2020

NASA EARTH SCIENCE
DATA SYSTEMS
PROGRAM HIGHLIGHTS

SEA LEVEL CHANGE

EARTHDATA
EOSDIS
NASA'S EARTH OBSERVING SYSTEM
DATA AND INFORMATION SYSTEM

National Aeronautics and
Space Administration

NASA

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Letter from the Program Executive

While 2020 was a challenging year, I am proud of how NASA's Earth Science Data Systems (ESDS) community came together to ensure that data users around the world had uninterrupted access to NASA Earth science data. The work and innovation over the past year furthered the ESDS goals of leading technology development, advancing open science data systems, setting the standard for the efficient production and stewardship of science-quality data, and leveraging the diversity of Earth science communities.

Our long-term data records played a key role in providing a better understanding of the environmental changes we've seen as a result of the ongoing COVID-19 pandemic. In June, NASA joined forces with the Japan Aerospace Exploration Agency and ESA (European Space Agency) to create the COVID-19 Earth Observing Dashboard. Leveraging the collective scientific power of data from this tri-agency constellation of Earth observing satellites, we created a simple-to-use platform to document how changes in human activity are affecting our air, water, and economy. This international collaboration demonstrates how, now more than ever, open data and open science are critical to understanding our changing planet.

New and upcoming high-data-volume missions require that we innovate to ensure that the research community has open access to not just data, but also the tools, software, and cyberinfrastructure needed to efficiently do open science. ESDS has strengthened our 25-plus year commitment to open science by investing in community tools for cloud computing through competitive programs to ensure that data from new missions will be easy to access and analyze. ESDS continues to show leadership in technological innovation by investing in machine learning technologies and the development of training datasets for the new era of data analysis.

This past year has been transformational for our cloud migration efforts. We continue to evolve data and services from EOSDIS Distributed Active Archive Centers (DAACs) to the commercial cloud to enable analyses using Big Data that would be impractical to perform on a local computer. A highlight of 2020 cloud efforts was the successful launch in November of the Sentinel-6 Michael Freilich mission. Thanks to the efforts of ESA and NASA's Physical Oceanography DAAC, this is the first natively cloud-hosted mission, which will allow researchers easy and efficient access to mission data.

On a personal note, I am delighted that Katie Baynes joined ESDS in August as a Program Executive. Katie brings to ESDS an intimate familiarity with Earthdata Cloud and will serve a critical role leading and managing ESDS as my deputy. Finally, we are pleased to welcome our new Earth Science Division director, Dr. Karen St. Germain, who joined in the summer. With this new leadership, we look forward to continuing our successes in the coming year – and in years to come.

Kevin Murphy
ESDS Program Executive

Introduction

Open Access for Open Science.

This succinct phrase sums up the overarching objective of NASA's Earth Science Data Systems (ESDS) Program. Open data are the foundation of ESDS efforts to fulfill the Program's vision of accelerating scientific advancement for societal benefit through innovative Earth science data stewardship and technology development. The ESDS Program oversees the life cycle of NASA Earth science data – from acquisition through processing and distribution – and seeks to maximize the scientific return from NASA Earth observing (EO) missions and experiments.
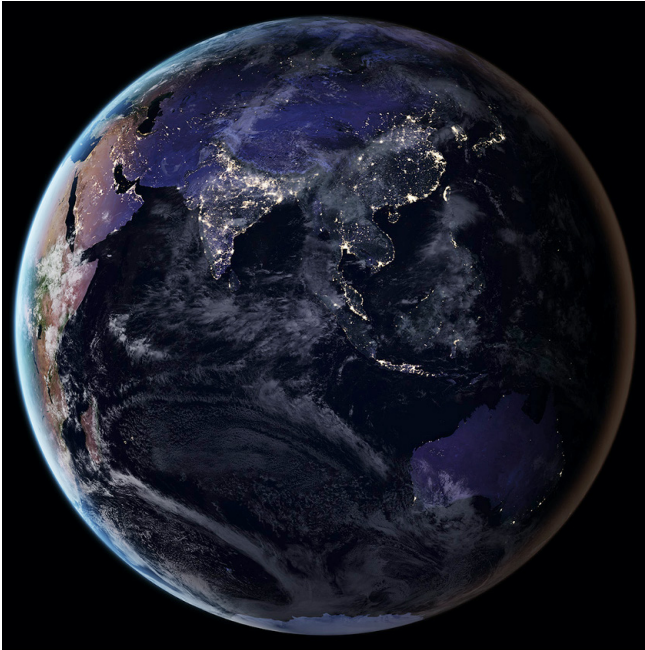
2020 was a transformative year for ESDS, and saw the culmination of a strategic process that began in 2019 to establish four foundational ESDS Goals:

- Set the standard for efficient production and stewardship of science-quality data.

- Advance open science data systems for the next generation of missions, data sources, and user needs.

- Lead research and development of technology for management and analysis of complex Earth science data.

- Leverage the diversity of global Earth science communities to advance open science.

These ESDS goals were crafted to complement the NASA Science Mission Directorate (SMD) Data and Computing Strategy goals of developing and implementing capabilities to enable open science ensuring the continuous evolution of data and computing systems, and harnessing community and strategic partnerships for innovation. They also help guide ESDS in fulfilling its vision.

As you will read in the following pages, the programs, projects, and initiatives comprising ESDS made great strides over the past year not only fulfilling the strategies necessary to achieve these goals, but also furthering the dissemination of free and open data.

Since 1994, NASA Earth science data have been free and open to all users for any purpose, and since 2015 all data systems software developed through NASA research and technology awards have been made available as Open Source Software (OSS). The adoption of open data policies leads to advances in research, the development of new applications, and the exposure of citizens around the globe to information essential for understanding our planet, managing the environment, and encouraging commercial innovation. The many constituent parts of ESDS make this possible.

NASA's Earth Observing System Data and Information System (EOSDIS) is a core ESDS capability, and the primary operational system facilitating end-to-end data operations – from data acquisition to distribution – for one of the largest archives of EO data on the planet. The more than 41 petabytes (PB) of data in this collection come from a vast array of sources, including satellites, aircraft, field measurements, and numerous other programs.

EOSDIS Mission Operations, which includes command and control, scheduling, data capture, and initial (Level 0) processing, are managed by NASA's Earth Science Mission Operations (ESMO) Project. The remaining capabilities of EOSDIS constitute EOSDIS Science Operations, which are managed by NASA's Earth Science Data and Information System (ESDIS) Project. These capabilities include the generation of higher level (Level 1 to 4) science data products and the archiving and distribution of data products. The 12 discipline-specific EOSDIS Distributed Active Archive Centers (DAACs) are the primary interfaces between global data users and these

data, and create a wide range of resources enabling the full and open use of the EOSDIS data they archive and distribute.

Along with 2020 achievements in data processing and distribution, EOSDIS data played (and continue to play) an integral role in the global response to the ongoing pandemic. The free and open distribution of these data are enabling critical research into the effects on Earth systems caused by global efforts to control the pandemic, and the analysis of these data using machine learning are providing valuable windows into changes in global trade and transport.

The Interagency Implementation and Advanced Concepts Team (IMPACT) is an interdisciplinary team that works to maximize the scientific return of NASA's missions and experiments through developing interagency collaborations, assessing and evaluating ESDS processes, and deploying strategic and technical expertise for rapid prototyping, development, and testing of advanced concepts in data and information systems for Earth observations. Along with the many IMPACT achievements in 2020, their

collaborative work facilitating cloud-based production of Harmonized Landsat Sentinel-2 (HLS) data is a major technological highlight of the past year.

Other ESDS program components include the Data System Evolution Program, which includes ESDS Competitive Programs and the Earth Science Data Systems Geographic Information Systems Team (EGIST); collaborative projects such as the Multi-Mission Algorithm and Analysis Platform (MAAP); and new data-acquisition initiatives such as the Commercial Smallsat Data Acquisition (CSDA) program. ESDS also supports user working groups and the development of standards for data quality, formats, metadata, discoverability, and usability. Working together, these ESDS Program components compiled a record of accomplishment in 2020 that will serve as a firm foundation for an exciting new era for the open use of Big Data.

The talented individuals responsible for the many ESDS Program accomplishments you'll read about in the following pages rose to the challenges of 2020. These Program highlights show not only how ESDS is fulfilling its goals, but also the tremendous power of a simple concept –

Open Access for Open Science. ■

Special Report: Using Open Data to Monitor the Human Response to COVID-19

The ongoing global pandemic created not only challenges to data production and dissemination, but also tremendous opportunities for the use of open data. Open access to NASA Earth observation (EO) data provides the critical information necessary to assess, monitor, and investigate the ecologic and economic impacts of continually changing efforts to control the spread of the novel coronavirus and of COVID-19, the disease caused by the virus.

In June, NASA joined with the Japan Aerospace Exploration Agency (JAXA) and ESA (European Space Agency) to create the COVID-19 Earth Observing Dashboard. This joint effort leverages the collective scientific power of EO satellites from all three agencies to document how changes in human activity caused by the pandemic are affecting the planet ecologically and economically.
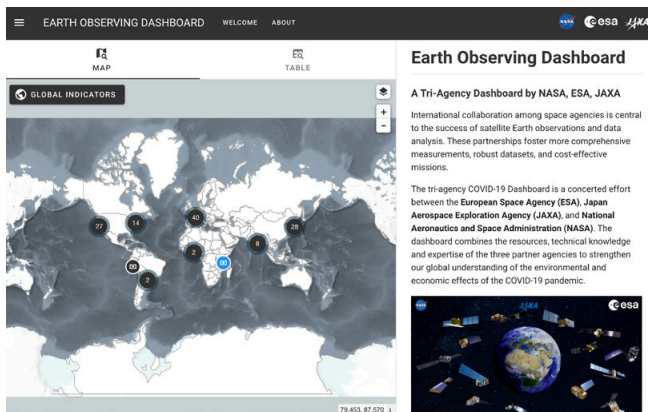

The tri-agency Earth Observing Dashboard is an easy-to-use interface for exploring global indicators related to the COVID-19 pandemic.

As governments implemented, eased, and re-implemented restrictions limiting travel to help slow the spread of the virus, researchers used the dashboard to document the effects of this reduced travel. For example, the earliest observed responses to COVID-related restrictions were darkened streets and drops in nitrogen dioxide concentrations along highways from reduced vehicle activity in China. Restrictions to human activity implemented in Europe, the United States, and elsewhere resulted in similar drops in nitrogen dioxide. These changes in atmospheric nitrogen dioxide concentrations – data continually collected by sensors aboard EO satellites – affect local air quality and could have long-term climate impacts. Commercial satellite data and machine learning also are being used to track shipping activity at major ports around the world to see how the pandemic is affecting the shipping sector and the global movement of goods.

To complement the tri-agency Earth Observing Dashboard, NASA developed a stand-alone COVID-19 Dashboard to highlight EO research findings and share narratives about how the world has changed. The three primary sections of the NASA dashboard (Explore, Indicators, Discoveries) provide entry points to global information about COVID-19 based on data acquired by NASA EO satellites. This open source experimental dashboard will continue to evolve as more data become available.
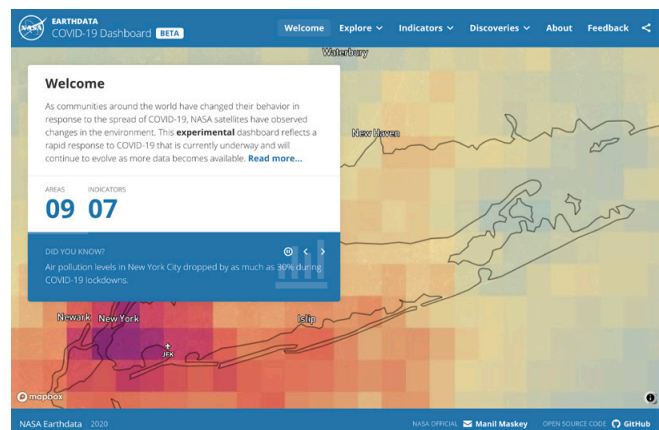
NASA's open source COVID-19 Dashboard (currently in beta release) features data collected and analyzed by NASA.

Along with the dashboards, existing datasets in NASA's EOSDIS collection are being leveraged to improve our understanding of the spread of COVID-19. NASA's Socioeconomic Data and Applications Center (SEDAC) created an interactive mapping tool combining EOSDIS socioeconomic data available through SEDAC with near real-time COVID-19 data from the Johns Hopkins University & Medicine Coronavirus Resource Center. The Global COVID-19 Viewer: Population Estimates by Age Groups and Sex is unique in its ability to allow users to visualize age and sex data for any user-determined area, including areas that cut across country boundaries, through simple age-and-sex structure charts or age pyramids. The COVID-19 Viewer provides continually updated national and sub-national data on the number of confirmed COVID-19 cases and deaths and the number

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of people who have recovered. This freely available application may be especially helpful for use in countries with limited access to spatial demographic data.

Finally, in May 2020, NASA facilitated a special COVID-19 Space Apps Hackathon in collaboration with ESA, JAXA, the French Centre National d'Etudes Spatiales (CNES), and the Canadian Space Agency. More than 15,000 participants from 150 countries used EO data to help solve challenges related to the COVID-19 pandemic. IMPACT, in collaboration with Amazon Web Services (AWS), made numerous EOSDIS datasets available in Cloud Optimized GeoTIFF (COG) format, which enables data to be dynamically analyzed very efficiently. Making these COG-formatted data available for the hackathon showcased the NASA/AWS partnership and emphasized IMPACT's efforts in making analytics-optimized data stores available to the science community. A special COVID-19 Data Pathfinder was developed and published on the Earthdata website to help hackathon participants and other researchers find specific NASA EO data related to the pandemic. ∎

Goal: Setting the Standard for Efficient Production and Stewardship of Science-Quality Data

The return on investment of any EO mission is data. ESDS constantly seeks better ways to produce, deliver, and preserve the data entrusted to us and uses the lessons learned from these efforts to further improve the production and stewardship of these data.

ESDS has four specific strategies for achieving this goal:

- Continually improve cost-efficient operations without compromising quality and service to the community;

- Continually improve capabilities to ensure that NASA EO data are available for science today and in the future;

- Facilitate interdisciplinary Earth science investigations by providing efficient and harmonized data systems; and

- Invest in people and organizations to advance the state of the art of science data stewardship.

EOSDIS Data Achievements and Archive Growth

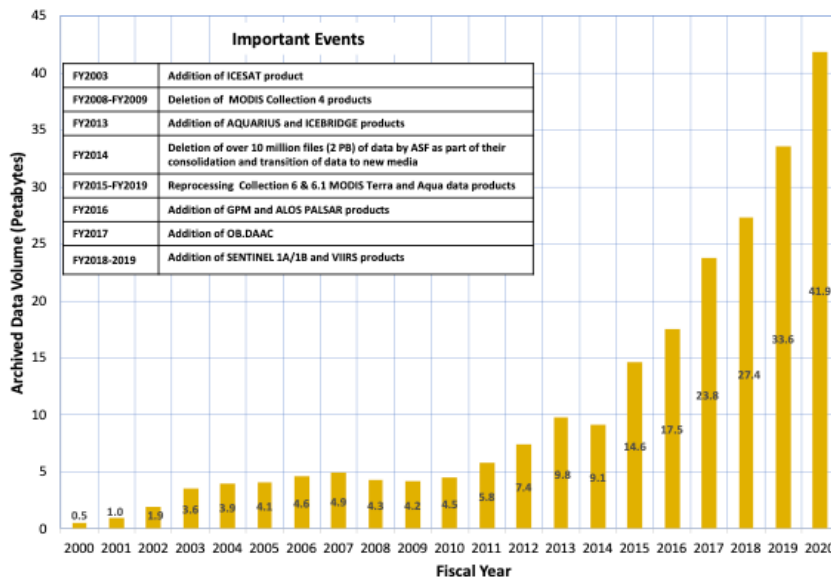The primary contact with NASA EO data for a majority of data users is through data in the EOSDIS collection, which are archived at and distributed by discipline-specific DAACs under the management of the ESDIS Project. Over the 2020 Fiscal Year (1 October 2019 through 30 September 2020), the volume of data in the EOSDIS collection grew from 34 PB to 42 PB, an almost 24% increase. DAACs added more than 524 new and reprocessed datasets to the EOSDIS collection and assigned more than 8,700 Digital Object Identifiers (DOIs) to datasets in the EOSDIS collection.

EOSDIS provides data stewardship to over 12,800 unique data products from more than 100 instruments and had an average archive growth of almost 33 TB per day in FY 2020, according to ESDIS metrics. Data from several missions contributed significantly to the EOSDIS archive growth during FY 2020: the ESA Sentinel-1 mission, which is distributed by NASA's Alaska Satellite Facility DAAC (ASF DAAC) under an international agreement with the European Commission; high-resolution data from NASA's ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS); new data from the Visible Infrared and Imaging Radiometer Suite (VIIRS) and other instruments aboard the joint NASA/NOAA NOAA-20 satellite; and the Global Ecosystem Dynamics Investigation (GEDI), which is a collaboration between NASA's Goddard Space Flight Center and the University of Maryland.

EOSDIS data users once again recognized the high quality of service provided by EOSDIS DAACs and the high quality of EOSDIS data. In the annual American Customer Satisfaction Index (ACSI) survey of users of EOSDIS DAACs conducted by the CFI Group (an independent organization contracted by the federal government to assess user satisfaction with products and services at numerous federal entities), EOSDIS received a Customer Satisfaction Index (CSI) aggregate score of 79 (an increase from the 2019 score of 78 and an indication of strong performance, according to the CFI Group). The EOSDIS score remains well above the

Total EOSDIS Accumulated Data Archive Volume (Petabytes) Trend: FY2000-FY2020

	Important Events
FY2003	Addition of ICESAT product
FY2008-FY2009	Deletion of MODIS Collection 4 products
FY2013	Addition of AQUARIUS and ICEBRIDGE products
FY2014	Deletion of over 10 million files (2 PB) of data by ASF as part of their consolidation and transition of data to new media
FY2015-FY2019	Reprocessing Collection 6 & 6.1 MODIS Terra and Aqua data products
FY2016	Addition of GPM and ALOS PALSAR products
FY2017	Addition of OB.DAAC
FY2018-2019	Addition of SENTINEL 1A/1B and VIIRS products

Growth of EOSDIS data volume from FY 2000 to FY 2020. Inset box highlights significant data additions to the archive. The addition of data from upcoming high-data-volume EO missions such as NISAR and SWOT is expected to increase the volume of data in the EOSDIS collection to almost 250 PB over the next five years. Table based on metrics from the ESDIS Metrics System (EMS).

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latest reported federal government score of 68. The 2020 EOSDIS ACSI survey utilized a substantially larger survey pool of users (9,178) than previous years, adding nearly 3,000 additional respondents over the 2019 survey. The 2020 survey marks the 17th consecutive year NASA has performed an independent review of EOSDIS data and services using the CFI Group.

In 2020, the ESDIS Project also undertook an independent customer satisfaction survey of LANCE using the CFI Group. The LANCE aggregate score of customer satisfaction with products and services was 80, which is a strong score based on the ACSI survey methodology. The likelihood of survey respondents to use LANCE services again was an even higher 89, which is exceptionally strong.

Commercial Smallsat Data Acquisition (CSDA) Program

Following the successful completion of the CSDA pilot in December 2019, CSDA became an operational program in 2020. Of special note in 2020 was the launch of the web-based Smallsat Data Explorer (SDX) tool that enables users to search, discover, and access NASA's mirrored commercial smallsat data. Planet and Spire data currently are mirrored in SDX, and the tool is being further enhanced to support data from Maxar (formerly DigitalGlobe) and Teledyne Brown Engineering, Inc., and to improve the user experience. At the end of 2020, approximately 3 PB of Planet, 12 TB of Spire, and 4 TB of Maxar data were mirrored in CSDA.

In the summer of 2020, CSDA initiated the long-term sustained use phase of the program by augmenting data from the EOSDIS with CSDA commercial data. Operational use of EOSDIS for ingest, archive, catalog, and distribution of purchased commercial data is planned for early in FY 2022.

Near Real-Time (NRT) Data

The ability to produce and deliver low-latency data, generally within three hours of a satellite observation, is a landmark achievement. While these data do not have the extensive processing required for scientific research, they are an invaluable resource for applications including severe storms, wildfires, volcanic ash and smoke plume tracking, dust storms, floods, drought, sea ice, and air quality.

EOSDIS NRT data are coordinated and produced by the Land,

Atmosphere Near real-time Capability for EOS (LANCE). LANCE provides more than 200 NRT products from data acquired by almost a dozen satellite-borne instruments. NRT imagery can be accessed through NASA's Global Imagery Browse Services (GIBS) for interactive exploration using the NASA Worldview data visualization application or similar client systems. During FY 2020, LANCE distributed more than 2.5 TB of data per day and distributed approximately 90 million products to end users.

The active 2020 hurricane and wildfire seasons in North America drove an increase in demand for NRT data and imagery. EOSDIS saw a number of spikes in visits to Worldview and the Fire Information for Resource Management System (FIRMS), which provides NRT fire data. Fueled by social media and news articles, FIRMS had over a million views and Worldview had almost 400,000 hits in 30 days during the 2020 California fire season.
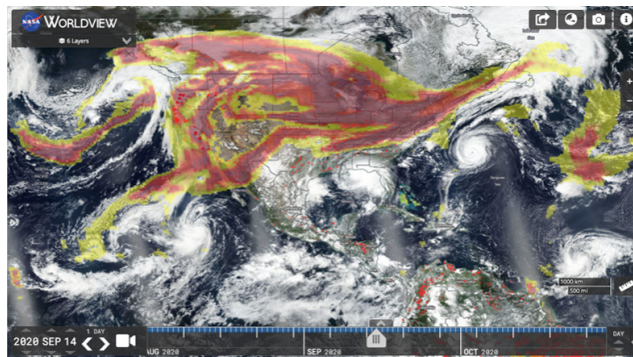
NASA Worldview image acquired 14 September 2020 showing high aerosol concentrations from wildfires in Oregon and California and their track across the U.S. Aerosol data are from the Suomi NPP OMPS instrument. Interactively explore this image in NASA Worldview at https://go.nasa.gov/38k6Awe. NASA Worldview image.

GIBS and Worldview

The NASA Worldview data visualization application provides the capability to interactively browse over 1,000 global, full-resolution satellite imagery layers available through GIBS and download the underlying data. Throughout 2020, Worldview added numerous enhancements to improve its search and discoverability capabilities. The Layer Picker now enables users to browse imagery products by mission, science area, temporal period, and other variables. Additionally, a new timeline panel helps users determine the availability of layers loaded in the Layer List and a new measurement tool enables users to quickly measure distance or area within an image and export the measurements.

Support for New Missions and Field Campaigns

ESDS worked closely with science and ground systems teams to support the routine collection and archiving of new datasets in 2020.

- GEDI: In January, the first data from the Global Ecosystem Dynamics Investigation (GEDI) mission became publicly available through NASA's Land Processes Distributed Active Archive Center (LP DAAC). The mission launched on 5 December 2018 and is installed on the International Space Station's Japanese Experiment Module-Exposed Facility (JEM-EF).

- Sentinel-6 Michael Freilich: The joint U.S.-European Sentinel-6 Michael Freilich Mission launched in November and is NASA's first natively cloud-hosted EO mission. As of December 2020, Level 0 mission data along with some Level 1 ancillary and auxiliary data are being ingested by NASA's Physical Oceanography DAAC (PO.DAAC) into the Earthdata Cloud. The success of this real-time support operations activity and the first forward stream cloud ingestion are major Program and mission milestones.

- Harmonized Landsat Sentinel-2 (HLS): NASA's HLS project combines data from the Operational Land Imager (OLI) aboard the joint NASA/USGS Landsat 8 spacecraft and the MultiSpectral Instrument (MSI) aboard the ESA Sentinel-2A/B spacecraft into a harmonized, analysis-ready surface reflectance product. Through the joint efforts of the HLS project science team at NASA's Goddard Space Flight Center, IMPACT, and LP DAAC, provisional S30 data were publicly released in October (provisional L30 data were released in early-2021). These data are stored as Cloud Optimized GeoTIFFs in the Earthdata Cloud. HLS is the first EOSDIS data product fully contained in the cloud and marks the beginning of a new chapter for ESDS data production and distribution.

- IMPACT's Airborne Data Management Group (ADMG) improved airborne and field data discovery and access by working on several tasks that addressed issues inherent to these data. Data discovery was made easier by supplying humanizing terms and tagging data for inclusion in a Suborbital Earthdata Search Portal. In addition, a prototype of the Catalog of Archived Suborbital Earth Science Investigations (CASEI) was developed that allows for more effective exploration of investigations using detailed metadata added for all NASA Earth science airborne and field activities. CASEI will be released in FY 2021.

- Two new NRT products were added to LANCE in 2020 that were produced using data acquired by the Visible Infrared Imaging Radiometer Suite (VIIRS) aboard the joint NASA/NOAA Suomi National Polar-orbiting Partnership (Suomi NPP) satellite. The VIIRS Level 2 Deep Blue Aerosol Product uses measurements from multiple satellites to determine the concentration of atmospheric aerosols along with the properties of these aerosols. The VIIRS Cloud Mask is a Level 2 product created using a series of visible and infrared threshold and consistency tests to assess cloud cover and the confidence that an unobstructed view of Earth's surface is being observed.

Improving Metadata and Data Standards

ESDS continues to recognize the importance of maintaining data standards and a comprehensive metadata repository. NASA's Common Metadata Repository (CMR) is a high-performance, high-quality, continuously evolving metadata system that catalogs all EOSDIS data and service metadata records and is the authoritative management system for all EOSDIS metadata. The CMR is used to manage more than 710 million files of sensor data from NASA EO missions.

IMPACT continues to improve NASA EO data products by reviewing and improving the CMR. During 2020, IMPACT's Analysis and Review of CMR (ARC) team completed metadata quality assessments for approximately 3,500 data products, making significant progress toward the major milestone of completing metadata assessments for NASA's entire collection of more than 8,000 Earth science data products. ARC has conducted quality assessments of more than 6,000 CMR metadata records and evaluated the information provided in each metadata record for correctness, completeness, and consistency. The ARC team provided metadata quality reports to all EOSDIS DAACs with recommendations on how to improve their metadata. The end result has been an increased consistency in metadata across the DAACs, more complete metadata records, and the addition of new elements resulting in updated and improved metadata content, all of which improve the data stewardship and usefulness of NASA EO data.

Representatives from IMPACT presented a demo of the CMR Metadata Curation Dashboard tool at an ESDIS Metadata Tools Workshop. The tool is used to identify and report potential CMR metadata issues to appropriate

stakeholders and to maintain and help improve the quality of NASA's Earth science metadata to better serve end users. The workshop brought together users and stakeholders of the suite of ESDIS metadata management tools to discuss new tool features, improvements, and priorities.

Additionally, IMPACT's Algorithm Publication Tool (APT) entered its second phase of development in 2020. APT enables efficient data production by helping scientists write standardized, high-quality Algorithm Theoretical Basis Documents (ATBDs) collaboratively via a single end-to-end authoring tool. New work in 2020 focused on enhancing existing authoring capabilities, establishing a centralized discovery portal for ATBDs, and implementing Schema.org markups for each ATBD. The APT is expected to transition to full use in FY 2021. ATBDs help ensure reproducible science by documenting key scientific assumptions made when writing algorithms and also promote understanding of EO data for users. The APT facilitates the standardized ATBD development process by providing a single authoring tool for NASA's Earth Science Division.

ESDIS Project efforts in 2020 provided better guidance and standards for EO data development and stewardship, both internationally and within the agency. Between 2017 and 2020, ESDIS led an international effort to develop the International Organization for Standardization (ISO) standard 19165-2: *Geographic information – Preservation of digital data and metadata – Part 2: Content specifications for Earth observation data and derived digital products*. The standard was approved through international ballots and published in July 2020. The standard defines how Earth science data and associated knowledge should be documented to facilitate future reuse. There had not been a standard in this area before.

Finally, the EOSDIS Standards Office published the *Data Product Development Guide (DPDG) for Data Producers*. The guide was written by the DPDG Working Group, one of the Earth Science Data System Working Groups (ESDSWGs). Approved as a Suggested Practice for ESDS in July 2020, the DPDG draws upon existing resources such as standards, conventions, best practices, and data format manuals to provide a step-by-step process for data producers to design and develop NASA Earth science data products that best serve end-user communities. ■

Goal: Advance Open Science Data Systems for the Next Generation of Missions, Data Sources, and User Needs

As stewards of NASA EO data, NASA's ESDS Program strives to foster a collaborative culture enabled by technology that empowers the open sharing of data, information, and knowledge. As the volume of Earth Science mission data continues to increase, so too does the need for technologies that easily can adapt and scale to facilitate the use of these data. Throughout 2020, ESDS continued its groundbreaking work developing the systems, tools, and architecture to support the next generation of missions, data sources, and user needs.

ESDS utilizes four primary strategies to advance open science data systems:

- Enable operational production of new multi-sensor products for research and applied science users;

- Develop an open data system that enables integration of data from NASA and other related Earth science data providers;

- Promote community development models for open software systems; and

- Develop data architectures for new sensor technologies and ground systems.

Earthdata Cloud Migration and Data Systems Efficiency

Through the Earthdata Cloud effort, the ESDS Program has adopted a strategic vision to develop and operate multiple components of the EOSDIS in the commercial cloud. This effort had a transformational year in 2020, including the migration of a significant amount of EOSDIS data into the cloud and the launch of the first of many missions whose data will be cloud-native.

The Earthdata Cloud is now in operation serving the entire ESDS community with a secure infrastructure that allows comprehensive, customized financial controls. Not only has the Earthdata Cloud framework been reviewed and granted an authorization-to-operate by NASA, it also is evolving business processes, monitoring costs, providing reports, and managing budget and execution activities.

These accomplishments represent a significant success story within NASA and the federal space for cloud-based computing controls. Following the deployment of software (Cumulus) to manage the ingest and archive of data files in the Earthdata Cloud, the focus is now on developing and enhancing data services that can be customized for use by specific science discipline users.

Migration of data and services from EOSDIS DAACs into the commercial cloud continued in 2020. A major accomplishment was the migration of all data archived at NASA's Global Hydrology Resource Center DAAC (GHRC DAAC). Migration of data from the National Snow and Ice Data Center DAAC (NSIDC DAAC) to the Earthdata Cloud was approved by the ESDIS Project in April. High-priority datasets from other DAACs continue to be evaluated for migration to the cloud based on criteria such as data interoperability, mobility, turnaround time, and science value.

As mentioned previously, another significant 2020 accomplishment was the public release of provisional data products from the Harmonized Landsat Sentinel-2 (HLS) effort. Thanks to collaboration from the HLS science team, IMPACT, and NASA's Land Processes DAAC (LP DAAC), HLS is the first EOSDIS data collection that is fully contained in the cloud and marks the beginning of a new chapter for ESDS data production and distribution. Along with HLS, Terra Fusion, an ESDS Advancing Collaborative Connections for Earth Systems Science (ACCESS) program 2015 project comprising 20 years of fused data from Terra's five instruments, was migrated to the cloud in early-2020.

As part of the NASA/Amazon Web Services (AWS) Space Act Agreement executed by IMPACT for ESDS in January 2020, Multi-scale Ultra-high Resolution Sea Surface Temperature (MUR SST) data from NASA's Physical Oceanography DAAC (PO.DAAC) were incorporated into the AWS Registry of Open Data. MUR SST Data are available from 2002 to present in Zarr format and are optimized so that researchers can do large-scale analyses in the cloud.

Along with the migration of data to the commercial cloud, the evolution of imagery from NASA's Global Imagery Browse Services (GIBS) to the commercial cloud – an effort called GIBS In The Cloud or GITC – will provide

global users with fast, efficient access to high resolution imagery along with the data behind this imagery. As this effort becomes operational in 2021, users will reap the benefits of faster imagery time-to-availability along with the ability to conduct imagery analysis in the cloud. GIBS could migrate as much as 550 TB to the Earthdata Cloud during FY 2021; the entire GIBS data archive (750 TB) could be migrated by the end of FY 2022. In addition to these projections, as much as 350 TB of additional data could be added to the GIBS archive through processing of the entire HLS historical record, which is expected to occur during FY 2021.

Finally, November 2020 saw the successful launch of the joint U.S.-European Sentinel-6 Michael Freilich Mission – the first natively cloud-hosted mission. The immediate success of Sentinel-6 Michael Freilich is not only a tremendous achievement by the entire mission team, but a monumental accomplishment in cloud-based data operations and a blueprint for future cloud-native missions. As of December 2020, Level 0 mission data along with some Level 1 ancillary and auxiliary data are being ingested by PO.DAAC into the Earthdata Cloud. Sentinel-6 Michael Freilich provides measurements of sea surface height with very high precision, giving researchers a global view of sea level change within a few millimeters and continuing a consistent record of sea surface height dating back to 1992.

Facilitating Cloud-Based Research

As Earth science data and computations move into the cloud, researchers and commercial users will be able to do more work with more data than ever before, enabling new science and large-scale analytics. ESDS is leading and supporting several initiatives to develop the tools and computing environments that will facilitate cloud-based research using Big Data collections.

ESDS work in 2020 furthered efforts to enable large-scale analytics in the cloud by making it easy for researchers to analyze data in place and work next to data in the cloud. Development continued in 2020 on the Harmony project, a cross-EOSDIS framework to implement data transformation services in the Earthdata Cloud. Harmony was inaugurated in 2019 and enables users to customize data via subsetting, regridding, and reprojection directly in the cloud and go right to their analyses. In addition, a Cloud Primer for Amazon Web Services was published in 2020. Along with DAAC tutorials, the Primer provides

step-by-step guidelines to help data users get started in the AWS cloud.

ESDS is committed to fostering collaborative efforts in the Earth science community to make cloud-based data easy to access without significant technical expertise. One such ESDS-supported effort is Pangeo, which is an ESDS ACCESS 2017 project. Pangeo helps the Earth science community analyze data in the cloud using an ecosystem of collaborative, open-source tools. These tools allow researchers to easily access and visualize data using open-source Jupyter notebooks. During 2020, Pangeo helped EOSDIS add functionality to support the SpatioTemporal Asset Catalog (STAC) in both Harmony and in the CMR.
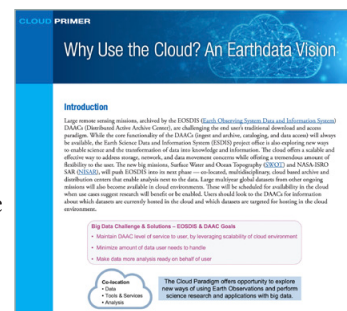
The Earthdata Cloud also enables and accelerates the ability of ESDS to innovate in new technologies such as artificial intelligence (AI). In January 2020, ESDS and the Radiant Earth Foundation hosted a workshop for experts to discuss the advancement of machine learning techniques on NASA EO data. The report from this workshop was published in May and discusses the key challenges and recommendations on how to effectively move forward with machine learning research in the Earth sciences.

Machine learning techniques rely heavily on the availability of large, high-quality training datasets, and a pressing need identified at the workshop was for more open source training datasets for machine learning applications. The 2019 ACCESS program solicitation resulted in awards to several projects that will develop machine learning training datasets for use in land cover and disturbance mapping and for estimating vegetation structure, streamflow, and cloud properties.

Finally, a tool released by a cross-disciplinary team at IMPACT monitors tropical cyclone intensities using a deep-learning technique on infrared satellite imagery. The Deep Learning-
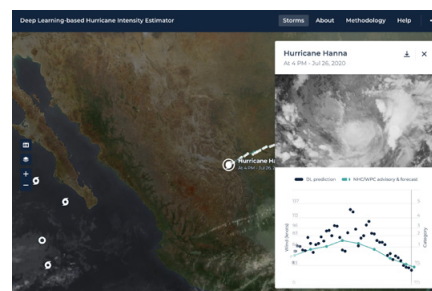
Screenshot from the Deep Learning-based Hurricane Intensity Estimator showing wind speed and hurricane category information for Hurricane Hanna on 26 July 2020.

based Hurricane Intensity Estimator is an experimental framework investigating the application of AI technologies and cloud computing resources to provide automated and accurate estimation of tropical cyclone intensity. This portal, one of the first of its kind, is a collaborative effort between IMPACT, members of NASA's Short-term Prediction Research and Transition Center (SPoRT), and hurricane scientists.

Collaborations, Systems, and Strategies to Improve Open Data Use

ESDS is dedicated to incorporating data from both NASA and its partners into systems promoting non-proprietary access, solutions, and standards. A prime example of these efforts in 2020 was the support of IMPACT in the rapid development of the NASA/ESA/JAXA COVID-19 Earth Observing Dashboard. IMPACT led and coordinated NASA efforts in this undertaking, which provides global access to open EO data collections of all three agencies to help the science community track the global impacts of COVID-19.

Additionally, IMPACT co-led a joint collaboration between ESDS and NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) focused on cloud computing activities. Representatives agreed to establish quarterly meetings to discuss selected topics related to cloud technologies and their implementation within both organizations with the goal of enabling information exchange and collaboration on best practices that can be shared by both NASA and NOAA.

Finally, IMPACT team members hosted and participated in the Frontier Development Lab (FDL) 2020 Challenges, which is part of the executed Space Act Agreement with Google, LLC. FDL is an applied AI research partnership with Google focusing on developing future AI applications in data-intensive challenges in the areas of space science, planetary science, and Earth science. IMPACT challenged Earth science FDL researchers to demonstrate a Knowledge Discovery Framework (KDF) using AI and machine learning techniques. The objective of the KDF is to discover unusual patterns and events in NASA's EO data archive by enabling users to provide an example image for which the KDF would search for similar images in the NASA repository.

Also in 2020, the ESDS Geographic Information Systems Team (EGIST) delivered the NASA Earth Science Geographic Information Systems (GIS) Strategy, a document that serves as a guide for future GIS deployment and emphasis areas in ESDS. With myriad competing solutions available, a formal strategy in this area enables efficient and economic procurement along with the highest impact delivery of NASA Earth science data products.

EGIST continued to engage with EOSDIS DAACs and with the broader Earth science user community, providing innovative solutions for GIS activities within ESDS and promoting the use and expansion of NASA GIS data and services. Significant progress was made in expanding appropriate NASA use of ArcGIS Online (AGOL) and assisting in gathering the necessary information for making sound policy related to GIS procurement and use at the agency. ∎

Goal: Lead Research and Development of Technology for Management and Analysis of Complex Earth Science Data

Throughout 2020, ESDS projects, programs, and initiatives continued their work leading the research and development of innovative tools and technologies for working with large Earth science data collections. ESDS leadership in these efforts revolves around three core strategies:

- Invest in targeted high-risk, high-reward technology, which is accomplished primarily through ESDS Competitive Programs and strategic partnerships along with internal research and development activities and pilot projects;

- Accelerate the adoption of new technologies for broader use by eliminating roadblocks to transitioning pilot programs to operations and deprecating redundant capabilities; and

- Demonstrate leadership in Earth science data system technology and techniques through the development of systems and tools that are considered benchmarks.

ACCESS Progress in Developing New Technologies

NASA-funded projects that are part of the competitive Advancing Collaborative Connections for Earth System Science (ACCESS) program are selected based on their proposed use of innovative techniques to address existing and anticipated needs of the research and applied Earth science communities to manage and analyze Big Data. Ongoing ACCESS projects made great strides in developing technology to advance open science and cloud-based systems during 2020, especially in the areas of machine learning and in supporting existing open source tools and libraries. Open source tools and libraries have become a critical component to research activities and need to be continuously updated to support new datasets, efficient processing, maintenance, and security. The five funded projects from the ACCESS 2017 solicitation (selected from a field of 39 proposals) entered their second year of work in 2020.

The ACCESS 2019 solicitation closed in January 2020 with 72 submitted proposals. Following a peer review by an expert panel, the Earth Science Division of NASA's Science Mission Directorate selected 11 proposals for three-year awards. The selected projects are working on technology developments in one or more of the following areas:

- Machine learning for ESDS, including new training datasets for machine learning;

- Enabling science in the cloud; and

- Improving, maintaining, and supporting high-value open source Earth science tools and libraries.

Additionally, two ACCESS 2015 projects were awarded supplemental funding: OpenAltimetry and Terra Data Fusion. OpenAltimetry, a cyberinfrastructure platform that supports the discovery, access, and visualization of data from NASA's Ice, Cloud, and land Elevation Satellite (ICESat) and ICESat-2 missions, received one year of supplemental funding to support infusion of the tool into the Earthdata Cloud.
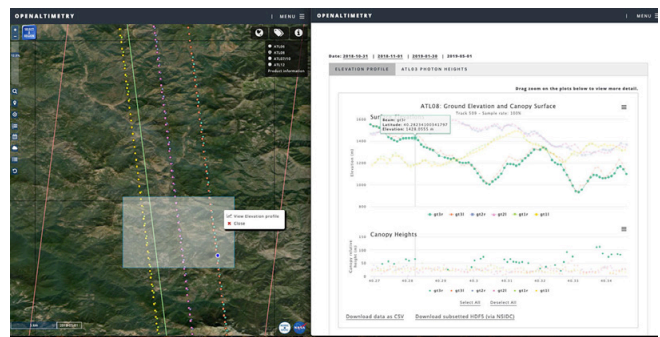
This screenshot of the OpenAltimetry map interface shows a highlighted query box (left, shaded area) and the elevation profile (right) for the ATL08 ICESat-2 data within the query box.

Terra Data Fusion combines data from different instruments aboard NASA's Terra satellite and enables scientists to derive new data products that better examine surface-based and atmospheric changes using more than 20 years of mission data. The supplemental funding awarded to this project enables the Terra Data Fusion team to use the fusion technology they developed to explore impacts of COVID-19 on the planet's systems.

Efforts to Facilitate More Efficient Management of Cloud-Based Data

Along with the significant Earthdata Cloud accomplishments previously noted, numerous enhancements were made to cloud-based data and services to improve the efficiency of managing and working with cloud-native data.

An IMPACT collaboration with the ESDIS Project led to the development of a formal ESDS cloud strategy for further leveraging the benefits of cloud computing within and on behalf of the ESDS Program. The strategy is aimed at furthering the ESDS commitment to open science, providing for operational improvements, and accelerating data systems resolution. Elements addressed in the strategy include high-value dataset migration, robust data preservation, elastic processing, analysis in the cloud, capacity building for the user community, strategic partnerships, and open-source software.

Also in 2020, the ESDIS Project obtained approval to proceed with conditions on delegating NASA domain name space to Amazon Web Services (AWS) in support of the Earthdata Cloud. The approval means that ESDIS can streamline its cloud operations for security and for web applications. In addition, this will lead to cost savings as ESDIS will be using free Amazon certificates instead of fee-based Entrust certificates for its public web sites.

The Alaska Satellite Facility DAAC (ASF DAAC) ingest and Archive (I&A) team completed the migration of all Sentinel-1 Synthetic Aperture Radar (SAR) data in the NASA-compliant General Application Platform (NGAP) AWS US-East account to a new account in NGAP AWS US-West and decommissioned the US-East account. This effort efficiently consolidates all ASF DAAC Sentinel-1 data in one storage location.

LP DAAC deployed Cumulus version 1.18 into the NGAP production environment in preparation for ingesting, archiving, and distributing HLS datasets and other LP DAAC data products. In addition, the Thin Egress App (TEA) became part of Cumulus. TEA is a fully Earthdata Cloud-compliant application that enables distribution of EOSDIS data from Amazon simple storage service (S3) buckets while ensuring that data providers have all the tools, controls, and metrics required for facilitating data distribution restriction and reporting compliance. ASF DAAC moved the distribution of Sentinel-1 data to use TEA behind Enterprise Egress. All ASF DAAC-distributed Sentinel-1 data are now using TEA with Enterprise Egress.

Technological Innovation in Data Analysis and Management

EOSDIS DAAC teams created numerous enhancements to data analysis and management tools throughout 2020. These enhancements are helping to improve data search and discovery along with facilitating the open use of these data.

LP DAAC's Application for Extracting and Exploring Analysis Ready Data Samples (AppEEARS) enables users to subset data spatially, temporally, and by layer, which greatly reduces the volume of data downloaded. The release of the AppEEARS application programing interface (API) offers users programmatic access to all features available in AppEEARS, with the exception of visualizations.

LP DAAC along with the IMPACT Production Team and the GIBS team completed a successful Production Readiness Review of the production, ingest, archive, distribution, and data management systems for HLS data. HLS is the first major EOSDIS dataset hosted fully in the commercial cloud and enables users to work seamlessly with high resolution terrestrial imagery from both Sentinel-1 and Landsat 8. The success of HLS, including development of HLS data products, their processing, and their distribution, is a major steppingstone in preparing for upcoming high-volume NASA Earth science data missions. Provisional Sentinel HLS data were publicly released at LP DAAC in October, and provisional Landsat HLS data were released in early-2021.
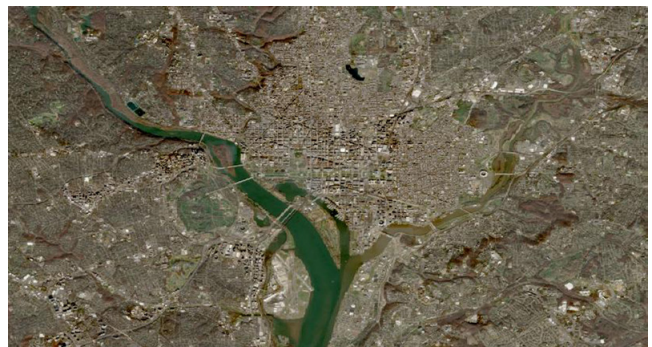
The Potomac River flows by Washington, D.C., in this cloud-free HLS image from December 11, 2020. The Mall is clearly seen in the center of the image, as is Arlington National Cemetery and Ronald Reagan National Airport just left of center. Interactively explore this image in NASA Worldview.

The ASF DAAC Data Access Team deployed a new API endpoint that allows download of individual files from within a product package in the ASF datapool. This enables users to retrieve small metadata files from large data collections, saving the user time and reducing the

amount of data downloaded. When applied to cloud-based data, such as the Sentinel-1 data distributed by ASF DAAC, this innovative system benefits both the Program (through reduced egress costs) and the data user (through reduced download time).

The ESDIS Cumulus Development Team completed all work on the known requirements of the Surface Water and Ocean Topography (SWOT) mission Operations Qualification Testing. SWOT will be capable of collecting and transferring more than 7 TB of science data per day, with an expectation of 23 PB of science data over the three-year mission. The development emphasis for this cloud-native mission (which is scheduled for launch in 2022) is now shifting to development of data transformation services to support the suite of SWOT data products.

Multi-Mission Algorithm and Analysis Platform (MAAP)

MAAP is a collaborative project between NASA and ESA designed to improve the understanding of

aboveground biomass and terrestrial carbon dynamics. MAAP brings together relevant data, algorithms, and computing capabilities in a common cloud environment to address the challenges of sharing and processing data from field, airborne, and satellite measurements related to NASA and ESA missions. This project is a showpiece for the next generation of collaborative platforms and a prime example of an ESDS strategic partnership for innovation.
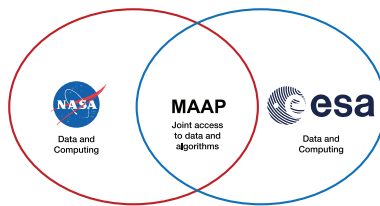
Entirely in the cloud, the common MAAP platform features a set of lidar and SAR data from NASA's GEDI mission, data from the joint NASA/ESA AfriSAR airborne campaign, and products from other NASA/ESA EO missions. The platform is fully available and interoperable, workspaces are fully functional, performance computing with the ability to address hundreds of virtual machines at once is fully available, and cutting-edge data formats
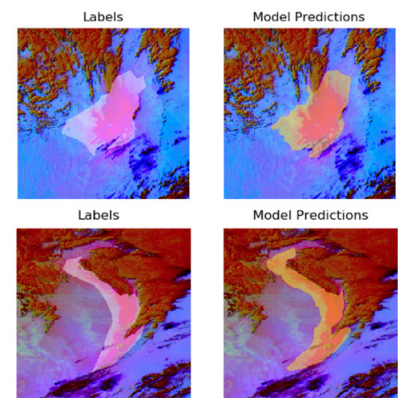
and visualization and analysis options are functional and being finalized.

Commercial Smallsat Data Acquisition (CSDA) Program

ESDS established CSDA to identify, evaluate, and acquire data from commercial sources that can complement NASA Earth science research and application goals. In 2018, NASA's ESD selected and augmented the funds of 41 researchers that could potentially benefit from and had the expertise to evaluate the commercial smallsat imagery and/or data being considered for longer-term purchase. In April 2020, the results of these evaluations were published in the *Commercial SmallSat Data Acquisition Program Pilot Evaluation Report*. A majority of these evaluations demonstrated the usefulness of commercial data and imagery for advancing scientific research and applications.

AI/Machine Learning Efforts for Real-Time Dust Detection

Using AI and deep learning techniques, IMPACT's Machine Learning team in partnership with NASA's Short-term Prediction Research and Transition Center (SPoRT) developed software that automatically

*Left images show areas of dust labeled by subject matter experts. **Right images** show the AI model's predictions of dust. Image: NASA IMPACT.*

detects atmospheric dust in real-time. The team modeled dust as a semantic image segmentation problem and developed a dataset labeled at the pixel level, with classifications executed for every pixel within an image. The predictions from the model portion-out the region within the image pertaining to dust. The success of this AI can speed up the process of atmospheric evaluation of impending dust storms. ■

NASA Earth Science Data Systems Program

Goal: Leverage the Diversity of Global Earth Science Communities to Advance Open Science

The global reach of ESDS partnerships throughout 2020 helped advance the NASA Science Mission Directorate (SMD) Data and Computing Strategy of harnessing community and strategic partnerships for innovation and advancing open science. Extensive ESDS communications efforts continued to reach a broad, diverse global audience to demonstrate the many uses of open data, encourage the development and use of open data systems, and advocate open data policies.

ESDS has three primary strategies for achieving this goal:

- Develop and maintain partnerships to expand the use of NASA's open data, promote open science, and increase the use of data across multi-disciplinary and multi-agency organizations;

- Expand the participation of diverse communities to access data and build science data systems; and

- Articulate and advocate for open science policy.

Expanding Access to Open Science

ESDS works across the agency to expand access to open science and engages with likeminded agencies through means including the IMPACT Satellite Needs Working Group (SNWG) and the federal interagency U.S. Group on Earth Observations (USGEO) to expand the use of NASA Earth science data.

In 2020, the Program continued its ongoing participation in the International Science Council World Data System (ISC-WDS). The WDS is an Interdisciplinary Body of the ISC that promotes long-term data stewardship, open data access, and the adoption of codified data standards. All EOSDIS DAACs are WDS members, and DAAC representatives hold positions of responsibility in the organization and in their international Forum meetings.

The ESDS also maintains an active role with the Committee in Earth Observation Satellites (CEOS), a leading science consortium of 61 agencies that operate EO satellites and work together to foster international coordination of Earth science research. ESDS provided leadership to the CEOS Working Group on Information Systems & Services (WGISS) through coordination of the International Directory Network (IDN), providing worldwide researchers access to metadata about scientific data. ESDS representatives also chaired several CEOS workshops in 2020 related to analysis ready data (ARD), on which NASA Earth science is a recognized world leader.

The Program provided additional support for open data efforts of the Group on Earth Observations (GEO), which is a partnership of more than 100 national governments and participating organizations working to foster full and open access to Earth observation data, information, and knowledge.

In support of GEO, NASA provides open data resources to aid in the creation of a Global Earth Observation System of Systems (GEOSS). This work helps integrate global EO systems and facilitates the sharing of data by connecting existing infrastructures using common standards.

The ESDS Commercial Smallsat Data Acquisition (CSDA) program works with the private sector to include specialized services and incorporate proprietary data in ESDS systems. Through these efforts, ESDS is able to bring together a multitude of like-minded communities and leverage their combined power to improve and enhance open data and the science enabled by these data.

Community Development of Open Systems

A key ESDS initiative for engaging the resources of the broader Earth science community is the Citizen Science for Earth Systems Program (CSESP). CSESP leverages the work of thousands of citizen scientists directly in NASA research, harnessing these community and strategic partnerships for innovation and multiplication of effort in NASA EO endeavors. Throughout 2020, CSESP projects continued to yield results in diverse areas of Earth science, including validating remotely sensed snowpack observations, classifying kelp forests, and monitoring bird diversity.

2020 CSESP highlights include:

- In April, the ESDS Citizen Science Data Working Group released a white paper with standards for citizen science data collection and management. The white paper provides information for ensuring usability of citizen science data and communication regarding its use and best practices for long-term archival of citizen science data.

- The 2020 NASA CSESP Research Opportunities in Space and Earth Sciences (ROSES) solicitation was released. Two types of proposals were requested: (1.) Citizen Science Research Gathering New Data, and (2.) Proposals for Reuse, Enhancement, or Characterization of Existing NASA Citizen Science Data.

Citizen scientist measuring snow depth for the CSESP project: Community Snow Observations. Snow depth measurements are being used to better interpret satellite and airborne snow observations collected by NASA and other agencies. Image from Community Snow Observations.

Proposals were required to demonstrate clear linkages between citizen science and NASA observation systems to advance NASA's Earth science mission. The next round of funded projects will be announced in 2021.

- Data from an ongoing CSESP project found a correlation that might shed light on the ongoing COVID-19 pandemic. The project, *Can Citizen Science and Low-Cost Sensors Help Improve Earth System Data? Implications to Current and Next Generation Space-Based Air Quality Measurements,* found preliminary evidence of air quality changes related to the outbreak of COVID-19. While further analyses are needed to rule out confounding factors, this citizen science project revealed an interesting trend that will be more closely investigated.

Efforts to Improve Science Keywords Across Agencies

The IMPACT Data Curation for Discovery (DCD) project assists other agencies in incorporating NASA EO data into their research efforts. In FY 2020, the DCD
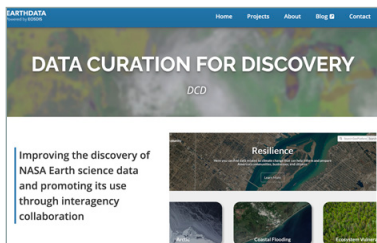
collaborated with the U.S. Global Change Research Program (USGCRP) to add 54 new science keywords to the Global Change Master Directory (GCMD) keyword catalog. These keywords are being leveraged by the Global Change Information System (GCIS) to tag figures in the Fourth National Climate Assessment for increased discoverability.

Smallsat Partnerships

NASA's Earth Science Division recognizes the potential impact commercial smallsat constellations may have in encouraging and enabling efficient approaches to advancing Earth science and applications development for societal benefit. The ESDS Commercial Smallsat Data Acquisition (CSDA) program continued to build partnerships and collaborations to identify, evaluate, and acquire data from commercial sources that support NASA's Earth science research and application goals. Significant 2020 partnerships include the National Reconnaissance Office (NRO) Geospatial Intelligence Systems Acquisition Directorate Commercial Systems Program Office (CSPO), NOAA's Commercial Data Pilot (CDP) and Commercial Radio Occultation Data Purchase, the United States Group on Earth Observations (USGEO) Commercial Task Force, the Working Group for the Interagency Coordination of Commercial Weather Data (ICCWD), and ESA's Earthnet Data Assessment Pilot (EDAP).

CSDA issues a Request for Information (RFI) every 12 to 18 months to identify data that may be valuable for NASA's Earth science research and application activities. Procurements resulting from the second RFI are underway, with awards anticipated in mid-2021. The third CSDA RFI was released in December 2020.

Communicating Open Science

Articulating and advocating open science is a foundational element of ESDS activities, one that was accomplished throughout 2020 through numerous ESDS communications efforts designed to reach diverse communities
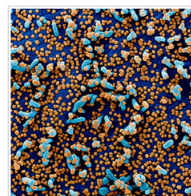

The COVID-19 Pathfinder was one of many resources developed by ESDS communications teams to provide information about NASA Earth science data resources that could aid research efforts into the pandemic.

of global data users. With the shift to telecommuting and virtual conferences in 2020 due to the global pandemic, these efforts were a critical component of ESDS outreach to not only communicate data efforts and accomplishments, but to further partnerships with like-minded organizations and agencies.

Communication activities with global data users in 2020 were active across the whole of the ESDS Program. Significant 2020 accomplishments include:

- Almost 100 articles were published on the Earthdata website in 2020. These included 11 EOSDIS Data User Profiles showcasing the breadth of work enabled by open data; quarterly EOSDIS newsletters highlighting data activities, webinars, DAAC data recipes, and data use tutorials; four special Data Chats focusing on Earthdata Cloud efforts; and 12 data Pathfinders and Toolkits to guide users to NASA Earth science data and help them maximize their use of these data.

- A special feature article as part of a joint campaign with NASA's Terra mission team celebrating 20 years of the Terra mission was published on the Earthdata website.

- The cover feature article in the January/February issue of NASA's *The Earth Observer* magazine described the history and development of NASA NRT efforts and LANCE.

- Dozens of peer-reviewed articles were published by ESDS-affiliated authors highlighting research advancing open data, AI, machine learning, and a host of other topics. Posts on the IMPACT and GIBS blogs reached additional global data users, and the first IMPACT Annual Newsletter was released.

- The Earthdata webinar series entered its seventh successful year with 17 data discovery and data access webinars, including a special Pangeo cloud computing webinar. During FY 2020, just over 2,800 attendees from more than 180 countries participated in the live webinars (a 67% increase over FY 2019).

- Recorded EOSDIS webinars and tutorials on the Earthdata YouTube channel garnered 96,000 views in FY 2020, a 62% increase over FY 2019.

- A new *Getting Started with NASA Worldview* video tutorial received more than 3,400 views by the end of 2020. A new Worldview tutorial is slated to be released in 2021 to further highlight this popular resource.

- Two major 2020 campaigns highlighted NASA science data and missions. A spring campaign focused on biodiversity research using open data and a fall campaign supported the NASA Earth Science Division-wide Sea Level Rise communications efforts as part of the Sentinel-6 Michael Freilich launch. The special articles, Data User Profiles, Data Chats, Pathfinders, Toolkits, and other materials developed for the four-month Biodiversity campaign garnered almost 20,000 Earthdata website page views; materials developed for the one-month Sea Level Rise campaign received almost 2,000 views.

- Several EOSDIS DAAC websites were re-designed or enhanced to provide a better user experience and a new IMPACT website was released.

- The EOSDIS Communications and NASA Worldview teams supported the agency-wide NASA Earth Day at Home campaign by developing the *Explore Our Magnificent Earth with NASA Worldview* activity. This activity launched on 16 April 2020 as part of the larger NASA Earth Day campaign and was included as an interactive activity on the NASA webpage. The success of the agency-wide Earth Day at Home effort was recognized with a NASA Group Achievement Award.

- NASA's ESDS was represented at almost a dozen national and international conferences through booth staffing, presentations, and poster sessions, reaching thousands of global data users both in-person and virtually. ◼

Of Special Note . . .

Two individuals affiliated with ESDS received 2020 agency Honor Awards recognizing their lifetime of accomplishments supporting, developing, and innovating NASA Earth science data.

Dr. Christopher Justice, Chair of the Department of Geographical Sciences at the University of Maryland, was awarded NASA's Distinguished Public Service Medal for his many years of leadership developing NASA near real-time data efforts leading to the creation of LANCE, which has transformed the way NASA EO data are used. The Distinguished Public Service Medal is NASA's highest form of recognition awarded to non-government individuals whose distinguished services have directly contributed to the advancement of agency objectives.

Dr. Christopher Justice with inset of NASA's Distinguished Public Service Medal.

In response to the award, Dr. Justice said, "I am deeply honored to receive this prestigious NASA award and very much appreciate this recognition. The near real-time (NRT) capability for EOS and User Working Group were established by Martha Maiden (NASA HQ) in 2009, and due to the usefulness of near real-time data, has grown to include NRT data from other NASA sensors. I would like to emphasize that the success of the NRT data delivery system (LANCE) is due to the long-standing commitment of [ESDS Program Executive] Kevin Murphy and the dedication of Dawn Lowe, Karen Michael, Diane Davies, and the excellent team at NASA Goddard responsible for its implementation."

Computer Engineer Alfreda Hall received NASA's Exceptional Service Medal for her numerous achievements supporting NASA Earth science initiatives. Specifically, she was recognized

Alfreda Hall with inset of NASA's Exceptional Service Medal.

for her efforts bringing data from the Suomi National Polar-orbiting Partnership (Suomi NPP), Joint Polar Satellite System (JPSS), and the Commercial Smallsat Data Acquisition (CSDA) to the ESDS. Ms. Hall has been with NASA for more than 30 years, and with the ESDIS Project for more than 20.

The Exceptional Service Medal is awarded to a government employee for sustained performance that embodies multiple contributions that enhance NASA projects, programs, or initiatives. The award criteria must include all of the following:

- Sustained performance that has made a significant improvement to NASA deliverables, operations, or image;

- A record of achievement that sets a benchmark for others to follow;

- Substantial improvement to a NASA program that yielded high quality results or improvements; and

- The impact and importance of the services performed have been instrumental to the past and ongoing success of NASA. ■

Summary

The challenges of the past year once again proved the value of open data. The tremendous accomplishments of the ESDS team in 2020 – accomplishments achieved in many cases remotely and through electronic collaborative connections – enabled Earth science data to be used more efficiently by a broader swath of global users than ever before. Data use and international partnerships facilitated by ESDS are helping scientists and researchers gain critical insights into Earth system changes caused by the novel coronavirus and of COVID-19, the disease caused by the virus. Data from the Sentinel-6 Michael Freilich mission, NASA's first cloud-native mission, continue to stream into NASA's PO.DAAC to become part of the Earthdata Cloud, and the collaborative work of IMPACT, NASA's LP DAAC, and the Harmonized Landsat Sentinel-2 (HLS) science team is ushering in a new era of terrestrial science.

The highlights in this report are the springboard to work being done in 2021 to further the open use of NASA Earth observing data. Some highlights of ESDS work data users will benefit from in 2021:

- ESDIS will continue moving popular datasets into the Earthdata Cloud while enabling a broad range of services to discover and access data in new and different ways. At the same time, the team will continue to ensure that rigorous Earthdata Cloud security mechanisms are in place and continuously monitored. In addition, ESDIS will improve EOSDIS components to allow external partners to participate in collaborative efforts by enabling ESA, NOAA, NSF, and others to access data in the Earthdata Cloud.

- The Global Imagery Browse Services (GIBS) and NASA Worldview teams will move GIBS into the commercial cloud, enabling ESDIS to handle imagery from high-volume missions and opening up new ways of using imagery, such as visualizing data "on-the-fly" rather than the current GIBS approach of pre-generating imagery and storing it. Additionally, Worldview plans to release its Smart Handoffs to Earthdata Search capability, allowing Worldview users to seamlessly download visualized data in Earthdata Search. The team also will add the capability to visualize individual granules for certain collections, a feature that will be particularly useful for "peeling apart" collections that have frequently overlapping swaths near the poles.

- IMPACT, in collaboration with LP DAAC and the HLS science team, will publicly release the full HLS S30 and L30 data products and begin back-processing HLS data. The team also will release the Airborne Data Management Group (ADMG) Catalog of Archived Suborbital Earth Science Investigations (CASEI) inventory user interface. Both of these efforts are major outcomes of the 2016 Satellite Needs Working Group (SNWG) survey assessment. IMPACT also plans to complete the design of the Algorithm Publication Tool (APT) for use in ATBD preparation by project scientists and, when released, allow for discovery of ATBDs by data product users.

Throughout the year, and in all operations, ESDS programs, projects, initiatives, and collaborative efforts will strive to accomplish the foundational Program goals of setting the standard for efficient production and stewardship of science-quality data; advancing open science data systems for the next generation of missions, data sources, and user needs; leading research and development of technology for the management and analysis of complex Earth science data; and leveraging the diversity of global Earth science communities to advance open science.

Thanks to ESDS, *Open Access for Open Science* is not just a slogan – it is a reality.