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Workshop on Using NASA Data for Time-Sensitive Applications

Over the past decade, there has been an increase in the use of NASA's Earth Observing System (EOS) data and imagery for time-sensitive applications such as monitoring wildfires, floods, and extreme weather events. In September 2016, NASA sponsored a workshop for data users, producers, and scientists to discuss the needs of time-sensitive science applications.

TIME-SENSITIVE APPLICATIONS OF NASA DATA: WORKSHOP OVERVIEW

A workshop titled "Time-Sensitive Applications of NASA Data" was held at the NASA Langley Research Center (LaRC) in Hampton, Virginia, on 27–29 September 2016 to identify, coordinate, and focus attention on low-latency satellite data. The meeting, supported by NASA's Earth Science Data System Program and NASA's Applied Sciences Program, was the first time a group of NASA data users, producers, and scientists had gathered to discuss the needs of time-sensitive science applications.

Applications are uses of satellite remote-sensing data products by individuals and organizations for a variety of purposes that fall mainly within the NASA Applied Science Program's application areas, including disasters, health and air quality, water resources, wildfires, and ecological forecasting [1]. Many of these applications have short decision time frames that require rapid processing and analysis of data to inform daily decisions [2]. Such time-sensitive applications require satellite data with very short data latency. The workshop attendees agreed that *data latency* should be defined as the time between data acquisition and the availability of a data product for end users to employ in decision making, and, in the following, we use the term in this sense throughout.

The objectives of the workshop were as follows:

- describe and characterize the existing NASA low-latency data portfolio in Earth science
- articulate the issues and challenges of low-latency data acquisition and management

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- determine which NASA low-latency data requirements are not being met
- determine which data sets could be provided in the coming decade.

All discussions were framed with the intent of developing a strategy to enable low-latency data for future NASA missions. A series of plenary sessions and breakout meetings were organized to achieve the meeting's objectives.

WHAT DO WE MEAN BY LOW LATENCY?

The terms *near real-time* (*NRT*), *low latency*, and *expedited* all refer to data that are made available more quickly than routine processing allows. Initially, the terms were used interchangeably, but workshop attendees categorized the latency of data sets as follow:

- real time: under 1 h
- NRT: 1–3 h
- low latency: 3–24 h
- expedited: 1–4 d.

For the purposes of this article, the term *low latency* will be used to describe all data sets made available more quickly than routine processing allows.

In the context of NASA data, low-latency products are distinct from EOS standard data products, which provide an internally consistent, well-calibrated record of Earth's geophysical properties to support scientific research. One key difference between low-latency and standard data products is that low-latency geolocation may not be as accurate because the standard products use the best knowledge of the spacecraft position and attitude, which may not be available until after the low-latency products are produced. For example, the geolocation difference between moderate resolution imaging spectroradiometer (MODIS) NRT and standard products is routinely fewer than 100 m; however, there are situations, particularly before and after spacecraft maneuvers and during space weather events, when the difference can increase up to several kilometers [3]. A second key difference is the relaxed requirements that enable products to be delivered with reduced processing times; these vary for each low-latency product.

NASA AND DATA LATENCY

NASA missions are designed to address Earth science research questions. These questions are used to derive level 1 science requirements, which are defined early in the mission development process and provide the basis for the engineering decisions made throughout the planning of the mission. For a science mission to be successful, the data generated must be sufficiently accurate and observed over enough time to address the science questions within cost and schedule constraints. In this context, data latency is not always a primary concern during mission development and can be a secondary objective. For applied science and operational uses as well as some scientific investigations, data latency is a major factor in determining the utility of data for making decisions.

To produce low-latency data products, many components of the EOS satellite operations, ground, and science processing systems have been made more efficient without compromising the quality of science data processing. This is largely achieved by creating a dual processing stream that leverages components originally developed for science data processing and augments them with features that allow for more efficient processing within NASA's EOS Data and Information System (EOSDIS). The main components of EOSDIS are

- the EOS spacecraft and instruments
- the ground systems, which include flight operations, data capture, and level 0 processing (see https://science.nasa.gov/earth-science/earth-science-data/data-processing-levels-for-eosdis-data-products)
- the science data segment responsible for producing data products
- the websites, search clients, or other methods of making the data available.

In addition to data latency, users of low-latency data also need to consider the time to the next observation. This measure is important to data users because, in most cases, they will need to update the information to make the next decision. For example, if the satellite passes over a location once a day but this overpass is 1 h after a decision needs to be made, then the user will have to use observations that are 23-h old, regardless of when the data product is made available.

NASA HEADQUARTERS' PERSPECTIVE

Staff from NASA's headquarters provided workshop participants with an overview of how low-latency data fit within the Earth Science program. Dr. Michael Freilich, director of NASA's Earth Science Division (ESD), reminded plenary participants that NASA's ESD is primarily a science organization and that science research objectives outweigh support for NRT uses of data when they are in direct conflict. However, NASA's ESD endeavors to provide low-latency data products when doing so involves small additional costs and increases the societal value of NASA's investment in Earth observation.

Christine Bonniksen, Soil Moisture Active Passive (SMAP) mission program executive with the ESD, provided NASA's mission perspective on support for NRT data production. Dr. Bonniksen said that data latency for new missions must be considered in the embryonic stage of mission planning. Once the design process begins, changes in latency design should not be expected unless funding from a source outside of flight programs is identified.

Kevin Murphy, the program executive for Earth Science Data Systems with the ESD, emphasized the importance of discoverability and usability of low-latency data. Acknowledging that most searches begin with a search engine, he highlighted the need to develop keywords for data products and services that serve a global audience. He encouraged workshop participants to leverage existing frameworks (see Table 1) to raise the visibility of NASA low-latency data within and outside of NASA. David Green, program manager for Disaster Applications at NASA headquarters, emphasized the

TABLE 1. COMMON FRAMEWORKS THAT KNIT NASA'S DATA AND SERVICES TOGETHER AND SO CAN BE USED TO RAISE THE VISIBILITY OF LOW-LATENCY DATA WITHIN AND OUTSIDE NASA.

ROLE	FRAMEWORK	DESCRIPTION
Data inventory	CMR*	The CMR combines several existing metadata systems, such as the EOS Clearing House, into a single unified metadata model that will be able to support the growing needs of EOSDIS in the future.
Image repository	GIBS†	GIBS continually acquires imagery from NASA data providers, creates a global mosaic of the data, and then partitions it into an image tile pyramid. This enables GIBS to rapidly serve low-latency and standard imagery products. GIBS enables users to interactively explore data to support a wide range of applications, including scientific research, applied sciences, natural hazard monitoring, and outreach. Data visualizations provided through GIBS can also be viewed using the EOSDIS Worldview.‡
Data access	Open-Source Project for a Network Data Access Protocol (OPeNDAP)	OPeNDAP provides remote access to individual variables within data sets in a form usable by many tools. NASA provides a subset of all data through OPeNDAP.**

*https://earthdata.nasa.gov/cmr; †https://earthdata.nasa.gov/gibs; ‡https://worldview.earthdata.nasa.gov/; **https://www.opendap.org/.

TABLE 2. APPLICATIONS AND LOW-LATENCY DATA PRESENTATIONS AT THE WORKSHOP.

PRESENTATION	SPEAKER AND AFFILIATION
"Hazards Data Distribution System/NRT Landsat Data"	Brenda Jones, U.S. Geological Survey
"NRT Data for Committee on Earth Observation Satellites and Group on Earth Observations"	Stuart Frye, NASA Goddard Space Flight Center (GSFC)
"Advances in Technology: Improving Delivery and Accessibility of NASA's NRT Data"	Mike Little, NASA headquarters
"Agricultural and Drought Monitoring Through the Global Agricultural Monitoring System"	Bob Tetrault, U.S. FAS; Chris Justice, University of Maryland (UMD), College Park
"Use of Satellite Data Within Weather Decision-Support Systems"	Brad Zavodsky, NASA Marshall Space Flight Center (MSFC); Short-Term Prediction Research and Transition Center
"Fire Data and Users"	Wilfrid Schroeder, UMD; Karyn Tabor, Conservation International
"Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP)-Derived NRT Aerosols Applied in Naval Research Laboratory (NRL) NRT Data Products"	Dave Winker, LaRC; Kim Richardson, NRL
"Low-Latency Data Sets for Time-Sensitive Applications under the U.S. EPA AirNow Program: Regional-to-Global Air Quality"	Jim Szykman, NASA LaRC
"NASA Satellite Imagery–Based Cloud Property and Clear-Sky Temperature Retrieval Data Sets"	Patrick Minnis, NASA LaRC

importance of NRT for time-sensitive applications and the disasters community.

LOW-LATENCY DATA FOR TIME-SENSITIVE APPLICATIONS

Low-latency data from NASA's current missions have been incorporated into applications that support operational agencies, including the U.S. Department of Agriculture's Foreign Agriculture Service (FAS) [4], the Environmental Protection Agency (EPA) [5], and the U.S. Forest Service fire monitoring [6].

Presentations at the workshop (see Table 2) highlighted the importance of low-latency data for a range of applications and concluded that ongoing investment in the development of low-latency data and products will enable increased societal benefits, particularly if data discoverability is improved.

The tolerance for data latency is often explicit to a given application [7]. Many future NASA missions have data products that may be extremely valuable for operational and decision-making purposes if they can reach the applied communities quickly after collection.

SOURCES OF LOW-LATENCY DATA

NASA low-latency data can be obtained from several sources, including the Land, Atmosphere Near-Real-Time Capability for EOS (LANCE; https://earthdata.nasa.gov/lance) (see "Land, Atmosphere Near-Real-Time Capability for EOS"); NASA's Precipitation Processing System (https://pps.gsfc.nasa.gov/); The Distributed Active Archive Centers (DAAC), such as the Ocean Biology DAAC (https://oceancolor.gsfc.nasa.gov) and the Physical Oceanography DAAC (https://podaac.jpl.nasa.gov); the Alaska Satellite Data Facility (https://www.asf

.alaska.edu); and direct broadcast stations (https://directreadout.sci.gsfc.nasa.gov). In addition to satellite missions, low-latency data are captured from NASA instruments on board the International Space Station (ISS) and those deployed during field campaigns. Presentations during the workshop (Table 3) highlighted the types and sources of NASA low-latency data.

Land, Atmosphere Near-Real-Time Capability for Earth Observing Systems

In 2009, the NASA Earth Science Division sponsored the development of Land, Atmosphere Near-Real-Time Capability for EOS (LANCE; https://earthdata.nasa.gov/earth-observation-data/near-real-time) to provide a central point of access to high-quality near-real-time (NRT) data products and imagery for land and atmosphere studies [8]. LANCE offers more than 100 NRT data products created from data collected by sensors aboard NASA's orbiting *Aqua, Aura, Suomi National Polar-Orbiting Partnership* (*S-NPP*), and *Terra* satellites and, for the purpose of data continuity, also from the Advanced Microwave Scanning Radiometer 2 aboard the Japan Aerospace Exploration Agency's Global Change Observation Mission–Water.

The latency requirement for level 2 products from LANCE is 3 h from instrument observation to product availability to users for download. NRT imagery is generally available in Global Imagery Browse Services (GIBS) Worldview 3–5 h after observation. The 3-h data latency requirement was enforced at the first LANCE User Working Group (UWG) meeting in November 2010 by representatives requiring satellite-derived products to monitor fires, dust storms, floods, crops, volcanic clouds, and various weather conditions where direct broadcast data were not available [9]. The Worldview tool enables users to conduct NRT visual analysis of dynamic global processes as they are occurring, such as wildland fires, dust storms, and volcanic eruptions (Figure S1) and then download the underlying data.

LANCE is managed by NASA's Earth Science Data and Information System (ESDIS) but steered by a UWG responsible for providing guidance and recommendations concerning a broad range of topics related to the LANCE system, capabilities, and services. The UWG represents the broad needs of the LANCE applications user communities, while maintaining close ties with the various science teams for the instruments included in LANCE. The UWG meets at least once a year to ensure that LANCE capabilities are aligned with the NRT community needs and to consider adding new products to LANCE. UWG recommendations are made to ESDIS and evaluated in terms of feasibility and cost of implementation [3].

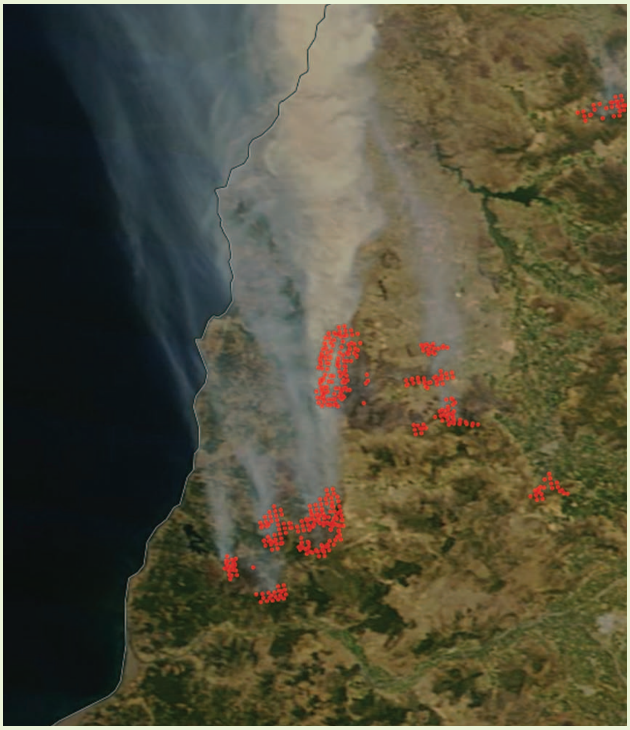

FIGURE S1. LANCE, GIBS, and Worldview enable events like wildfires to be observed in NRT, such as this image of forest fires in central Chile from 20 January 2017. The red dots are hotspots detected by the moderate resolution imaging spectroradiometer instruments aboard the *Aqua* and *Terra* satellites and by the Visible Infrared Imaging Radiometer Suite instrument aboard the *S-NPP* satellite. The white areas are smoke. (Image courtesy of NASA Worldview; https://go.nasa.gov/2urWtlm.)

TABLE 3. PRESENTATIONS ON SOURCES OF LOW-LATENCY DATA.

SOURCE	PRESENTER AND AFFILIATION
"LANCE"	Chris Justice, UMD, LANCE User Working Group chair
"Direct Readout Laboratory (DRL)"	Kelvin Brentzel, DRL, NASA GSFC
"Overview of the Near-Real Time Data Potential of the International Space Station"	William Stefanov, associate ISS program scientist for EO, NASA Johnson Space Center
"RapidScat from the ISS"	Alex Fore, NASA Jet Propulsion Laboratory
"Lightning Imaging Sensor from the ISS (Expected 2017)"	Michael Goodman, NASA Marshall Space Flight Center
"NRT Data from Field Campaigns"	Don Sullivan, NASA Ames Research Center; Jay Al-Saadi, NASA LaRC

LOW-LATENCY DATA INVENTORY

Key information presented at the meeting was an inventory of all low-latency Earth science data sets currently available, as well as those expected to be available from new sensors in the coming decade. The inventory was created using an online spreadsheet. Information captured in the inventory includes the product name, data provider, expected latency, and a list of applications for which each data product is potentially useful. Low-latency data sets that are currently available are summarized in Table 4.

During the next five to ten years, the data products from the following missions are expected:

- Joint Polar Satellite System-1 and -2
- Ice, Cloud, and Land Elevation Satellite-2
- Gravity Recovery and Climate Experiment Follow-On
- Surface Water Ocean Topography
- Plankton, Aerosol, Cloud, Ocean Ecosystem
- Hyperspectral Infrared Imager
- Time-Resolved Observations of Precipitation Structure and Storm Intensity with a Constellation of SmallSats

TABLE 4. A SNAPSHOT OF CURRENTLY AVAILABLE EARTH SCIENCE LOW-LATENCY DATA SETS FROM THE INVENTORY.

EXISTING MISSIONS	INSTRUMENT	NUMBER OF PRODUCTS	LATENCY TERM	LATENCY RANGE
Aqua	Clouds and the Earth's Radiant Energy System (CERES)	5	Expedited	4–5 d
Aqua	MODIS	26	NRT	<3 h
Aqua	Atmospheric Infrared Sounder	8	NRT	<3 h
Aura	Ozone Monitoring Instrument	5	NRT	<3 h
Aura	Microwave Limb Sounder	7	NRT	<3 h
CALIPSO	CALIOP	5	Expedited	6–30 h
Global Change Observation Mission–Water	Advanced Microwave Scanning Radiometer 2	8	NRT	<3 h
Global Precipitation Measurement	Global Microwave Imager/Multiple	12	NRT expedited	1–16 h
Gravity Recovery and Climate Experiment	Multiple	1	Expedited	Monthly
Suomi National Polar-Orbiting Partnership (S-NPP)	Advanced Technology Microwave Sounder	2	NRT	<3 h
S-NPP	CERES	5	Expedited	4–6 d
S-NPP	Visible Infrared Imaging Radiometer Suite	20	NRT	<3 h
S-NPP	Ozone Mapper Profiler Suite	4	NRT	<3 h
Terra	Advanced Spaceborne Thermal Emission and Reflection Radiometer	2	Low latency	<24 h
Terra	CERES	5	Expedited	4–6 d
Terra	MODIS	33	NRT	<3 h
Terra	Measurement of Pollution in the Troposphere*	1	NRT	<3 h
Terra	Multi-Angle Imaging SpectroRadiometer	3	NRT	<3 h
JASON-2, 3	Poseidon-3, 3b	1	Expedited	<24 h
Landsat 7	Enhanced Thematic Mapper Plus	1	Low latency	4–8 h
Landsat 8	Operational Land Imager/Thermal Infrared Sensor	1	Low latency	4–8 h
SMAP	L-band Passive	2	Low latency	4–7 h
ISS Missions	Cloud-Aerosol Transport System	4	Low latency	4–7 h
ISS Missions	Lightning Imaging Sensor*	2	Real time	<30 min
ISS Missions	High-Definition Earth Viewing	1	Real time	<30 min
ISS Missions	Crew observations	1	Expedited	24+ h
Geostationary	Advanced Baseline Imager for Geostationary Operational Environmental Satellites (GOES)	6	Real time	5–30 min
GMAO Models	GOES 5 processing	1	NRT	6 h
	Total	**173**		

*Not yet active/proposed. Real time: <1 h; NRT: 1–3 h; low latency: 3–24 h; expedited: 1–4 d. For more about each mission, see https://www.nasa.gov/missions.

- Tropospheric Emissions: Monitoring of Pollution
- NASA-India Space Research Organization synthetic aperture radar.

The complete table is available online (http://tinyurl.com/nhmv9ky).

DATA DISCOVERABILITY AND USABILITY

Creating an inventory is one step toward making data more visible, but workshop attendees emphasized that improving discoverability and usability would make the data more accessible. Data discoverability enables potential end users to determine what data are available and where they can be obtained; the inventory documents the low-latency data, but users expect to be able to find data through geospatial search clients and search engines.

Data usability enables users to easily visualize or integrate the data into analysis tools to facilitate data use; this could be through making data available in easy-to-use formats (e.g., Geographical Information System-ready formats), making the data available for machine-to-machine access, or enabling users to interactively browse full-resolution imagery. NASA's EOSDIS has existing capabilities for discovery and visualization. Such capabilities include the Common Metadata Repository, Global Imagery Browse Services (GIBS), Worldview, and the Earthdata Search Client (https://search.earthdata.nasa.gov).

SUMMARY OF WORKSHOP RECOMMENDATIONS

The workshop highlighted the importance of low-latency data for a range of applications and concluded that ongoing investment in the development of NRT data and products will enable increased societal benefit, particularly if outreach and data discoverability are improved. The workshop recommendations include

1) actions to accelerate data discoverability and access
2) improved data usability
3) early engagement between new missions and the NRT community to encourage mission development in support of NRT data (when feasible within science requirements).

NASA could improve data discoverability by requiring that all NASA programs producing low-latency Earth observation data register their products in the CMR. The CMR could consider registering both NASA applications products and non-NASA–funded operational products that use NASA data. Where feasible, imagery from low-latency data products should also be added to GIBS to enable visualization. Specific actions to increase data access include custom low-latency data portals and adding key low-latency modeling products into Worldview and GIBS.

Improving data usability is as important to the community as accelerating data discoverability and access. It was recommended that NASA increase training opportunities and conduct case studies that enhance data usability. NASA already makes some data sets available as web-based mapping services and is working to expand this capability further. This is particularly relevant, as many operational and application users do not have appropriate remote-sensing expertise or capability to process data at their facility computers.

As the uptake of NRT data increases, there is a need to engage with new missions to encourage NRT data availability for operational decision makers. The workshop recommended that future solicitations and directed missions evaluate data latency and the benefits and costs of providing NRT data vis-à-vis the benefit to operational decision makers. Adding such an evaluation within phase A (mission proposal review) would help ensure that mission teams have an opportunity to explore the benefits of including low-latency data products in their mission concepts. To do this, it is recommended that, during the prephase A stage (concept formulation), mission teams survey the user communities to determine the value of low-latency products and the possibilities for accommodating NRT data without compromising a mission's primary science objectives.

> **IMPROVING DATA USABILITY IS AS IMPORTANT TO THE COMMUNITY AS ACCELERATING DATA DISCOVERABILITY AND ACCESS.**

CONCLUSIONS

NASA successfully leverages existing systems to provide low-latency ESD data at little extra cost to the standard processing, search, and delivery systems. Looking to the future, representatives from NASA headquarters agreed to continue this approach and consider additional low-latency data sets from new missions where large populations of supporters would significantly benefit from their delivery. In doing so, NASA will continue to increase the societal value of its investment in Earth observations.

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