Integrated Digital Earth Analysis System (IDEAS)
An Open-Source Framework for Earth System Digital Twins

Clearance: CL#23-6057

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Agenda ID: 2023.10.24_14.50
WGISS-56
Paris, France (CNES)
24-26 October, 2023
Past, Present, Future

It is about
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/](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
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)
Interactive Sea Level Analysis

Sea Level Rise
https://sealevel.nasa.gov
Welcome to VIRGO!
Click a groundwater subbasin to explore.

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

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

E. Tropical Pacific SSH: ECCO vs. NASA MEaSUREs Satellite Product
Verify ECCO OBP vs. NASA/JPL GRACE-FO Product
Actionable Science – New Observing Strategies

- 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

IDEAS Framework

STAC, OpenSearch, ISO-19115

Apache SDAP API

Series of images showing different aspects of the IDEAS Framework, including:

- Latest Observations
- Analysis Ready Data
- Advanced Numerical Models
- Advanced AI Predictions
- Scalable Visualization
- On-Demand Value-Added Product Generation

Languages supported by IDEAS 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 Martis, Stepheny Perez, Wai (William) Phyo, Catalina M. Oaida, and Joe T. Roberts

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

**Vortex.io:** Guillaume Valladeau and Jean-Christophe Poisson

What are the environmental and infrastructural impacts of floods?

https://ideas-digitaltwin.jpl.nasa.gov/hydrology/
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-Suquet/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:**

- CERFACS
- QUANTCUBE
- Airbus Defence & Space
- NASA
- JPL
- THALES
- CNES
What-If Garonne: 3x Precipitation

NoahMP – Surface Runoff

NoahMP Surface and Subsurface Runoffs

NoahMP – Subsurface Runoff

RAPID Discharge

Garonne RAPID Discharge (Reach ID 23023522 (44.3917, 0.295))

RAPID Discharge (NoahMP 2x)
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
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
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?
ESDT for Wildfire and Air Quality

Automate access to fire data repositories for 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

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

Forecast and Prediction
NASA’s Open-Source ESDT Platform for Air Quality

- Web-based Data Analysis Tool
- Immersive Science
- 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

Real-time AQ Prediction

https://ideas-digitaltwin.jpl.nasa.gov/airquality/
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 PM2.5
2023-05-15 – 2023-06-14
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
Greenhouse Gas (XCO2 in LA and Wuhan)
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?