Revealing Our Melting Past: Rescuing Historical Snow and Ice Data

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Publication Statement

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GeoResJ 14 (2017) 92–97

Contents lists available at ScienceDirect

GeoResJ

journal homepage: www.elsevier.com/locate/georesj

Revealing our melting past: Rescuing historical snow and ice data

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ARTICLE INFO

Article history:
Received 14 May 2017
Revised 16 October 2017
Accepted 27 October 2017
Available online 28 October 2017

ABSTRACT

Analog archival data can supplement modern digital research, but only if those data are preserved, described, and migrated to appropriate formats. The National Snow and Ice Data Center (NSIDC) at the University of Colorado Boulder (CU) is responsible for managing, archiving, and disseminating cryospheric and polar data. The clear majority of these data are digital, but the NSIDC also houses a collection of historical archival materials that include measurements related to the earth's glaciated regions prior to the development of modern instrumentation. Their formats, however, are not conducive to contemporary analysis, rendering them ostensibly "lost" to research. This paper describes a series of efforts to provide access to these collections that date back to their original acquisition, as long ago as the mid-nineteenth century, with focus primarily on activities over the last 15 years. The most recent effort was funded by the Council on Library & Information Resources and won the 2016 International Data Rescue Award. The intent is to highlight key challenges, and our proposed own solutions to those challenges, in designing a digitization project centered on providing online access to analog data in glaciological, geomorphological, and related research.

1. Introduction

The International Coalition of Scientific Union's Committee on Data (CODATA) long included a Data at Risk Task Group, which was "concerned with the plight of many sets of scientific data which are not in modern electronic formats and whose information is therefore not accessible to the research that needs it" [1]. Somewhat synonymously referred to as 'legacy' or 'heritage' data (or with respect to format, as "analog" data), they are usually available from one generation to the next not due to foresight or active planning or preservation efforts, but "more by circumstance than by design, and reflect a woeful lack of any planning for use by future generations for whatever purpose(s) they might eventually serve" [2]. Preserving these data, whether for intentional or potential analysis, can be a costly process, requiring labor-intensive physical processing, arranging, curating, description, and digitization. The effort and expense, however, has contributed greatly to research in biodiversity, oceanography, climatology, and other disciplines [2].

Such is the case with NSIDC's Analog Archives Collection, which houses legacy sea ice charts, maps, explorer diaries, more than 20,000 glacier photograph prints dating back to the 1850s, and other imagery of ice covered regions. The collection began when William O. Field started collecting historical materials, including many taken by Harry F. Reid, recognized as one of the early pioneers in geophysics and glaciology [3]. Collected by Field after Reid's death in 1945, the materials include approximately 5000 prints, 600 glass plate negatives and prints, 22 expedition notebooks, and about 1 cubic foot of manuscript materials (including drafts of Reid's map of Glacier Bay). Other subsets include:

- 13 Rocky Mountain National Park Glacier Survey Reports and the accompanying 264 glacier photographs;
- 79 terrestrial photographs taken by chemist and mountaineer Fred D. Ayres in Peru during the 1950s;
- 360 images of Colorado's Arapaho Glacier taken in the early 1900s by Junius Henderson (first curator of the University of Colorado Museum of Natural History), and;

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https://doi.org/10.1016/j.grj.2017.10.002

- Over 1200 photographs of Greenland glaciers, donated by the U.S. Coast Guard.

Additional materials, such as images from southern Colorado, Glacier National Park, the Cascades, and much of Alaska across several decades, have been added to the collection, which continues to grow even today.

These analog, heritage data have been carefully preserved for over forty years by volunteers, scientists, librarians, and archivists, and are a part of the history and current activities of NSIDC.

1.1. Scientists looking to the future: a data center's history

Photographing discoveries of glaciological expeditions began with the invention of the camera. The first International Polar Year (IPY) of 1881–1884 created a wealth of data [4]. One expedition, led by Lieutenant Adolphus Greely, to Lady Franklin Bay off the northeastern shore of Ellesmere Island, endured immense hardship, sacrifice, and even death, all to preserve data they had so laboriously obtained:

"Greely was aware that if a relief steamer did not arrive after their second winter they would be forced to retreat to safety on their own. He made condensed copies of their scientific records (amounting to some 500 observations per day for two years), and when they abandoned Fort Conger in August 1883 they took with them—in lieu of extra rations—these copies sealed in three tin boxes weighing 50 pounds each…The scientific records were the only meaningful legacy of their effort. If they were lost, all of their hardships would have been for nothing" [5].

Of the 24 men that started the expedition, only six, including Greely, survived. They realized the paramount need to preserve their work for use by other scientists in the future, and other scientists have also had this same realization, including William O. Field.

As a young glaciologist, Field realized the need for a place to house historical photographs and notebooks like those from the Greely expedition. In 1932, Field started a collection with $100 USD remaining from one of his earlier expeditions [6]. Initially, the collection was housed in the office of another glaciologist at the Library of Congress. Field found various funding sources through the years for the collection, finally bringing it under ownership of the American Geophysical Society (AGS) in 1945 where he worked at the time.

In 1957, during the first International Geophysical Year (IGY), the U.S. National Committee for the IGY awarded the operation of World Data Center A for Glaciology (WDC-A) to the AGS under the direction of Field. World Data Centers were formed to handle the unprecedented data of IGY. The WDC-A for Glaciology was particularly responsible for archiving all available glaciological information at the time. In 1970, the WDC-A was moved to Tacoma, Washington, where it was operated by the U.S. Geological Survey, Glaciology Project Office, under the direction of Dr. Mark F. Meier until 1976.

In 1976, responsibility for the WDC for Glaciology was transferred to the National Oceanic and Atmospheric Administration (NOAA) Environmental Data and Information Service (EDIS); and the center moved to the University of Colorado in Boulder, Colorado, under the direction of Professor Roger G. Barry. As Director of the WDC for Glaciology, Barry saw the need for a data center dedicated to the archiving of snow and ice data and suggested that such a data center be created [7]. In 1982, NOAA officially established NSIDC.

During the next two decades, NSIDC expanded with NASA funding for the Snow and Ice Distributed Active Archive Center (DAAC) and National Science Foundation (NSF) funding to manage selected Arctic and Antarctic data and metadata.

To help capture the history of the center, NSIDC digitized 1694 files documenting the history of the WDC for Glaciology in Boulder and NSIDC. This was accomplished through support from a NOAA Preserve America Initiative Grant (PAIG), an effort by NOAA to preserve the nation's heritage by promoting preservation and developing conservation plans for historically significant resources [8].

2. Modernizing NSIDC's archives

As NSIDC's efforts expanded and included massive amounts of digital data collected through modern instrumentation, including satellites, projects began to further organize and migrate analog datasets into modern formats. As resources permitted, records of arctic ice dynamics, cold land field experiments, drifting stations, sea ice charts and historical glacier photographs were digitized and described in order to integrate these paper records and prints into NSIDC's data discovery tools. Most efforts have focused on sea ice charts and glacier photographs, and they have added value to research in several projects.

2.1. Sea ice charts

Funding from NOAA's Climate Database Modernization Project (CDMP) and the National Geophysical Data Center (NGDC) allowed NSIDC to digitize approximately 6800 sea ice charts donated by the estate of William H. Dehn. These hand drawn maps can be viewed as image files that record ice edge position and some ice concentration information for waters around Alaska. The charts were made between 1953 and 1986, primarily using visual observations gathered during aerial ice reconnaissance missions. Relatively costly and extensive scanning of these charts has contributed to a variety of analyses. One project used them to compare with and validate recovered satellite data in order to more accurately measure arctic ice cover at the dawn of the satellite era. Part of a larger analysis, the recovered and validated satellite record "will yield a climate record of sea ice approaching 50 years in length that will put the recent changes, especially the dramatic decline of Arctic summer sea ice extent, into a longer-term context" [9].

The digitized chart series predates the satellite record, thereby pushing the start of the record even further back in time. Another project used them and other analog data, including records of nineteenth century whaling ships, to create a database of sea ice fluctuations dating to 1850. This study demonstrated "there is no precedent as far back as 1850 for the recent minimum extent of sea ice on the pan-Arctic scale," and that "the rate of retreat since the 1990 s is also unprecedented in the historical record for the pan-Arctic total ice cover" [10].

Findings such as these, of great importance not only to climatology, but also to public policy, relied in part on the work of efforts to rescue analog data at NSIDC.

2.2. Historical glacier photographs

Another example of efforts to modernize the data in these archives is the digitization of glacier photographs. Glacier photographs have helped demonstrate regional climate change in Alaska [11], lateral moraine retreat of specific glaciers (through lichenometrical dating) since the sixteenth century [12], and even contributed to studies of human history and living conditions in Alaska dating to the fourth millennia B.C.E. [13].

They also provide striking testament to the rapid glacial retreat typifying the last century, rendering them useful in a variety of contexts. Repeat photography projects (see Fig. 1) enable analysis and interpretation that yield information related to geomorphology and glacier dynamics [14]. In addition to journal articles, dissertations, and exhibits in closely related disciplines, these images have

Fig. 1. Images of Okpilak Glacier, Alaska. On the left: 1907 [16]. On the right, 2004 [17].

been used in other scientific endeavors, popular television documentaries, artist books, text books, and even children's books [15].

Perhaps more importantly, these images and other analog data must be rescued and made accessible for techniques not yet invented by researchers not yet born. Could additional geospatial metadata be added to the images over time in order to enable GIS analysis? Would other metadata, such as descriptions of glacial moraine or vegetation cover, contributed by scientists analyzing the images or their locations, further future discovery? The repurposing of data collected for specific reasons in discrete projects has been shown to yield new discoveries [18].

Unless these data are rescued and migrated into modern formats that may never happen.

3. Completing and integrating the glacier photographs

The analog data at NSIDC were preserved many times over the decades, thanks to the foresight of scientists who understood their value. But such foresight is not always the case. Analog media is perishable and requires careful ambient environmental control, (typically colder and more humid than people find comfortable), and time-consuming treatment with respect to housing, processing, and inventorying, before it can even be migrated into digital formats. The knowledge required to plan for long-term care, investing in both facilities and specific skill sets, is not normally accounted for in many of the institutions that have held these media over the decades, where the primary focus is research or digital data management. The expense itself can be prohibitive as well, and even foresight can be thwarted by associated costs.

For decades NSIDC invested in rescuing these data, and funding through the CDMP and other sources allowed the digitization of approximately 14,000 glacier photographs, but funding was subsequently lost when Congress eliminated that program and the remaining 10,000 prints were not digitized. Several funding efforts followed, including grant proposals to several federal agencies and private donations, but met with limited success.

Several years passed until researchers, librarians, archivists, and data scientists at CU and NSIDC secured approximately $150,000 in funding to complete the digitization of the remaining print images, and to provide all images in both the NSIDC's and CU Library's databases. The former will allow co-discoverability with born-digital data and geospatial metadata searches, and the latter supports the Open Archives Initiative Protocol for Metadata Harvesting (OAI-PMH) [19], in order to facilitate sharing of the images with other institutions and repositories. Discovery in the CU Digital Library will be alongside other special collections, including aerial photographs and maps of Colorado. The project will also address long-term digital preservation issues by storing master images on CU Boulder's PetaLibrary, an NSF-supported service for storage and archiving of digital data.

Ultimately, these are next-step solutions, but are neither endgoal nor optimal. However, they will enable exploration of access, metadata, and preservation techniques that may facilitate future, broader collaborations that could one-day bridge the crevasse between analog and digital data description and access in glaciology and related disciplines.

3.1. Metadata considerations

Digitizing the historical print photographs is only the beginning of providing the analog data in this archive to researchers. Metadata being captured for these images include original media (e.g., print or microform); photographer, province/state, glacier name, date of photograph, description (including size of print usually), and coordinates. Compliant with appropriate standards, such as ISO 19115 [20], Dublin Core [21], MODS [22], and METS [23], these metadata are nonetheless project-specific and may not always best serve future use cases. They should provide, however, a framework into which future enhanced metadata can integrate (potentially provided by users in a feedback mechanism, something that has been done with previous digitization projects at NSIDC).

Enhancements or refinements to the processing and outputs of this project could therefore provide a significant learning opportunity. For example, geospatial metadata enhancements could prove particularly useful. The coordinates for these images are either approximate center-points for glaciers or the location of the photographer, and when possible spatial coverage metadata from the Getty Thesaurus of Geographic Names Online [24] is being added. These are valuable, but potentially incomplete for some researchers. The center-point of the glacier changes over time, and in the case of the coordinates of the photographer, the glacier could be miles in the distance. While repeat photography can be accomplished with the latter coordinates, additional analysis of the glacier may require more accurate center-points, or additional descriptors (such as if a glacier has a terminal or lateral moraine, and other defining characteristics) for any further analysis to be accomplished. Determining these coordinates would require detailed analysis and domain expertise may be necessary, so such enhancements would require additional resources and perhaps only be possible for small subsets of the collection. In order to facilitate repeat photography, in part, photo station coordinates for W.O. Field's photographs from 1931–1970 are being added to about 1000 photographs.

Much of the metadata being captured, in fact, has already been provided by previous volunteers, archivists, and glaciologists. The prints were mounted on cardstock and in most cases, metadata were written on the mounts (Fig. 2). Many items do not provide coordinates or glacier names, however, and considerable effort is being spent on determining these valuable fields.

In addition to enhanced geospatial metadata, descriptions that may facilitate humanistic or social science research are other possibilities. Some of the images have people in them and were taken using a variety of photographic techniques (e.g. silver gelatin or albumen). Photographic paper type metadata are being added, which opens the collection to photographic historians. Describing these aspects of the images may yield discoveries related to the history

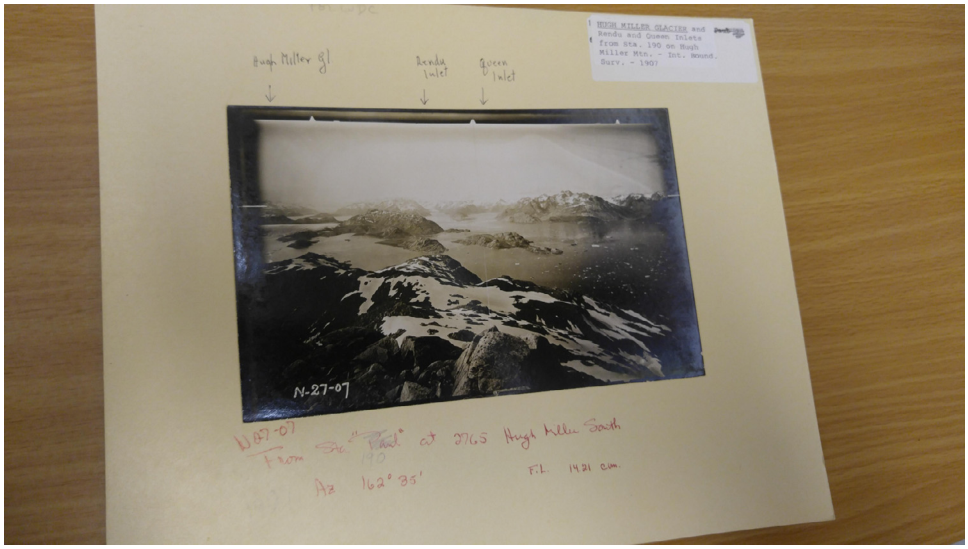

Fig. 2. Example of physical item. This print includes indications of peaks and inlets in the background.

Fig. 3. Just a portion of the archive. The film canisters at left include tens of thousands of aerial sea ice imagery taken by the U.S. Navy in their 1960s “Birds Eye” project. These are the only existing copies.

of photography, exploration, or the role of women or minorities in these areas.

Finally, the print glacier photographs are only a portion of the archive. In addition to the prints, over 100,000 images on microfilm, 1400 glass plates, 1600 slides, over 100 cubic feet of manuscript material (including hand-written 19th century exploration diaries and observational data) and over 8000 ice charts are included in this archive (Fig. 3).

All of these data have been repeatedly chosen for rescue over decades in close consultation with domain experts. All, then, are very likely of considerable scientific value. Only through digitizing, describing, and providing them online can that value be fully realized.

3.2. Preservation and sustainability

Much as the efforts to sustainably preserve the analog data required costs and labor over the decades, simply digitizing the images does not amount to preservation: a more thorough process is required.

Images of both the prints and their accompanying card mounts are being archived as TIFF files. The TIFF images will be generated according to the standards set by the Federal Agencies Digitization Guidelines Initiative (FADGI) [25]. These master images will be stored in CU’s PetaLibrary. This service is run by the Research Computing group on the Boulder campus and the Libraries are co-investigators and partners in the initiative. One copy of each master image will reside on the arrays of hard disk drives employed by PetaLibrary and managed with IBM’s General Parallel File System technology. These arrays are organized in pools of ten drives for data redundancy; staff for the PetaLibrary are notified of any drive failures. A second copy will be located on an LTO-6 tape drive system also used by the PetaLibrary and managed with IBM’s Tivoli Storage Manager technology. The existing 14,227 TIFF files will also be archived in this manner, so as to create a full corpus of these images. This solution will become the prime archive for the collection.

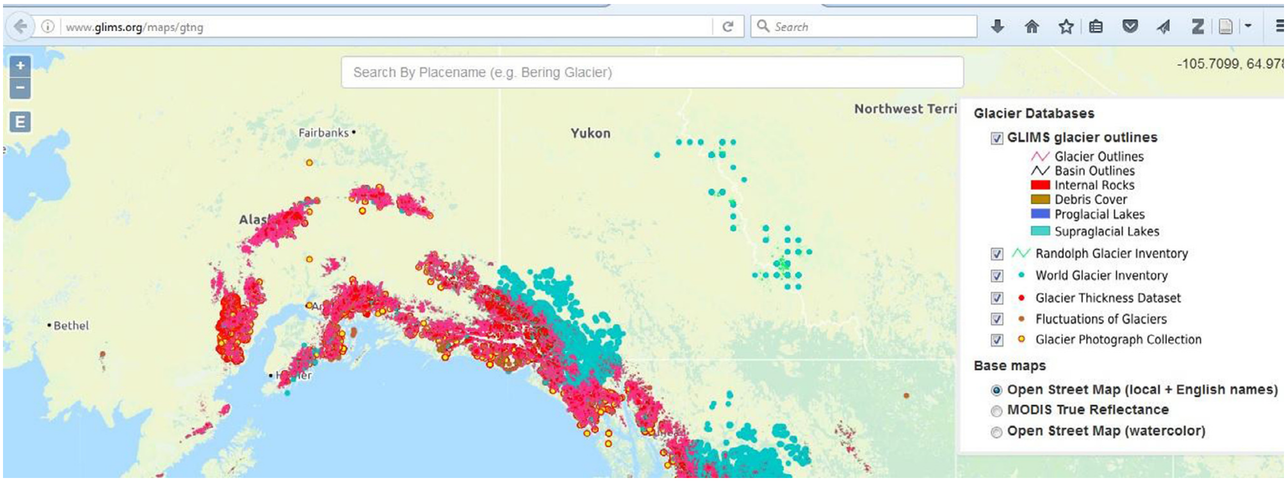

Fig. 4. GLIMS interface for glacier data, including the Glacier Photograph Collection.

Images will be ingested into PetaLibrary along with any accompanying item-level metadata, such as photographer, date, and glacier name. Master images will be bundled with metadata through the BagIt program [26], which will provide a grouping mechanism for the item and metadata, a manifest of the content, and a unique alphanumeric value derived from the file content for each file in the bundle. The latter feature will also allow verification of the content whenever it is retrieved. Along with the persistent values accompanying the content, images and metadata will be transferred to PetaLibrary through the Globus file transfer service, which can ensure the transfer completed without error. The master TIFF images and metadata will also be transferred back to the NSIDC for their own long-term retention and use, in addition to creating distributed backups of the collection. The images will then be archived in the NSIDC non-public archive on spinning disk, backed up to tape, and synched to NSIDC's offsite backup at the University of Colorado Denver campus.

High quality to thumbnail-quality JPEGs will also be stored in the Library's own storage servers, presently managed locally with the FileTek storage management system. This storage layer is meant to support the Libraries' digital access system. Archival content on Library servers is redundantly copied to tape as well. This LTO-6 tape library is managed year-round. When tapes are full, they are moved to a storage facility also in Colorado.

3.3. Improving discovery and integration

At the end of the currently-funded project phase, over 20,000 of these images will have item-level metadata and will be discoverable through NSIDC's data discovery platform, its glacier photograph database [27], and CU Libraries' Digital Library. Search fields will include all those already noted, and "bounding box" and spatial search capabilities will be possible in the NSIDC platforms. These fields will be limited to text searches in the Libraries platform.

Co-discoverability alongside digital datasets in the NSIDC data search platform provides an interesting opportunity to unite analog with digital data discovery. This will also be possible through a partnership with the Global Land Ice Measurements from Space (GLIMS) project [28]. This project provides a global spatial interface portal with access to glacier data such as outline, internal rocks, lakes, a worldwide inventory of glaciers, and these historical images (Fig. 4). Adding unique identifiers from the GLIMS project is no easy feat, but greatly facilitates discovery and integration with existing sources of digital data.

But this project is a prototype intended to create future opportunities. Other historical glacier photograph collections may be harvestable, and existing, large scale projects capturing images of glaciers that do not have long-term sustainability plans may benefit from the project as a future repository. Ideally, the project could lead to a comprehensive discovery platform for glacier images, and more standard metadata schematics for items.

4. Conclusion

Rescuing analog data collections is time consuming, relatively expensive, and does not always yield the volume of data to which science has become accustomed to having available. But in many cases, and certainly with respect to historical cryospheric data, it is vital that it be rescued and made available.

Many efforts at NSIDC, particularly those focusing on sea ice charts and historical glacier photographs, have shown the labor and cost involved can contribute to contemporary research in ways that justify the investment. These data often predate modern instrumentation and mere preservation and description in native formats renders them "lost." They must be migrated to digital formats and significant metadata work is necessary to make them discoverable alongside other data. Over four decades of work at NSIDC has preserved the collection, but the vast majority remains accessible only to researchers who visit in person. The glacier photograph collection will soon contain over 20,000 images with metadata provided for each image, potentially providing a model for how such data should be described to maximize discovery and use in research.

The 2016 Fall Meeting of the American Geophysical Union may forever be remembered for the passionate remarks delivered by California governor, Jerry Brown. Governor Brown spoke, in part, about the need for scientific data to be collected and preserved, and its importance in understanding climate change. Later that week at the same meeting, the glacier photograph digitization project described in this paper, funded by the Council on Library and Information Resources, received the International Data Rescue Award in the Geosciences [29]. This was certainly a validating reward, but much work remains. The entirety of the archive is valuable, and a sustainable and accessible future for it all remains to be planned.

Acknowledgments

The authors would like to thank the Council on Library & Information Resources, the University of Colorado, the National Oceanic

& Atmospheric Administration, the National Snow & Ice Data Center, the Cooperative Institute for Research in Environmental Science, the Ronin Institute for Independent Scholarship, the Denver Botanic Gardens, and the University of Denver for their support in this project.

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