The U.S. Arctic Observing Viewer: A Web-Mapping Application for Enhancing Environmental Observation of the Changing Arctic

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ABSTRACT. Although much progress has been made with various Arctic Observing efforts, assessing that progress can be difficult. What data collection efforts are established or underway? Where? By whom? To help meet the strategic needs of programs such as the U.S. Study of Environmental Arctic Change (SEARCH), the Arctic Observing Network (AON), Sustaining Arctic Observing Networks (SAON), and related initiatives, an update has been released for the Arctic Observing Viewer (AOV; http://ArcticObservingViewer.org). This web mapping application and information system has begun to compile the who, what, where, and when for thousands of data collection sites (such as boreholes, ship tracks, buoys, towers, sampling stations, sensor networks, vegetation sites, stream gauges, and observatories) wherever marine, terrestrial, or atmospheric data are collected. Contributing partners for this collaborative resource include the U.S. NSF, ACADIS, ADIwg, AOOS, a²dc, AON, ARMAP, BAID, CAFF, IASOA, INTERACT, and others. While focusing on U.S. activities, the AOV welcomes information exchange with international groups for mutual benefit. Users can visualize, navigate, select, search, draw, print, and more. AOV is founded on principles of interoperability, with open metadata and web service standards, so that agencies and organizations can use AOV tools and services for their own purposes. In this way, AOV will reinforce and complement other distributed yet interoperable cyber-resources and will help science planners, funding agencies, researchers, data specialists, and others to assess status, identify overlap, fill gaps, optimize sampling design, refine network performance, clarify directions, access data, coordinate logistics, collaborate, and more in order to meet Arctic Observing goals.

Key words: Arctic research; Arctic Observing networks; GIS; web mapping application; science management; cyberinfrastructure

RÉSUMÉ. Malgré les progrès réalisés dans le cadre de nombreux efforts d'observation de l'Arctique, les progrès peuvent être difficiles à évaluer. Quelles initiatives de collecte de données sont en cours ou sont établies? À quel endroit? Et qui gère ces initiatives? Pour aider à répondre aux besoins stratégiques de programmes comme ceux de l'organisme américain Study of Environmental Arctic Change (SEARCH), du réseau Arctic Observing Network (AON), des réseaux Sustaining Arctic Observing Networks (SAON) et d'autres programmes connexes, on a procédé à la mise à jour de l'Arctic Observing Viewer (AOV; http://ArcticObservingViewer.org). Ce système d'information jumelé à une application de mappage sur le Web a amorcé la compilation des coordonnées et des renseignements se rapportant à des milliers de sites de collecte de données (comme les trous de forage, les trajets de navires, les bouées, les tours, les stations d'échantillonnage, les réseaux de capteurs, les sites de végétation, les fluviomètres et les observatoires) où des données marines, terrestres ou atmosphériques sont prélevées. Parmi les partenaires qui collaborent à cette ressource, notons U.S. NSF, ACADIS, ADIwg, AOOS, a2dc, AON, ARMAP, BAID, CAFF, IASOA, INTERACT et d'autres encore. Bien que l'AOV se concentre sur les activités américaines, il accepte l'échange d'information avec des groupes internationaux lorsqu'il existe des avantages mutuels. Les utilisateurs peuvent visualiser les données, naviguer dans le système, faire des sélections et des recherches, dessiner, imprimer et ainsi de suite. L'AOV fonctionne moyennant des principes d'interopérabilité, avec des métadonnées ouvertes et des normes de service sur le Web afin que les organismes et les organisations puissent utiliser les outils et les services de l'AOV pour leurs propres fins. De cette façon, l'AOV sera en mesure de consolider et de compléter d'autres cyberressources à la fois réparties et interopérables, en plus d'aider les planificateurs de la science, les bailleurs de fonds, les chercheurs, les spécialistes des données et d'autres encore à évaluer les statuts, à repérer les dédoublements, à combler les écarts, à optimiser les plans d'échantillonnage, à raffiner le

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rendement des réseaux, à clarifier les consignes, à accéder aux données, à coordonner la logistique, à collaborer et ainsi de suite afin de répondre aux objectifs d'observation de l'Arctique.

Mots clés : recherche dans l'Arctique; réseaux d'observation de l'Arctique; SIG; application de mappage sur le Web; gestion de la science; cyberinfrastructure

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INTRODUCTION

The Arctic Observing community is at a crossroads. A great deal of progress has been made with observing systems and data-related activities such as 1) planning and coordination associated with the International Polar Year (IPY), the U.S. Arctic Observing Network (AON), and the Sustaining Arctic Observing Networks (SAON) initiative, among others; 2) an increase in both the quantity and quality of observing activities and datasets; and 3) improvements in data access, management, and preservation by national and international data centers and systems. However, it can still be difficult for science planners, Arctic science organizations, and research scientists to assess progress systematically and comprehensively, to assure that appropriate sampling designs are being implemented, and to know where to invest in new deployments. Questions that remain are "How can we know where to go if we don't know where we've been?" "What resources already exist?" "Is there overlap?" and "Where are the gaps?"

Indeed, the community input questionnaire for the 2013 Arctic Observing Summit in Vancouver, British Columbia, highlighted the need for synthesis and assessment to better meet scientific objectives. Questions included the following: "What are major issues facing coordination of Arctic Observing activities, and how can these be resolved?" "What are the current redundancies in Arctic Observing activities?" and "What are the current major gaps in Arctic Observing activities, and why should these be addressed?"

A fundamental obstacle is that Arctic science is fragmented. Arctic research tends to be decentralized and spread across academia, international organizations, government agencies, scientific disciplines, and various other initiatives. For this reason, it can be challenging for scientists or planners to obtain a complete or representative perspective on Arctic data holdings and observing activities. For a variety of reasons, it is unlikely that there will be a single data catalog or portal covering all related datasets and efforts. Furthermore, it can understandably take time for datasets to be released and become a part of the total picture.

What is needed is a resource focusing on a new level of granularity: "data collection sites" (long-term monitoring locations such as towers, boreholes, moorings, ship tracks, weather stations, vegetation plots, stream gauges, shoreline transects, observatories, etc.). Such a tool would assist strategic assessment of ongoing data collection activities tied to the Study of Environmental Arctic Change (SEARCH), AON, and other initiatives. It would not be a data portal, because details such as sensor names and serial numbers, as well as the datasets themselves, are more appropriately maintained at the data archives. Nor would it be a project tracking system, which would lack the spatial resolution and details needed for data-related activities. Instead, it should be an interagency and international resource guide, available well before data are archived, that provides high-order information (the who, what, when, where, and how of monitoring efforts) to improve the effectiveness of Arctic Observing activities.

Because funding, administration, data collection, and data dissemination are broadly distributed among multiple organizations, the success of such a resource for strategic assessment would hinge on interoperability. Information about ongoing data collection activities would need to be shared in such a way that it is compatible with contributions from other entities and could be harmonized and reprocessed. Furthermore, the information would need to be kept up to date. Fortunately, there are successful precedents for establishing both 1) community-based metadata standards (as has been done for project tracking, or with dataset-level metadata) and 2) open, interoperable web services (live data streams between database management systems; e.g., Yang et al., 2010; Johnson et al., 2011).

The end result would be a distributed yet comprehensive tracking of Arctic data collection activities. Agencies could make use of this distributed system, a network of interoperable nodes, for information sharing through standards and web services in their own web applications, or they could take advantage of shared applications. This approach would help assess status, optimize sampling design, fill gaps, and gauge progress. It could also improve data access, facilitate logistics, assist with emergency response and resource management, and foster coordination and collaboration. The system would benefit strategic assessment and Arctic science alike.

Here we describe the development and implementation of the Arctic Observing Viewer, a collaborative tool to help with the programmatic, strategic assessment of Arctic Observing data collection activities (AOV; http://ArcticObservingViewer.org). We also review a related tool, the Arctic Research Mapping Application (ARMAP; http://armap.org). We outline mechanisms for interoperability, including an evolving metadata standard, the Project Metadata Standard established by the Alaska Data Integration Working Group (ADIwg), which is being modified to accommodate higher spatial resolution for data collection sites, as well as interoperable web service formats. Last, we touch on scalability and the mutual benefits of collaboration.

STRATEGIC NEEDS FOR ARCTIC OBSERVING

The various and sometimes overlapping national and international efforts that have identified data and information management needs for Arctic Observing cover a broad spectrum. This range includes not just IPY, SAON, and the component of AON funded by the U.S. National Science Foundation (NSF), but other U.S. agencies contributing to AON through the Observing Change component of the SEARCH program (e.g., NRC, 2006; SAON, 2010; Parsons et al., 2011; ADCN, 2012; ADI Task Force, 2012; cf. NSTC, 2013; Pulsifer et al., 2014; White House, 2014). Similar data and information management needs have been identified through planning and coordination led by the Arctic Data Coordination Network (ADCN), the Global Earth Observing System of Systems (GEOSS), the World Data System (WDS), the WMO Information Service (WIS), the International Council for Science (ICSU), the U.S. Interagency Arctic Research Policy Committee (IARPC) Arctic Data collaboration team, a new Arctic Data Committee (ADC) jointly led by SAON and the International Arctic Science Committee (IASC), and a new SAON Committee on Observations and Networks (CON), among others. These efforts have helped to clarify and advance objectives for data sharing and publication, as well as interoperability, preservation, coordination, and governance of data systems (see Parsons et al., 2011). Importantly, most of these efforts are focused on the level of datasets. The scope and interconnectedness of data catalogs and data portals are increasing with adoption of standards, and particularly through metadata harvesting and "brokering" technologies (Yarmey and Khalsa, 2014).

On the other end of the spectrum are project tracking systems for high-order information to guide science planning and logistics. These systems vary in presentation, scope, and audience: for example, multiagency and circum-Arctic (ARMAP; http://armap.org; Johnson et al., 2011; Gaylord et al., 2014); multiagency for the North Slope of Alaska (through the North Slope Science Initiative, NSSI; http://catalog.northslope.org); the Alaska Ocean Observing System (AOOS; http://www.aoos.org); the U.S. Geological Survey Alaska Science Portal (http://alaska.usgs.gov/portal); the SEARCH Project Catalog (http://www.arcus.org/search/catalog/display); the Advanced Cooperative Arctic Data and Information Service (ACADIS; http://www.aoncadis.org); through the Arctic Landscape Conservation Cooperative (ALCC; http://arcticlcc.org/search/projects); the Research in Svalbard effort (http://www.forskningsradet.no/prognett-ssf/RiS_database/1253983007548); an upcoming ESFRI initiative through the Svalbard Integrated Arctic Earth Observing System (SIOS, http://www.sios-svalbard.org/); and others.

But to meet the strategic needs for Arctic Observing, an intermediate level of tracking, through a metric of data collection sites, is needed. Such a resource should be circum-Arctic for marine, terrestrial, and atmospheric sites. It could help address some of the objectives or goals expressed by the various planning and coordination initiatives:

…improvement of observation density, co-location, and integration; improvement of coverage to close observation gaps; [and] development of optimal observation and sampling strategies.

(ARCUS, 2015)

The Goal of SAON is to enhance Arctic-wide observing activities by facilitating partnerships and synergies among existing observing and data networks ("building blocks"), and promoting sharing and synthesis of data and information.

(SAON, 2011)

The United States and the other Arctic nations require strong, coordinated research efforts to understand and forecast changes in the Arctic. … Toward that end, and in furtherance of goals developed by the Arctic Research Commission, this plan focuses on those research activities that would be substantially enhanced by multi-agency collaboration.

(NSTC, 2013)

A common or distributed resource for tracking data collection activities for Arctic Observing would help meet these goals. More timely information would be possible without the lag between efforts and dataset release. Such information would likely be less fragmented and more comprehensive than existing data holdings, and it could assist with gap analysis and network design.

THE ARCTIC OBSERVING VIEWER

The Arctic Observing Viewer (AOV) was developed to help meet the programmatic and strategic needs of AON, SEARCH, SAON, and related initiatives. It is a web mapping application and information system for visualization, assessment, synthesis, and decision support that covers the who, what, where, and when of data collection activities across the Arctic (Manley et al., 2015). Released as a prototype in 2012, AOV was updated in 2014 and has grown into a collaborative, cross-disciplinary resource. It allows policy makers, program managers, science planners, logistics planners, data management specialists, researchers, and others to assess status, identify overlap, fill gaps, optimize sampling design, refine network performance, clarify directions, coordinate logistics, access data, and collaborate with others to meet Arctic Observing goals.

AOV is circumpolar and now encompasses more than 5400 terrestrial, marine, or atmospheric data collection platforms and sites, including boreholes, towers, sampling stations, sensor networks, vegetation plots, and stream gauges, wherever repeat Arctic Observing measurements have been collected (Fig. 1). It includes data collection efforts funded by NSF for AON; boreholes with the Thermal State of Permafrost (TSP) project; mass balance
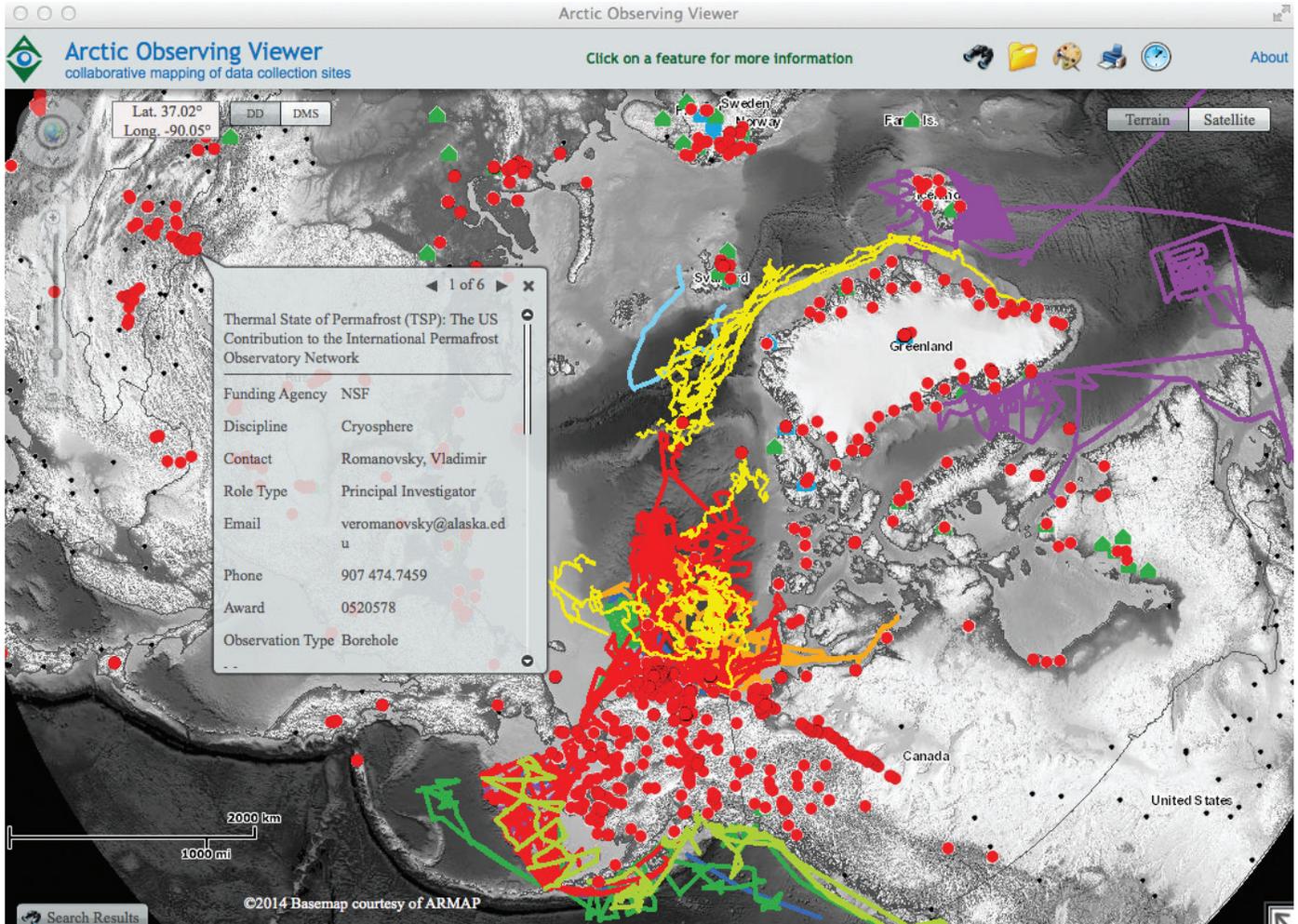
FIG. 1. Screenshot of the Arctic Observing Viewer, showing data collection sites and a pop-up window with descriptive information for one of the sites.

measurements and ice cores from the Seasonal Ice Zone Observing Network (SIZONET); sites associated with the Conservation of Arctic Flora and Fauna's (CAFF) Arctic Terrestrial Biodiversity Monitoring Program; vegetation plots revisited as part of the NSF-funded Back to the Future (BTF) project; monitoring locations associated with the Circum-Arctic Lakes Observation Network (CALON); and stations with the U.S. Geological Survey Permafrost and Climate Monitoring Network on Alaska's North Slope.

The viewer also displays information for scientific cruises and drifting buoys: Sampling sites from the National Oceanic and Atmospheric Administration (NOAA) for the Russian-American Long-term Census of the Arctic (RUSALCA) program; ship tracks dating from 2007 for the *Healy, Knorr, Louis S. St-Laurent, Marcus G. Langseth, Thomas G. Thompson*, and other research vessels; and buoy tracks for the Naval Postgraduate School's Autonomous Ocean Flux Buoy program.

Furthermore, the viewer and underlying database include major Arctic research facilities: field stations from the International Network for Terrestrial Research and Monitoring in the Arctic (INTERACT), as well as observatories and facilities from the International Arctic Systems for Observing the Atmosphere (IASOA) initiative.

Users can interact with a range of information pertaining to Arctic Observing activities: they can visualize, navigate, select, search, draw, print, and export this information, as well as access more detailed project-level information and data through embedded links. The application has an interactive, geospatial interface. Users can view and click on observation sites—represented by points, lines, or polygons—to view pop-up windows with details on project title, funding agency, award number, contact information, discipline, type of measurement, keywords conforming with the Global Change Master Directory (GCMD), location, latitude and longitude, start date, end date, links to more information, whether data are archived, and links to datasets.

Users can also select or search for multiple sites of interest, view a table with these details, and export the results (Fig. 2). AOV includes a "time slider" that enables users to visualize change in data collection activities over time (Fig. 3). Other interface elements enable the user to pan, zoom, or move to full extent; choose a variety of map layers to view; draw graphics; add text; view a legend; measure
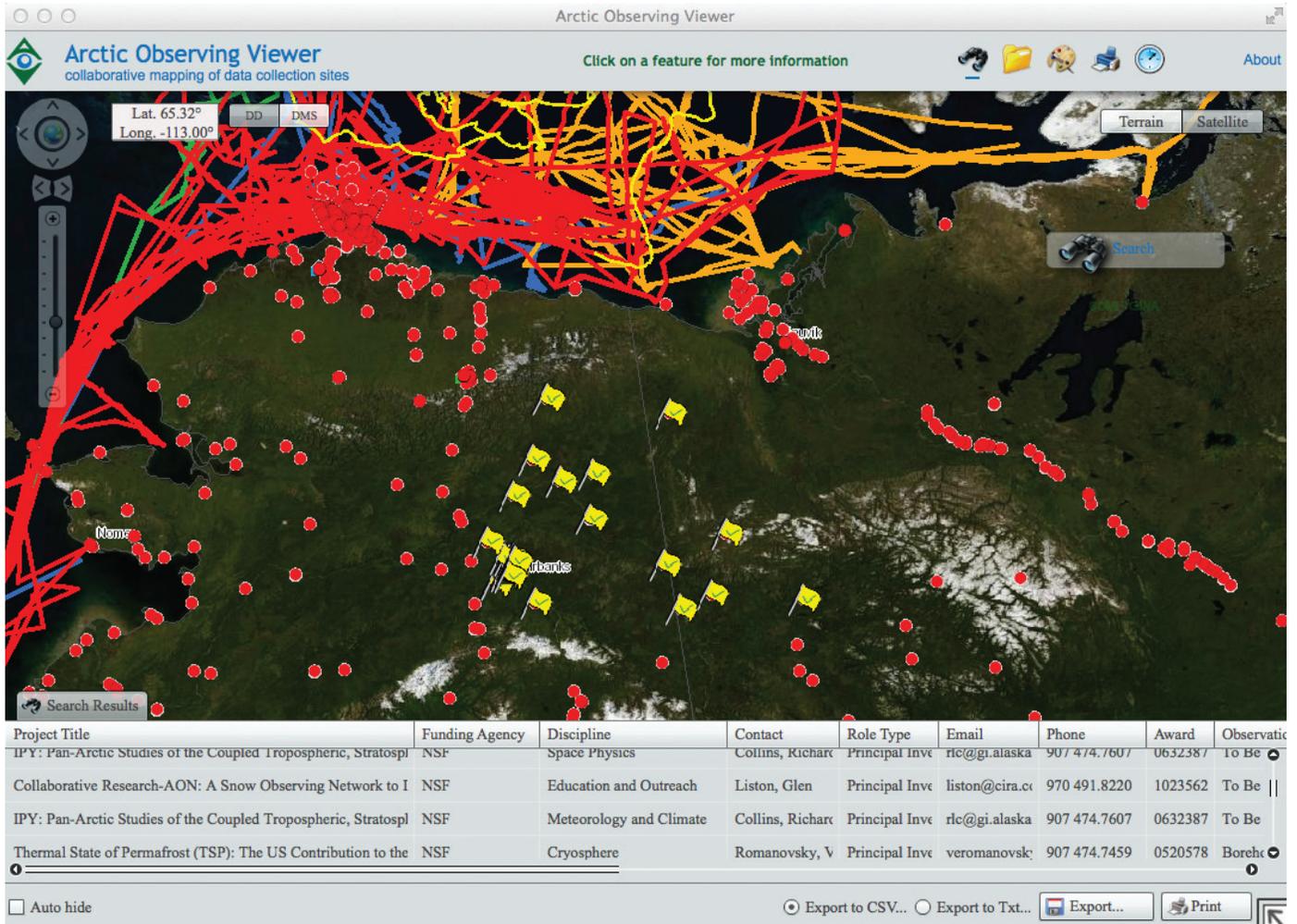
FIG. 2. The AOV, showing the Search Results table after selecting a rectangular area. The table includes numerous details of the data collection sites, including the funding agency, and it can be exported or printed. The base map can be toggled between terrain and satellite views.

distances and areas; view cursor location by latitude and longitude; save and print the map; and follow links to project reports and data catalog pages.

Various agencies, organizations, and initiatives have actively contributed data and information for this collaborative resource. To date, these partners for AOV include the ACADIS, ADIwg, AOOS, the Antarctic & Arctic Data Consortium (a²dc), AON, the Barrow Area Information Database (BAID), CAFF, the Geographic Information Network of Alaska (GINA), IASOA, INTERACT, NSF, the National Snow and Ice Data Center (NSIDC), and the U.S. Geological Survey (USGS). It is envisaged that AOV will become more comprehensive with time and will more thoroughly represent the collective efforts of a greater number of U.S. agencies and other organizations. We also welcome opportunities to improve linkages internationally.

Improvements are underway, and feedback is appreciated. Our highest priority is to build out the application, underlying database, and web services for interoperability. Information is stored in a spatially enabled relational database management system. "Pathways" for contributions of site information have been enabled with an online data entry form, via upload of files, and will soon include the ingestion of web services (live data streams that follow a compatible standard). We also plan to release core fields from the database as a web service, using one or more open standards, and to encourage re-use by other interested parties. At this time, we further plan to add regional views (Alaska, Canada, Greenland, northern Europe, Russia), refine the user interface to enhance usability, and add new tools (potentially Share Link, Go To XY, Advanced Search), new map layers (e.g., "supersites," imagery basemap, perhaps weather stations, web cams), and more sites and ship tracks.

The AOV is built on—and relies on—a systems architecture of hardware and software. ArcGIS Desktop and ArcGIS Server 10.2 were used to create and host the Geographic Information Systems (GIS) layers containing both spatial and non-spatial data of the application. The hosting environment includes Dell PowerEdge R620s servers, virtualized via VMware vCenter Server 5.1.0, and iSCSI storage housed within the Research and Academic Data Center at the University of Texas El Paso on the high-speed Lonestar Education and Research Network. Data are imported
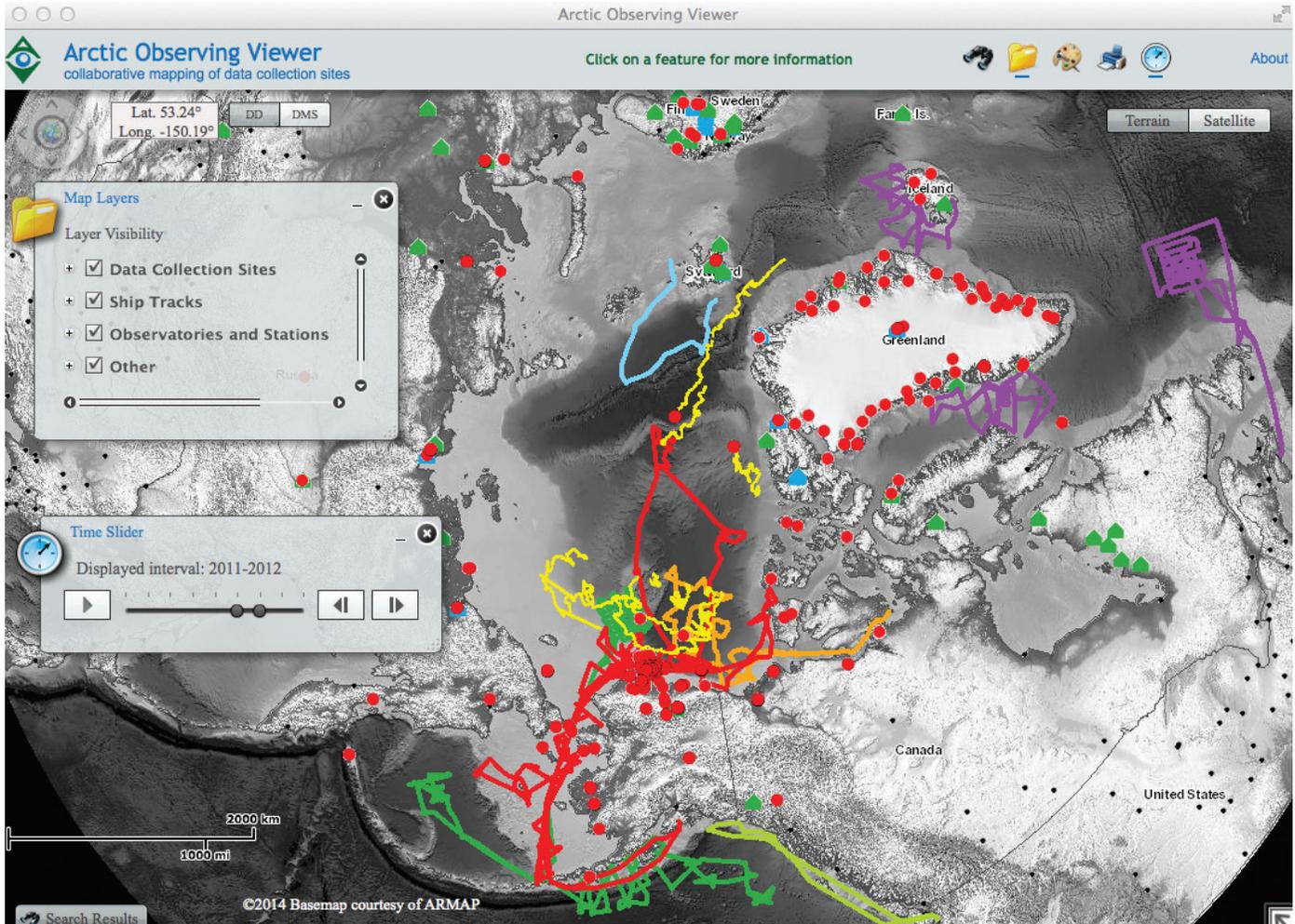
FIG. 3. The AOV showing the "Time Slider," an embedded animation for display of data collection activities through time, from 2005 to 2015.

to the SQL Server database via custom data forms, ensuring that entries are normalized. Customized views are then created in the database and accessed by ArcGIS via python scripts to create data layers for use in the ArcGIS services. ArcGIS Desktop and ArcGIS Server 10.2 and an enterprise geodatabase (Microsoft SQL Server 2012 coupled with ArcSDE v 10.2) work with common standards to deliver open services. Apache Solr has been implemented to provide enhanced search functionality. Bulk purchasing agreements for university hardware and enterprise software licenses are leveraged at no cost to this project while ensuring support for open web service standards, such as those endorsed by the Open Geospatial Consortium (OGC).

The 2012 release of AOV was developed for use in common Internet browsers via the ArcGIS Viewer for Flex framework (v3.0). The preferred Integrated Development Environment (IDE) for coding was Adobe Flash Builder 4. In the foreseeable future, the viewer will be ported to Javascript/HTML5 to take advantage of more modern web browsers. The new release will likely be more responsive for use on desktop, tablet, and mobile devices.

The database underlying the AOV is designed to house information on projects and associated data collection sites.

The database supports core fields adopted by the ADIwg Project Metadata Profile for ISO 19115-2 and 19115-1 (http://www.adiwg.org/), which extends the hierarchy level MD_ScopeCode to include "project" and "data collection site(s)" as options. To handle information specific to data collection sites, the elements under the EX_Extent class may include optional qualifiers, such as date, time instant, time period, name, description, and identifier (see class diagram and examples at ADIwg, 2015). Data collection sites for AOV are stored as ISO components (NOAA, 2015) and associated with a given project metadata record via XLinks (http://en.wikipedia.org/wiki/XLink). The AOV database exposes services to the web map viewer by using the Spatial extensions for Microsoft SQL Server and ArcGIS Server.

For many environmental observing efforts, web mapping applications (WMAs) have become common Software as a Service (SaaS) tools that have proven capacities for enhancing data discovery, retrieval, integration, and visualization (Yang et al., 2010). Tools and widgets provide functionality to allow users, for example, to zoom to different geographic extents, measure distance, query and filter data, plot graphs, and view RSS feeds and webcam images. WMAs can be built on top of several proprietary

or open-source viewers and frameworks, but all interact with similar geospatial and other data. Current trends in WMA development focus strongly on a higher level of sophistication with widget development and improved data interoperability using a range of web services (Yang et al., 2010; Johnson et al., 2011). Although WMAs have arguably helped to transform the ways in which end users interact with environmental data, the generic data hierarchies used by most WMAs have restrictions similar to those of other infrastructures (such as hierarchical databases) that require a developer to understand the content of the database and manually integrate it to provide a syntactical match for the names of attributes.

THE ARCTIC RESEARCH MAPPING APPLICATION

A companion application, the Arctic Research Mapping Application (ARMAP; Johnson et al., 2011, Gaylord et al., 2014; http://armap.org), serves a somewhat different purpose, scope, and audience. ARMAP is a suite of online, interactive maps and data services in support of U.S. Arctic science. ARMAP allows users to learn more about research projects in any region of interest or scientific discipline, explore available data or possible collaborations, plan and coordinate field logistics, and use the online mapping tools to meet a project's specific goals.

Users can navigate to areas of interest and explore information about field-based scientific research in the Arctic (Fig. 4). Research sites are shown as points with links to details about project investigators, disciplines, funding programs, years of activity, related websites, and other elements. Locations are typically mapped to a base of logistic support and do not include detailed sampling locations. ARMAP provides satellite imagery, other base maps, links to scientific datasets, and map layers for places, roads, and natural features. Users can print or export maps for presentations, export selected data, select from a "map gallery" of predefined images, or link directly to a variety of database web services. ARMAP strives to benefit scientists, science logistics experts, educators, and the general public.

In contrast to AOV, ARMAP focuses on projects, not data collection sites. Also, ARMAP includes AON-related projects, but goes beyond this scope to include thousands of other Arctic research projects. The ARMAP viewer is broadly interagency, and now includes projects from 18 U.S. agencies and organizations (NSF, the Bureau of Land Management, Bureau of Ocean Energy Management, NOAA, National Park Service, U.S. Geological Survey, plus others affiliated with IARPC). ARMAP provides a range of web services (ArcGIS Geoservices REST Feature Service, OGC-compliant Web Map Service [WMS] and Web Feature Service [WFS], Representational State Transfer [REST], and Text [TXT]) for cross-platform data sharing and re-use by other entities in web or desktop applications (i.e., Field Research Projects, Site Place Names, Arctic Base Map).

To be comprehensive and interoperable, ARMAP makes use of the project tracking standards established by ADIwg. The 2011 release of the ADIwg Project metadata standard is largely based on the Federal Geographic Data Committee (FGDC) metadata standard and Keyhole Markup Language (KML) for spatial domain information. In 2014, ADIwg released a community implementation for project metadata consistent with a standard established by the International Organization for Standardization (ISO). ARMAP will continue to provide support for the existing FGDC-inspired web service, and recently added support for both ISO 19115-2 and ISO 19115-1 via new REST endpoints (Fig. 5). The web service for Field Research Projects is consumed by a variety of organizations. More to the point, some of the projects in the ARMAP viewer are accessed dynamically—on the fly—from agencies that have released their own web service endpoints conforming to this standard. It is in this way, through coordination and collaboration on compatible standards and web services, that progress can be made for strategic assessment.

INTEROPERABILITY

Interoperability for information sharing fundamentally relies on the creation and adoption of community-based metadata standards and web service formats. Although challenges remain, the concept of interoperability among data systems through use of open standards is not new (e.g., see Kling and Scacchi, 1982; Berners-Lee et al., 2001; Association of Research Libraries, 2006). Various ongoing planning and coordination efforts for Arctic data management have identified interoperability (generally speaking, and usually in the context of dataset-level metadata) as a priority (e.g., SAON, 2010; Parsons et al., 2011; ADCN, 2012; ADI Task Force, 2012; Pulsifer et al., 2014). A broad range of standards, protocols, and best practices are well established in the geospatial community, as well as in other aspects of cyberinfrastructure and data management (e.g., Sorenson et al., 2001; Di and Ramapriyan, 2010; Johnson et al., 2011; see also the OGC, http://www.opengeospatial.org). Interoperability is enhanced when adopted standards are open, broadly compatible, and cross platform.

To advance strategic assessment of Arctic Observing activities tied to U.S. SEARCH, AON, and other initiatives, we support the project metadata standards established by ADIwg (2015). The original FGDC-based version of this U.S. standard was designed for compiling high-order project information and drew primarily from the FGDC Content Standard for Digital Geospatial Metadata (CSDGM) standard (as well as KML for the spatial domain). ADIwg has crosswalked the Project Metadata Standard to ISO 19115-2 and ISO 19115-1 and has released a new community-based implementation with support documentation for ISO 19115-2. Core fields are defined in XML or JSON schemas, along with corresponding physical data models and templates. ISO provides better support than did the
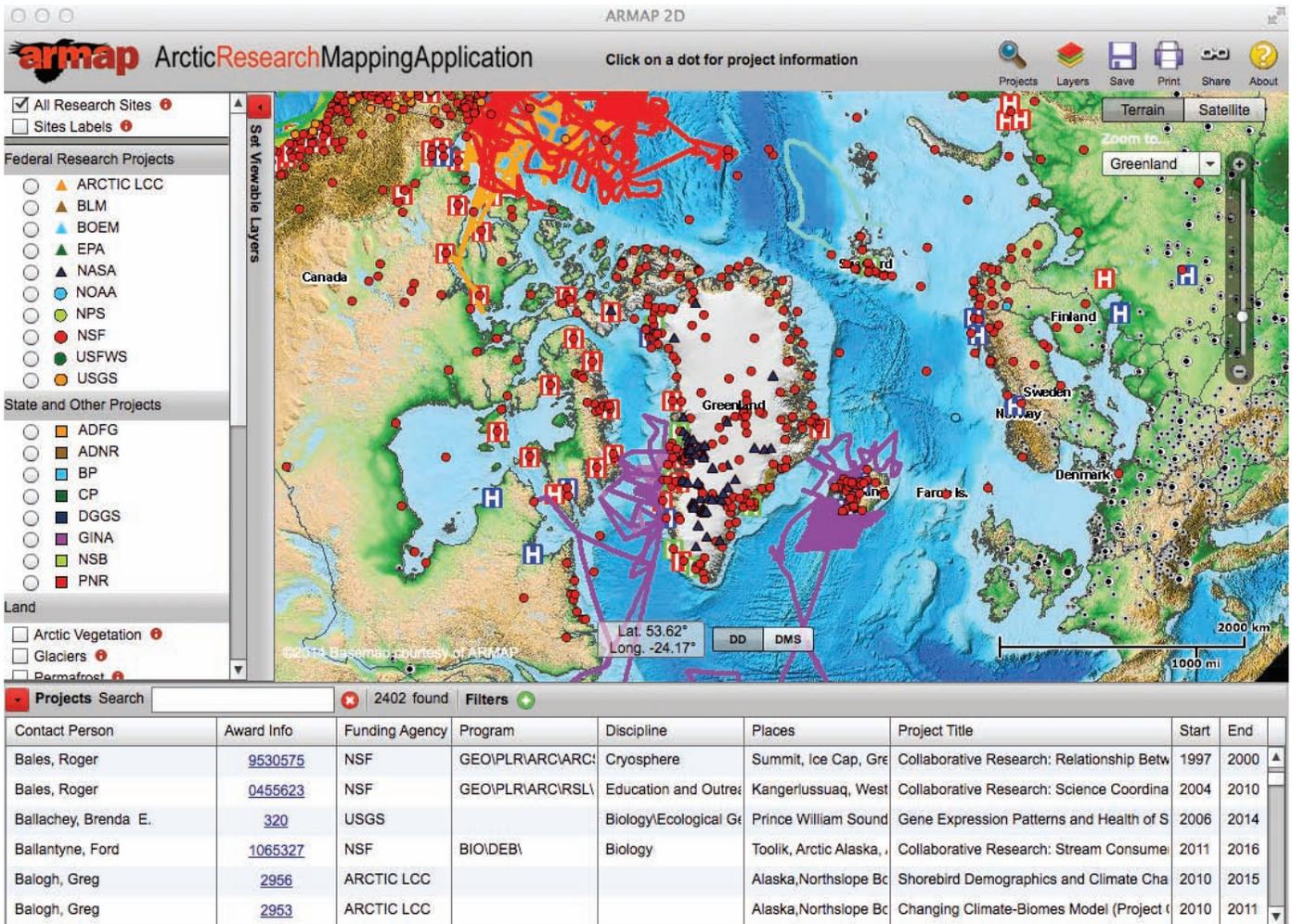
FIG. 4. The Arctic Research Mapping Application (ARMAP), with thousands of Arctic research projects either funded by or carried out by 18 agencies and organizations.

original FGDC-based standard by enabling a nested hierarchy of metadata describing projects, data collection sites, and datasets.

The ADIwg Project Metadata Standard, while being refined to accommodate the increased spatial and temporal granularity of data collection sites, requires a bare minimum of fields to facilitate adoption and use. This approach is not intended to duplicate metadata standards for datasets or sensors. ADIwg, the AOV team, and other ADIwg participants are working to troubleshoot and advance an enhanced exchange of information and are exploring the possibility of coordinating this effort with the SAON/IASC ADC, the IARPC Arctic Data collaboration team, and other groups (Pulsifer et al., 2014).

For delivery of the information, we propose that participating organizations make a variety of web services available. Various geospatial web service standards exist, such as KML network feeds; OGC WFS and WMS formats; an open GeoServices REST specification, which is under review for adoption by OGC; and the OGC/ISO Simple Features Access specification. RESTful web services and Simple Object Access Protocols (SOAP) are also used extensively by other groups for geospatial or non-geospatial content. In the end, each web service format has its pros and cons (related to performance; compatibility with database management systems, web applications, and GIS software; and capabilities and functionality for display and customization). Perhaps most effective would be adoption of the REST web service formats established by ADIwg for project-level information. But usually it does not take much more effort to release ("publish") web services in a variety of formats to promote broader use. Most important is that the services be open and compatible.

For interoperability of data collection sites tied to the Arctic Observing Viewer, we envision interconnected sources, processing, and hosting (Fig. 6). Sites already in the AOV database will be augmented by "data wrangling" (manually harvesting information from data centers) and, more effectively, through contributions from partner organizations via 1) an online entry form, 2) static upload of files compatible with the new metadata standard, and preferably 3) ingestion of compatible web services hosted by the partner agencies directly into the web mapping application. Site information contributed in the first two ways will be

FIG. 5. Example implementation of the ADIwg Project Metadata standard for ISO 19115-1, shown above as XML code captured from the ARMAP REST endpoint that is publicly available (see http://armap.org). This web service provides information on more than 2500 field-based and modeling projects in the circum-Arctic region, funded primarily by U.S. entities.

quality-checked. Manually intensive reprocessing and harmonizing of site-level metadata can be minimized substantially through use of community-based standards and schemas. In some cases, it is possible to use crosswalks or metadata translators to shift from one schema to another.

We hope to collaborate with agencies and data centers without creating extra work for investigators. Collaboration toward interoperability is enhanced when a relationship has grown between groups or entities through face-to-face meetings, or while working toward common goals. Open web services generated from AOV's servers could be used by partner organizations and others in their own databases, web applications, or desktop applications for their own purposes. And anyone could take advantage of the display and functionality in the Arctic Observing Viewer itself.

A resource already in existence is comparable in terms of an intermediate level of granularity. AOOS (http://www. aoos.org) has released a suite of web mapping applications, including two that are relevant to Arctic Observing: the Arctic Monitoring Efforts application and a Real Time Sensors application. Both are part of the AOOS Data Portal. The AOOS tools are mainly marine, primarily target sensors, and largely encompass the Alaska region, whereas AOV covers marine, terrestrial, and atmospheric realms, includes sensors as well as other types of sites where data were collected, and is circum-Arctic. There is some overlap (as is optimal in a distributed system, through exchange of information). But for the reasons above, we consider the AOOS tools and AOV as distinct but complementary.

There is also the Barrow Area Information Database (BAID, 2015), which has web mapping applications for data collection sites and other information and map layers, with a special focus on the research hubs of Barrow, Atqasuk, and Ivotuk on the North Slope of Alaska. This resource is also complementary, with relevance at a finer scale.

COLLABORATE FOR MUTUAL BENEFIT

Arctic Observing, spread as it is among various national and international initiatives, could benefit from an improved cyberinfrastructure that facilitates further integration, discovery, and analysis among funding bodies, principal investigators, data centers, and users. One piece of that vision is to have an observing activity for the observing program (beyond individual projects, datasets,
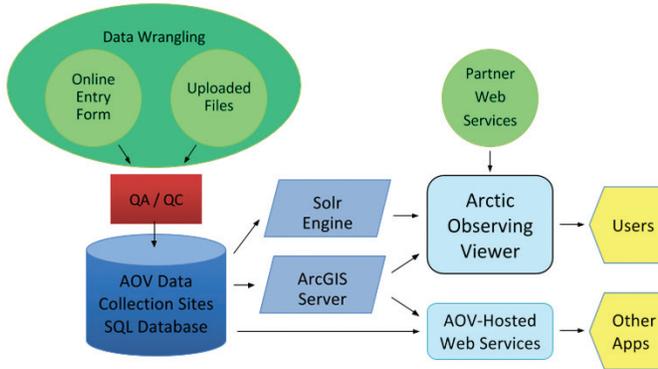
FIG. 6. Components for information flow related to Arctic Observing data collection sites, the Arctic Observing Viewer, and interoperable web services.

and individual agency or initiative efforts) to enable programmatic and strategic assessment. Without such a common activity, it will be difficult for any of the stakeholders to optimize networks or to achieve the stated scientific objectives. Key characteristics are to go beyond the capacities of static inventories or even interconnected data portals and to visualize and analyze status and progress in a time series. It is possible to build such a distributed system from the foundation already established by targeting key strategic improvements in focal areas. This process will require both bottom-up and top-down input. And such a resource (or interconnected set of multiple resources in an "ecosystem") should be adaptable to changing science needs, observing platforms, innovations in data and information systems, and technology.

The AOV team has begun to test, vet, and promote pathways for interoperability. Through collaboration with partners, we can troubleshoot the process for information exchange. Because the anticipated metadata standards and web service formats are a natural extension of solutions achieved by ADIwg, the near-term collaboration is facilitated among agencies that are currently part of ADIwg (with ties to the goals of U.S. multiagency AON, SEARCH, IARPC, or a combination). Collaboration is also proceeding through direct contact or participation with various entities or planning efforts. The development of this resource should be agile, and top-down endorsement is desirable. The AOV team appreciates feedback (send to info@ArcticObservingViewer.org).

Specifically with regard to SAON and other international initiatives, the AOV team is open to collaboration and coordination to meet common goals and needs. In other words, information sharing for data collection sites could be enhanced to function internationally as well. Beyond the viewer, most important is to ensure compatibility of metadata standards and related web services. In this regard, AOV could benefit from ties to other initiatives. For example, the goals and specifics described here could be coordinated with those embodied by the SAON/IASC ADC and the SAON Committee on Observations and Networks (CON). These goals and specifics also tie into

efforts described in other papers in this special issue and in white papers submitted for the 2013 AOS (e.g., McCammon, 2013; Moore et al., 2013; Pulsifer et al., 2013, 2014; Lee et al., 2015), as well as to each of the four themes of the AOS. It is hoped that through planning and coordination, advances in interoperability can be made for the benefit of all parties involved.

For the strategic assessment of Arctic Observing efforts, an intermediate-level resource is needed that focuses on data collection sites, with a bare minimum of metadata fields for ease, comprehensiveness, timeliness, and interoperability. Agencies and organizations tied to Arctic Observing can take advantage of the new application and use the collaborative and distributed web services as a tool for their own purpose; for example, to help assess status, optimize sampling design, fill gaps, or gauge progress.

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