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PRACTICE PAPER

Importance and Incorporation of User Feedback in Earth Science Data Stewardship

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Since August 1994, The National Aeronautics and Space Administration's (NASA's) Earth Observing System Data and Information System (EOSDIS) has been serving a global community of users, currently over 4 million each year, with Earth science data in a variety of disciplines. NASA's Earth Science Data and Information System Project (ESDIS) is responsible for EOSDIS with its 12 Distributed Archive Centers (DAACs). During the life of EOSDIS, various mechanisms for user feedback have been extremely important and valuable to its evolution. Some inputs from user groups have resulted in fundamental changes in EOSDIS, while others have provided ideas for incremental changes. The purpose of this paper is to share this experience and the benefits that have resulted from the user feedback. Notable among user community groups that have had significant influence on EOSDIS are: the EOSDIS Advisory Panel, the National Research Council's Committee on Global Change Research and the DAAC User Working Groups (UWGs). In addition, an annual survey of EOSDIS users resulting in the American Customer Satisfaction Index (ACSI) provides a score as well as very helpful user suggestions for system improvements. Also, each DAAC has a user services group that receives on-going requests for help and other comments from users. The ESDIS Project has established a mechanism through the "earthdata" web site (http://earthdata.nasa.gov) for users to provide feedback which is routed to appropriate individuals. In addition, focused efforts have been made for user needs assessment, and usability studies are used in making changes to the systems for improving user experience.

Keywords: Data Systems; User Feedback; Usability Assessment; User Working Groups; NASA EOSDIS; DAAC

1. Introduction

Since August 1994, The National Aeronautics and Space Administration's (NASA's) Earth Observing System Data and Information System (EOSDIS) has been serving Earth science data in a variety of disciplines to a global community of users, currently over 4 million each year. EOSDIS processes, archives and distributes data and derived digital products resulting from spaceborne and airborne instruments as well as in situ measurements from field campaigns. For the 12 months ending on September 30, 2018, the total distribution of data worldwide exceeded 1.6 billion files of data (products). The volume distributed during this period was over 24 Petabytes, averaging 66.8 Terabytes per day. The Earth Science Data and Information System (ESDIS) Project at the NASA Goddard Space Flight Center manages EOSDIS with its 12 Distributed Active Archive Centers (DAACs) at various locations in the United States. The ESDIS Project is a Network Member of the International Science Council (ISC)/World Data System (WDS) and 10 of the 12 DAACs are its Regular Members. During the entire life of EOSDIS, starting with the establishment of the ESDIS Project in 1990, various mechanisms for user feedback have been extremely important and valuable to its evolution and proven performance.

The ESDIS Project makes sure to engage users in many ways to ensure broad participation using survey mechanisms, focus groups and individual feedback. Using a survey mechanism, we are able to access thousands of users for information on their interactions with NASA and Earth science data in a broad context. Using focus groups allows the Project to meet face-to-face on a continuous basis to get in-depth insight to

user needs and data access patterns. These group sessions serve to uncover detailed information on usage and future requirements. Finally, users can request help with our systems directly through help buttons on our websites. These are particular conversations with individual users allowing deeper insight into problems, issues, and suggestions which later on can be mined in aggregate for trends and user needs. The sample sizes of users (ranging from tens to thousands) and the depth of the feedback provided are illustrated in **Figure 1** below. The larger the sample size, the less deep is the users' evaluation of the capabilities. However, the feedback is valuable in all cases.

Some inputs from user groups have resulted in fundamental changes in the architecture, design and operations of EOSDIS, while others have provided ideas for incremental changes. The fundamental changes have come from review groups that have performed focused assessments at a conceptual level, looking at the overall system and advising on how the components should be organized to benefit the user community. For example, a new DAAC was added in 2008 based on community input. The ideas for incremental change come from groups using the system capabilities on an on-going basis and advising on how specific capabilities and services can be improved or added. A User Needs Group (UNG) with cross-DAAC membership holds regular technical interchange meetings to assimilate the feedback from various sources, categorize the needs, organize them into topical areas, and make recommendations for implementation. The purpose of this paper is to share this experience and the benefits that have resulted from the user feedback, with the expectation that the experiences from this long-lived project can be applied by other organizations developing and operating data systems.

The rest of the paper is organized as follows. Section 2 covers the early influences on the development and architecture of EOSDIS by the inputs by various user groups and committees. Section 3 presents the charter, functions and examples of feedback by DAAC User Working Groups. Section 4 describes currently active feedback mechanisms including user surveys that have been conducted annually since 2004, usability studies and direct inputs from users on the coordinating central website for EOSDIS (https://earthdata.nasa.gov). Section 5 presents the activities that the ESDIS project conducts with other NASA-funded data system activities through the Earth Science Data System Working Groups (ESDSWG), and with the broader community of Earth Science Information Partners (ESIP). These groups bring together data system professionals to help discuss users' needs and technology improvements required to satisfy them effectively. Section 6 describes mechanisms used by the ESDIS Project to assimilate and act on the user feedback from various sources discussed earlier. Section 7 provides a summary and conclusions.

2. Early Influences

In early to mid-1990s, the Earth Observing System (EOS) Investigators' Working Group (IWG) formed several panels for providing inputs to various aspects of the EOS Program. Among them, the EOSDIS Advisory Panel (a.k.a. Data Panel), consisting of experts representing the broad Earth science community of poten-

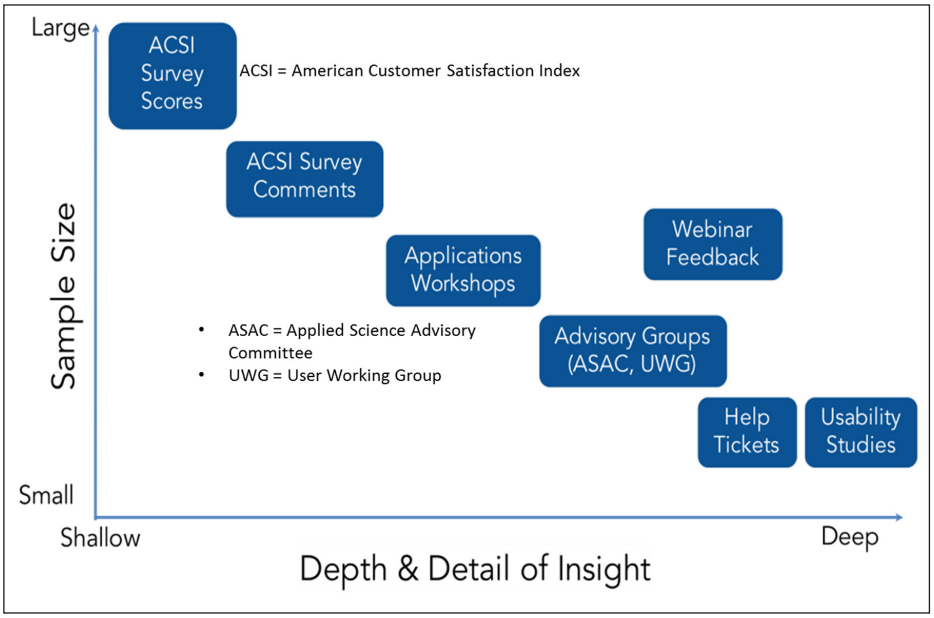

Figure 1: Sample size vs. depth and detail of insight in user feedback.

tial users of EOSDIS, provided significant inputs for the architecture and design of EOSDIS (Dozier, 1990). Recognizing the long life expected of EOSDIS, and consequent changes in information technology and user needs, this panel strongly recommended a flexible, distributed, portable and evolutionary design. The panel also urged NASA to take advantage of existing expertise in Earth science data management and develop prototype systems to gain experience and prepare for the onslaught of data expected with the launch of EOS Terra in 1999. In response, NASA established a set of DAACs collocated with expertise in various Earth science disciplines, and initiated development of a "working prototype with operating elements" called Version 0 EOSDIS (Ramapriyan and McConaughy 1991), which went into operation in August 1994. The Data Panel also participated in many of the requirement and design reviews and influenced the design through their comments.

In 1995, the U.S. National Research Council's Committee on Global Change Research conducted a review of the U.S. Global Change Research Program and NASA's Mission to Planet Earth/EOS, including the plans for EOSDIS (NRC 1995). One of this committee's recommendations was that the "Responsibility for product generation and publication and for user services should be transferred to a federation of partners selected through a competitive process open to all". NASA did not follow this recommendation literally but, for some aspects of Earth science information management, initiated an experiment with a "self-governing" federation. It consisted initially of 24 competitively selected Earth Science Information Partners (ESIPs), one half chosen to produce specialized research products and the other for products suitable for applications with commercial potential. This experimental federation was called the Working Prototype ESIP (WP-ESIP) Federation (Isbell and Kenitzer 1997). While this experiment was in progress NASA constituted a "New Data and Information Systems and Services (NewDISS) Strategy Team", which consisted of expert scientific users, Earth science data managers, information technologists and NASA program personnel. In the early 2000s, this team looked at the evolution over the next 6–10 years of data systems to serve the Earth science research community, given the state of the development of EOSDIS and the on-going WP-ESIP activities (Maiden et al. 2000). The recommendations from this team included a transition to a more decentralized and competitive data system, while taking advantage of the progress made with the DAACs and the on-going EOSDIS development. In implementing the recommendations of the NewDISS Strategy Team, NASA continued its sponsorship of and support for the evolution of the WP-ESIP into a "real" federation (i.e., dropping the Working Prototype nomenclature), and established competitive programs to select and fund data system components for innovative technology development as well as new products (ESIP 2017). As a result of this, EOSDIS has two major types of capabilities: 1. Core capabilities for ensuring stable, sustained operational support for processing, archiving and distributing data; and 2. Competitively selected community capabilities where a broader set of participants can contribute innovative ideas for data system capabilities that could migrate into the core capabilities in the future. Earth Science Data System Working Groups (ESDSWG) were established by NASA to catalyze interactions between the core and community data system groups and ensure that various technical issues affecting system evolution were analyzed and recommendations made for improvement (Ramapriyan 2009).

This federation, with support from NASA, the National Oceanographic and Atmospheric Administration (NOAA) and the U.S. Geological Survey (USGS), has now grown into the Earth Science Information Partners (ESIP) with over 120 member organizations including the EOSDIS DAACs as well as several government agencies, universities and commercial entities. The ESIP celebrated its 20th anniversary in 2018 (ESIP, 2019). Individuals from the ESDIS Project and the DAACs take an active role in many of the ESIP committees, clusters and working groups. Such participation facilitates exchange of information about technologies relevant to NASA's Earth science data management.

The current activities of the ESDSWG and ESIP will be presented briefly in section 5 below.

3. DAAC User Working Groups

In the 1990's when the DAACs began operations, it was determined that they would need a focus group of science users to advise them and NASA on issues facing data management and progress in discipline science. Each of the EOSDIS DAACs has a User Working Group (UWG) that represents broad user communities in the Earth science disciplines it serves. The UWGs range in size between 10 and 15 members. This appears to be a good size to allow for active discussions, while covering the breadth of disciplines served by a given DAAC. The membership changes with regular rotation of members, typically 3 years where a subset of members is replaced. This provides sufficient time for new members to familiarize themselves with the DAAC and the UWG, and to contribute ideas before leaving the UWG. However, the 3-year rotation is not a strict rule, given the voluntary participation by experts. Each of the UWGs has a charter. Common aspects of these charters are (Ramapriyan and de Sherbinin 2018):

- 'Ensure science user involvement in the planning, development, and operations of the DAAC.
- Provide recommendations on the DAAC's annual work plans and long-range planning.
- Represent the science user community in reviewing and guiding the DAAC activities.
- Review progress and performance of the DAAC relative to its missions.
- Assess data-products and service quality by periodically reviewing applications of the data products made by the broad user community, and by sampling the confidence of the user community.
- Communicate users' assessment of the DAAC performance to the DAAC and NASA.
- Advise the DAAC on the levels of service provided to the user community.
- Advise the DAAC on improvements to the user access, user interface and relative priorities for DAAC-related functions.
- Recommend to the DAAC and NASA the addition of new data products and new services based upon documented NASA research needs.
- Provide advice on research and development in support of product prototyping and generation.'

The UWGs meet periodically (typically once a year) with the respective DAAC personnel and the ESDIS Project to assess progress and provide feedback on the dataset and service priorities. Occasionally, UWGs for two or more DAACs that serve data in similar disciplines hold joint meetings to ensure cross-fertilization. As regular users of the data and services of the DAAC and experts in the scientific disciplines, the UWG members provide valuable inputs for planning and prioritizing the services as well as addition of new datasets for the benefit of the community. As a result of the interactions with the UWGs, NASA has developed systematic processes for accessioning new, community-proposed datasets and adding community-developed tools and services. The processes involve assessment of the value of such datasets, tools and services by the UWG, assessment by the DAACs and the ESDIS Project of resource requirements for accommodating them and approving implementation at the appropriate NASA management level depending on the extent of resources needed.

4. Other On-going Feedback Mechanisms

Among on-going mechanisms for user feedback are user surveys that have been conducted annually since 2004, usability studies, and direct inputs from users on the coordinating central website for EOSDIS (https://earthdata.nasa.gov). These are discussed briefly in the subsections below.

4.1. User surveys

The EOSDIS is evaluated annually through a survey of its users resulting in the American Customer Satisfaction Index (ACSI). This has been conducted by the CFI Group, an organization external to NASA (CFI Group, 2013), starting in 2004. The CFI Group performs such evaluations, as an unbiased independent entity, for over 235 companies and over 130 customer programs and services in US federal agencies, thus providing a basis for comparison across a large number of organizations. The core part of the survey consists of approximately 30 questions that apply across all of EOSDIS. Each DAAC has the ability to provide 10 specific questions in addition to the core questions. Most of the questions can be answered in 15 minutes using a picklist or provide a rating of capabilities on a scale of 1 to 10. There are also some open-ended questions calling for comments and suggestions from the users. The questions cover the following areas: Customer Support, Product Selection and Order, Product Search, Product Documentation, Product Quality, and Delivery. However, the ACSI methodology for the CFI Group's exclusive customer satisfaction index relies on three basic facets: perceived value, perceived quality and customer expectations. More details about the methodology are available from https://m.theacsi.org/about-acsi/the-science-of-customer-satisfaction.

Each year the questionnaire is reviewed, updated and distributed to several thousand users of the DAACs. Our user community has grown since 2004 and the present number of users receiving the surveys has grown from about 10,000 to 285,000. The numbers of responses each year have been in the thousands, while the response rate has varied from 11% when the number of requests was small to 1% when the number was large. In all years, the numbers of responses were large enough to be considered by the CFI Group to be statistically significant for the purposes of evaluation. The detailed results from each year's survey are available at ESDIS (2019). The survey provides an ACSI score as well as free-form suggestions from users, for each of the DAACs as well as for EOSDIS as a whole. The free-form suggestions are very helpful in making specific system improvements. The EOSDIS scores over the period 2004–2018 have ranged between 74 and 79, with an average of 76.8. This compares with the overall US federal government scores that have ranged between 64 and 72, with an average of 68.3. The consistently high scores in light of all the changes incorporated in the EOSDIS framework over the 15 years of the survey shows that the attention to users pays off.

4.2. Usability studies

The ESDIS Project sponsors periodic studies of usability of its websites and systems. The websites include https://earthdata.nasa.gov developed and maintained by the Project, as well as those of the individual DAACs. One such study, assessing the websites, was conducted by Blink (2019), a user experience research and design firm. It consisted of detailed interviews with 91 representative users of the 12 DAACs to record the details of their experiences when they performed various tasks requiring interactions with the websites. The interviews were conducted while the users were performing tasks, or immediately thereafter, so that the experiences would be fresh in their minds. Each user was asked to name a primary DAAC and a secondary DAAC with which they would interact to accomplish their tasks. The stages in their tasks included: Background study to decide which DAAC to go to for their data of interest, Data Discovery, Finding the Right Dataset, Evaluating the Data, Downloading the Data, Preparing the Data, Processing the Data, and Creating the Output. Each of the users was queried as to the processes they went through at each stage and the challenges they faced, and recommendations were made as to how the challenges could be alleviated by improved design of the structure and content of the websites. While the details of the study and the in-depth recommendations are beyond the scope of this paper, some of the recommendations are summarized below to illustrate the types of the study outputs.

- Improve consistency in navigation while allowing for DAAC uniqueness.
- On the front of the DAAC, allow for DAAC themes, which help explain the purpose of the DAAC and allows users to quickly access the data.
- Reducing additional cognitive load will aid participants. For example, user interactions on web pages could be the same across all DAACs and all tools and consistent navigation structures across DAACs should also allow for flexibility for individual DAAC uniqueness.
- Improvements for non-website issues that would help participants include the following:
    - Display clear messaging during system downtime.
    - Create a clear path/link to the new location when data are moved.
    - Display search results by relevance within DAACs.

This study is one way that the Project is looking at for improving the user experience and user interfaces at the DAACs following the latest commercial trends.

4.3. User services

Each DAAC has a user services group that can be contacted by users for assistance as well as for providing suggestions for improvement in capabilities. The DAACs may receive information directly via e-mail or inputs on their websites. Also, the website https://earthdata.nasa.gov offers a “feedback” button where users may offer suggestions and/or request assistance. Such inputs are routed to the appropriate DAAC user services’ staff or individuals in the ESDIS project with the relevant expertise. Typically the DAACs receive over 300 help requests per month. Each question is tracked as a ticket using the Kayako software system. User questions are addressed within 24 hours of receipt with 72% of all questions (i.e. tickets) closed within a two-week period. Another 7% of the Kayako tickets remain open for at least 8 weeks pending reply from the user before the staff closes them as non-responsive. The other 21% of the tickets take longer than two weeks to resolve. Having a tool, such as Kayako, allows the entire staff to understand the nature of the user questions and how well we answer these questions. For example, common questions can be moved to Frequently Asked Questions (FAQ). Some questions may be examples of errors or miscommunication, which we directly address. This personal interaction is one of the reasons that the ACSI satisfaction index, mentioned in section 4.1, is high as shown in the annual reports. Despite the success we have in responding to user questions today, our system has issues. For example, a few questions from users today cross science disciplines and could be addressed better by two or more DAACs, where the current system assigns a single ticket to be addressed by a single DAAC. Scalability is another issue that we need to resolve as more users want help, the current system would break down if we have twice as many questions as we do today. The ESDIS Project is currently engaged in looking at Customer Relationship Management (CRM) software to improve our current mechanisms to interact with current and potential customers and to develop alternative ways to get users the information that they need.

4.4. Webinars

The ESDIS Project conducts regular webinars attended by many members of the global user community (ESDIS 2018). The webinars cover various topics related to discovering, accessing and using Earth science data. The speakers are technical staff members from the ESDIS Project and DAACs as well as expert scientific

users of EOSDIS data and services. At each webinar, attendees provide feedback about the presentation as well as the data and services. Feedback generated on-line during each webinar and a question and answer session following it is sent to the speakers following the event. User input and data tool/data product feedback gleaned from these online interactions are often considered and addressed in a future webinar held by the same DAAC. This in-depth input may be used by the DAACs in evaluating where there are gaps in addressing user needs, and the ESDIS Project for identifying future webinar topics. Since the inception of the Earthdata Webinar series in May 2013, we have held 105 webinars attended by over 9,500 participants from over 100 countries. These webinars are saved and posted on our Earthdata YouTube channel. There are over 100 video recordings of these webinars located at: https://www.youtube.com/c/NASAEarthdata.

5. Cross-fertilization for Technical Information Exchange

In addition to feedback from users of Earth science data, communications among organizations involved in managing Earth science data and information are also highly beneficial for continued evolution of system capabilities to benefit the community. The Earth Science Data System Working Groups (ESDSWG) and the Earth Science Information Partners (ESIP) were introduced briefly in section 2 above. Each of these will be discussed in the subsections below.

5.1. ESDSWG

The ESDSWG was established by NASA in 2004 as a mechanism for communications among the NASA Earth science data system entities consisting of staff members from the ESDIS Project, the DAACs, and other organizations competitively selected by NASA for data system research opportunities. This "working group" represents the collection of experts in science data systems that are directly funded by NASA. Each year, members from these teams assess key technical topics of interest for their benefit to the users of the data systems. They initiate subgroups to address the topics, define and analyze problems, and recommend solutions to be considered for implementation in EOSDIS. The duration of activities taken up by the working groups may range from less than a year to a few years. Topics being considered by the working groups during 2018–2019 are: Cloud Analytics Reference Architecture, Data Product Developers Guide, Data Quality, Dataset Interoperability, and Implementations of Data Value Filtering among others. More information on the ESDSWG can be found at: https://earthdata.nasa.gov/collaborate/esdswg. Some examples of results from ESDSWG groups include: updates to the NASA data management plan templates that included more data quality information, adoption of recommendations on data interoperability through a review conducted by the ESDIS Standards Office, adoption of specific variable naming conventions, etc.

5.2. ESIP

The ESIP is a "virtual" organization with over 120 organizational members including the ESDIS Project, EOSDIS DAACs as well as several government agencies, universities and commercial entities (ESIP, 2019). The governance structure of the ESIP permits voluntary collaboration among members through a number of committees, working groups and clusters. There are currently four committees (Data Stewardship, Education, Information Technology and Interoperability, and Semantic Technologies) and two working groups (Data Management Training Clearinghouse and Visioneers). There are 28 clusters covering a wide range of interests expressed by ESIP members. Examples of clusters are: Cloud Computing, Data to Decisions, Data Model, Discovery, Documentation, Information Quality, Machine Learning, Research Data Management, Software and Services Citations, Usability, and Web Services. There are common topics of interest between the NASA Working Groups described in subsection 5.1 above and the ESIP committees, working groups and clusters. Participation in the ESIP provides opportunities for EOSDIS entities to exchange ideas in a broader community and feeds into evolution strategies for EOSDIS. Examples of impact of ESIP participation on EOSDIS are: adoption of OpenSearch, use of Digital Object Identifiers for datasets, development of a citation and acknowledgement policy, development of Earth Science Data Preservation Content Specifications and its adoption for NASA missions, etc.

6. Assimilating and Acting on User Feedback

The feedback gathered from users through the various mechanisms discussed above is analyzed by the ESDIS Project and the DAACs regularly and actions are taken for improving the EOSDIS capabilities. A User Needs Group (UNG) with cross-DAAC membership holds regular technical interchange meetings to assimilate the feedback, categorize the needs, organize them into topical areas, and make recommendations for implementation. Its main objective is to identify high impact needs that can resolve issues common to multiple

DAACs. A User Needs Repository is used to assist in gathering needs expressed through various feedback mechanisms. A few recent examples of recommendations from the UNG are given below:

- Formalize science communications activities across EOSDIS
- Conduct a new usability study for end-to-end journey of accessing and using data
- Investigate ways to measure impact of social media and outreach
- Continue to track bulk data download-related recommendations to ensure a positive user experience for bulk data download
- Explore, define, and document benefits of common user experience on EOSDIS Application Program Interfaces (APIs)

The ESDIS Project also holds regular technical interchange meetings of a cross-DAAC system engineering group, which considers all aspects of system development. Recommendations from the UNG are factored into the system development and evolution plans and systematically dispositioned.

7. Summary and Conclusions

Figure 2 summarizes the history of the various user feedback mechanisms that have influenced and continue to affect EOSDIS as described in the above sections.

Today, the focus on user needs is more important than ever. Looking toward a future where we will be ingesting and archiving well over 60 PB of science data per year from just two new NASA missions in addition to the current operational load from existing missions, the users will need improved services to discover the data that they need. Over the years the ESDIS and its component groups, e.g., the DAACs, have learned new ways to reach out to the user community. Being aware of software and applications trends in the market will allow the Project to take advantage of new ways to support the user community. Efforts to increase connection with the community include more focused sessions with users. For example, usability studies are performed periodically through personal interviews and observations as volunteer users interact with EOSDIS to discover and access data. Results of such studies are organized and ranked in order to focus the development efforts on the most needed services. Technical interchanges among our user services staff also help us assign priorities to system modifications for improving user experience. All of these are input to our latest efforts and system evolution, which will substantially rely on commercial cloud structures to improve access to large quantities of temporally and spatially organized Earth Science data.

The various means of receiving user feedback and responding to them have been extremely valuable in evolving the EOSDIS from the initial concepts to today's major system that serves a global community with consistently high user satisfaction ratings. It is through these working groups, surveys and direct communications with users that the detailed feedback on specific actions is received. These are ideas for incremental changes such as improvements to documentation, data formats supported, metadata completeness, provision of data quality information, subsetting, reprojection and visualization services. While the

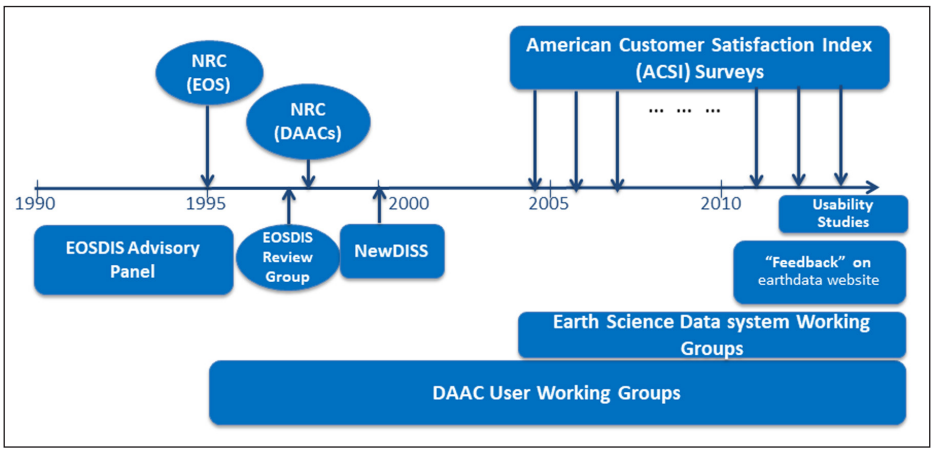

Figure 2: User feedback mechanisms over the life of EOSDIS. Arrows in the figure represent reports provided at specific times. Boxes with no arrows represent longer-term activities that have feedback throughout, with occasional formal reports. The boxes at the right end of the figure represent on-going mechanisms.

experience of EOSDIS is based on the size and longevity of the system, some of the user feedback mechanisms that have developed over the life-time of EOSDIS can be adopted by other data repositories and systems that serve various user communities.

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Competing Interests

The authors have no competing interests to declare.

Author Contribution

Both authors are experienced in the work of NASA's Earth Science Data and Information System (ESDIS) Project and contributed significantly to writing this paper that documents the interactions of the Project with its user community. Ramapriyan prepared the initial draft of the paper and both authors edited and revised to prepare it for publication.

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