Geoscience Data for Educational Use: Recommendations from Scientific/Technical and Educational Communities

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ABSTRACT

Access to geoscience data has been difficult for many educators. Understanding what educators want in terms of data has been equally difficult for scientists. From 2004 to 2009, we conducted annual workshops that brought together scientists, data providers, data analysis tool specialists, educators, and curriculum developers to better understand data use, access, and user-community needs. All users desired more access to data that provide an opportunity to conduct queries, as well as visual/graphical displays on geoscience data without the barriers presented by specialized data formats or software knowledge. Presented here is a framework for examining data access from a workflow perspective, a redefinition of data not as products but as learning opportunities, and finally, results from a Data Use Survey collected during six workshops that indicate a preference for easy-to-obtain data that allow users to graph, map, and recognize patterns using educationally familiar tools (e.g., Excel and Google Earth). © *2012 National Association of Geoscience Teachers*. [DOI: 10.5408/12-297.1]

Key words: geoscience data, data use, data access, workshop

INTRODUCTION

The use of scientific data can best be characterized in the context of workflow: from data acquisition and documentation regarding acquisition quality, to raw storage, to analysis resulting in derivatives of the original data, such as model output and visualizations (Reichman et al., 2011). Access to scientific data at each stage has been difficult for educators. Newly acquired data are often proprietary or, if available, only open to users well versed in the acronymic vocabulary. Raw data are often stored in formats (e.g., hierarchical data format, or HDF) that are unusable with the simple data analysis software (e.g., Excel) common among educators. Finally, data derivatives such as LandSat images provide useful information but don't provide much opportunity for data analysis (unless the user is well versed in remote sensing).

Hence, what can we learn about data access and use from 7 years of Digital Library for Earth System Education data services (DDS) and subsequent AccessData workshops (http://serc.carleton.edu/usingdata/accessdata/index.html)? Attending the workshops were scientists and data providers (scientific/technical community) and educators and curriculum developers (educational community). Participants were organized into teams of four to six participants, with each area of community expertise represented. We present here a three-part discussion. First, we briefly examine the history of the data workflow problem (in regards to scientific/technical and educational communities). Second, we clarify scientific data in terms of usefulness for the educational community. Finally, we present what DDS and AccessData workshop participants, representing both the scientific/technical and the educational communities, said about data use.

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THE DATA WORKFLOW PROBLEM

Despite recognition in *Science for All Americans* that science demands evidence derived from data (Rutherford, 1990), scientific data are perceived by educators as enigmatic. This often leads to frustration in accessing and selecting data, because the data type and usability are unclear. Almost always, the tasks of parsing the data and making decisions about how to conduct proper analyses are up to the end user or, in this case, the educator (Ledley et al., 2008).

As handheld devices (e.g., Vernier probes) became more popular in schools during the late 1990s, teachers and researchers found learning value in student-collected data (Tatar et al., 2003). However, school network infrastructure and functionality, including access to outside scientific dataset sources, were still a challenge for teachers. Moreover, teachers lacked the necessary knowledge to extract, parse, and import datasets into data visualization and analysis software tools still largely reserved for scientists (e.g., ArcInfo).

Notwithstanding the technical barriers, the education community in the late 1990s and early 2000s recognized the importance of the use of scientific data in supporting student inquiry. Access to raw, derivative, or model data streams supports students' knowledge construction about data uncertainties and improves students' quantitative skills (Manduca and Mogk, 2002; Creilson et al., 2008). Simultaneously, curriculum developers looked for data that could be easily incorporated into labs or activities without the need for middleware, extensive data analysis, or expensive display software. Educators agreed that data provide a rich context from which inquiry can be learned (Bransford et al., 1999).

Since the early 1990s, there have been rapid advances in climate research and remote-sensed data sources—so much so that the National Aeronautics and Space Administration

(NASA) and other government agencies began making data readily available to both scientists and the public. Initially, publicly available data products were images, as exemplified by NASA's announcement in 1994 that it intended to make space and science data available via the World Wide Web (Bell, 1994). The workflow problem for public (educators) still existed. In the scientific/technical community, workflow concerns about data moved beyond storage to the richness and usefulness of data (Baraniuk, 2011). Usefulness still meant *for scientists*.

In the early 2000s, the DDS project was born. Our goal was to engage the educational community in access to and analysis of scientific data—essentially, responding to the workflow issue of usefulness. The workshop model presented by Ledley et al. (2012, in this issue) provides a good structure for the educational community to engage in real-world questions and analysis with the scientific/technical community. Essentially, the workshop model solves the workflow problem for the educational community.

From 2004 to 2009, we conducted annual workshops with teams consisting of a scientist, data provider, tool specialist, curriculum developer, and educator. Each team was charged with identifying a particular dataset or several datasets that would be of interest to the geoscience education community. A team initiated this focus by completing a DataSheet (Ledley et al., 2008), which described a particular scientific dataset with human-readable, educationally relevant metadata to facilitate exploration of the data by educators and students (http://serc.carleton.edu/usingdata/browse_sheets.html). Essentially, the DataSheet provided a critical opportunity for both the scientific/technical and the educational communities to openly discuss and resolve the data workflow problem.

DataSheets highlight the connections among datasets, specific topics in science, and skills students can build by using the dataset. DataSheets also identify the analysis tools that can be used to access and analyze the data and provide examples of resources, when available, of how to acquire, interpret, and analyze the data. Information is presented at a level appropriate for those who don't have specialized knowledge of the discipline in which the data are commonly used. DataSheets are designed to support novice or out-of-field data users by providing them with the knowledge necessary to obtain and use data appropriately for scientific explorations. DataSheets also provide the meanings for acronyms and other jargon that users are likely to encounter and include links to journal articles and educational resources that cite or use the data.

Parallel to the identification of the dataset, the workshop team determined an appropriate analysis tool would assist the team in developing a case study. The case study provided the foundation for much of the team's workshop efforts: developing a story line that afforded a reason for caring about the data and a framework for creating an Earth Exploration Toolbook chapter (Ledley et al., 2011), an online activity that provides step-by-step instructions for accessing and analyzing the data around a scientific concept or issue.

DEFINING LEVELS OF DATA FOR LEARNING OPPORTUNITIES

In 2004, the NASA Earth Observing System (EOS) created four levels of data products, which were both spatially and temporally described, and served as the basis for data distribution to the broader geoscience community (King et al., 2004):

- Level 0—Raw binary
- Level 1A—Unprocessed instrument data
- Level 1B—Processed data into sensor units
- Level 2—Data derived into geophysical variables
- Level 3—Geophysical variables mapped in uniform space and time
- Level 4—Model output or analysis output that includes lower-level data.

The processed EOS data were almost entirely stored and distributed in HDF—a format not useful to the educational community.

If we are to consider the workflow characteristic *usefulness* for educators, then we must rethink the data products in terms of learning opportunities (Table I). Thus, we consider rethinking level 2 data—the first opportunity for data analysis—to be stored in universal formats rather than technical formats. In addition, level 2 data should include metadata characterized from the scientific workflow. Finally, adding level 5 data as easy-to-use or display-image data distinguishes the data product from level 4, which may still provide data analysis opportunities.

With the data levels redefined, the first opportunity for educational use is with level 1A data. Here, a student collecting "temperature" data in the field with a handheld, electronic datalogger would really be collecting electronic signals (i.e., millivolts). However, the datalogger's firmware would interpret the millivolt readings as temperature outputs. The student may not be fully aware of the firmware, unless the student task is to check the sensor operability by analyzing the millivolt output. Scientists and data providers might consider publishing level 1A data, particularly for students who might be interested in sensor analysis.

Educators could also find level 1B data useful, because level 1B data provide an opportunity for students to check for erroneous data outputs. In the era of simpler, easier-to-use data visualization tools—such as MyWorldGIS (http://www.myworldgis.org/), Environmental Systems Research Institute's (ESRI's) ArcGIS Explorer (http://www.esri.com), and Google Earth (http://www.google.com)—redefining level 2–4 data becomes increasingly important.

Despite inherent ease of use, EOS did not describe a level 5 product. However, we define level 5 as static derivative imagery, such as Graphics Interchange Format (.gif) or Joint Photographic Experts Group (.jpg), used primarily in education for presentations. ImageJ (http://rsbweb.nih.gov/ij/index.html) was presented in the 2006 AccessData workshop as a tool for displaying, editing, analyzing, and processing of 8-bit, 16-bit, and 32-bit .gif and .jpg images. Using ImageJ in the educational setting constitutes use at level 4 with level 5 data formats.

WHAT WORKSHOP PARTICIPANTS SAID ABOUT DATA USE

Data informing this commentary were collected through the use of an anonymously delivered Data Use Survey, which consisted of 10 questions (Table II). A total of 237

TABLE I: Levels of data defined based on data format and learning opportunities. Adapted from NASA's EOS; levels 0, 1a, 1b, 3, and 4 are the original four data levels described by EOS.

Level	Characterized by	Learning Opportunities	Possible Education Obstacles	Example End-User Analysis
Level 0	Raw binary format; sensory input	Where data comes from	Often requires engineering knowledge; needs an expert observer	
Level 1A	Reconstructed, unprocessed instrument data	Interpretation and uncertainty	Requires software-specific programming knowledge	Analyze sensor output for functionality
Level 1B	Data reprocessed into sensor units but perhaps with both known and unknown errors	Spatial and temporal data discovery skills; improved certainty in data, particularly with analysis of error	Teacher time constraints related to data extraction; students' lack basic of statistical knowledge for examining errors	Analyze for sensor error that may lead to erroneous results
Level 2	Data in a basic, universally acceptable format (e.g., .txt)	Importing data for analysis; opportunity for error analysis if complemented by metadata (data about data)	Time constraints for importing data into analysis software	Spreadsheet applications: graphing; statistics
Level 3	Variables mapped with known spatial scales (latitude and longitude or grid)	Different ways to visually display data in response to new scientific questions; user control of data; distributed data access	Metadata, if missing; potentially expensive analysis and/or display software	GIS mapping; queries
Level 4	Visual (usually) display of data analysis or modeling output (e.g., line graph or map)	Quick access to data/ information; visually stimulating; good gateway for sophisticated data analysis on data from all levels	Metadata, if missing; potentially expensive analysis and/or display software	Visualization or image (pixel) analysis; modeling; classification
Level 5	Easy-to-use/universal display-image data	Presentation of information	Cannot be manipulated in pursuit of new questions	Pattern recognition on static images

participants responded to the Data Use Survey (2005–2009). In the survey, participants self-identified with one or more workshop roles: scientist, data provider, educator, tool specialist, or educator. However, for the purpose of this analysis, we only examined the participant's primary self-identification. Of the 237 total respondents, 56% primarily identified with the scientific/technical community and 46% identified with the educational community.

The Data Use Survey provided insight into the participants' current experience of using geoscience data in

TABLE II: Questions asked on the data use survey (2005–2009). Questions in 2004 were revised to inform the survey.

Number	Type	Question
1	Multiple response	What is your primary role at the Data Services workshop? (Please mark your primary role with a "1" and check any others that apply.)
2	Multiple response	For which learning goals have you successfully used data within educational contexts? (Check all that apply.)
3	Multiple response	Which of the following data have you used successfully? (Check all that apply.)
4	Multiple response	Which of the following data formats have you used successfully? (Check all that apply.)
5	Multiple response	Which of the following data sources have you used more than once? (Check all that apply.)
6	Single response	Have you found it necessary to modify datasets before they were used by an end-user/learner (e.g., selected subset, imported into Excel)?
7	Multiple response	What data analysis/visualization tools do you commonly use?
8	Multiple response	What data analysis procedures have your end-users/learners performed on the data? (Check all that apply.)
9	Rank	Have you made any attempts to obtain and use datasets that were NOT successful? If yes, what barriers did you encounter? (Please rank 1, 2, and 3 in order of priority.)
10	Multiple response	What types of instruction or support are most helpful to you when using specific datasets? (Check all that apply.)

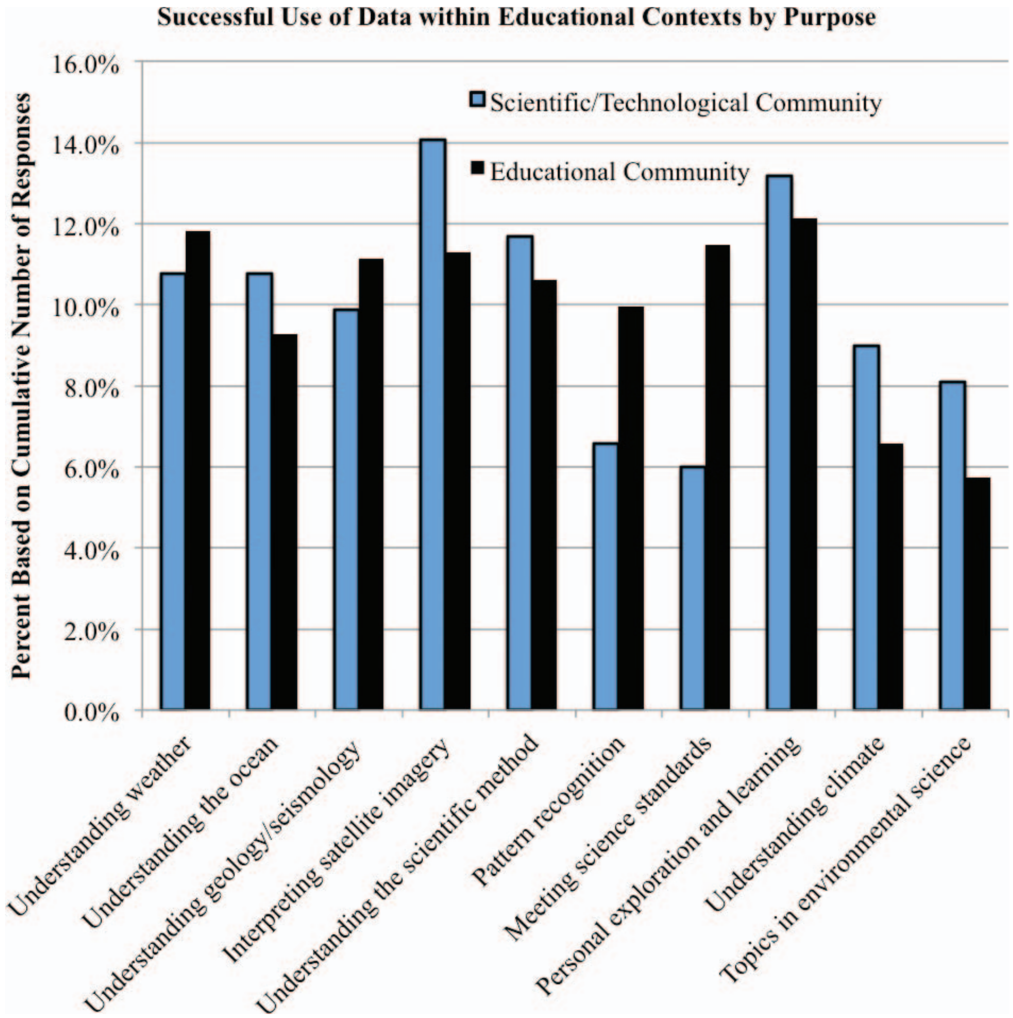

FIGURE 1: Successful use of data within educational contexts, as identified by purpose, derived from Data Use Survey question 2, "For which learning goals have you successfully used data within educational contexts? (Check all that apply.)" Understanding Climate and Topics in Environmental Science were added in 2007.

achieving educational goals. Open-ended questions were categorized and coded for dominant themes. Surveys were distributed to participants by an external evaluator in scheduled sessions, and time was allotted for participants to complete the surveys before leaving the session. This methodology is helpful in maximizing response (>90%).

The first workshop (2004) provided opportunities to refine the Data Use Survey questions. The 2004 survey asked open-ended questions that led to the development of the pointed survey questions for subsequent workshops. Each workshop provided a unique population of attendees giving unique responses. Most questions resulted in multiple response data and were categorized using dichotomies. The data were then analyzed using a simple frequency procedure for all variables that constituted the set of possible answers. The frequency procedure used in the analysis produced both counts and percentages for all variables that made up the multiple response set. The advantage here is that the reported percentages are based on the total number of responses for each participant role (i.e., the educational community or the scientific/technical community).

Successful Use of Data in Educational Contexts

When asked about the purpose for which a participant successfully used data within educational contexts, the scientific/technical community identified *interpreting satellite imagery* (14.1%) and *personal exploration and learning* (13.2%) as their top two choices (Fig. 1). The educational community identified *personal exploration* (12.1%) and *understanding weather* (11.8%) as their top two choices. Not surprisingly, weather maps and satellite imagery are visual and offer both geoscientists and educators an opportunity to quickly view and analyze level 4 data, level 5 data, or both (Table I). In addition, 11.5% of the educational community is interested in using data to *meet science education standards* and for *pattern recognition* (a common task for performing inquiry in the classroom), whereas only 6% of the scientific/technical community is interested in using data for meeting science standards.

The educational and scientific/technical communities both value *graphing*, *data visualization*, and *mapping* as end-user analysis methods (Fig. 2). This complements the desire for science educators to have students experience *doing science* (Manduca and Mogk, 2002). Graphing of level 1–3 data provides unique opportunities to understand uncer-

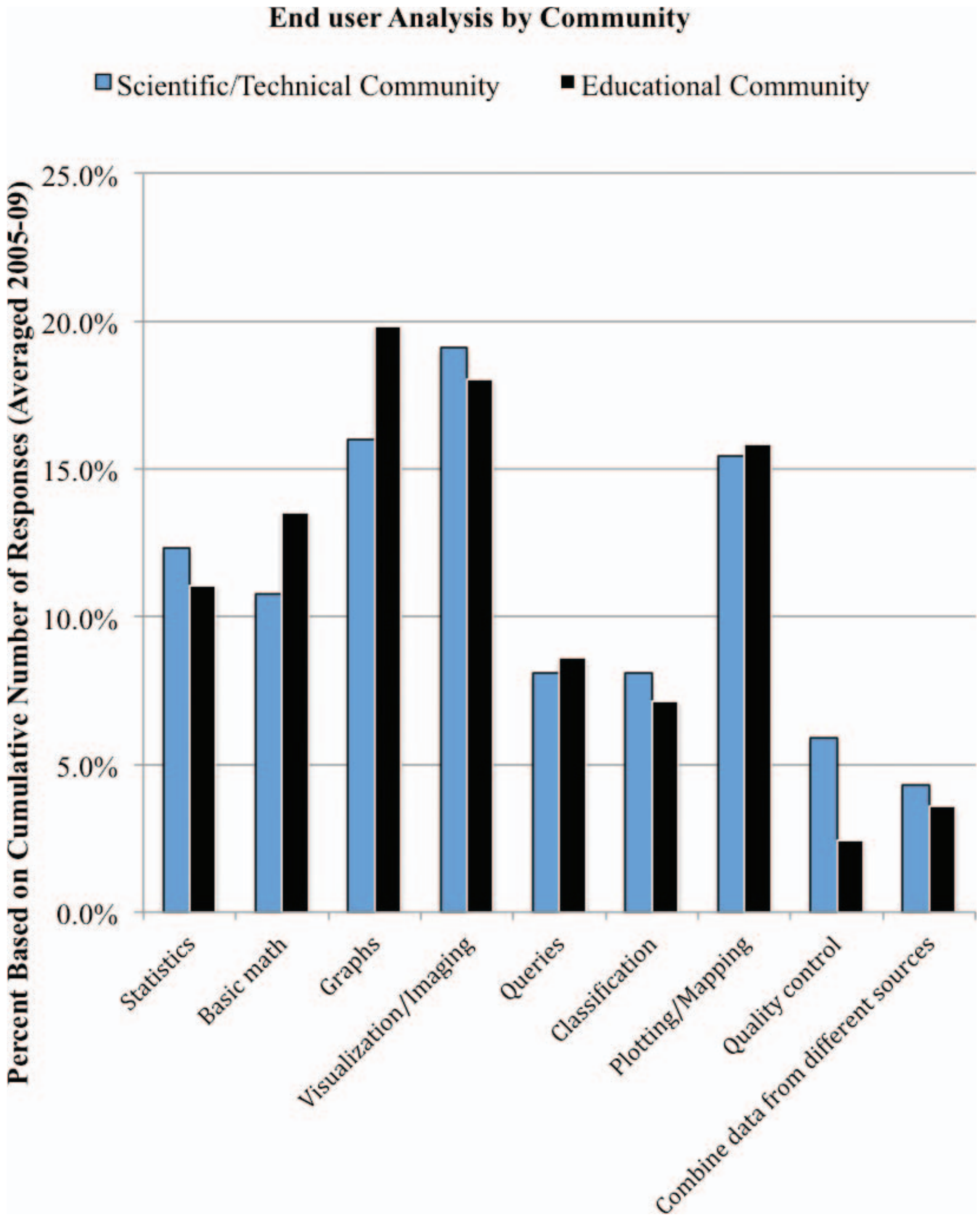

FIGURE 2: Preferred end-user analysis methods as differentiated by community. Data derived from Data Use Survey question 8, "What data analysis procedures have your end-users/learners performed on the data? (Check all that apply.)"

tainty and the importance of manipulating data (Metz, 2004). The visualization and mapping of level 2 data, with geographic coordinates, and the manipulation of level 3 data provide learners with the opportunity to learn symbolism, associated with developing the necessary cognitive spatial and temporal skills to conduct queries on multiple datasets (Downs et al., 1988; Kastens et al., 2009; Montello, 2009). Further analysis on the end-user preference of data analysis methods did not reveal any significant trends from 2005 to 2009.

Workshop attendees were asked to indicate preferred geoscience data formats (.txt, NetCDF, .jpg, etc.) for successful educational use of data. Initially, in 2005, users from both the educational and the scientific/technical communities preferred level 4 or 5 image data (Table I), because the data were readily available and easy to use (e.g., in presentations) without the need for sophisticated, specialized application–server interfacing software or middleware (Fig. 3). However, by 2007, all users indicated a preference for visualization-based level 3 data (i.e., geographic information system, or GIS). This more than likely coincides with the emergence of virtual "globes," such as NASA's WorldWind, ESRI's ArcGIS Voyager, Pasco Scientific's MyWorld GIS, and Google Earth, as educator-friendly tools for teaching about the Earth (Kerski, 2008).

NASA and the United States Geological Survey (USGS) were the predominant choices for data sources of both user communities (Fig. 4). This is most likely due to both government agencies offering all levels of data for the public. Moreover, NASA and the USGS, along with the

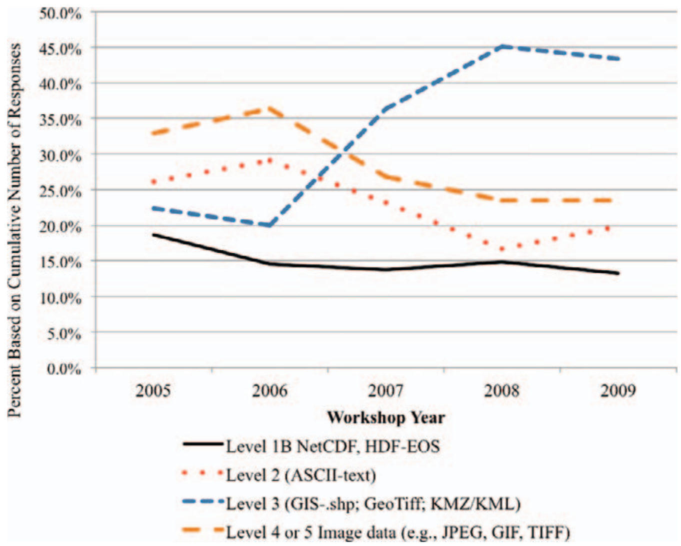

FIGURE 3: Change in data preference by level from 2005 to 2009 workshops. Data by all users are presented. The increase in 2007 for level 3 data preference was dominated by an increase in preference by the educational community. NetCDF, or network common data form, is a collection of data libraries commonly used by atmospheric scientists. HDF-EOS is a multiobject file format commonly used in NASA's EOS. ASCII-Text is a common form of data usually presented as .csv or comma-separated values. GIS (.shp) is a spatial data file commonly used in ESRI products. GeoTiff is a metadata file embedded in a Tagged Image File Format image. A KMZ file is a compressed Keyhole Markup Language file used by Google Earth. The .jpg and .gif files are commonly used in digital imagery.

Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA), have geoscience data collection as an important part of their mission. Interestingly, the EPA and the Global Learning and Observations to Benefit the Environment (GLOBE) program were preferred more by the educational community than by the scientific/technical community. In the case of GLOBE, data are largely collected and used by the educational community.

RECOMMENDATIONS

Continued Need for Overcoming Barriers to Accessing Data (Educational Workflow)

During the first three workshops (2004–2006), scientific/technical and educational communities both identified five primary barriers to data access:

1. Users not being able to locate desired data
2. Unusable formats or unknown file extensions associated with the data
3. Poor documentation (metadata)
4. Datasets too large for parsing
5. Users not having required software for processing or analyzing datasets.

By 2006, workshop participants indicated a reduction in some barriers. In particular, participants indicated major improvements in the first two barriers: locating data and finding data in usable formats. Participants also indicated slight improvements in locating metadata associated with datasets. However, datasets are still either too large or too difficult to parse for meeting the specific learning needs of educators. In addition, developing sophisticated analysis (e.g., knowledge about building Google Earth's .kmz files) is beyond the knowledge of most classroom teachers.

The AccessData team conducted a follow-up workshop in February 2010, where previous workshop participants were invited to a special Impacts workshop. The participants were placed in three groups of 10 people and asked to reflect on open-ended questions, such as "Has participation in the workshop(s) impacted the way you have used/prepared geoscience data or tools in/for education?"

Self-identified scientists in the Impacts workshop articulated the importance of having an educator as a partner on the scientific research team. The educator provides expertise in helping the scientist determine how to make the research data easier for educators to use. Educators in the Impacts workshop indicated that involving information technology specialists at the institutional level was key to overcoming issues with data access. Thus, involving educators in scientific projects and technology specialists in educational activities are two significant recommendations (Lynds and Buhr, 2009, 2010a, 2010b).

One final recommendation is related to the support necessary for successful use of data for education activities. Both user communities suggested three critical components for improving data access and use (listed by priority):

1. Providing real-world examples, in the context of scientific questions, for users accessing data
2. Developing step-by-step instructions to fully understand how to conduct analysis on the data
3. Providing online (video) tutorials, coupled with metadata.

Data can now be delivered using a client server approach, where the end user no longer has to mine the Web for data sources that match formats required by analysis software. The scientific/technical community needs to portray quality, integrity, and relevance of data. This means presenting data in context (e.g., a visual image of an ocean ridge providing a link to geophysical data, such as a USGS earthquake map). The scientific/technical community also needs to provide detailed metadata with its datasets. The metadata should provide sufficient detail so that required insider information to access data (e.g., the name of the ship or cruise number if the user is looking to plot ocean salinity data) is either not necessary or easily indexed.

Importantly, scientists should engage educators at the beginning of research projects so that the project team can make informed decisions about how and in what context data will be accessed, processed, and analyzed. Clearly, the educational community has a strong desire for data that offer opportunities for data analysis by students.

Educators need to be aware of the potential for metacognitive learning that data levels 2–4 present. Educators know knowledge building happens when the learner can conduct meaningful analysis. As the scientific/technical

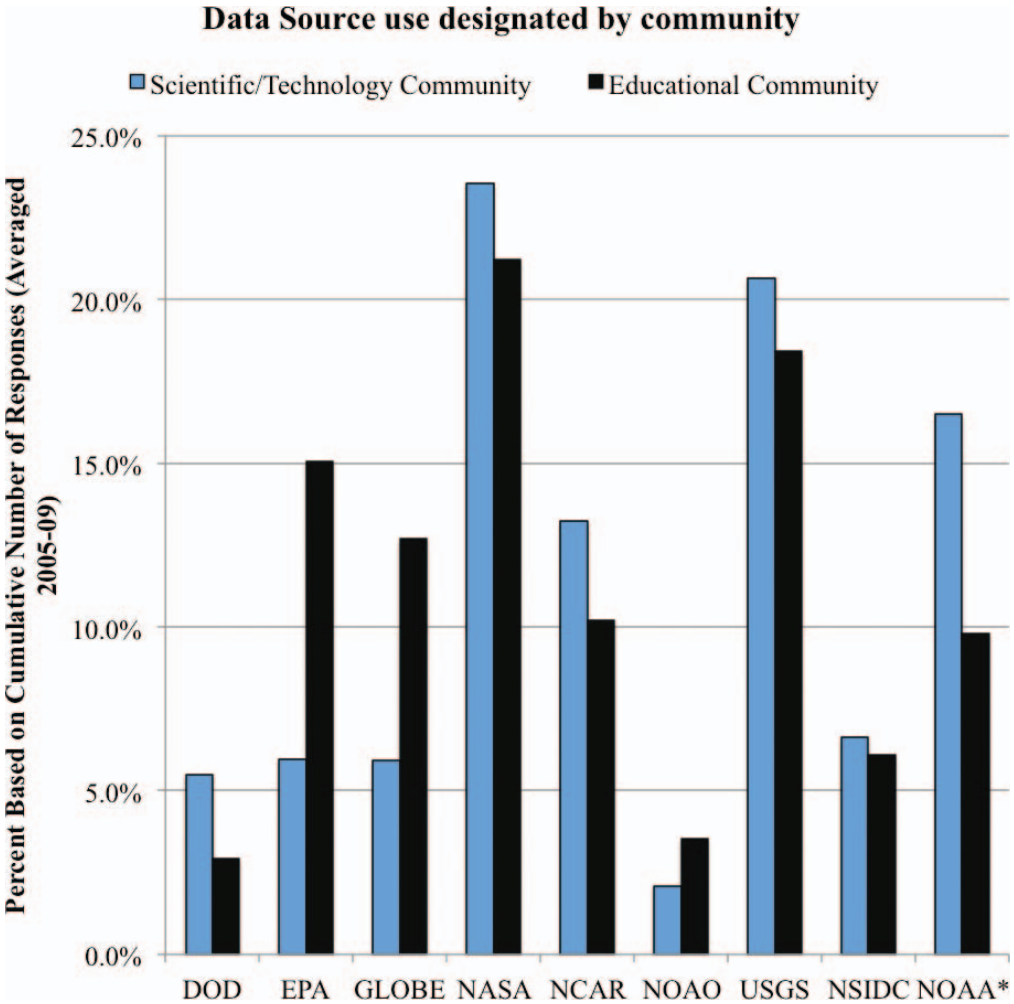

FIGURE 4: Data source use designated by scientific/technical and educational communities. Data derived from Data Use Survey question 5, "Which of the following data sources have you used more than once? (Check all that apply.)" *NOAA data sources include the National Climatic Data Center, National Weather Service, National Geophysical Data Center, and National Oceanic Data Center. NOAA received a single count per survey if one or more of the preceding sources were selected.

community makes level 2 and 3 data access and use easier, the educational community needs to revisit the curriculum, adding the extra time necessary for students to process level 2 and 3 data. Tools such as spreadsheet applications and spatial analysis are becoming increasingly important for educators to embrace and integrate into their teaching. As the scientific/technical community moves to engage the educational community more significantly in research projects, the end result will be a richer, scientifically based, user-friendly set of data available for the classroom.

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