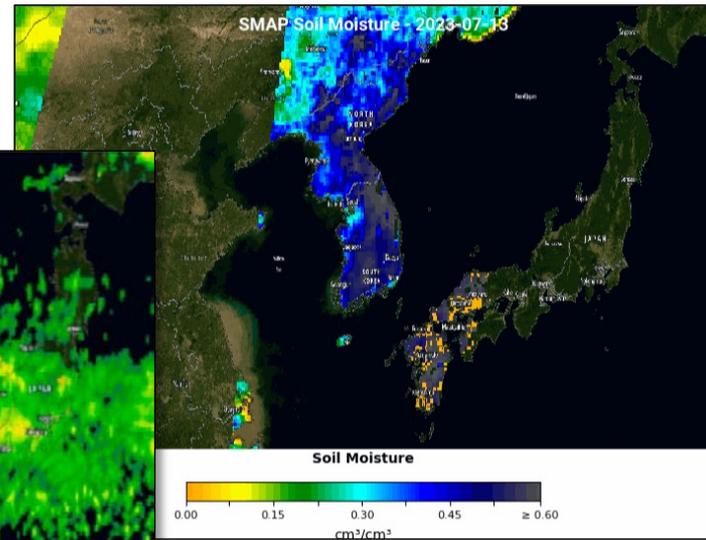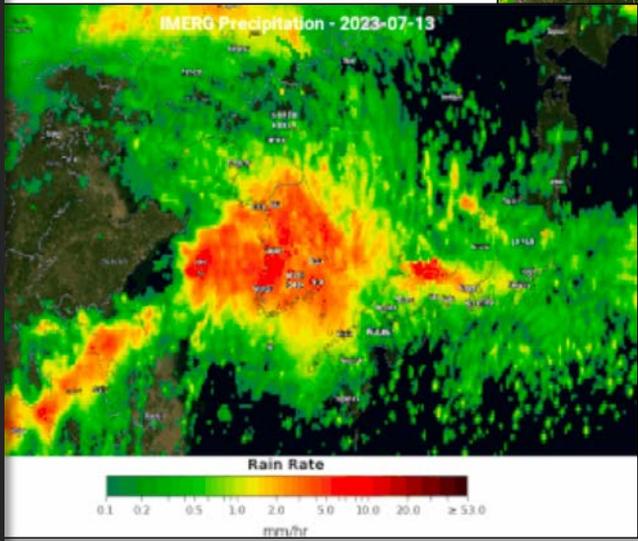
# Analyze South Korea Floods



South Korea floods: Dozens die in flooded tunnel and landslides

By Kelly Ng & Jean Mackenzie
in Singapore and Seoul

At least 40 people in South Korea have died after a weekend of severe rains caused widespread flooding and landslides across the country.

The disasters have prompted calls from President Yoon Suk Yeol to "overhaul" how the country combats extreme weather arising from climate change.

On Monday, the nation was reeling from a tunnel tragedy where at least 13 people died in their vehicles after becoming trapped by floodwaters.
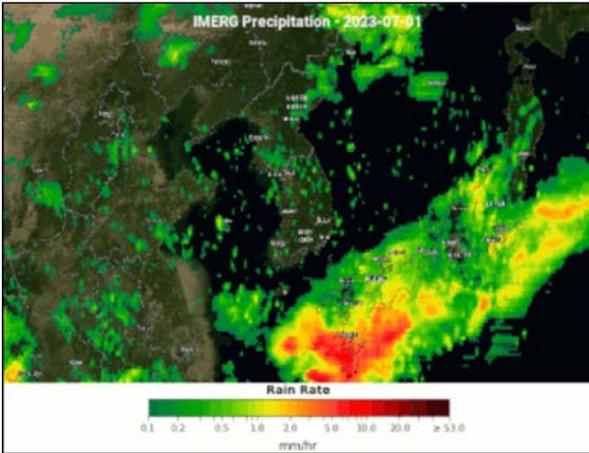


IMERGE Precipitation July 2, 2023 – July 16, 2023
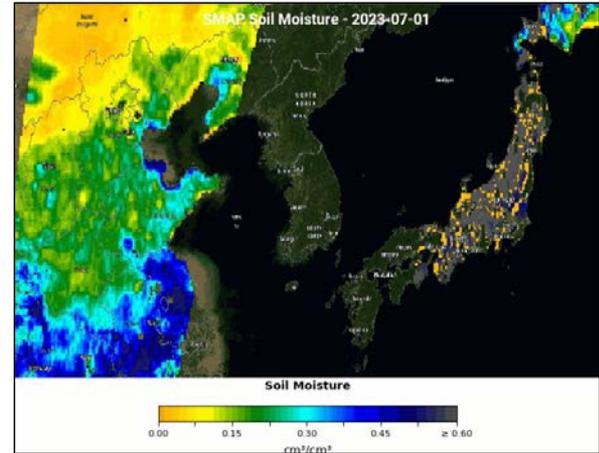


SMAP Soil Moisture July 2, 2023 – July 16, 2023
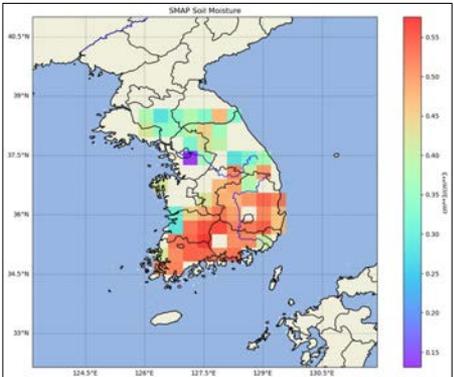


Data Inbound
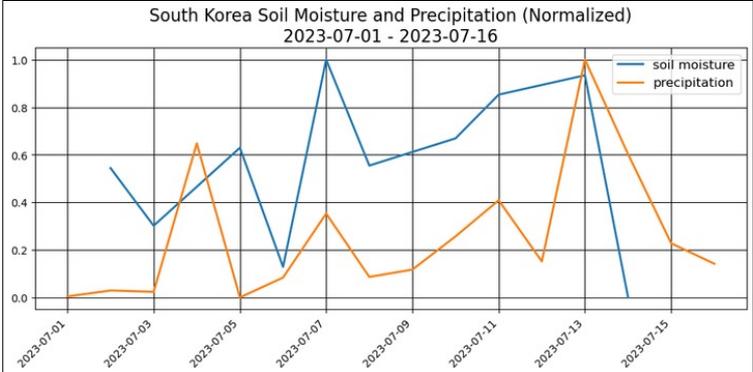


Normalized Timeseries Analysis

https://www.bbc.com/news/world-asia-66209578

NCAR CISL Seminar

# 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

**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?

# Big Picture Up Front

Improve usability of science data for air quality analysis and prediction

Leverage advanced assimilation of numerical and AI models to Improve Decision Making

Develop sustainable technology solution for sustainable science
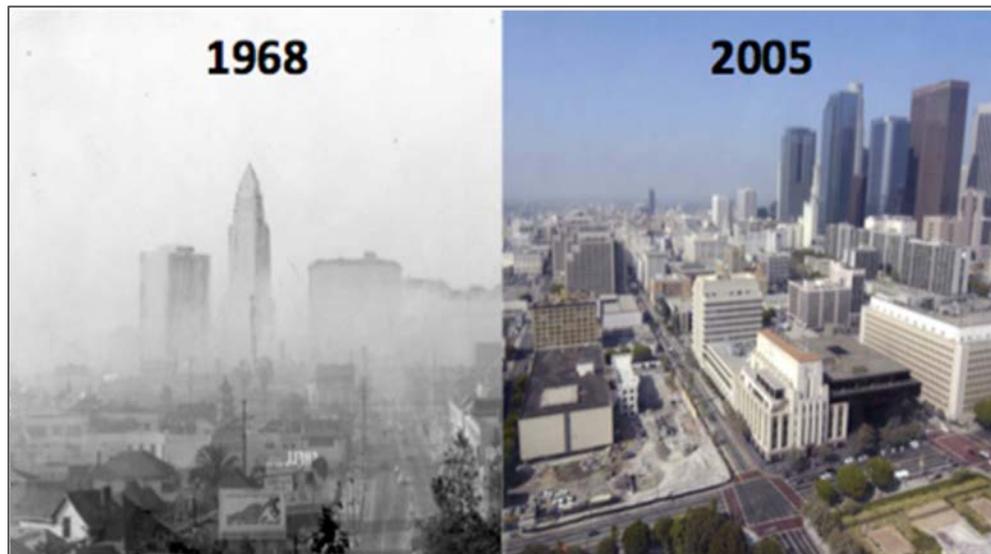


**"Characterize, understand, and improve the quality of air in urban areas across the planet."** – Jeanne Holm, Deputy Mayor for Budget and Innovation at LA

# ESDT for Wildland Fire and Air Quality



Automate access to fire data repositories for the each fire event of interest
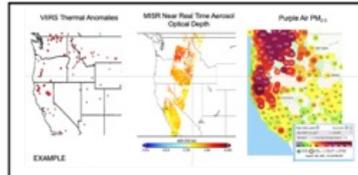
Harmonize datasets to track pre-fire, active fire, and post fire impacts for the event of interest

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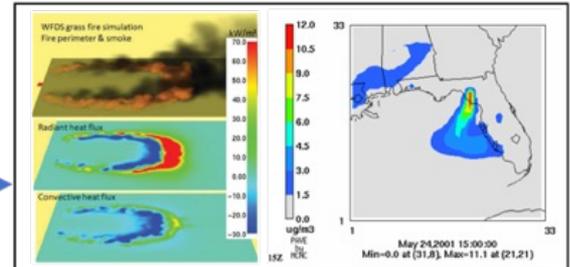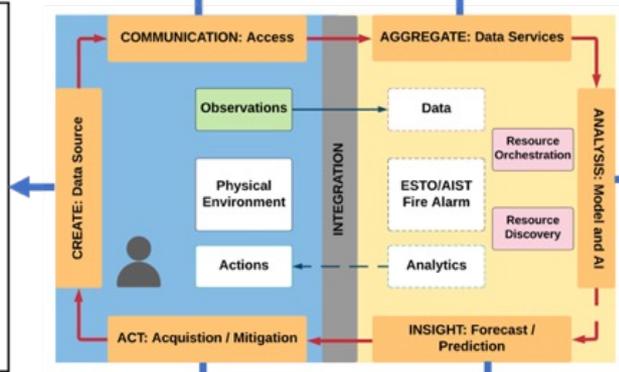
Dynamic Data Assimilation; AI-based Models; Dynamic Downscaling;

Decision Support and Science

Forecast and Prediction

# OMI $NO_2$ and $SO_2$ for the eastern U.S. 2005 & 2022
Long-term Record
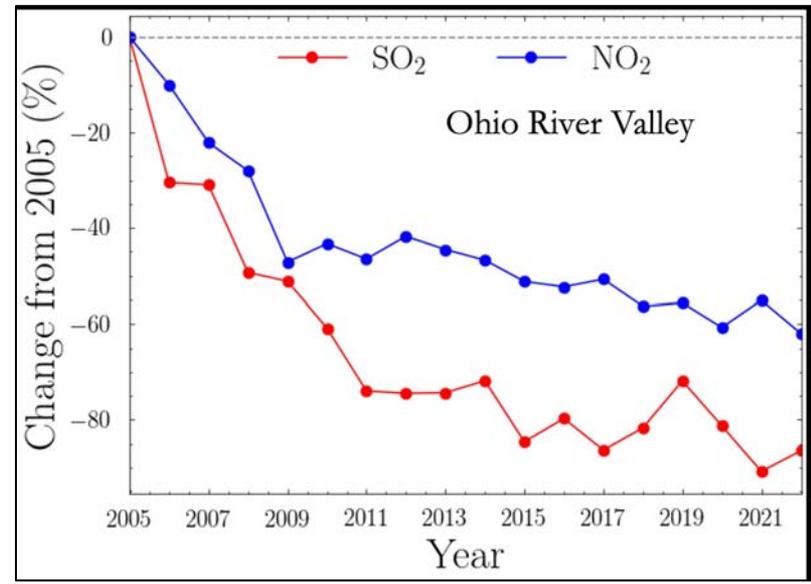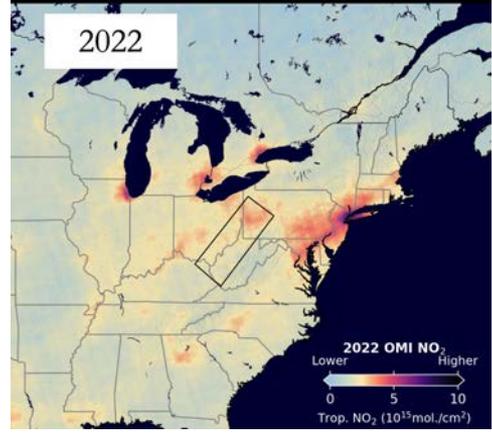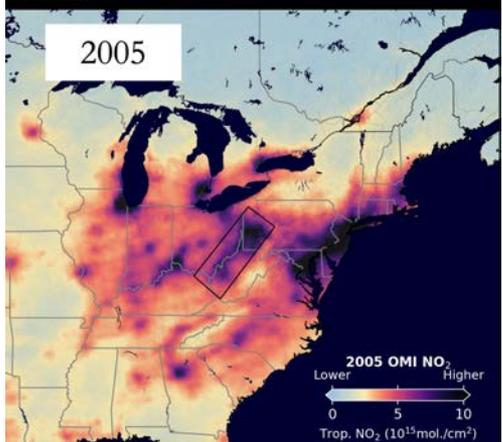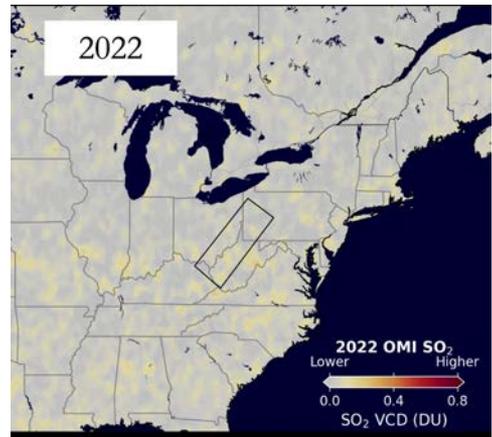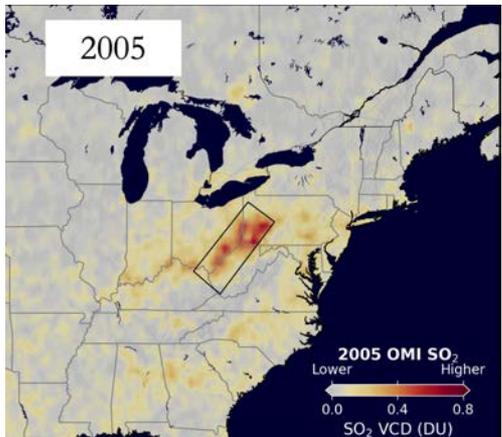


- Decreases in the U.S. can be attributed to the improved catalytic converters in cars and trucks

- Implementation of newer technology trapping the nitrogen and sulfur oxides in powerplant smokestacks

# OMI NO$_2$ and SO$_2$ for China 2005 & 2022
Long-term Record
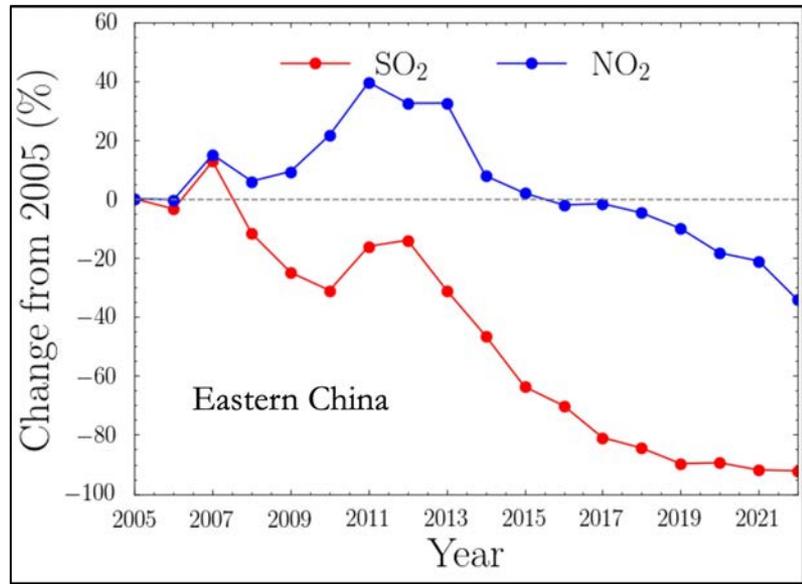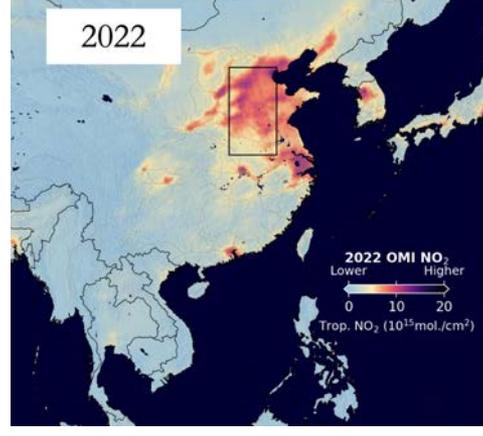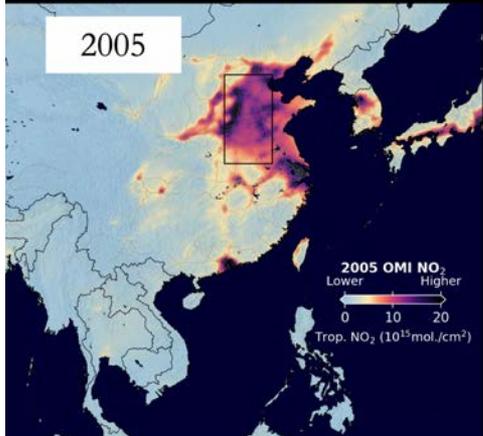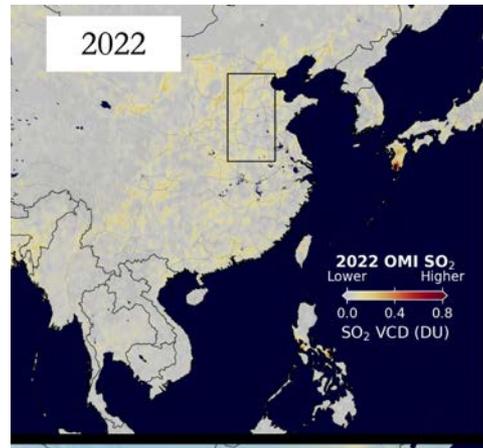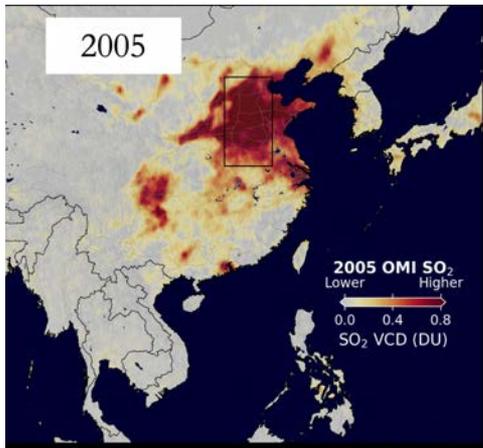


- 90% SO$_2$ reduction

- As of 2021 the atmospheric NO$_2$ abundance is approximately 20% lower than the start of the OMI record

- Highlights the different strategies and technologies employed to reduce these two pollutants

# OMI NO$_2$ and SO$_2$ for India 2005 & 2022

Long-term Record
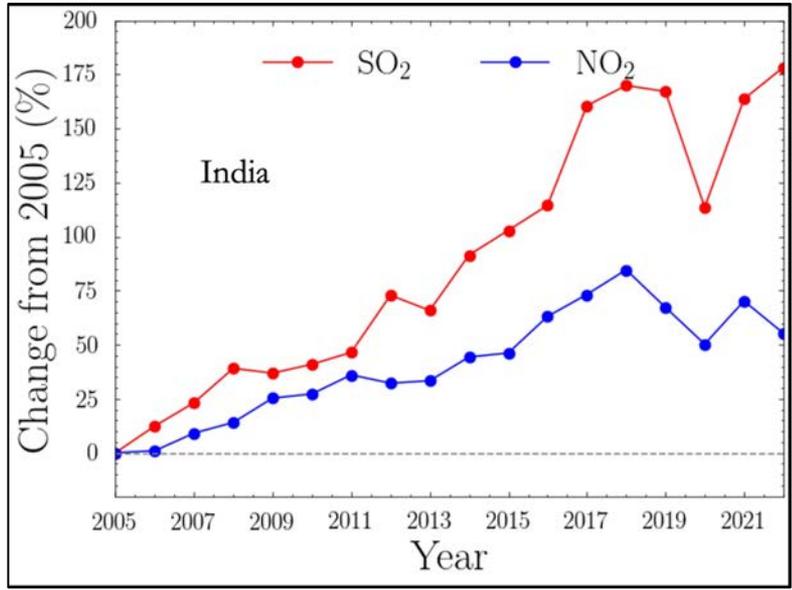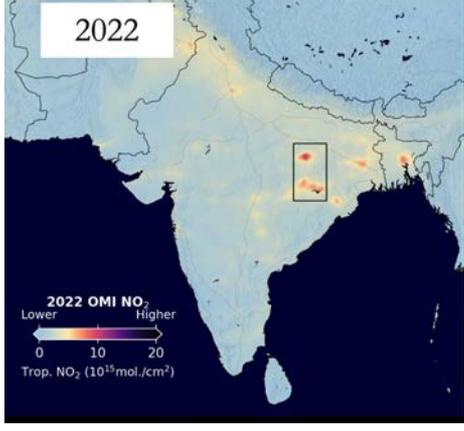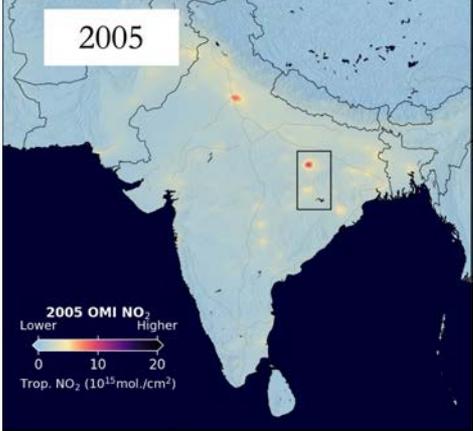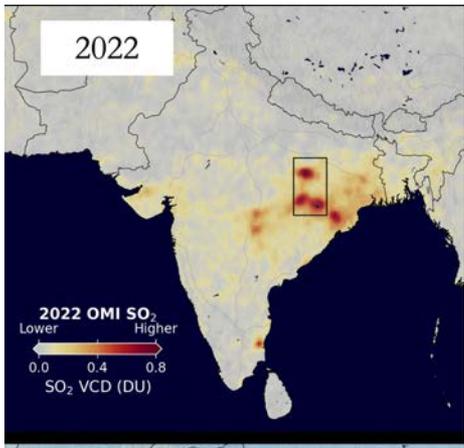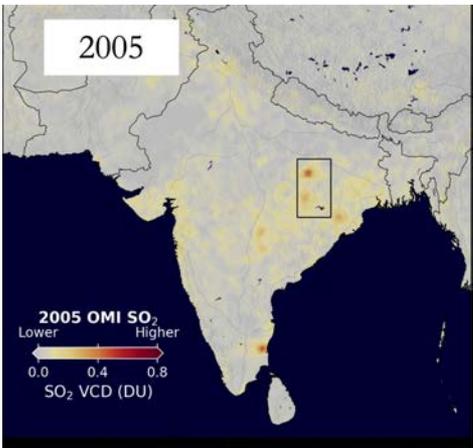


- Steady increase for both NO$_2$ and SO$_2$ from 2005 to 2018

- Significant drop in both SO$_2$ and NO$_2$ for 2020 is most likely the result of COVID-19 lockdown (i.e., reduction in fossil fuel combustion)

- Amount of pollution appears to have leveled off over the past few years (i.e., sign that air pollution control technology deployed on large pollution sources)

Atmospheric Composition Virtual Constellation (AC-VC)

Source: NASA LaRC

# Public-facing Project Website
https://ideas-digitaltwin.jpl.nasa.gov/aqacf/

# Information System and Data Platform for Air Quality



<https://ideas-digitaltwin.jpl.nasa.gov/aqacf/>
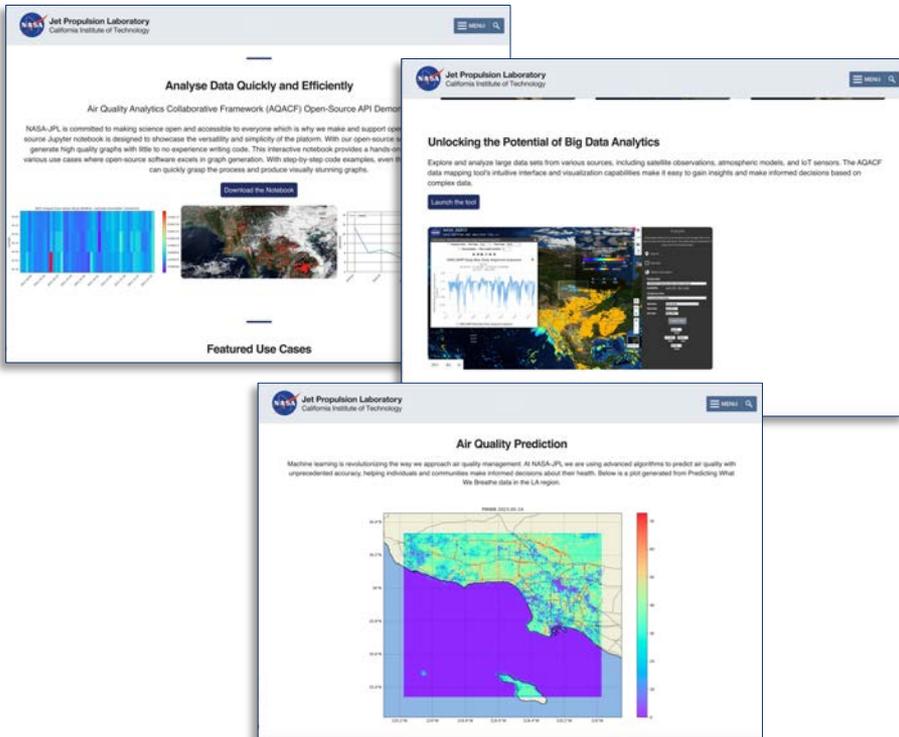
- Professional Open-Source Air Quality Platform
    - Harmonize data management, analysis, and visualization
        - Satellite
        - Model
        - In-Situ
    - Automate onboarding latest observation and model data
    - ML-base Air Quality Prediction
    - Production-Quality Applications
        - Web-based AQ Data Analysis Tool
        - AQ Notebook for API tutorial and receipts
        - VR-powered Immersive Science
- This year we are introducing
    - Earth System Digital Twins architecture
    - Scenario-based analysis
    - Expand support for wildfire, air quality, and health impact
    - 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

# Integrated Observing System for Air Quality
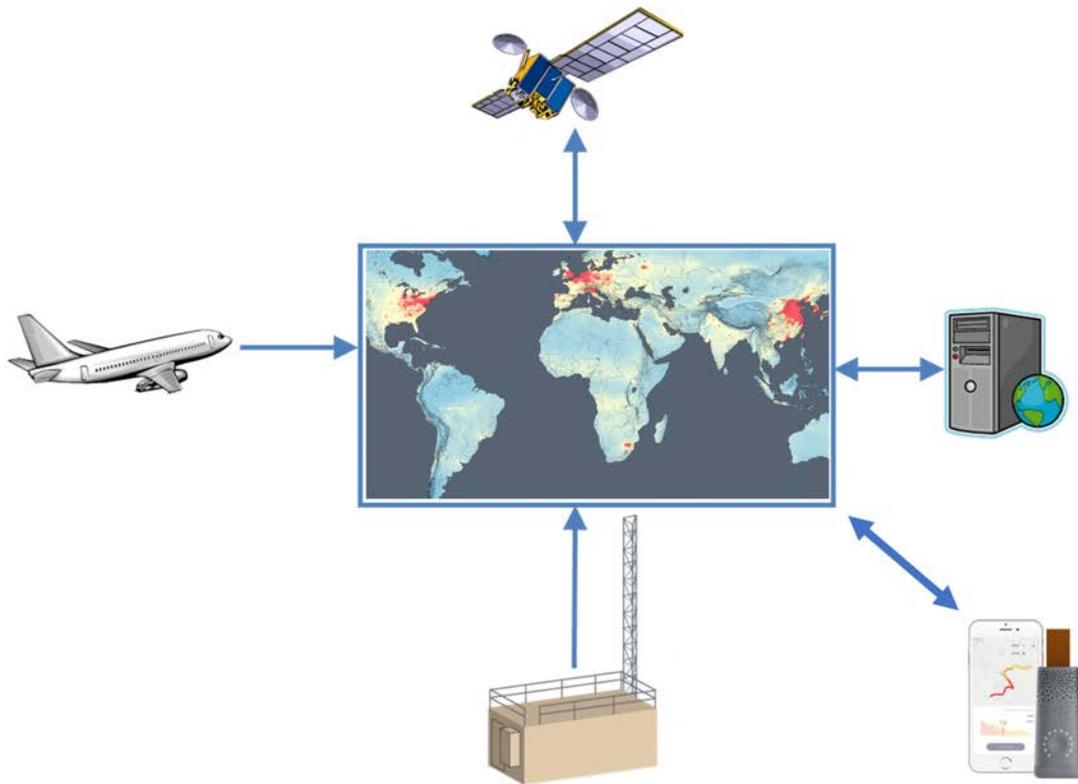
# Visualize Canadian Wildfire Smoke
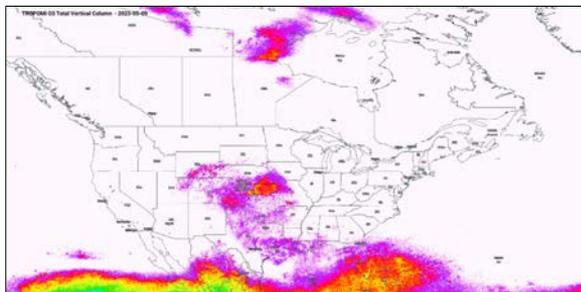




TROPOMI O3 Total Vertical Column
2023-05-09 – 2023-06-08
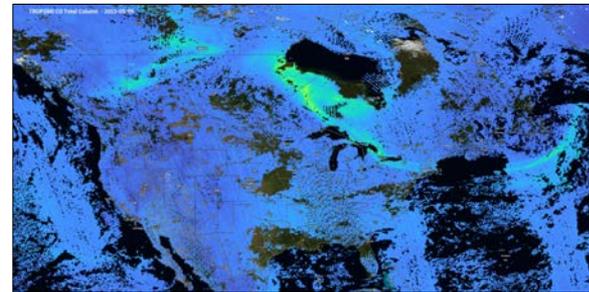


TROPOMI CO total column
2023-05-10 – 2023-06-09
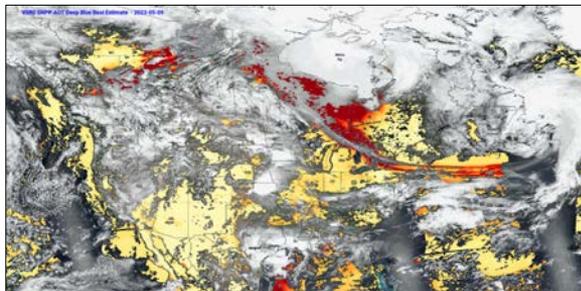


VIIRS SNPP Aerosol Optical Thickness
Deep Blue Best Estimate
2023-05-10 – 2023-06-09
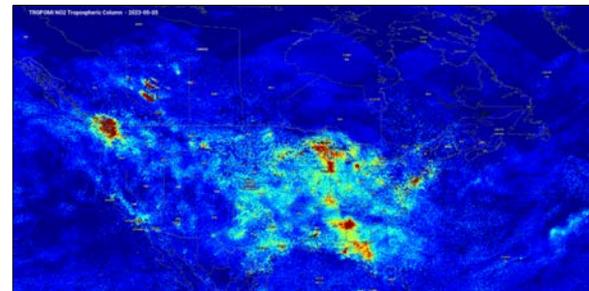


TROPOMI NO2 Tropospheric Column
2023-05-06 – 2023-06-05

# Analyze Canadian Wildfire Smoke

https://github.com/EarthDigitalTwin/FireAlarm-notebooks/blob/main/AirQuality_Demo.ipynb
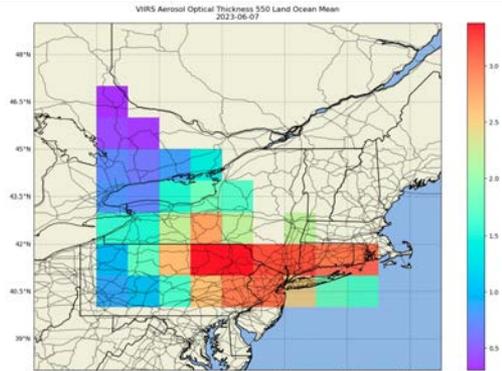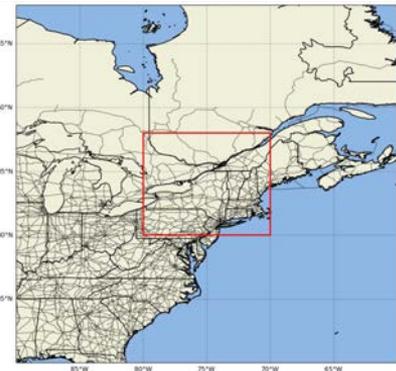


VIIRS Aerosol Optical Thickness
2023-06-07
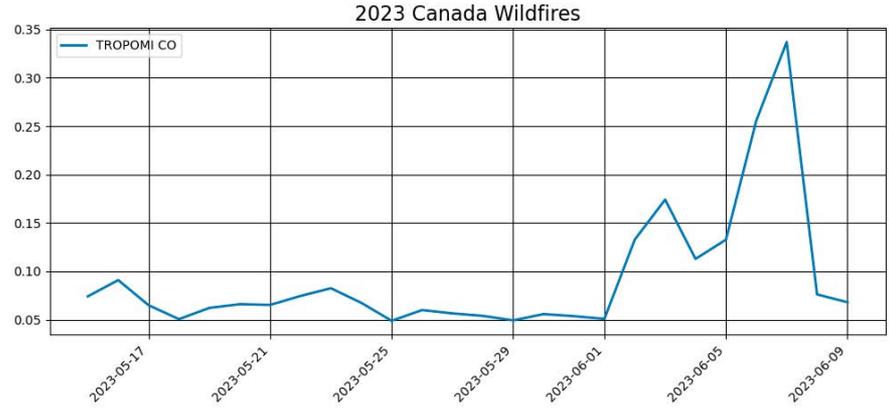


TROPOMI CO 2023-05-15 – 2023-06-09
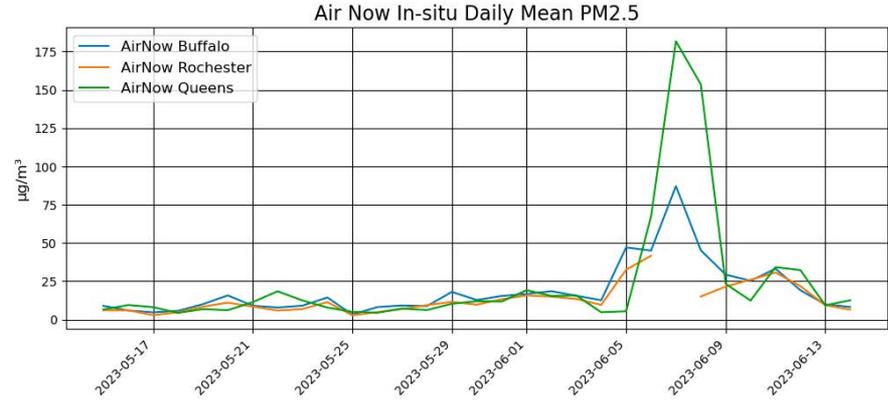
AirNow Buffalo, Rochester, and Queens PM$_{2.5}$ – 2023-05-15 – 2023-06-14

# Analyze In-situ Data
Example: $PM_{2.5}$ and Black Carbon from July 4th Fireworks

Earth Science Technology Office



Source: San Gabriel Valley Tribute

Dynamic retrieval of in-situ measurements
$PM_{10}$, $PM_{2.5}$, BC, CO, $NO_2$, $O_3$, AOD, etc.
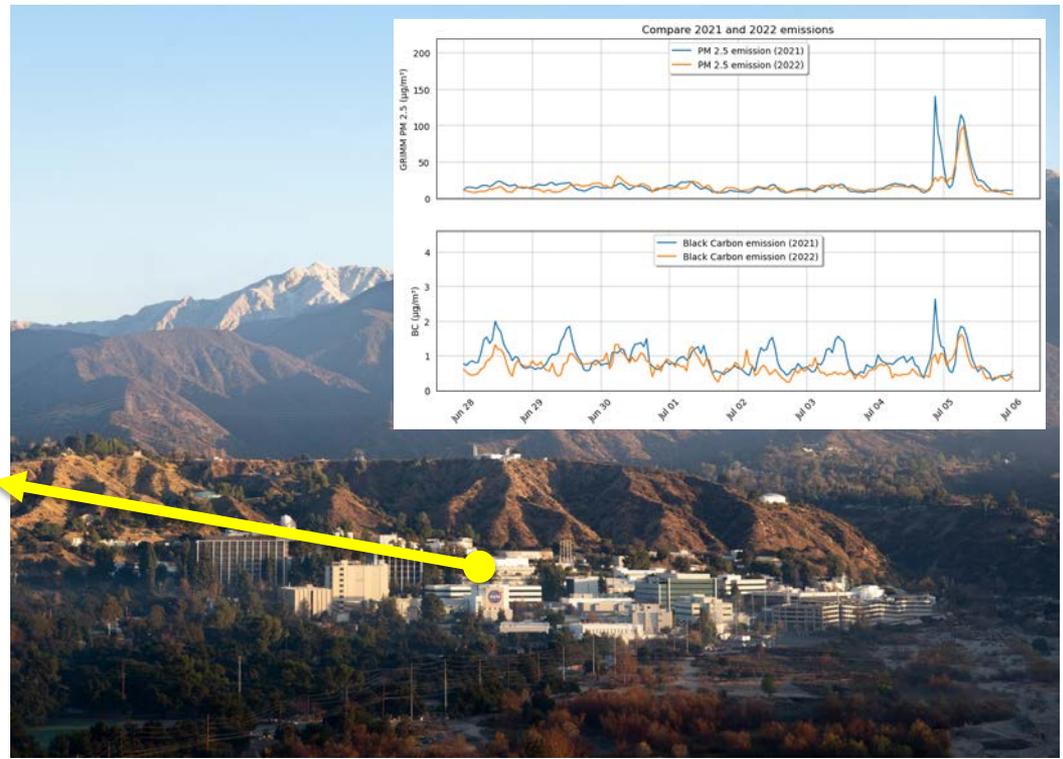
NASA Jet Propulsion Laboratory (JPL), Pasadena, CA

# Satellite to Satellite Match-up – CA Wildfire Season
2021-08-07 to 2021-08-09



Plot of Aerosol_Optical_Thickness_550_Land_Ocean_Mean
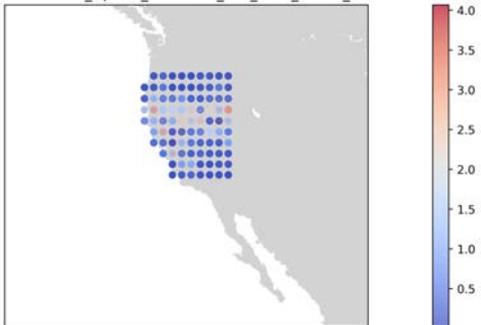
Plot of Aerosol Optical Depth
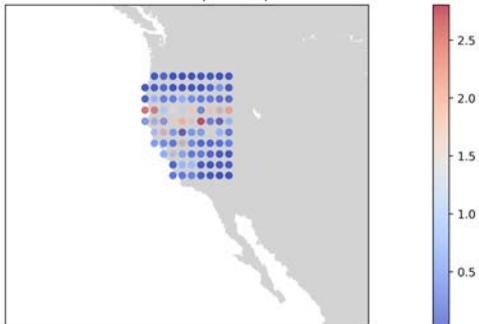
Difference plot between VIIRS Aerosol Optical Thickness and MODIS Aerosol Optical Depth
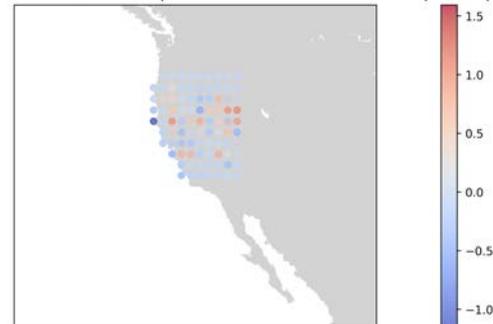


Aerosol Optical Depth scatter
VIIRS vs. MODIS
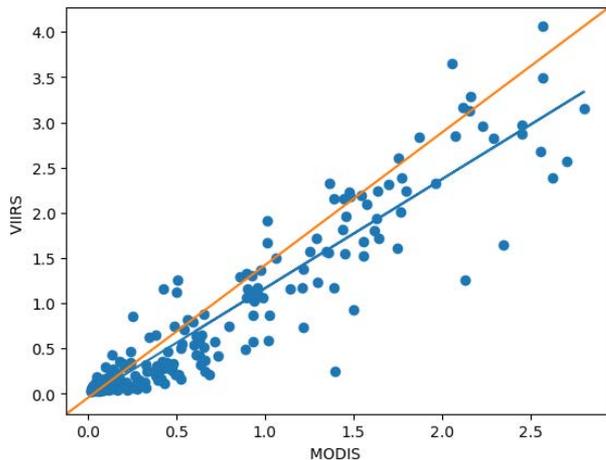
- Collaborated with NASA ACCESS Cloud-Based Data Matchup Service (CDMS) project to integrate matchup capability with AQ data holdings.
- Coordination between MODIS Aerosol Optical Depth and VIIRS Aerosol Optical Thickness

# $CO_2$ Emissions During the Course of the COVID-19 Pandemic
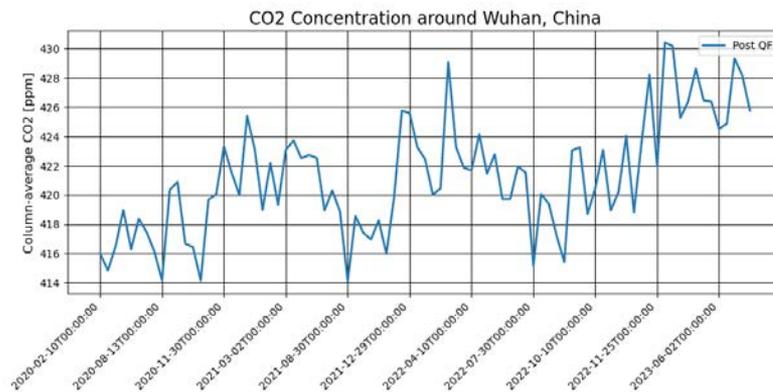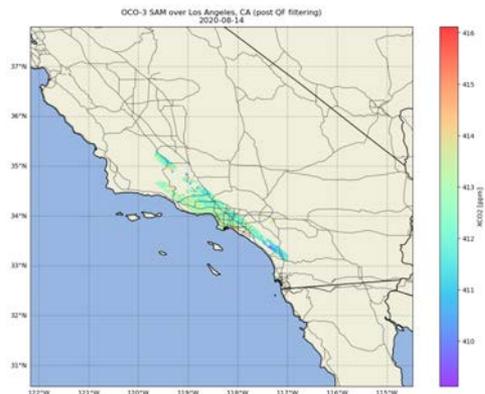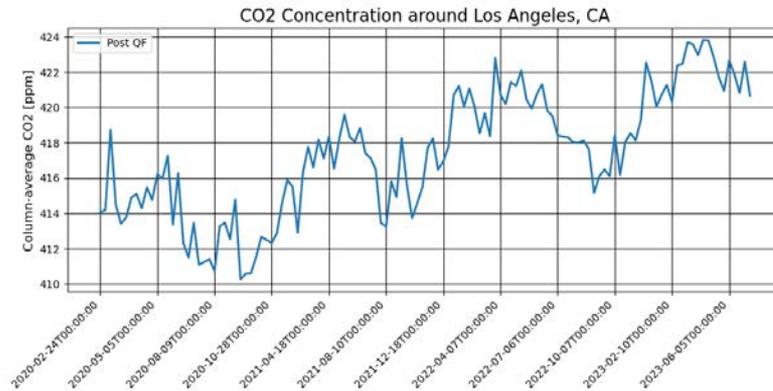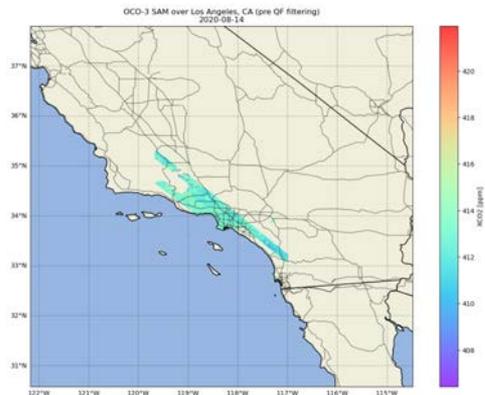


- One platform for different types of Analysis Ready Data (ARDs)
- Complete collection of OCO3's $CO_2$ measurements (Long-term Record)
- Automate transformation of OCO-3's $CO_2$ granules into ARD (i.e., Zarr tiles)
- Interactive visualization and analysis

**National Aeronautics and Space Administration**

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

Tracking $CO_2$ emission reductions from space: A case study at Europe's largest fossil fuel power plant (Using NASA OCO-3)

Paper: Nassar R, Moeini O, Mastrogiacomo J-P, O'Dell CW, Nelson RR, Kiel M, Chatterjee A, Eldering A and Crisp D (2022) **Tracking CO2 emission reductions from space: A case study at Europe's largest fossil fuel power plant.** Front. Remote Sens. 3:1028240. doi: 10.3389/frsen.2022.1028240

# NASA's Open-Source ESDT Platform for Air Quality





- 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

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  - Satellite
  - Model
  - In-situ
  - ML Predictions

# Web-based AQ Data Analysis Tool
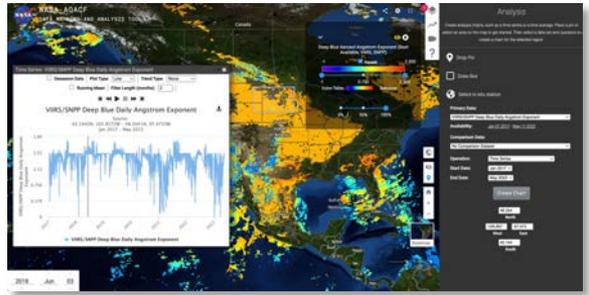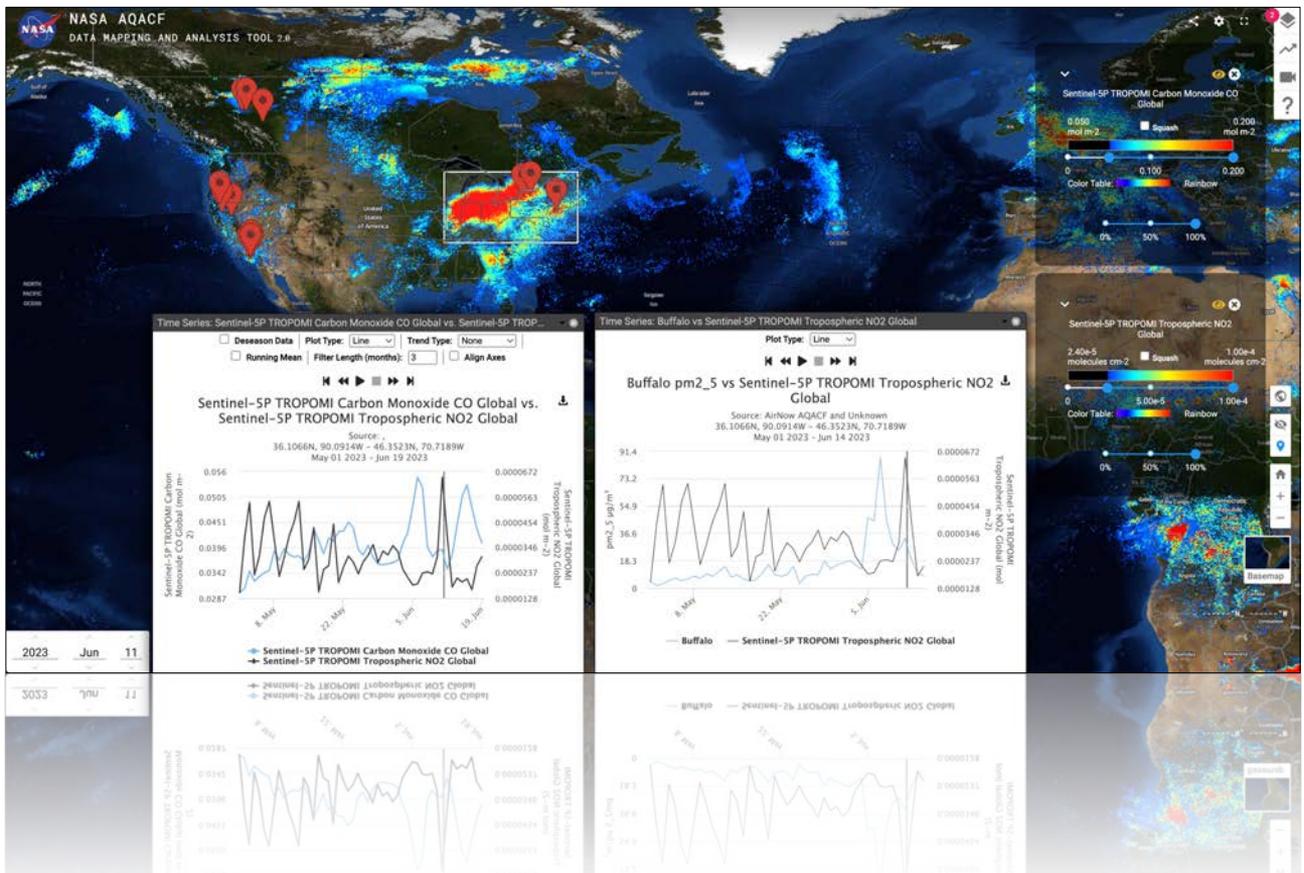
# Immersive Air Quality, and Health Impact Analysis
Powered by IDEAS
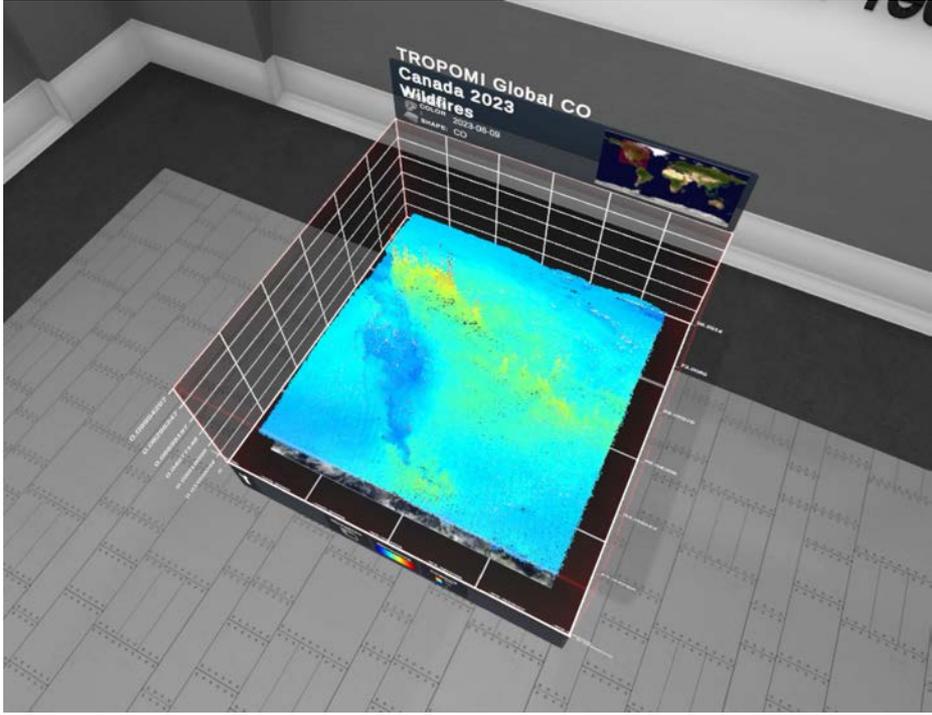


TROPOMI CO Canada Wildfires
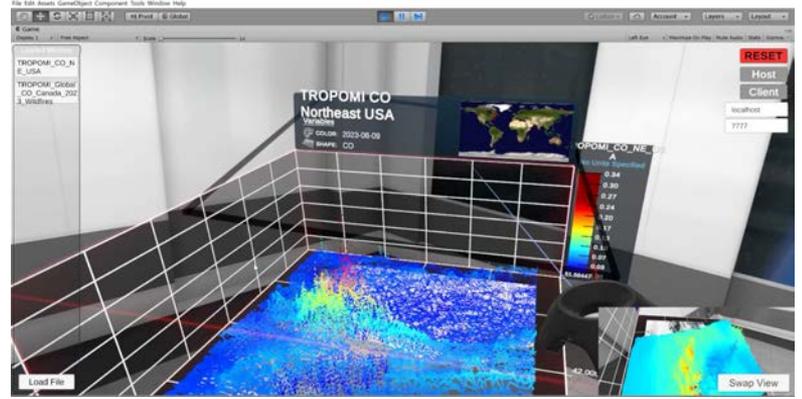


TROPOMI_2023_Fires
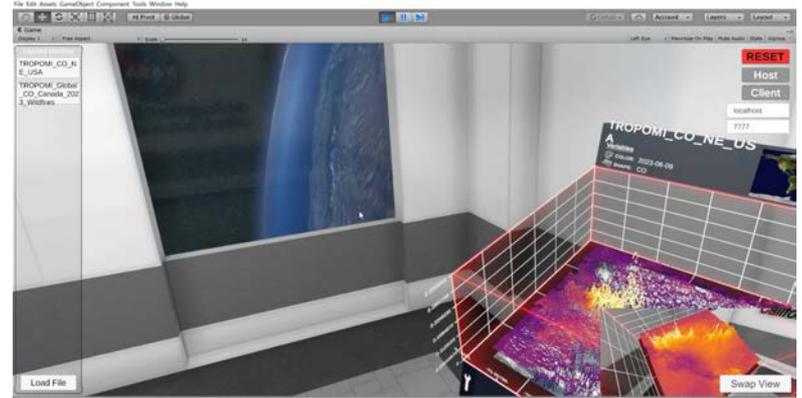


TROPOMI_2023_Inferno

# Multi-Angle Imager for Aerosols (MAIA)

- 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*

Credit: Dr. Dave Diner, NASA JPL

# MAIA integrates several key mission elements



**Satellite instrument**
- Multiangular/spectro-polarimetric aerosol observations



**Surface monitor network**
- Calibration of relationship between satellite aerosol data and PM concentrations
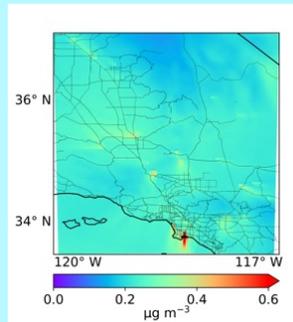


**Chemical transport model**
- Meteorological data, spatio-temporal PM gap-filling



**Health records**
- Privacy-protected birth. death, and hospitalization data

Daily concentration maps of $PM_{10}$, $PM_{2.5}$, and $PM_{2.5}$ sulfate, nitrate, organic carbon, elemental carbon, dust at 1-km spatial resolution
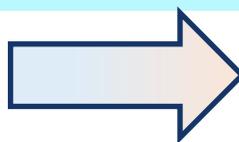
- PM exposure levels
- Epidemiological studies

Credit: Dr. Dave Diner, NASA JPL

# Share with the world



Available Now



AMS Interview
July 2023
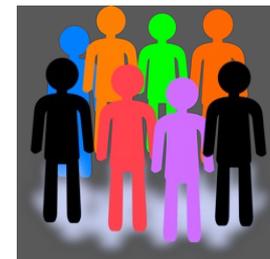
# Open-Source Science and Community Collaboration

- 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
## If you want to go far, go together.

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?
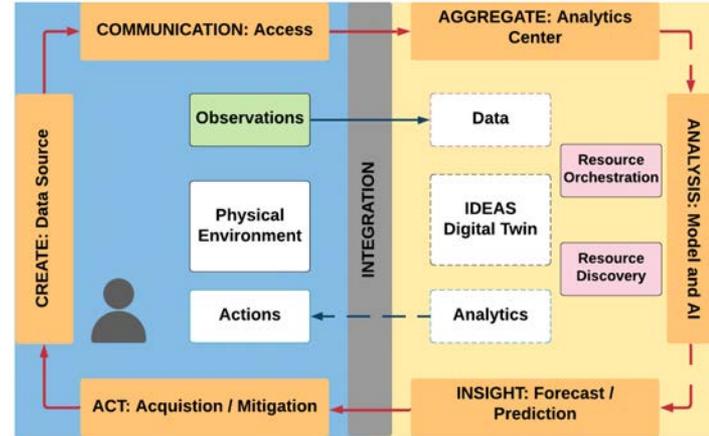


**NASA ESTO/AIST's Integrated Digital Earth Analysis System (IDEAS)** – an Earth System Digital Twin framework. Framework for pre-fire, during fire, and post fire analysis

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**DARE MIGHTY THINGS**
TOGETHER!