



The Next Generation Earth System Grid Federation



Forrest M. Hoffman (Oak Ridge National Laboratory)

**National Center for Atmospheric Research (NCAR)
Computational and Information Systems Laboratory (CISL) Seminar**

April 11, 2023



U.S. DEPARTMENT OF
ENERGY

Office of
Science



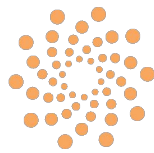
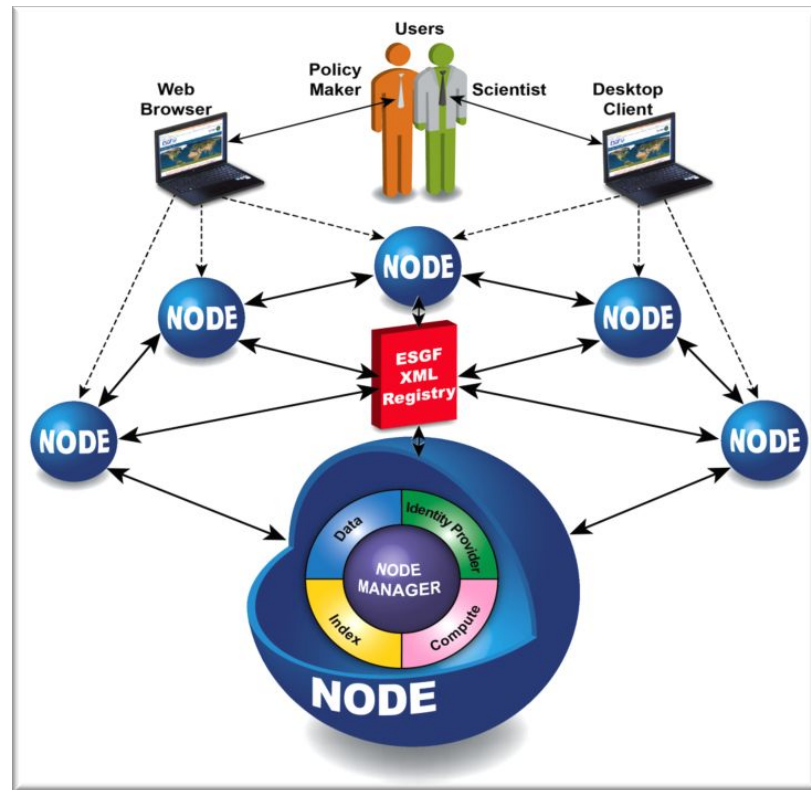
Forrest M. Hoffman, Computational Earth System Scientist

- Group Leader for the ORNL Computational Earth Sciences Group
- 34 years at ORNL in Environmental Sciences Division, then Computer Science and Mathematics Division, and now Computational Sciences and Engineering Division
- Develop and apply Earth system models to study global biogeochemical cycles, including terrestrial & marine carbon cycle
- Investigate methods for reconciling uncertainties in carbon-climate feedbacks through comparison with observations
- Apply artificial intelligence methods (machine learning and data mining) to environmental characterization, simulation, & analysis
- Joint Faculty, University of Tennessee, Knoxville, Department of Civil & Environmental Engineering



ESGF² US What is the Earth System Grid Federation?

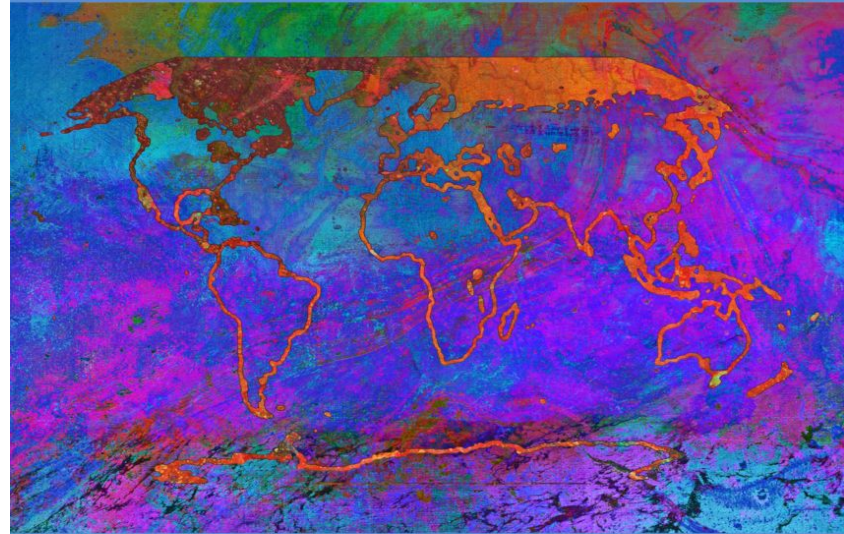
- The **Earth System Grid Federation (ESGF)** is an *international consortium* and a *globally distributed peer-to-peer network of data servers* using a common set of protocols and interfaces to archive and distribute climate and Earth system model output and related input, observational, and reanalysis data
- These data are used by scientists all over the world to investigate consequences of possible climate change scenarios and the resulting Earth system feedbacks



Logos represent primary international contributors: US Department of Energy, NASA, NOAA, NSF, European IS-ENES Project, and Australian NCI

- The United Nations' Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report from Working Group I was released on Monday, August 9, 2021
- All of the climate and Earth system model simulation output underpinning this report was produced by modeling centers participating in the World Climate Research Programme's (WCRP's) sixth phase of the Coupled Model Intercomparison Project (CMIP6)
- Nearly all of that model output was stored in and distributed to researchers via ESGF
- **Data are about the future of life on Earth!**

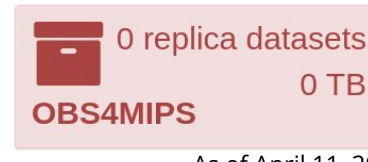
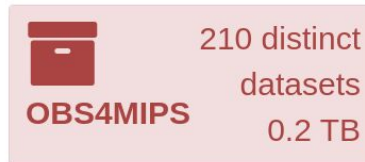
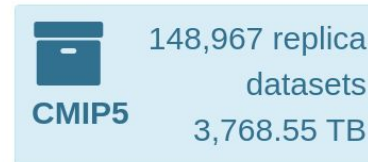
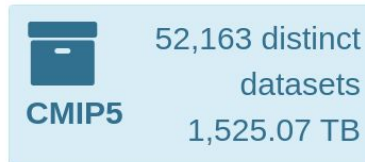
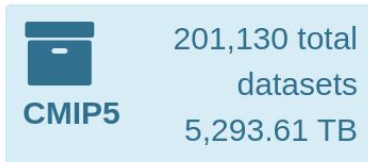
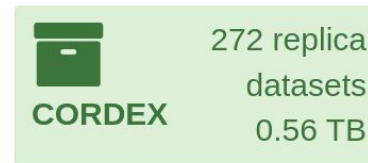
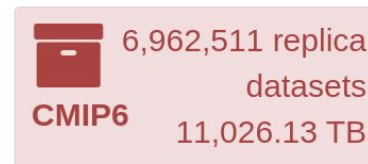
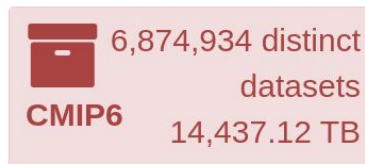
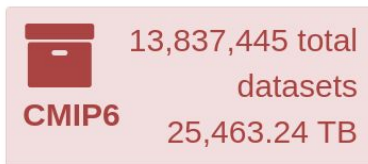
Climate Change 2021 The Physical Science Basis





ESGF Holdings are Large and Growing

- CMIP5 totals >5 PB (including replicas)
- CMIP6 totals >25 PB (including replicas)
- CMIP7 is expected to have more high resolution output & ensembles, totaling ~100 PB
- ESGF2-US will expand Federation holdings by adding other Earth science data projects for AI/ML, large ensembles, etc.





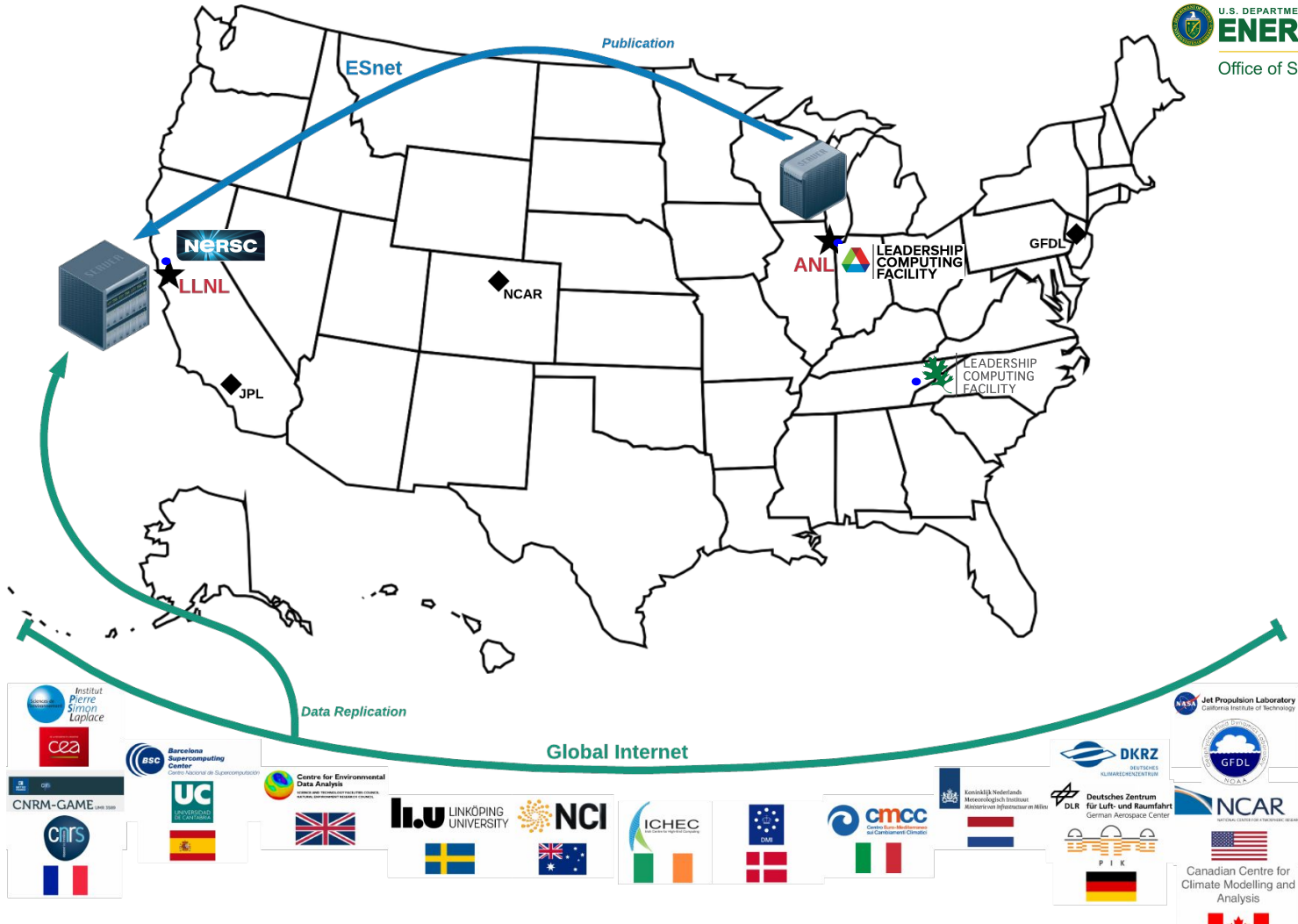
ESGF2 A New Consortium Project in the USA

- New team from **Oak Ridge National Laboratory, Argonne National Laboratory, and Lawrence Livermore National Laboratory** proposed to modernize the data backplane based on the Globus platform
- ESGF2-US proposal was reviewed by panel of 8 scientists in August 2021, and was **selected for funding** by the US Department of Energy starting in FY2022
- In **collaboration with international partners**, the project is developing and will deploy a new architecture based on the *Future Architecture Roadmap*
- In addition, ESGF2-US will develop new **data discovery tools and data access interfaces, server-side computing** (subsetting & summarizing), and **user computing** (Kubernetes & JupyterHub) with improved **user & system metrics**
- ESGF2-US added a **Resource & Project Liaison** group and a **Science, User & Facility Advisory Board** and will offer a help desk/user support



DOE's Current Earth System Grid Federation

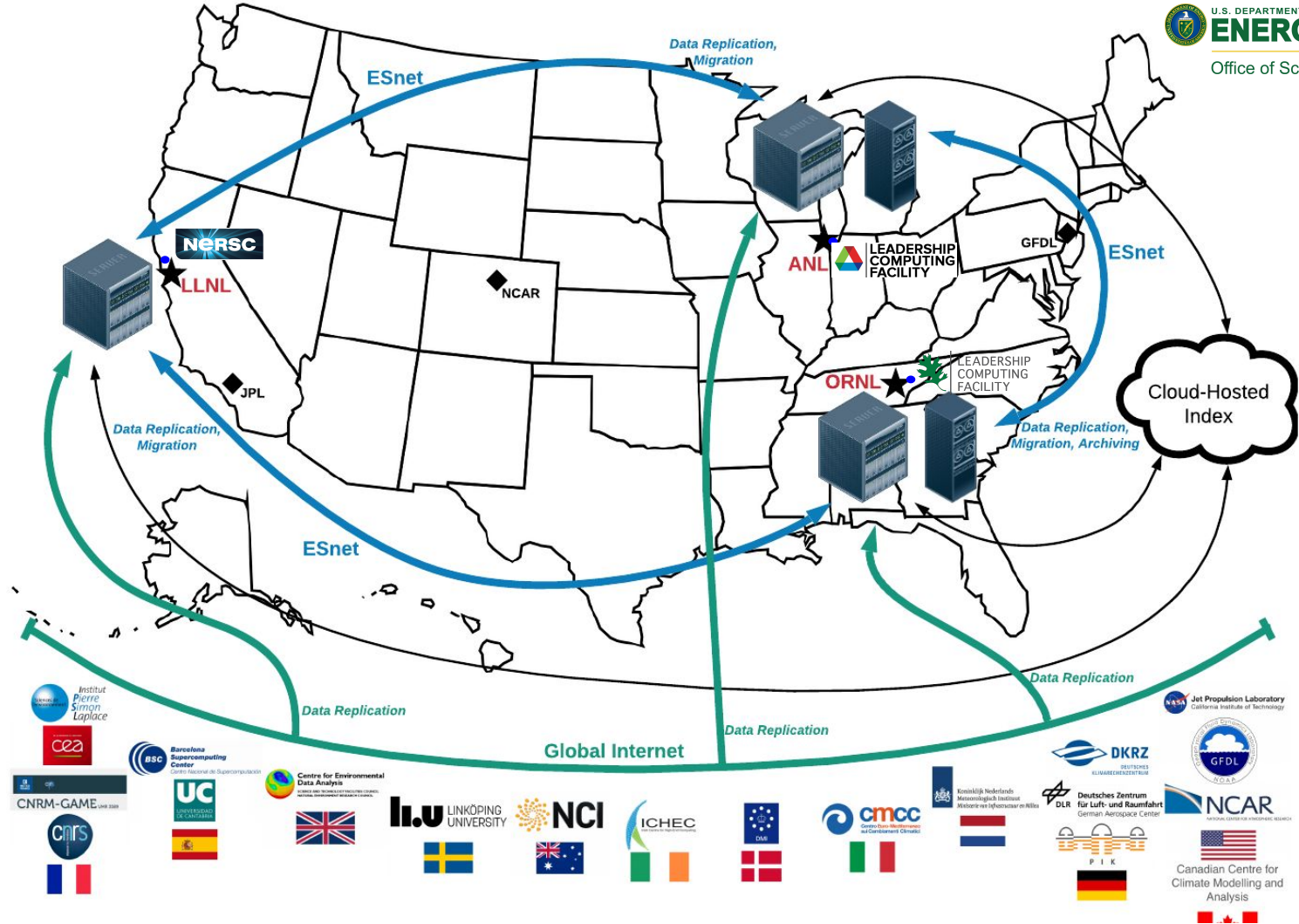
- Primary server at LLNL
- LLNL replicates data from the global Federation when possible (primarily up to daily output)
- Independent data node at ANL





DOE's Next Generation Earth System Grid Federation

- As many as three nodes co-located at DOE's major computing facilities
- Replicating data from the global Federation
- Providing cloud indexing and tape archiving



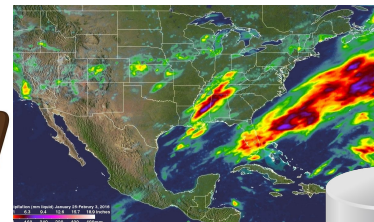


Design and implementation principles

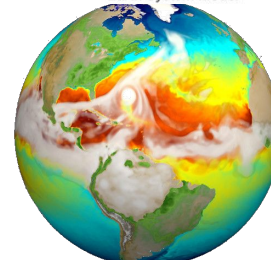
- **Open architecture and protocols**
 - Enable substitution of alternative implementations
- Leverage **highly available and scalable** central services from Globus
 - Reduce complexity, increase reliability, provide economies of scale
- Use proven, modern **security technologies and practices**
 - Integrated access control; protect against attacks and intrusions
- **Use case approach** to design, implementation, and evaluation
 - Ensure that solutions meet real user needs
- Integrated **instrumentation**
 - Metrics drive data management, data access features, capability development
- Focus on **performance** to deal with big data
 - High-speed data transfer, search, server-side processing

ESGF2 US Enabling a new level of research productivity

Logging in with her **institutional credentials**, Samantha is presented with **new data, code, and papers** relevant to her current research. Intrigued by a new report on extreme precipitation events, she examines a **Jupyter notebook** that implements the method used. Wondering how this method would work with higher-resolution E3SM data, she **quickly locates required datasets and runs the notebook on a subset**. Results are promising, so she **shares them with collaborators** via ESGF2-US federated storage, and they agree that a larger ensemble analysis is called for. ESGF2-US confirms that the full ensemble data are available at OLCF, so they submit a request to execute the analysis there. Within 24 hours, **results have been published to ESGF2-US for broader consumption**, along with the notebook used to produce and validate the results.

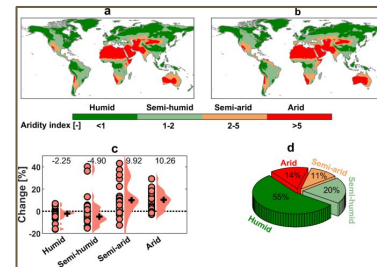


E3SM
Energy Exascale
Earth System Model



OAK RIDGE
National Laboratory

LEADERSHIP
COMPUTING
FACILITY



Flood risk increases with water availability

ESGF2 US ESnet Global Connectivity

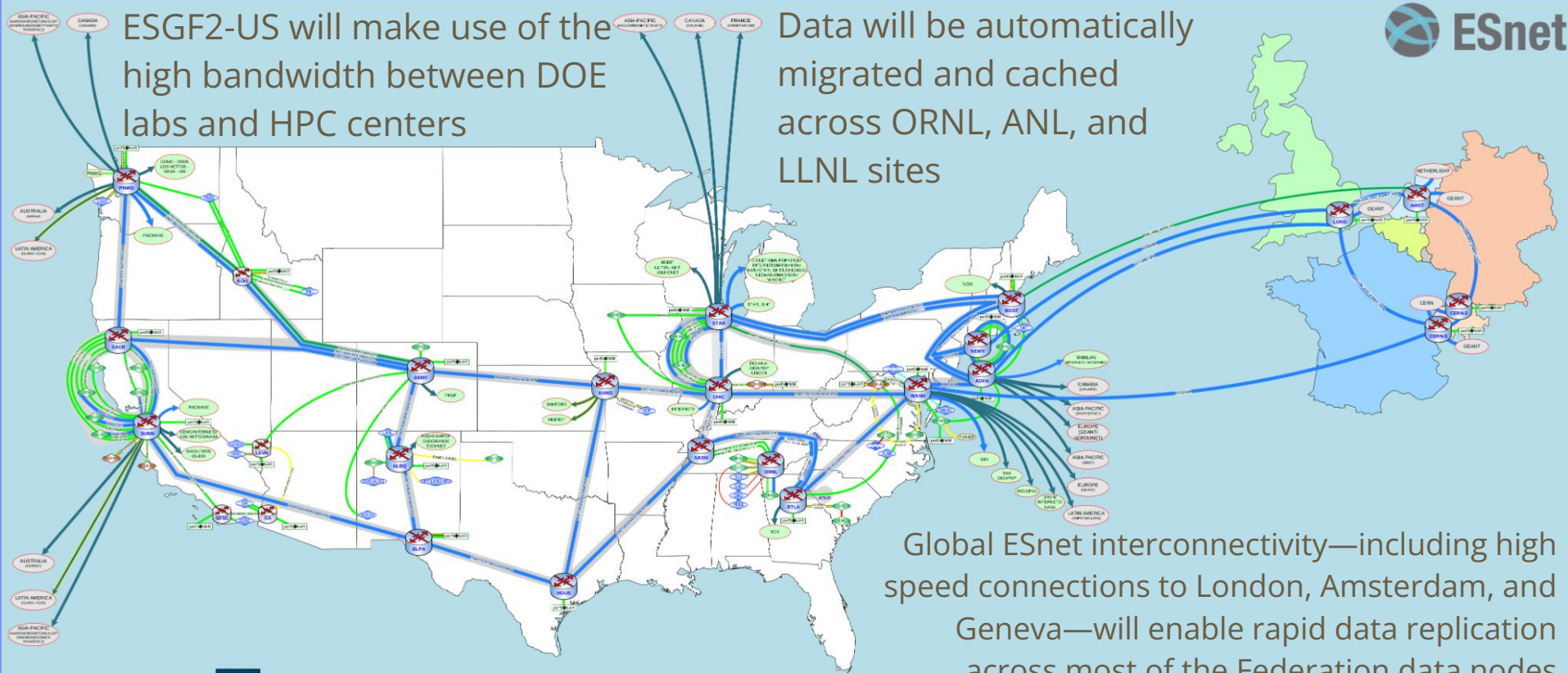


ESnet
ENERGY SCIENCES NETWORK

An ESnet representative is part of the new Resource & Project Liaisons group

ESGF2-US will make use of the high bandwidth between DOE labs and HPC centers

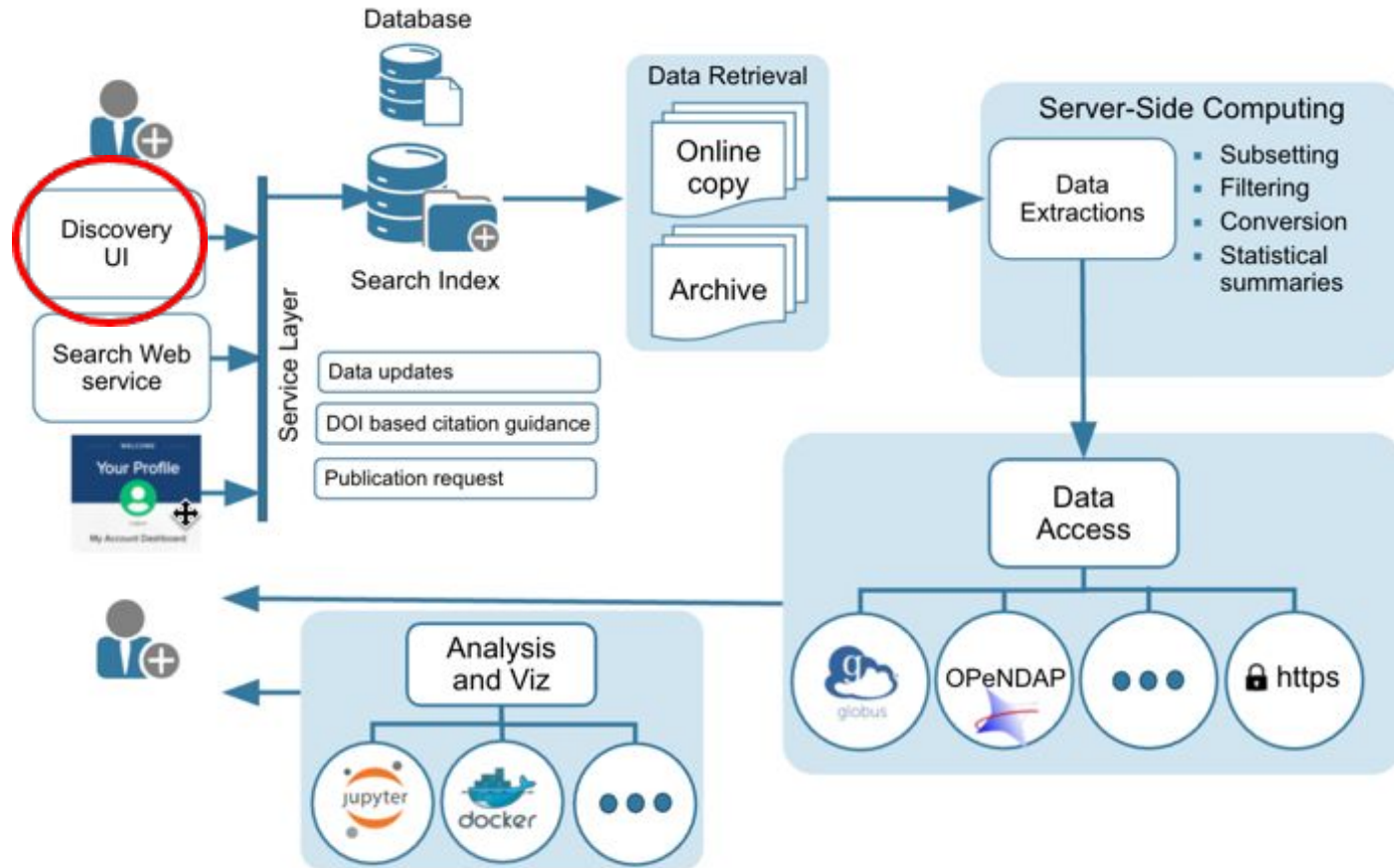
Data will be automatically migrated and cached across ORNL, ANL, and LLNL sites



Global ESnet interconnectivity—including high speed connections to London, Amsterdam, and Geneva—will enable rapid data replication across most of the Federation data nodes



Data Discovery Platform: Architecture



Outreach Activities

- Organize **Webinars, Tutorials, and Bootcamps**

- Data management lessons learned
- Ingest best practices
- Data discovery and access

→ **ESGF Webinar series playlist at** <https://www.youtube.com/@esgf2432>

- **Hackathons and Workshops**

- Data standards
- Data node deployment and user compute resources
- Hold at large relevant conferences, e.g.,
AGU Fall Meeting, EGU, and AMS Annual Meeting

- Organize and host annual
ESGF Developer and User Conferences

→ **Ninth ESGF Developer and User Dual-Hybrid Conference held January 18–20, 2023**

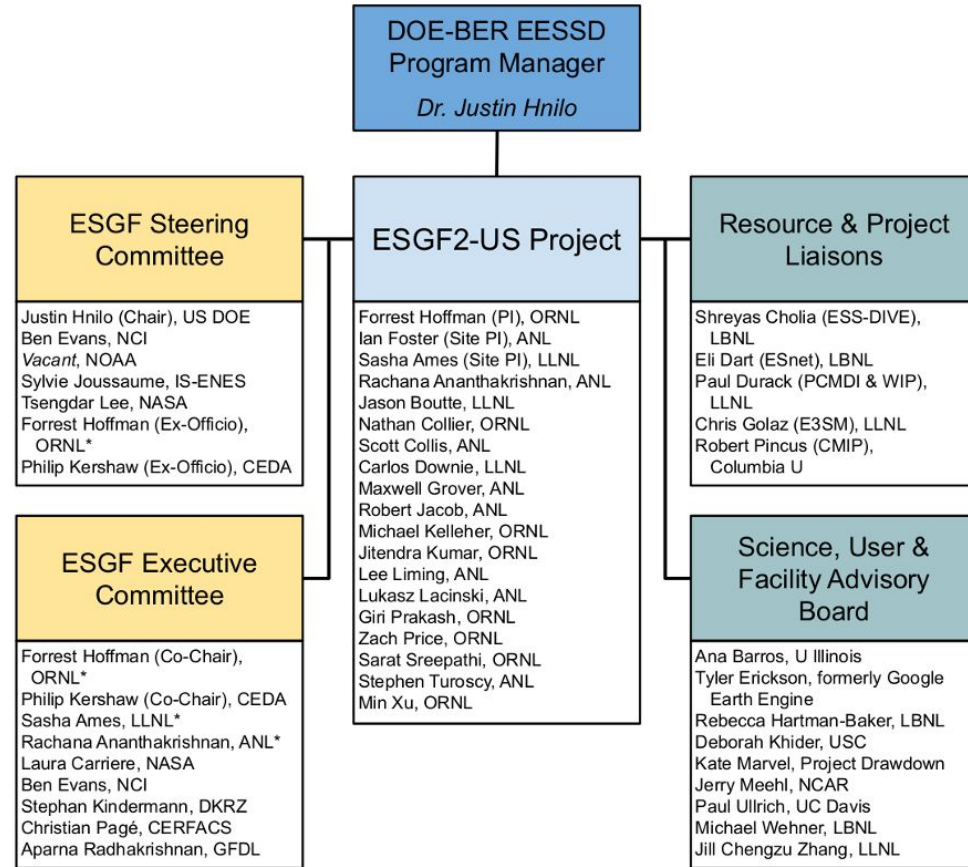


Ninth ESGF Developer and User Conference, held jointly between Oak Ridge National Laboratory (USA) and Toulouse (France), January 18–20, 2023



ESGF and ESGF2-US Project Governance

- ESGF is governed by an international **ESGF Executive Committee** that meets monthly
- The **XC** is directed by the **ESGF Steering Committee (SC)**, composed primarily of sponsoring agency representatives
- The ESGF2-US Project added
 - Resource & Project Liaisons** group to enhance communication with interdependent projects and critical resources
 - Science, User & Facility Advisory Board** to evaluate and prioritize project efforts with respect to community needs



*Indicates ESGF2-US team member

Updated April 11, 2023

The logo for ESGF US, featuring a stylized globe with the text 'ESGF' in large blue letters and 'US' in smaller blue letters below it.

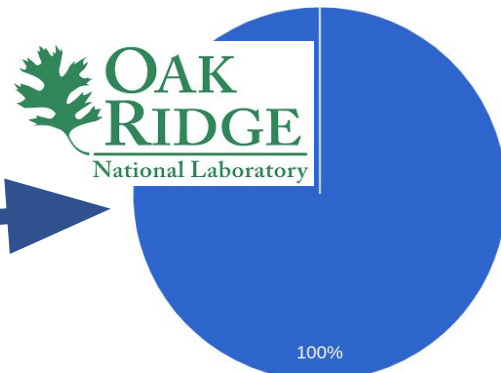
ESGF-US Failsafe Data Replication

- **In the US, LLNL operates the primary ESGF node**, which replicates much of the CMIP6 and related model output from around the globe
- Since the data at LLNL are contained only on spinning disk, we decided to replicate the **entire ~7.5 PB collection of data** to Argonne National Laboratory (ANL) and Oak Ridge National Laboratory (ORNL)
- **Solution: Use Globus to transfer all the data over ESnet**
- We used custom Globus scripting (*thanks to Lukasz Lacinski*), ESnet network monitoring and diagnostics (*thanks to Eli Dart*), DTN and GPFS optimized configurations (*thanks to Cameron Harr and others*), and debugging and problem-solving (*thanks to Sasha Ames, Lee Liming, and others*)



Data transferred to ALCF

Data transferred to OLCF



1.5 GB/s

4 to 6 GB/s



Replication to ALCF

ACTIVE, PAUSED and the latest SUCCEEDED transfers

7.5 PB transferred between mid-Feb and May 4
17,347,671 directories and 28,907,532 files

| No | Datasets | From | Requested | Completed | Status | Directories | Files | Bytes Transferred | Faults | Rate |
|----|---|------|---------------------|---------------------|-----------|-------------|--------|-------------------|--------|----------|
| 1 | /cmip5_css01_data/cmip5/output1/NSF-DOE-NCAR/CESM1-CAM5 | LLNL | 2022-05-03 08:46:03 | 2022-05-04 11:37:43 | SUCCEEDED | 7208 | 13540 | 29913341340 | 16 | 309 kB/s |
| 2 | /cmip5_css02_data/cmip5/output1/NCC/NorESM1-M | LLNL | 2022-05-02 09:52:03 | 2022-05-02 11:31:27 | SUCCEEDED | 4017 | 7548 | 5367692747060 | 0 | 900 MB/s |
| 3 | /cmip5_css02_data/cmip5/output1/NCAR/CCSM4 | LLNL | 2022-05-02 01:53:03 | 2022-05-03 00:50:23 | SUCCEEDED | 52571 | 48925 | 33455438769668 | 11 | 405 MB/s |
| 4 | /cmip5_css02_data/cmip5/output1/NASA-GISS/GISS-E2-R-CC | LLNL | 2022-05-02 01:28:03 | 2022-05-02 01:52:31 | SUCCEEDED | 2098 | 9576 | 1087745609416 | 0 | 741 MB/s |
| 5 | /cmip5_css02_data/cmip5/output1/NASA-GISS/GISS-E2-R | LLNL | 2022-05-02 00:42:03 | 2022-05-02 09:51:16 | SUCCEEDED | 30164 | 132059 | 24482369232188 | 5 | 743 MB/s |

Replication to OLCF

ACTIVE, PAUSED and the latest SUCCEEDED transfers

| No | Datasets | From | Requested | Completed | Status | Directories | Files | Bytes Transferred | Faults | Rate |
|----|---|------|---------------------|---------------------|-----------|-------------|--------|-------------------|--------|-----------|
| 1 | /cmip5_css01_data/cmip5/output1/NSF-DOE-NCAR/CESM1-CAM5 | LLNL | 2022-05-03 08:47:18 | 2022-05-04 11:41:11 | SUCCEEDED | 7208 | 13540 | 271068730 | 16 | 2.80 kB/s |
| 2 | /cmip5_css02_data/cmip5/output1/NCAR/CCSM4 | LLNL | 2022-05-02 13:58:03 | 2022-05-03 03:14:27 | SUCCEEDED | 52571 | 48925 | 33455438769668 | 1 | 700 MB/s |
| 3 | /cmip5_css02_data/cmip5/output1/NCC/NorESM1-M | ALCF | 2022-05-02 11:32:03 | 2022-05-02 12:15:48 | SUCCEEDED | 4017 | 7548 | 5367692747060 | 0 | 2.04 GB/s |
| 4 | /cmip5_css02_data/cmip5/output1/NASA-GISS/GISS-E2-R | ALCF | 2022-05-02 09:52:03 | 2022-05-02 12:30:08 | SUCCEEDED | 30164 | 132059 | 24482369232188 | 3 | 2.58 GB/s |
| 5 | /cmip5_css02_data/cmip5/output1/NASA-GISS/GISS-E2-R-CC | ALCF | 2022-05-02 05:34:04 | 2022-05-02 05:44:32 | SUCCEEDED | 2098 | 9576 | 1087745609416 | 0 | 1.73 GB/s |



<https://dashboard.globus.org/esgf>

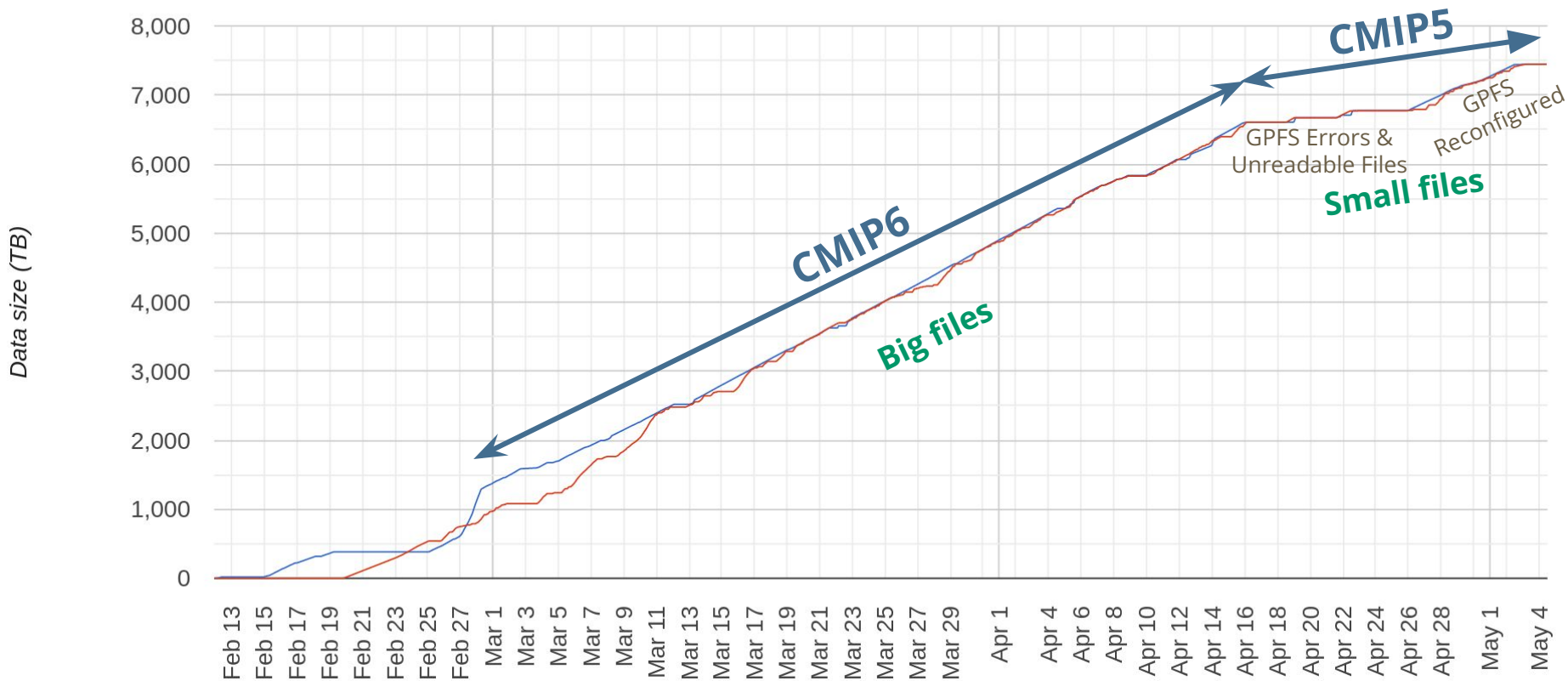
As of May 4, 2022



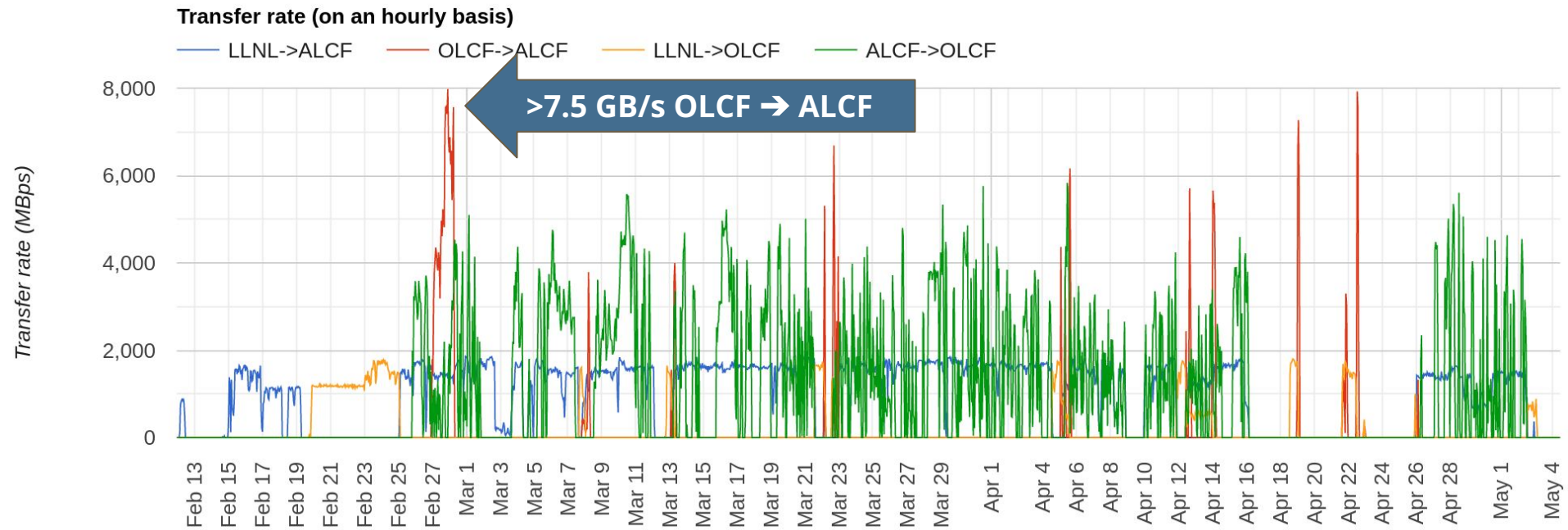
Cumulative Data Transferred Over Time

Progress of transfers

— to ALCF — to OLCF



ESGF² US Transfer Rates Over Time



ESGF US 2 ARM Data Center

ARM Research Facility

ARM

U.S. DEPARTMENT OF ENERGY Office of Science

DATA CAPABILITIES RESEARCH NEWS & EVENTS ABOUT

Data Discovery Data Sources Work with ARM Data Data Quality Program

DATA

Atmospheric Radiation Measurement (ARM) user facility data are collected through routine operations and scientific field experiments.

ARM focuses on obtaining continuous measurements—supplemented by field campaigns—and providing data products that promote the advancement of climate models. Serving users worldwide, the ARM Data Center collects and archives approximately 20 terabytes of data per month. Datastreams are generally available for download within 48 hours.

ABOUT ARM DATA

ARM data include routine data products, value-added products (VAPs), field campaign data, complementary external data products from collaborating programs, and data contributed by ARM principal investigators for use by the scientific community. Data quality reports, graphical displays of data availability/quality, and data plots are also available from the ARM Data Center.

As a U.S. Department of Energy national scientific user facility, ARM welcomes users from all institutions and nations. A free ARM user account is needed to access ARM data, a requirement of the Office of Management and Budget.

CREATE ACCOUNT UPDATE ACCOUNT

FINDING AND USING ARM DATA

All data obtained through ARM are monitored for quality and made available **free of charge** through the ARM Data Center via [Data Discovery](#).

GET ARM DATA Search ARM Data...

FEATURED DATA

Updated Stereo Camera Cloudiness Map Product Released for Evaluation
20 March 2023

Raman Lidar Vertical Profiles Product Expands to Oriskany Point, Alaska

ARM Data Discovery

ARM

HOME DATA SUPPORT CART

Click to interact

Data Search Guided Search Location Search Beta

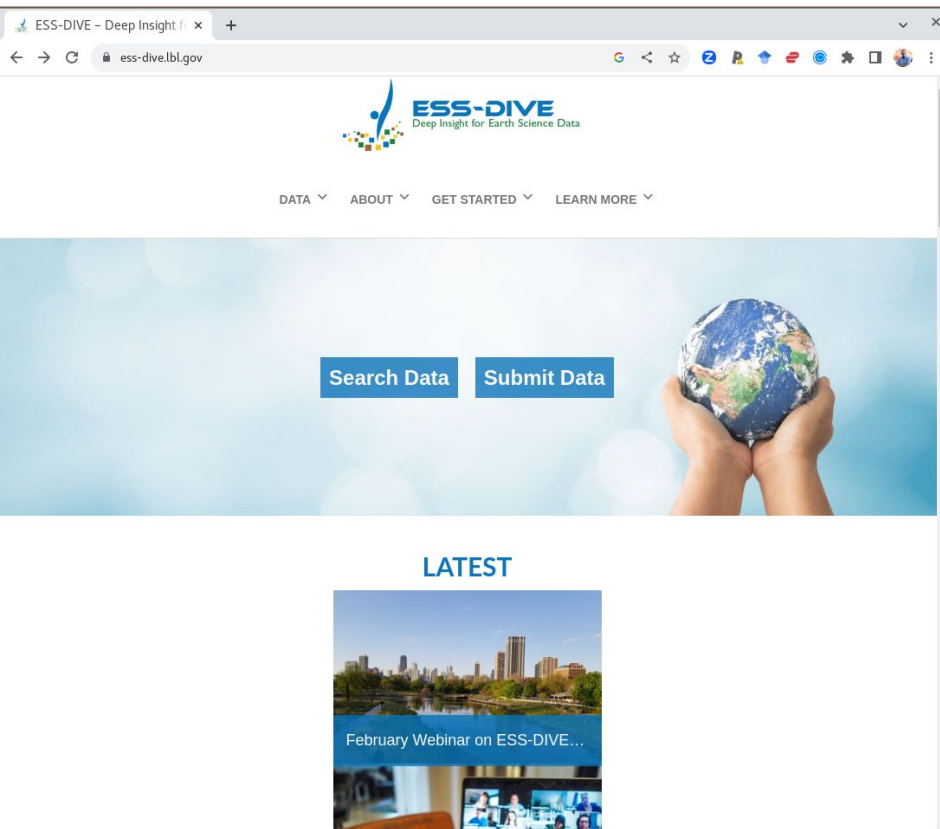
Data Search

Select one of the categories below or type in the search text box to get started.

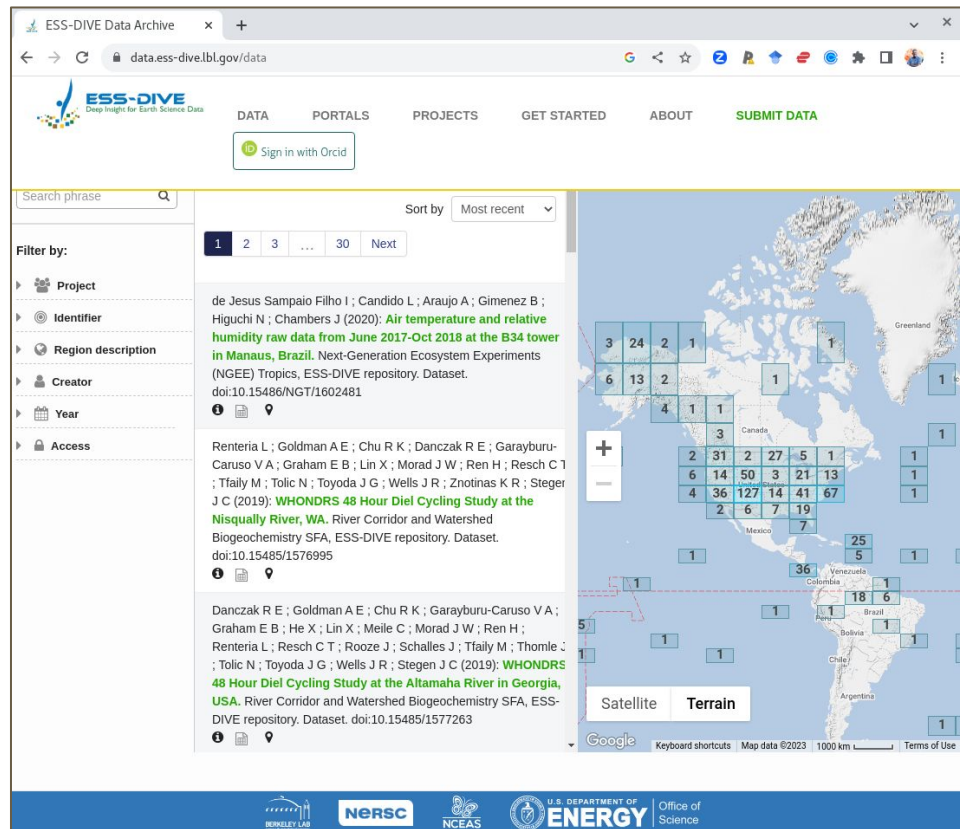
Enter a category, measurement, datastream, site, source or keyword to begin your search.

Atmospheric Radiation Measurement (ARM) Data Center – <https://www.arm.gov/data/>

ESGF US 2 ESS Deep Insight for Earth Science Data (DIVE)



The screenshot shows the ESS-DIVE homepage. At the top left is the ESGF US logo. The main header features the ESS-DIVE logo and the tagline "Deep Insight for Earth Science Data". Below this are navigation links for DATA, ABOUT, GET STARTED, and LEARN MORE. A large central image shows a pair of hands holding a globe of the Earth. To the left of the globe are two buttons: "Search Data" and "Submit Data". Below the main image is a "LATEST" section with a thumbnail for a "February Webinar on ESS-DIVE..."



The screenshot shows the ESS-DIVE Data Archive search results page. The URL is data.ess-dive.lbl.gov/data. The page has a navigation bar with links for DATA, PORTALS, PROJECTS, GET STARTED, ABOUT, and SUBMIT DATA. A search bar is at the top left, and a "Sign in with Orcid" button is at the top right. The search results are displayed in a list format. The first result is for "Air temperature and relative humidity raw data from June 2017-Oct 2018 at the B34 tower in Manaus, Brazil." The second result is for "WHONDRS 48 Hour Diel Cycling Study at the Nisqually River, WA." The third result is for "WHONDRS 48 Hour Diel Cycling Study at the Altamaha River in Georgia, USA." To the right of the search results is a map of the world with a grid overlay, showing the locations of the data sources. The map is titled "Satellite Terrain" and includes a "Google" logo and "Keyboard shortcuts" link.

Environmental Systems Science-Deep Insight for Earth Science Data (ESS-DIVE) – <https://ess-dive.lbl.gov/>



ESGF2 Summary

- The next generation **Earth System Grid Federation (ESGF2-US)**
 - Will be designed for an order of magnitude increase in data sizes
 - Will be highly available, scalable, and fast
 - Will automatically migrate data as needed
 - Will have improved data discovery and sharing tools
 - Will offer server-side computing for derived data
 - Will offer user computing capabilities (e.g., JupyterHub/JupyterLab) near the data
- All new **ESGF development is being performed collaboratively** with Federation partners all over the world
- ESGF2-US aims to add **new data projects** to support large-scale AI/ML data, multi-agency model intercomparisons, and model benchmarking
- **User computing** approaches initiated in the commercial cloud and deployed through on-premise cloud infrastructure will likely facilitate more research