Abstract

Proposal Number: RC20-B5-5050
Proposal Title: Arctic Environmental and Engineering Data and Design Support System
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Objective: The US Department of Defense (DoD) maintains infrastructure necessary for the strategic defense of the Arctic region including buildings, roads, bridges, runways, harbors, and communications and power systems. It is critically important to ensure that existing and future DoD infrastructure is functional under a wide variety of scenarios – including changing environmental conditions. Standards and codes used by DoD, other state and federal agencies, and industry to guide design decisions in Alaska and the broader Arctic require data that is more sophisticated and robust than currently existing information. Current design decisions rely on data that is outdated, sparse, and does not include state-of-the-science future projections. We propose to refine and link web-based technologies to provide an Arctic-focused engineering design support system – the **Arctic E**nvironmental and **E**ngineering **D**ata and **D**esign **S**upport **S**ystem (**Arctic-EDS**). Arctic environmental data represent core information needs that guide infrastructure design specifications at high latitudes, where rapid environmental changes and the widespread presence of permafrost and floating ice represent significant challenges for engineering design. This project focuses on decision support technologies, vetted Arctic-focused data, and decades of Arctic expertise and innovation to bridge those challenges and provide robust current and future design criteria.

Technology Description: We will refine, further develop, and deploy a suite of online technologies that curate and dynamically update relevant Arctic environmental data for use in web-based maps, modules, and notebooks. Our technical approach consists of data ingest adaptors, a geospatial data server and Application Programming Interface (API), client web maps and modules, and interactive engineering notebooks (i.e., web applications for creating and sharing code). The critical pieces of this technology are two open-source data management tools, GeoServer and Postgres. GeoServer is a geospatial publishing platform widely used in industry and civil applications. Postgres is a general database server that works in concert with its geospatial extension (PostGIS) to support large-scale geospatial data warehousing and publishing with GeoServer. The Arctic-EDS will replace the Environmental Atlas of Alaska (last revised in 1984) from a hardcopy Atlas to a modern web-based, dynamic platform with multiple opportunities for users to access, analyze, and export data. This contemporary implementation will provide up-to-date data collated by a number of different state and federal agencies. The Arctic-EDS will transform the outdated hardcopy Atlas into a sustainable technology where best-available data curated for engineering design needs are combined into a single online hub.

Expected Benefits: Government engineers and scientists working in all regions of the Arctic require easily obtainable engineering and environmental data. In particular, the US Army Corps of Engineers (USACE) is the primary design and contracting entity for 90% of DoD infrastructure projects, and many other Federal agencies as well. Often these Arctic DoD infrastructure projects require the varied engineering and science specialties which exist within USACE, but are located elsewhere in the continental U.S. and personnel may not be familiar with the available Arctic data and their sources. The Arctic-EDS system will provide a central repository for this fundamental data and promote constancy of data usage. The broader engineering and scientific community also will benefit from this Arctic-EDS development.

Technical Section

Descriptive Title: Arctic Environmental and Engineering Data and Design Support System

ESTCP Topic Area: B5

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Problem Statement: The U.S. Arctic is a strategic resource for the United States, because of its close proximity to Asia and the availability of vast stores of natural resources (CFR 2009). U.S. Department of Defense (DoD) maintains infrastructure necessary for the strategic defense of this region including: buildings, roads, bridges, runways, harbors, and communications and power systems. It is critically important to ensure that existing and future DoD infrastructure is functional under a wide variety of scenarios – including changing environmental conditions. Standards and codes used by DoD, other state and federal agencies, and industry to guide design decisions in Alaska and the broader Arctic require data that is more sophisticated and robust than currently existing information. Current design decisions rely on data that is outdated, sparse, and does not include state-of-the-science future projections. Engineers need access to data that accurately represent rapid environmental changes (e.g., air temperature and precipitation extremes, permafrost thaw, sea ice dynamics, etc.), which are critical for the design and planning of infrastructure.

Technology Description: We propose to refine and link web-based technologies to provide an Arctic-focused engineering design support system – the **Arctic E**nvironmental and **E**ngineering **D**ata and **D**esign **S**upport **S**ystem (**Arctic-EDS**). Arctic environmental data represent core information needs that guide infrastructure design specifications at high latitudes, where rapid environmental changes and the widespread presence of permafrost, seasonal snowcover, and floating ice represent significant challenges for engineering design. This project focuses on decision support technologies, vetted Arctic-focused data, and decades of Arctic expertise and innovation to bridge those challenges and provide robust current and future design criteria (Figure 1).

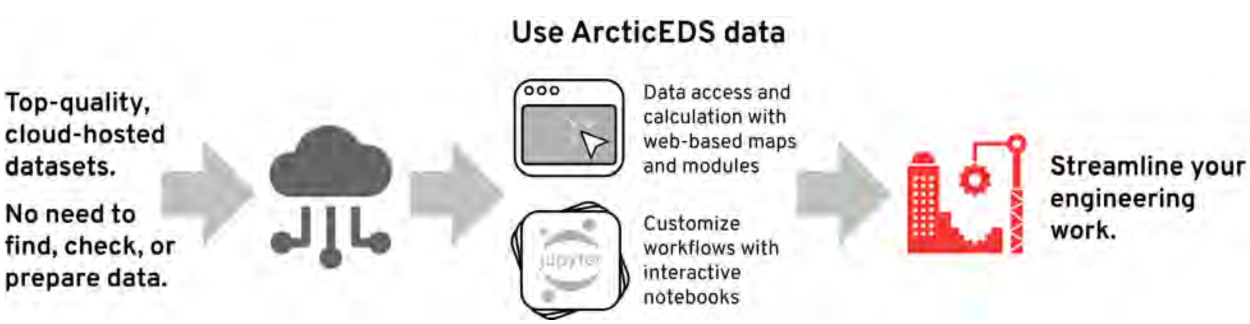

Figure 1. Conceptual overview of the Arctic-EDS.

Technical Objectives: There are four primary project objectives:

(1) Engage and entrain the Arctic engineering and scientific communities from project start to finish including formulation of disciplinary focus groups to guide, test, and validate the technology. This objective will leverage the project team's long-standing Arctic engineering expertise and applied collaborations with the Arctic engineering and scientific communities.

(2) Deploy an updated dynamic online version of the Environmental Atlas of Alaska that provides web-based maps of historical observations **and** both statistically- and dynamically-downscaled projections (including measures of uncertainty). This objective will leverage 10+ years of effort by the project team generating, deriving, and vetting downscaled historical climate observations and modeled (statistical and dynamical) projections to address a suite of climate impacts analyses and research activities.
(3) Curate data based on Arctic-focused engineering requirements and develop Application Programming Interface (API) libraries to make data ready to use for applications in planning, analysis, and engineering design. This objective will leverage the project team's multi-decade technical expertise in creating and working with multi-disciplinary Arctic-specific data.
(4) Support programmatic access, specialized engineering calculations, and knowledge dissemination through web-based notebooks and modules, including companion applications specific to supporting the upcoming new edition of the currently outdated Cold Regions Utility Monograph (CRUM) as well as life cycle cost analysis (LCA). This objective will leverage project team member's leadership activities with respect to updating the CRUM (Co-I Dotson) and Arctic-focused LCA (Co-I Larsen).

*Technology Description***:** We will refine, further develop, and deploy a suite of online technologies that curate and dynamically update relevant Arctic environmental data for use in web-based maps, modules, and notebooks. Once a standard reference in the industry, the Environmental Atlas of Alaska (henceforth referred to as the "Atlas") is grossly out of date, having been last revised in 1984. We propose a dynamically-updated web-based replacement for the Atlas that includes data from an additional 35 years of environmental measurements and research.

The Atlas remains the only collated source of environmental data collectively approved for engineering design purposes in Alaska. It contains information on five aspects of the environment: 1) physical description (e.g., geology, earthquakes, glaciation); 2) waters (e.g., coastal water depth, sea ice distribution, break-up and freeze-up dates, extreme tides); 3) light (e.g., hours of daylight); 4) climate (e.g., mean annual precipitation and snowfall, seasonal temperature variation); and 5) engineering information (e.g., design freezing and thawing indices). A previous online map-based representation of Atlas components, the Alaska Engineering Design Information System (AEDIS) was discontinued in 2009. AEDIS provided critical access to geographically-specific information on climate factors including precipitation, permafrost, and snow depth.

We propose to shift the product from a hardcopy Atlas to a modern web-based, dynamic platform with multiple opportunities for users to access, analyze, and export data (Figure 1). This contemporary implementation improves on the AEDIS by providing up-to-date data collated by a number of different state and federal agencies. This will transform the now static Atlas into a more sustainable (see Technology Transition section) model where best-available data curated for engineering design needs are combined into a single online hub. Our approach also solicits and integrates guidance from the engineering community (via surveys, workshops, and focus groups; see Technology Transition section) on current data usage to help prioritize needs. It also allows engineers to design infrastructure assets for environmental factors including observed and expected changes in climate and extreme events.

In order to facilitate dynamic/regular ingests of best-available data, our approach includes processes and technologies that we will use to collect, validate, and normalize datasets. This is critical as these processes can be time-consuming and introduce error into workflows. Data sources can be presented in uncommon or unfamiliar formats; the proposed system will implement automated "adaptors" that harvest data from sources and perform necessary validations and preprocessing before ingesting the data into Arctic-EDS. Automation and documenting any manual processes are important, even if the ingests are infrequent, because it provides a predictable and testable pipeline for assimilating heterogeneous data sources.

Additionally, our system architecture emphasizes *data interfaces* and use of *open, published data protocols* to decouple datasets from visualization and other analysis modules. By enforcing a loosely-coupled design approach, updates to modules and datasets can be performed independently without losing integrated functionality. This approach also includes the flexibility to support both standard and non-conventional data formats (e.g., NetCDF, GRIB, CSV) that are sometimes required for specialized engineering software. By providing the data in a consistent form, the Arctic-EDS will facilitate data discovery, exploration, and refinement of calculations.

We also will support access for advanced users of Arctic-EDS by developing a series of notebooks – these are open-source web applications for creating and sharing code. The notebooks will provide working examples of data importing, analysis and visualization that can be accessed, used online, or downloaded. This innovative approach will allow users to customize workflows for individual applications and facilitate documentation. The notebooks will contain the necessary code to access Arctic-EDS data via our data API, which will reduce the friction and difficulties engineers encounter when trying to access and use heterogeneous data. The notebooks also will provide a key source of information transfer between the engineering community for completing advanced calculations, and the technology team for optimizing those calculations and computational efficiency. We also will facilitate incorporation of the notebooks within university engineering curriculum. As an example, Arctic-EDS will be introduced in a thermal modeling course, providing the students with an updated resource of needed environmental data as well as training the next generation of engineers on use of this new technology.

The Arctic-EDS will provide a significant improvement in standardizing data and access used for engineering design in Alaska. As one example, the Atlas presented plates (i.e., maps) of freezing and thawing indices at a scale of 1 to approximately 18,900,000. At this scale, the user estimated freezing/thawing indices to the nearest 500 F degree days (DD) based on the design location's relative position to major features, such as the Yukon River. The degree day values came from a 1976 source, with a disclaimer that the data was "from low-lying coastal and river valley areas" and "probably not valid for higher elevations." While better than no data, these plates provided extremely rough estimates of environmental and engineering design values. The system that we envision will allow the user to view a map of Alaska with historic, current, or projected freezing/thawing indices across dynamic spatial and temporal scales allowing users to zoom in and select locations for site-specific index calculations.

Life cycle analysis (LCA) is an important tool for policymakers, planners, and other stakeholders interested in assessing the useful lifespan, depreciation schedules, and financial resources necessary for installing, operating, maintaining, and disposing of critical DoD infrastructure. For example, LCA has been used to estimate the economic value of critical Alaska infrastructure at risk due to climate change (e.g., Larsen et al. 2008, Chinowsky et al. 2009) and variations of LCA, which employ environmental data, have been successfully proposed for other ESTCP efforts outside of the Arctic (Larsen and Grussing, 2019). Information readily accessible to planners and engineers coupled with state-of-the-science environmental information from Arctic-EDS can be incorporated within specific modules/notebooks to allow for LCA of individual DoD assets or a collection of DoD assets. A more accurate picture of the lifecycle costs of DoD assets – along with their corresponding mission criticality indices – will help DoD planners prioritize future investments in infrastructure given budgetary constraints and environmental risk.

Through our current network of Arctic engineering experts, we have identified potential datasets for the Arctic-EDS based on original hardcopy Atlas plates. A detailed description can be found in Appendix 1. One main advantage is that our team currently produces and maintains several different versions of reanalysis and projected climate data. As part of this work, we also currently access and analyze meteorological station data from across the state of Alaska. Of the original 44 plates, 17 of them will be directly or indirectly produced using our climate products. We have identified several key partners for replacement datasets including NOAA for bathymetric and riverine data and the Alaska Division of Geological & Geophysical Surveys for earthquake and glaciation information. Many of the original plates have been expanded for modern engineering design; an example of this is permafrost in Alaska. Modern permafrost information should include extent (probability of occurrence), mean annual ground temperature at several depths, and active layer depths at a minimum. Ideally, information on thaw susceptibility in the first 1 m of ground, and massive ice distribution and type also would be included. One key component will be consistently using data sources that serve multiple purposes. For example, information on isostatic rebound due to glaciation is critical for surveying and geomatics engineering. This source should be consistent with the glaciation data in the Arctic-EDS.

Technology Maturity: The project team has a 10+ year track record for producing and distributing similar technology (https://www.snap.uaf.edu/tools-and-data/all-analysis-tools). Our MapVentures (http://mapventure.org/#/) technology is a framework that facilitates publishing interactive online maps and geospatial data. The critical pieces of this technology are two open-source data management tools, GeoServer and Postgres. GeoServer is a geospatial publishing platform, started in 2001, that is widely used in industry and civil applications. Postgres is a general database server, started in 1986, that works in concert with its geospatial extension (PostGIS) to support large-scale geospatial data warehousing and publishing with GeoServer.

Technical Approach: Our technical approach consists of data ingest adaptors, a geospatial data server and API, client web maps and modules, and interactive engineering notebooks (Figure 2).

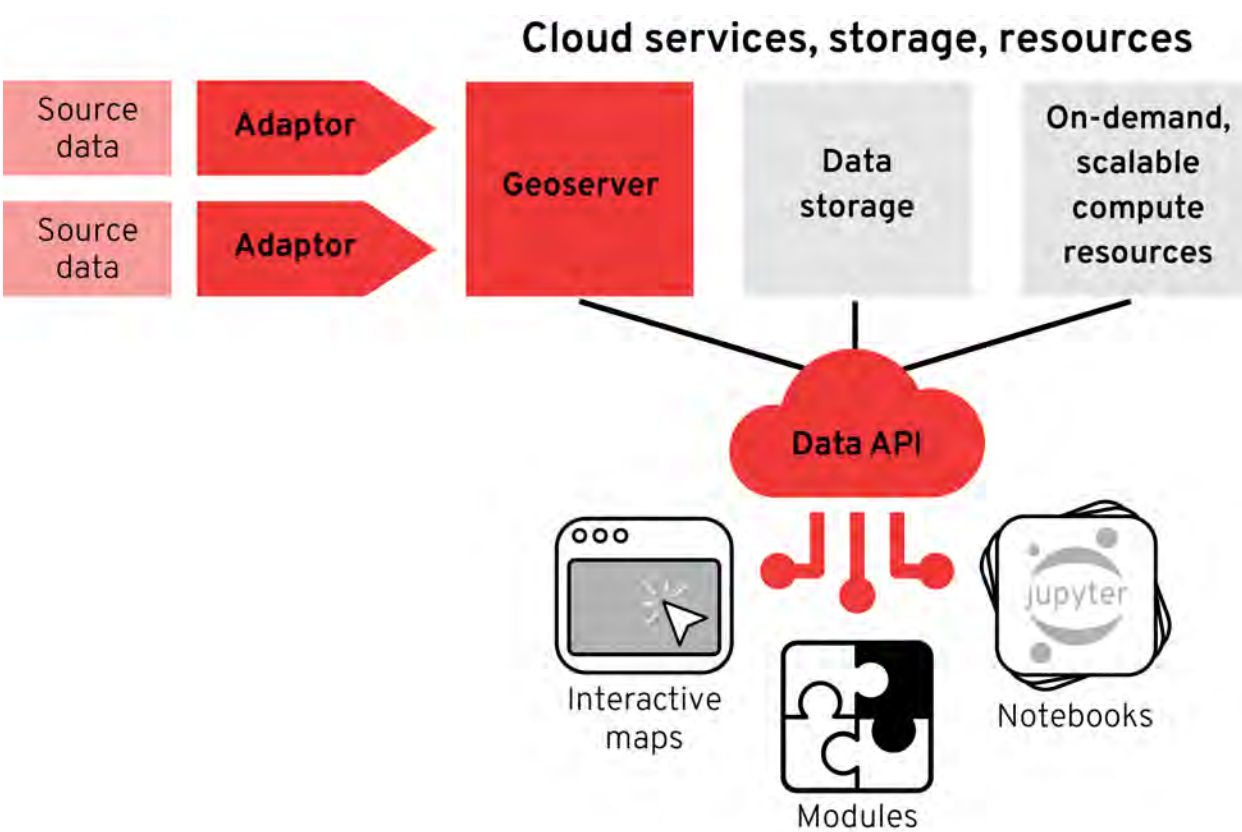

Figure 2. Arctic-EDS overview of the technical approach.

Data Ingest, Quality Assurance and Quality Control

Data is ingested into the Arctic-EDS through 'adaptors' that consist of software and documented manual processes required to obtain, normalize, and validate data before storing it in the Atlas. For example, an adaptor for ingesting a map of permafrost may involve scripts to apply a geospatial projection system, normalize the data format used, and develop a legend to be used when that layer is shown on a web map. Treating an adaptor as a unit of work improves sustainability because data ingest is not *adhoc* and can be repeated predictably when updated versions of data sets are available.

In coordination with our discipline-specific focus groups (see Technology Transition section below), we will develop processes for data quality assurance and quality control (QA/QC) and interoperability that will be documented and implemented as part of the data adaptors. Some of these processes will require manual effort, and others will be implemented as automated tests. We will establish a basic set of minimal metadata that will be associated with each dataset and collated into a data catalog. The catalog will facilitate direct data access via our data API, provide contact and data source information for users seeking original data, and document the normalization/enhancements/derivations that were performed on the original data set. This documentation will replace distributing or publishing normalized versions of source datasets as individual datasets outside of Arctic-EDS – minimizing data requirements for maintaining availability and access.

To reduce complexity of data access and processing, smaller vector and raster datasets will be stored in GeoServer as Shapefile or GeoTIFF; higher-dimensional datasets will be normalized to NetCDF and accessed via different programmatic interfaces. Where appropriate, preprocessed or intermediary data products may be produced in order to improve data access by clients.

Data API

The Arctic-EDS data API has two components: Geoserver and a data access API implemented in Python (Flask). Geoserver implements web standards (WMS, WFS, WCS) that support interactive web mapping applications and can be used to access imagery and perform very simple point-and-click data queries. Complementing this service will be a data access API implemented as a RESTful web service to deliver subsetting, timeseries, and simple operations such as averaging.

The reason to implement a data access API in addition to GeoServer is that many of the datasets that Arctic-EDS will provide are very large and require customized approaches to access, subset, and process data in a performant manner. This API will not be a general-purpose raster data processing engine. Instead, three subsetting operations to facilitate data access will be implemented per data set:

- Spatial subset: subset data by point or polygon
- Temporal subset: subset a temporal dataset by bounding start/end times
- Variable subset: subset a multivariate dataset by a specific variable. For example, return all precipitation data from a dataset that has additional variables.

These subsetting operations can be combined with a single API call to return a small dataset that can be used in client applications.

Web applications and notebooks will use Geoserver and the data API to access data. In addition, users will have multiple options for directly accessing data through the API including through GIS-specific software. Advanced users who need raw data also may access the geospatial database and data API directly to obtain data subsets. The data API is the main pipeline between the databases used to collate external data and further visualization and analysis in the web-based interface, modules, and notebooks.

Some users of the Arctic-EDS may find web mapping services (WMS) useful in their workflow, so for datasets where this makes sense, those services will be made available. Client GIS programs can pull these datasets in as layers for use in mapping applications specific to users' projects.

Web-based Maps and Modules

Web-based maps provide a simple, familiar interface to enable engineers to access spatial data and will be the primary replacement for the 'plates' in the outdated, hardcopy Atlas. Given user input of location, temporal range, and other variables, these web maps create interactive visualizations including comparisons, and allow data downloads of the results along with print-quality charts and graphs. These map tools will be geared towards point- and regional-based data access and will provide limited computational interaction.

For more sophisticated on-demand data processing, web-based modules will provide interactive interfaces to control complicated back-end computational processes, potentially including processes like modeling runs that require significant computational resources and/or special handling of the data in Arctic-EDS.

Web-based maps and modules will be implemented using common front-end Javascript frameworks and libraries (Vue, Leaflet). Users will access these apps using a desktop web browser, and we will support Internet Explorer 11 along with 'modern' versions of Chrome, Firefox, and Safari.

Notebooks

A notebook is a document that contains a combination of code and documentation that can be run interactively. This combination is powerful because it brings together the description of an analysis along with the results of that analysis, running in real time, all editable and configurable by the engineer using it (see Figure 3 in the Appendices – Supporting Technical Data). This approach is important for Arctic-EDS in several ways including the following. (1) It allows engineers the ability to customize analyses while maintaining the ability to easily access data via the Arctic-EDS. This customization can include nontrivial parameters or algorithms that engineers need to specify in order to yield useful results. (2) It allows the Arctic-EDS web tools to focus on applications with limited ranges of parameters and thus optimize development time. Since notebooks are commonly used in many science disciplines, supporting the development and application within the Arctic-EDS product provides an important foundation for future collaboration and knowledge exchange.

As an example, a notebook would calculate depth of freeze or thaw by pulling site-specific temperature data from web-based data sets and using user-defined input parameters for soil stratigraphy and properties. These notebooks will serve several additional functions: 1) they can include specialized calculations specific to Arctic engineering practices including those in the CRUM; 2) they can improve long-term estimates of the true lifecycle cost of mission-critical DoD infrastructure; and 3) they can facilitate information transfer within and between academic and professional environments. The notebooks will include examples of using the API to access data, and serve as "recipes" that users can customize and extend to an extent that is not possible with the online modules.

Specifically related to the CRUM, through the integration of engineering calculations spatially relevant environmental data will be used to generate site-specific parameters pertinent for infrastructure design. An example may include utilization of snowfall and snow density to determine water availability for snow reservoirs and potential/design requirements to ensure physical infrastructure is not impacted by snow drifting. A similar example may include the effectiveness of a facultative lagoon to treat municipal wastewater in Alaska using regional climate information to determine ice-free time and biological activity based on air temperature.

Similarly, incorporation of LCA considerations will be achieved through incorporation into notebooks (and possibly modules as well). High-level technical guidance on notebook development will focus on generally accepted frameworks, data requirements, and other information necessary for conducting LCA of mission-critical DoD infrastructure located across the Arctic.

This project will use the Jupyter notebook technology. Notebooks will be available online through the Arctic-EDS web interface via an API, and the underlying code will be published on Github, a web-based hosting service for version control and source code management. This allows engineers who use this workflow, licensed access to copy, customize, and run the notebooks on their own infrastructure.

Systems, Network, and Client Infrastructure

The Arctic-EDS system will be hosted entirely on a cloud-based service provider, such as Amazon Web Services (AWS). Services will be deployed using containers and managed using orchestration tools (either vendor-specific, or Kubernetes). No physical infrastructure will be built or maintained by UAF.

Bandwidth and latency between Alaska and cloud services are not a specific concern for the scope of this project, because all data transfers will be optimized data exchanges to support web applications and limited data queries; i.e., Arctic-EDS will not be providing full access to large, multi-gigabyte data sources.

Client computer requirements will be defined and used as a test matrix, targeting "modern" web browsers with support extending no further back than Internet Explorer 11 for Windows 10. Current versions of Chrome, Firefox, and Safari will be supported on their respective platforms. Mobile devices will not be supported in this phase of the Arctic-EDS due to a lack of clear use cases and the increased complexity of developing good user interfaces that interoperate between mobile and desktop platforms. While the engineering notebooks can be run on different infrastructure of the clients' choosing, supporting client environments is outside the scope of this proposal.

Some of our DoD partners may have specific technical requirements with respect to security, network access, and software change management that could impact their ability to fully access and utilize the Arctic-EDS system as proposed. There are two specific situations we can anticipate and that we plan to address as part of development. First, some installations may have enhanced security requirements that would mean external network access is limited or prohibited. If outgoing network access is permitted but restricted, we can provide a whitelist IP address range for the Arctic-EDS, and which will be sponsored through UAF. This can serve as a trusted proxy to any cloud-based resources. If outgoing network access is altogether disallowed, we will provide an "appliance" version of the Arctic-EDS that runs fully within the network of a particular installation. Second, due to change management policies, some of our partners may need to use older or very specific versions of internet browsers. Our main targets (indicated above) for web browser compatibility will include Internet Explorer 11+ and the current-generation versions of other common browsers (Firefox, Chrome). If specific compatibility with an older version of Internet Explorer or a different web browser is needed, we will work directly with our partners as required to make the necessary functionality available in those environments. Furthermore, we are committed to working with our DoD partners to address any other specific issue related to security, access, and/or IT management. Any issue outside the two primary situations described above will be addressed at the installation/group level.

Software Development and Design Methodology

We will use a variant of agile software development (Kanban). This approach to software development allows requirements and solutions to evolve through the collaborative effort of the programming team and end users, organized into milestones that deliver well-defined scopes of work. Automated unit and integration tests will be implemented as appropriate using language-specific frameworks, and peer review of all code and data in the Arctic-EDS will be required. End-users will ultimately validate and approve functionality of all tools, and all user feedback will be captured in a ticket system (Github). Github's Projects tool will be used as a simple, user-visible project management tool.

Source code will be managed using Git for version control, and we will adopt Google's style guides for Javascript and Python coding for all code developed for this project. Code developed as part of the notebooks will emphasize readability and follow current engineering conventions for calculations and analysis.

Excellence in user interface and design will be incorporated throughout this project. Our approach will be to apply a design reflecting resources used by engineers, and include elements of the original Atlas where appropriate to create a consistent theme that maximizes the utility of the Arctic-EDS. A comprehensive style guide will be developed and applied to all layers of the Arctic-EDS product, including interactive visualizations, print-quality charts and graphs, and notebook formatting.

Technical Risks: Our strategic use of cloud-based hosting through AWS allows the Arctic-EDS to harness up-to-date technology on a platform that will allow future iterations of the product to be improved and deployed efficiently. The team's experience with managing complex projects including scientific model creation, climate data generation and web-based tools for facilitating communication and knowledge provides a strong base for critical technical expertise and project management. This includes strategies for mitigating issues with synthesizing large datasets created both internally and externally. Some data present challenges with respect to access and normalization. In particular, it can take large differences in effort and resources to ensure that data are ingested properly and in appropriate spatial/temporal reference frames. The risk is not about what is technically feasible; instead, care must be taken to select and prioritize dataset development. Our main method of mitigating this risk is limiting the Arctic-EDS to the original datasets and then adopting a prioritization process co-created with the user community, project leadership and technical team. This process is described more fully in the Technology Transition section to ensure that our development reflects user needs, and to communicate the complexity of data ingest as part of our engagement with users. This engagement process also will provide critical guidance for developing the modules and notebooks to align the needs of users and to avoid building monolithic tools that are unsustainable. We will engage with the user community from the project start to drive priority and limit the scope for these extendable modules, and to ensure we are delivering a useful product.

Related Efforts: This project will take advantage of several relevant projects. PI Rupp is co-PI on the currently funded SERDP project (RC18-1108) entitled *Aquatic Ecosystem Vulnerability to Fire and Climate Change in Alaskan Boreal Forests.* We intend to draw on that project utilizing its high resolution (1-2km) dynamical downscaling runs for interior DoD lands. Rupp's research group (SNAP; www.snap.uaf.edu) is currently working on a project funded by the Alaska Department of Transportation and Public Facilities (ADOT&PF) to provide statewide dynamically downscaled (20km), bias-corrected projections of future liquid precipitation for every decade through 2100. We plan to integrate these data (scheduled completion is January 2020) into the Arctic-EDS. Rupp also serves as the University Director for the Alaska Climate Adaptation Science Center (AK CASC) – one of eight Department of Interior regional centers administered by the US Geological Survey. We will draw upon the AK CASC's extensive dynamical downscaling activities and data. The AK CASC provides the **only** available statewide dynamical downscaled climate scenarios and is the *de facto* expert authority for this domain.

Finally, Rupp is leading a new University of Alaska Fairbanks (UAF) supported initiative – the Arctic Data Collaborative. As the world's leader in Arctic research – including vast networks of instrumentation that make routine observations across the state of Alaska in areas from bioinformatics to climate change and space weather – UAF is uniquely poised to deliver data directly from, about, and for the Arctic. We will specifically leverage this initiative to advance the proposed data curation activities.

Co-I Larsen is PI on the currently funded ESTCP project (RC19-B5-5264) entitled *Weather Effects on the Lifecycle of DoD Equipment Replacement (WELDER)*. We intend to draw on aspects of this project to inform the inclusion of infrastructure replacement cost components into the proposed modules and notebooks. Co-I Dotson is leading a formal update of the CRUM (last updated in 1996) under the auspices of the American Society of Civil Engineers Cold Regions Engineering Division. The new edition will focus on both theory and current practices. We intend to use the Arctic-EDS as an opportunity to inform the CRUM and add application potentials by creating dynamic input values (i.e., climate, soil data, etc.) to equations to ensure accurate calculations and potentially enable projections of future environmental change.

Additionally, a parallel effort by Co-I Bjella serving as PI, is separately proposing to ESTCP to conduct a rewrite of the DoD Unified Facilities Criteria 3-130 Arctic and Sub-Arctic Construction guidelines (UFC 3-130). These guidelines are utilized by government and private sector engineers for design guidance of Cold Regions infrastructure. UFC 3-130 references to engineering and environmental data are either woefully out-dated or the sources are no longer available. This rewrite of UFC 3-130 would substantially cite the Arctic-EDS system as a primary source of information and data sources, and the web-based maps, modules, and notebooks will be integrated into the rewrite as they are developed. Permafrost temperature forecasting guidance will be included within the revision. This will be accomplished by linking the guidance to Arctic-EDS, where a permafrost-temperature forecasting map of Alaska is planned. That module would allow the user to choose a specific location, choose a representative concentration pathway (RCP), as defined by the Intergovernmental Panel on Climate Change (IPCC), and the forecast model will then determine temperature change at that location per the user-entered time duration. Permafrost temperature forecasting is crucial for proper design of infrastructure on ice-rich permafrost terrain. It is anticipated that the UFC 3-130 rewrite will be a catalyst for identifying additional data sets and functions for inclusion in the Arctic-EDS.

Expected DoD Benefit: Government engineers and scientists working in all regions of the Arctic require easily obtainable engineering and environmental data. In particular, the US Army Corps of Engineers (USACE) is the primary design and contracting entity for 90% of DoD infrastructure projects, and many other Federal agencies as well. Often these Arctic DoD infrastructure projects require the varied engineering and science specialties that exist within USACE, but are located elsewhere in the continental U.S. and personnel may not be familiar with the available Arctic data and their sources. The Arctic-EDS system will provide a central repository for this fundamental data and promote constancy of data usage. The broader engineering community, conducting geotechnical engineering design in Arctic locations for example, also will benefit from this Arctic-EDS development. Knowing that the Atlas is out of date and AEDIS is no longer supported, engineers obtain whatever air temperature data are available to calculate depth of freeze and/or thaw, and freezing and thawing design indices. For many locations, long-term historic data are not available; and if the data are available, they do not reflect current trends in climate. The Arctic-EDS notebooks we develop will provide a central location to obtain vetted historic data sets and/or dynamically downscaled data for locations without climate stations. This will be particularly valuable for remote sites maintained by DoD all over the state of Alaska.

The Screening Level Vulnerability Assessment Survey (SLVAS) Report (2018) produced by the Department of Defense to identify initial vulnerabilities to climate-related risks for DoD infrastructure highlighted six main extreme weather effects of concern. These included flooding due to storm surge, flooding due to non-storm surge events, extreme temperatures (both hot and cold), wind, drought, and wildfire. Both assets on the DoD sites as well as similar assets in the adjacent communities providing supporting services to the DoD site were considered. These include airfield operations, training/range facilities, transportation infrastructure, energy infrastructure, fuel infrastructure, water/wastewater systems, and housing. Alaska had DoD sites that were affected by each of the six main extreme weather events except for drought. Both flooding due to non-storm surge events and wind affected 10 sites each in the state as of 2015. The SLVAS responses were used to modify an USACE Civil Works vulnerability assessment tool to assist installations in: (a) consistent assessments for specific functional areas (e.g., water supply) and (b) integration into installation-level plans (e.g., real property master plans). The Arctic-EDS product will provide a key source of information for these vulnerability assessments as they are created and updated over time.

It is anticipated Arctic-EDS will provide the next level increase in environmental data resolution. This is crucial information necessary to characterize infrastructure sites, and more fully inform designs for a warming Arctic. For example, when future building locations across Alaska are identified to be of mixed permafrost character, thaw-stable and thaw-unstable, the cost savings in proactively locating on thaw-stable terrain is estimated to save $1.9 billion through 2099 (Melvin et al. 2017).

Schedule of Milestones: The project schedule of milestones breaks out activities and product delivery among the projects four primary objectives. The Gantt chart below identifies tasks by objective and provides estimated time required to complete by project quarters.

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Arctic-EDS Refinement & Deployment												
Develop backend scaffolding & design	X	X	X	X								
Deploy Geosever & network infrastructure			X	X	X	X	X	X				
User interface design and optimization		X	X	X	X	X	X	X	X	X	X	X
Sustainment activities									X	X	X	X
Data Curation and API Development												
Dataset curation including analysis		X	X	X	X	X	X	X	X	X		
API scaffolding	X	X	X	X								
Engineering Modules & Notebooks												
Module Development			X	X	X	X	X	X	X	X		
Notebooks: Module Specific					X	X	X	X	X	X		
Notebooks: CRUM & LCA Integretion							X	X	X	X		
Notebooks: Data Use & Access			X	X	X	X						
Outreach & Technology Transfer												
Kickoff user survey & user workshop	X											
Discipline-specific focus groups	X	X	X	X	X	X	X	X	X	X	X	X
University-education level classes							X	X	X	X	X	X
Professional development seminars						X		X		X		X
User documentation and demo videos						X	X	X	X	X	X	X
User training workshops												X
Annual ESTCP meetings				X				X				X
Quarterly reports	X	X	X	X	X	X	X	X	X	X	X	X
Final report												X
Science conference presentations				X				X				X
Peer-reviewed publications									X	X	X	X
Publish curated data developed by UAF		X		X		X		X		X		X
Codebase dissemination	X	X	X	X	X	X	X	X	X	X	X	X

Technology Transition: Stakeholder engagement is a primary objective and this engagement will drive all aspects of technology refinement, further development, and deployment. As part of our proposal development we jump-started our stakeholder engagement by conducting an informal survey of Alaskan engineer colleagues. Our 25 respondents included those working in civil (structural, transportation, environmental, water/wastewater), geological/geotechnical, mechanical, and mining engineering. Over half of the respondents have been practicing for 16-30 years. We asked them to rank potential precipitation and temperature products in terms of how much use and importance they have for completing their work. All precipitation products including mean annual precipitation, mean annual snowfall, flood frequency estimates and precipitation frequency estimates were identified as moderate to high use and importance. For temperature products, thawing and freezing indices were identified as the most used and important products. This was followed by design thawing and freezing indices, degree days (DD) below 0^{o}C and mean annual temperature. These responses clearly indicate that translating climate data into specific products for engineering is a critical step for making the information accessible and useable. Soil temperatures, evapotranspiration, and wind speeds and direction also were identified as desirable site-specific variables. Our respondents identified accessing the Atlas through a web-based interface as 80% importance out of a potential 100%. In contrast, they rated using their own scripts around 50% importance; however, it was noted that this capacity would be very valuable to other engineers. Additional feedback noted that considerable time and effort were spent researching data used for design, where access to downscaled climate projections would be valuable.

As part of our project, we will start by identifying our user demographics and minimum viable product needs through 1) a broad, formal, and complete user survey and then 2) a user-focused workshop at the beginning of the project. As part of the year 1 workshop we will form discipline-specific focus groups that will provide continuous feedback to the development team including testing and validation of the technology. We will take advantage of prototypes through our agile software development approach to maximize focus group feedback in the early stages of the project and continue multiple levels of Arctic-EDS review in year 2 and 3 including manual QA/QC by research professionals and peer review by engineers in Alaska. In years 2 and 3, we will focus on four technology transition activities. 1) Support the use of the Arctic-EDS in university-education level classes. UAF faculty involved in this project will introduce Arctic-EDS into undergraduate and graduate level classes, instructing the students how to use the data source for discipline-specific design needs. This effort will help to train future generations of engineers working in the Arctic. 2) Provide professional development through Alaska and national engineering societies by hosting seminars at annual meetings. For example, a short course detailing Arctic-EDS and its use in acquiring data needed for thermal modeling may be offered at venues such as the Cold Regions Engineering conference hosted by the American Society of Civil Engineers (ASCE). 3) Develop appropriate documentation including videos demonstrating common tasks within Arctic-EDS. Documentation and videos will be integrated into the Arctic-EDS. 4) Host two (Fairbanks and Anchorage) one-day workshops at the end of year 3 with the purpose of demonstrating the main functions of the Arctic-EDS and soliciting additional user community feedback. ***All of our implementation, communications, and outreach efforts will conform to the U.S. Interagency Arctic Research Policy Committee (IARPC) Principles for Conducting Research in the Arctic (2018).***

A primary focus of our stakeholder engagement and technology transition will be focused on the Alaska region and with a specific engagement focus on the U.S. Army Corps of Engineers (USACE) and Alaska installations (e.g., Ft. Wainwright, Eielson Air Force Base, Joint Base Elmendorf-Richardson). We are developing specific point-of-contacts (POCs) for this project at each installation. POCs identified using existing relationships such as the standing cooperative agreement with USACE that supports that Applied Environmental Research Center housed at the University of Alaska Anchorage (UAA). Such POCs may include those working on AERC projects such as, Charis Cooper (USACE), Kevin Thomas (USAF), Lori Roy (USAF), and Kristina Smith (US Army). This will help supplement our effort to reach out individually to each installation. The POCs will be the primary mechanism to facilitate coordination across various departments within the Department of Public Works or U.S. Air Force Civil Engineer Center at each installation including engineering and as necessary environmental personnel. We will request that POCs work with technical staff to make sure the Arctic-EDS tools and data have the potential to work behind DoD firewalls. We plan to coordinate a series of meetings specifically for the DoD installations in Alaska to understand their current processes, how this technology can be deployed most effectively for them and how it will need to be integrated into cost estimation and planning for future infrastructure

Our proposed plan for continued long-term housing and funding of the Arctic-EDS after the ESTCP funded portion ends are twofold. First, basic support to host and maintain the web-based platform and the web-based maps will be supported by the International Arctic Research Center (IARC) at the University of Alaska Fairbanks (UAF). Supporting the web platform and primary web-based maps aligns fully with the mission and objectives of UAF's Arctic Data Collaborative (ADC) initiative and the Alaska Climate Adaptation Science Center (AK CASC; see Related Efforts section) – both of which are housed within IARC. Second, we will work jointly with UAF's Office of Intellectual Property and Commercialization (OIPC), UAA Office of Technology and Commercialization (OTC), and UAA Business Enterprise Institute (BEI) to explore and identify commercialization opportunities that would sustain continued support and development of the web-based engineering modules and notebooks. Opportunities may include but are not limited to subscriptions, technology licenses, or spin-off companies.

The ADC and AK CASC will provide the hosting services as well as technical support of the web-based maps and associated data using base program funding that provides for data storage and hosting services as well as technical capacity via a full-time Data Steward and Data Management position. We envision ongoing long-term access to the base data layers and web platform that will be provided at no cost to users and will be available widely to anyone that may want access to the data.

Using the expertise and assistance of OIPC/OTC and BEI we will explore potential commercialization options and opportunities that could sustain the more significant efforts to further develop the maps, modules and notebooks and provide enduring value for the engineering community. We will develop and implement the framework of a commercialization plan during the project's three-year duration. This plan will be developed through market surveys of potential clients in coordination with outreach and training activities which are already part of the proposed project (i.e., the engineering community). Options that may be considered will include a subscription fee model for Software-as-a-Service and Data-as-a-Service, spinning off a technology start-up company to run the technical infrastructure and user support while continuing to leverage the project team for data science, or licensing technology and data to an existing company.

Disposition of Equipment: No major equipment will be purchased for this project and as such no disposition plan is required.

Performers:

T. Scott Rupp. Professor, International Arctic Research Center (IARC), UAF. *Ecosystem modeler with climate downscaling expertise. Overall project management. Lead and supervise web-based technology refinement and deployment, data curation, and associated frameworks.*

Margaret Darrow. Professor of Geological Engineering, UAF. *Expertise in frozen ground engineering and thermal modeling. Provide guidance on specialized module and notebook development. Integrate Arctic-EDS into classroom teaching of undergraduate and graduate engineering at UAF.*

Sveta Stuefer. Associate Professor of Civil and Environmental Engineering, UAF. *Expertise in cold regions hydrology and hydraulics. Provide guidance and feedback on data, modules, and notebooks. Integrate Arctic-EDS into classroom teaching of undergraduate and graduate engineering at UAF.*

Erin Trochim. Postdoctoral Fellow, IARC, UAF. *Geoscientist with expertise in Arctic hydrology, permafrost and geospatial data. Module and notebook development and environmental data linkages.*

Kevin Bjella. Research Civil Engineer, Cold Regions Research and Engineering Laboratory. *Geotechnical Arctic Engineer specializing in design and remediation of infrastructure in frozen environments. Focus on DoD user engagement module and notebook linkages to the UFC 3-130.*

Peter Larsen. Research Scientist/Deputy Group Leader, Lawrence Berkeley National Laboratory. *Applied economist specializing in infrastructure depreciation under alternative climate/weather scenarios. Provide guidance on notebook development and incorporation of LCA.*

Aaron Dotson. Professor of Civil Engineering, University of Alaska Anchorage (UAA). *Water and wastewater utilities expert. Coordinate linkage between the CRUM and development of functional design tools via notebooks and modules. Act as liaison to standing military POCs through the Applied Environmental Research Center.*

Paul Duffy. Vice President, Climate Change Program Leader, Neptune Inc.; Affiliate Faculty, UAF. *Mathematical statistician with expertise in statistical methods used to downscale gridded climate data. Provide guidance and feedback on the development and implementation of statistical methods including Bayesian hierarchical modeling and simulation work.*

ESTCP Review Comments:

The ESTCP Program Office requested the following feedback and actions be considered while constructing our full proposal. A summary of our response and a citation providing the location of the response in the proposal is provided immediately after the comment below and is identified in ***bold italics***.

- ESTCP provides a DoD liaison to assist you in your coordination efforts, your liaison is Dr. Martin Jeffries (martin.O.Jeffries@usace.army.mil, phone number: 603-646-4410). ***This comment did not require a response within the proposal text. PI Rupp did have a phone discussion with Dr. Jefferies about the proposal and clarified several different questions that assisted completion of of the full proposal.***
- The research will be performed under contract rather than grant; therefore, you should carefully consider including administrative costs specific to this research effort in the proposed budget. ***This comment did not require a response within the proposal text. This issue has been addressed as part of the budgeting process and is reflected in our submitted budget documents and within the cost section of the proposal.***
- The pre-proposal includes elements on how the team plans to continue to house/fund the work after the SERDP funded portion ends. We will need additional details on that effort. ***We present a full description of our plans for project sustainment after the funded portion of the project concludes, including university capacity to assist in commercialization and licensing opportunities. These plans are presented in the last two paragraphs on page 12 and the first paragraph on page 13.***
- Acknowledge that the proposed research will conform with the IARPC Principles for Conducting Research in the Arctic (2018). ***We acknowledge our intent to conform with the IARPC Principles for Conducting Research in the Arctic at the end of the first paragraph on page 12.***

Acronym List:

Acronym	Definition
AEDIS	Alaska Engineering Design Information System
AERC	Applied Evnironmental Research Center
ADC	Arctic Data Collaborative
ADGGS	Alaska Division of Geological and Geographical Surveys
ADOT&PF	Alaska Department of Transportation and Public Affairs
AK CASC	Alaska Climate Adaptation Science Center
API	Application Programming Interface
Arctic-EDS	Arctic Environmental and Engineering Data and Design Support System
ASCE	American Society of Civil Engineers
AWS	Amazon Web Services
BEI	Business Enterprise Institute
CRREL	Cold Regions Research and Engineering Laboratory
CRUM	Cold Regions Utility Monograph
CSV	Comma Separated Values
DD	Degree Days
DoD	Deparment of Defense
GIS	Geographic Information System
GRIB	General Regularly-distributed Information in Binary form
IARC	International Arctic Research Center
IARPC	Interagency Arctic Research Policy Committee
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Analysis
NetCDF	Network Common Data Form
NOAA	National Oceanic and Atmospheric Administration
OIPC	Office of Intellectual Property and Commercialization
OTC	Office of Technology and Commercialization
POC	Point of Contact
QA	Quality Assurance
QC	Quality Control
SLVAS	Screening Level Vulnerability Assessment Survey
SNAP	Scenarios Network for Alaska and Arctic Planning
UAA	University of Alaska Anchorage
UAF	University of Alaska Fairbanks
UFC	Unified Facilities Criteria
USACE	US Army Corps of Engineers
USAF	US Air Force
WCS	Web Coverage Service
WELDER	Weather Effects on the Lifecycle of DoD Equipment Replacement
WFS	Web Feature Service
WMS	Web Map Service

Cost Section

Appendices – Literature Citations

Chinowsky, P., K. Strzepek, P. Larsen, and A. Opdahl. 2009. Adaptive climate response cost models for infrastructure. Journal of Infrastructure Systems 16(3), 173–225.

Council on Foreign Relations (CFR). 2009. National Security / Homeland Security Presidential Directive on Arctic Region Policy. Accessed at: http://www.cfr.org/climate-change/national-security-homeland-security-presidential-directive-arctic-region-policy/p18215.

Department of Defense (DoD). 2018. Department of Defense Climate-Related Risk to DoD Infrastructure Initial Vulnerability Assessment Survey (SLVAS) Report. Accessed at: https://www.acq.osd.mil/eie/Downloads/Congress/Climate-Related%20Risk%20to%20DoD%20Infrastructure%20(SLVAS)%20Report.pdf.

Larsen, P., S. Goldsmith, O. Smith, M. L. Wilson, K. Strzepek, P. Chinowsky and B. Saylor. 2008. Estimating future costs for Alaska public infrastructure at risk from climate change. Global Environmental Change 18 (2008), 442–457.

Larsen, P. and M. Grussing. 2019. Weather Effects on the Lifecycle of DoD Equipment Replacement (WELDER). ESTCP Project RC19-B5-5264.

Melvin, A.M., Larsen, P., Boehlert, B., Neumann, J.E., Chinowsky, P., Espinet, X., Martinich, J., Baumann, M.S., Rennels, L., Bothner, A., et al. 2017. Climate change damages to Alaska public infrastructure and the economics of proactive adaptation. Proc. Nat. Acad. Sci. U.S.A. 114: E122–E131. doi: 10.1073/pnas.1611056113.

Appendices – Abbreviated Curricula Vitae (CV)

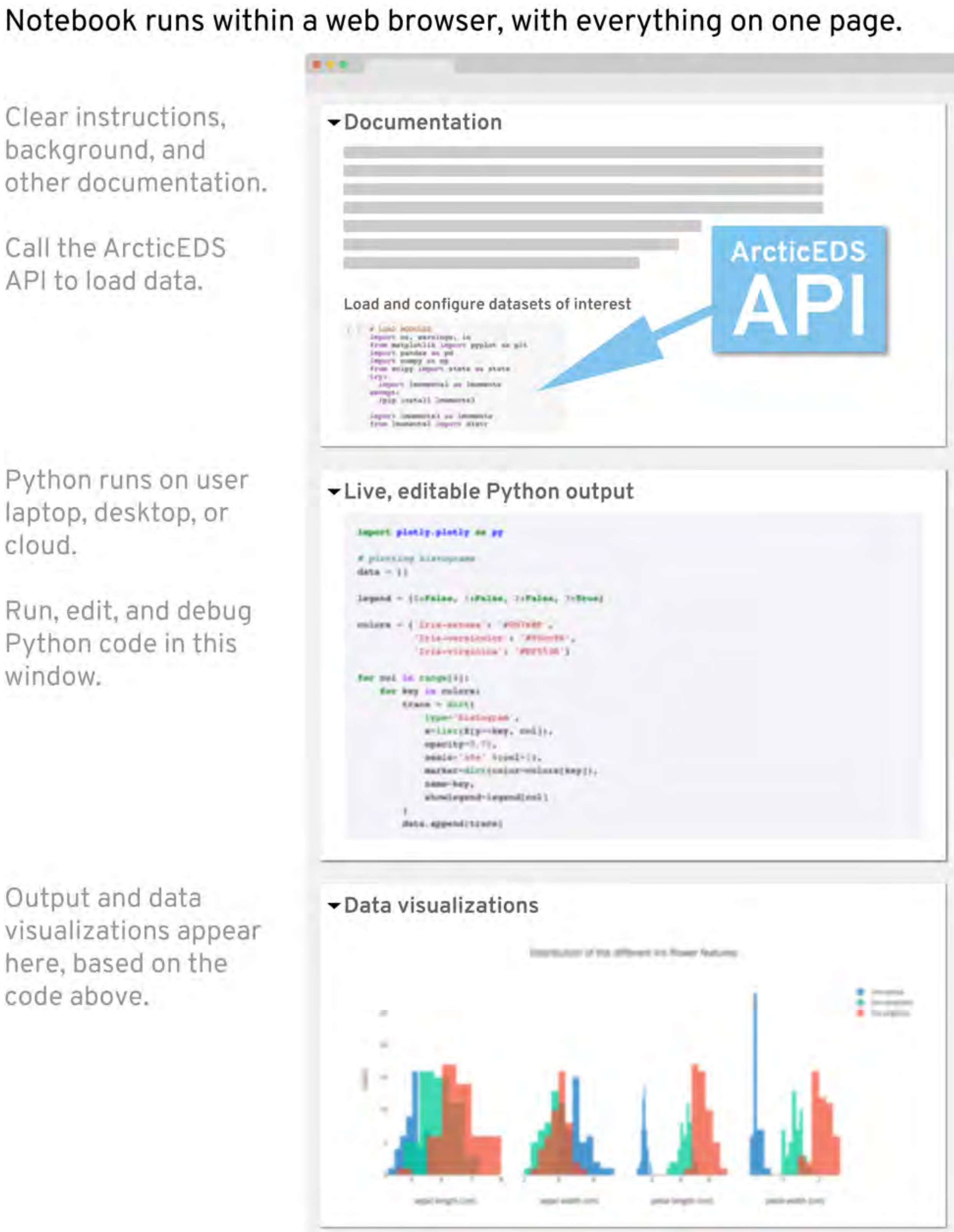

Figure 3. Notebook example identifying key benefits.

Table 1 - Original plates from Atlas matched with potential replacement datasets

Chapter	Description	Potential replacement
1. Physical Description of Alaska	Alaska and its Neighbors	Standardized web-based map
1. Physical Description of Alaska	Alaska and the Lower 48	Standardized web-based map
1. Physical Description of Alaska	Scandinavia and Alaska	Standardized web-based map
1. Physical Description of Alaska	Strategic Location of Alaska + ports	NOAA vessel traffic density
1. Physical Description of Alaska	Distances within Alaska	Web-based look-up table
1. Physical Description of Alaska	Physiographic Provinces of Alaska	Standardized web-based map
1. Physical Description of Alaska	Geological Map of Alaska	DGGS, also add soils from USDA NRCS
1. Physical Description of Alaska	Earthquakes in Alaska	DGGS
1. Physical Description of Alaska	Permafrost in Alaska	UAF GI Permafrost data
1. Physical Description of Alaska	Glaciation in Alaska	DGGS and UAF Alaska Earthquake Center
1. Physical Description of Alaska	Forest Types in Alaska	
1. Physical Description of Alaska	Definition of the US Arctic	USARC US Arctic Region maps
2. Alaskan Waters	Depths of Alaskan Coastal Waters	NOAA bathymetry
2. Alaskan Waters	Currents of Alaskan Coastal Waters	Notre Dame modeled product
2. Alaskan Waters	Sea Temperatures off Alaska °F	NOAA satellite data
2. Alaskan Waters	Sea Ice Distribution	
2. Alaskan Waters	River and Coastal Ice Seasons	NOAA River Forecast Center
2. Alaskan Waters	Extreme Tides at Alaskan Harbors	
2. Alaskan Waters	Alaskan Water Crop	DDGS
3. Light	Sun Path Diagrams	
3. Light	Sunlight in Northern Latitudes	
3. Light	Twilight in Northern Latitudes	
3. Light	Sunlight Plus Twilight in Northern Latitudes	

4. Climate	Climatic Zones of Alaska	
4. Climate	Mean Annual Precipitation in Alaska	SNAP climate data
4. Climate	Wet Days per Year in Alaska	SNAP climate data
4. Climate	Probability of a Wet Day at Selected Stations	
4. Climate	Mean Annual Snowfall in Alaska	
4. Climate	Mean Minimum and Maximum January Temperatures °F	SNAP climate data
4. Climate	Mean Minimum and Maximum July Temperatures °F	SNAP climate data
4. Climate	Alaskan Seasonal Temperature Variation °F	Derived from SNAP climate data
4. Climate	Alaskan Seasonal Index °F	Derived from SNAP climate data
4. Climate	Alaskan Seasonal Lag °F	Derived from SNAP climate data
4. Climate	Mean Annual Diurnal Temperature Variation in Alaska °F	Derived from SNAP climate data
4. Climate	Wind Chill Equivalent Temperature	
4. Climate	Wind Chill Index Nomogram	
5. Engineering Information	Freezing Index, Alaska	Derived from SNAP climate data
5. Engineering Information	Design Freezing Index, Alaska	Derived from SNAP climate data
5. Engineering Information	Thawing Index, Alaska	Derived from SNAP climate data
5. Engineering Information	Design Thawing Index, Alaska	Derived from SNAP climate data
5. Engineering Information	Heating Degree Days in Alaska	Derived from SNAP climate data
5. Engineering Information	Degree Days below 0°F in Alaska	Derived from SNAP climate data
5. Engineering Information	Building Design Criteria in Alaska	