Snow Today

Improving Usability of Snow Data Through Web-based Visualizations and Tutorials

Bren School of Environmental Science & Management, University of California, Santa Barbara
Technical Documentation

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As developers of this Capstone Project documentation, we archive this documentation on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

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The Capstone Project is required of all students in the Master of Environmental Data Science (MEDS) Program. The Project is a six-month-long activity in which small groups of students contribute to data science practices, products, or analyses that address a challenge or need related to a specific environmental issue.

This Capstone Project Technical Documentation is authored by MEDS students and has been reviewed and approved by:

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Abstract

Snowpacks store valuable water resources, influence global climate dynamics, and provide outdoor recreational opportunities. The spatial and temporal distribution of its properties are hard to quantify and are sensitive to climate change. Remotely sensed snow data provides valuable information, but technical expertise can be a barrier to extracting meaningful insights from this data. Scientists at the University of California, Santa Barbara Earth Research Institute help communicate remotely sensed snow conditions through the Snow Today website, which presents daily images and monthly updates of snow variables, such as albedo. The data used to generate these insights are available on the website, but since the analysis is completed with Matlab, a proprietary computational software system, the workflow does not follow open-source data practices. Our Project addresses these limitations by creating an open-source workflow that improves the usability of snow data through interactive web-based visualizations and Python-based tutorials. As the impacts of climate change continue to affect snow conditions, the improved usability of Snow Today's datasets allows for customized analyses of snow data for specific regions of interest to support decision making for water supply allocation, hydrologic research, and recreational planning.

Executive Summary

Snow is one of the most important natural water resources present in nature. It stores water in winter and releases it in spring during the melting season. Snow also influences the Earth's ability to regulate its temperature (Newton 2021). Knowing the spatial extent of snow cover and understanding its properties is critical for water resource management and modeling global climatic conditions (Liston 1999).

Snow data collection includes snow cover extent and albedo percentages. Albedo measures how much solar radiation is reflected from a surface. Obtaining accurate information on snow coverage and albedo data is critical to modeling and analyzing water resource availability. Estimating snow cover variability and spatial extent is essential for proactive water management, and monitoring snow cover is important for planning and facilitating winter recreation activities. For these reasons, a centralized repository of snow data accessible to water managers and scientists is essential.

The Snow Today website is a leading source of seasonal snow condition data products for environmental remote sensing and field observations. The site's intended audience includes scientists, water resource managers, and recreationalists who access up-to-date information on the state of snowpack properties from the watershed basin to the regional level across the Western United States. Spatial products offered by Snow Today include snow-covered areas, snow cover days, albedo percentages, and snow water equivalent (SWE). Snow Today is currently expanding its spatial domain from the Western United States to all of North America, Greenland, and High Mountain Asia. The researchers at Snow Today are taking this opportunity to increase the usability and accessibility of their website to try and reach a wider audience of users. In support of these updates, affiliates of Snow Today, including researchers from the UC Santa Barbara Earth Research Institute (ERI) and the University of Colorado Boulder Institute of Arctic & Alpine Research (INSTAAR) (the Client), have requested the Bren Masters of Environmental Data Science Snow Today Group (the Group) to recommend how to incorporate these changes. Integrations of these changes will assist Snow Today with increasing the usability and accessibility of the website in hopes of reaching a broader audience of the scientific, water management, and recreational communities.

The Snow Today Capstone Project (Project) delivers recommendations to update the current Snow Today website by creating an information architecture plan, wireframe mockups, a web application prototype with interactive visualizations, and end-user tutorials that run in Python. The information architecture plans and wireframe mockup suggestions will help make the existing website interface easier to navigate for site users. Updating the current static visualizations with interactive visuals will increase the website's value by allowing users to customize and compare temporal ranges. End-user tutorials will help users access, process, and visualize the complex structure of Snow Today's snow cover and albedo datasets. These elements will help the Client achieve their goals of increasing the usability and accessibility of an updated Snow Today website to reach a wider audience and enable a larger set of users to access and interpret seasonal snow condition data.

Interactive visualizations serve as a template to replace the existing static models currently displayed on the Snow Today website. The interactive maps and charts are presented in an R Shiny application

that allows users to select a specific date and view snow cover and albedo maps, then zoom in/out on the maps to view specific areas. The Shiny app also displays annual and monthly snow cover, albedo averages, and anomalies. Users can use this app to learn more about snow science, the importance of albedo, nuances of the snow and albedo metadata, and background information on the Capstone Project and Group members from supplemental tabs within the Shiny app. The “Tutorials” tab on the Shiny app directs users to notebooks on our Group Github repository

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1. Problem Statement

1.1 Project Background

Snow Today is a scientific analysis website that provides data on snow conditions using satellite data and surface observations in the Western Region of the United States. Snow Today comprises researchers from ERI, INSTAAR, Oregon State University, and the National Snow and Ice Data Center (NSIDC). The site is funded by the National Aeronautics and Space Administration (NASA) and hosted by the NSIDC.

Snow Today offers real-time data on snowpack properties from the watershed basin to the regional level across the Western United States. Spatial products offered by Snow Today include snow-covered areas, snow cover days, and albedo percentages across the Western United States. Snow Today is currently expanding its scope from the Western United States to all of North America, Greenland, and High Mountain Asia. Snow Today is taking this opportunity to explore options to expand the usability and accessibility of the website in order to reach a broader audience of scientific, water management, and recreational communities.

1.2 Project Significance

The Snow Today site offers valuable resources to aid snow research and track the temporal and geospatial range of snow cover and snow albedo. However, given Snow Today's limited spatial domain, the website's usefulness is restricted to a small group of relevant end-users interested in Western United States snow cover extent and albedo. The Client plans to expand the website's spatial coverage from the Western United States to all of North America, Greenland, and High Mountain Asia to broaden the website's applicability to a greater audience. Moreover, Snow Today's existing albedo and snow cover datasets do not comply with NASA's Hierarchical Data Format - Earth Observing System's (HDF-EOS) metadata requirements. Geospatial software and Python packages have difficulty interpreting Snow Today's snow-related datasets, further limiting users' access to data and applicability.

2. Project Objectives

2.1 Objectives

This Project's goal was to improve the usability of snow data through web-based visualizations and tutorials by creating an open-source workflow for processing and visualizing snow data. We achieved this goal by improving users' usability of the data, creating an interactive web application to visualize the expanded and geographical extent of Snow Today products, and offering suggestions to enhance users' experience.

2.1.1 Website Recommendations

The Group provided the Clients with recommendations to improve the Snow Today website framework, navigation, and visualizations. These suggestions include improvements to the website's aesthetics with an emphasis on updated content, data access, and engaging interactive data visualizations.

2.1.2 Interactive Visualizations

The Snow Today Project provided the Clients with suggestions on how to display the newly expanded data scope on the Snow Today website through interactive visualizations. Interactive charts and geospatial maps were developed to display daily, monthly, and annual snow cover and albedo values to help users gain meaningful insights into the snow-related datasets. For example, scientists may be interested in displaying this year's albedo measurements and compare those measurements with historical values to help predict temporal trends and identify seasonal anomalies.

2.1.3 Tutorials

Snow Today's snow cover and albedo datasets are stored in an HDF5 file structure, which can be challenging to navigate for users unfamiliar with the data's structure. In addition, the dataset's metadata is in a non-standardized format, making it difficult for certain geospatial software and Python packages to interpret the stored data. As such, the Snow Today Group thought it would be helpful to develop Python-based notebook tutorials to provide end-users with instructions on accessing, analyzing, and visualizing 19 years' worth of snow cover and albedo data. The tutorials include steps to embed geographic information and transform datasets into more familiar and easily interoperable file types, such as GeoTIFFs and NetCDF file formats. These tutorials are meant to improve the ease of use of the datasets to interested users.

3. Solution Design

3.1 Approach and Methods

The Snow Today Group approach focused on how to process and present the data in a way that would better deliver meaningful content to end-users with a range of technical expertise through website recommendations, interactive visualizations, and tutorials. To provide open access to the Project workflow, all code used to create the deliverables is documented on the MEDS Snow Today public GitHub organization. A flow diagram of the Project's workflow is included in **Appendix A: Solution Design Workflow**.

The workflow began with understanding how to access and view the raw HDF5 data files, then moved to processing the data to calculate statistics, such as minimum, maximum, and median values and monthly and yearly averages and anomalies (Stillinger 2022). The data processing steps were documented on the Project GitHub Organization. Once the data was processed, the Group created website recommendations, interactive visualizations, and educational tutorials based on what we had learned about the data. Iterative reviews were a continual part of our approach. For example, the data processing step was revised based on reviews of preliminary tutorials and visualizations. Revisions

were also made based on feedback from the client. Finally, all deliverables were incorporated into an interactive web application that was created using R Shiny.

To elaborate further on our methods, the Snow Today Group used Python to access and interpret the snow cover and albedo datasets. The processed data was then converted to GeoTIFF and NetCDF files with spatial reference coordinate system information attached in a format that could be recognized by standard mapping packages. These data processing steps were documented in Python-based tutorials to provide a reproducible workflow. The Project used raster stacks of these georeferenced files to create interactive maps in R for the Shiny application.

Using MindMup mapping software, the current Snow Today website architecture was mocked up to map navigation processes a user would conduct in order to access data, and newsletters, and learn more about Snow Today research (**Appendix B**). The Project then redesigned the website flow to optimize the user experience when accessing the site (**Appendix B**). Using this new architecture design, the Group created a website wireframe to present recommended format and content updates to the Snow Today website (**Appendix C**). The website wireframe was designed in the Miro whiteboard application.

4. Products and Deliverables

The Snow Today Group produced three deliverables to achieve the Project objective of improving the usability of snow remote sensing data:

- Created recommendations for an information architecture plan and wireframe mockups of the proposed Snow Today website;
- Developed visuals of snow cover area and albedo on an interactive website application; and
- Generated "How To" example tutorials to guide various end users through the process of using the data to extract meaningful insights.

4.1 Website Recommendations

Website recommendations were created to facilitate future discussions between the Clients and NSIDC web developers. These recommendations include an information architecture plan and wireframe mockup and suggest updates to features, user selection options, pages, and aesthetics. NSIDC web developers will create the new and expanded Snow Today website informed by the Project's recommendations. These recommendations provide a smooth user experience, present new albedo visualizations, and integrate an expanded geographic extent that includes North America, Greenland, and High Mountain Asia. Evaluating the uncertainty of the SPIReS model was outside the scope of this Project, and we suggest that the Clients include a statement quantifying the uncertainty of Snow Today products and steps taken to minimize uncertainty.

The Project's Snow Today website wireframe provides layout recommendations for the Snow Today website page order, content, and visualizations. The wireframe consists of six pages, which include a landing page, an about page, a page for the researchers' monthly newsletters titled "Insights," snow science research and data pages, and a page dedicated to tutorials. The Snow Today website landing

page currently hosts the researchers' monthly newsletter. We suggest that they update the landing page with a short introduction to Snow Today research and what is available to users on the website. Also, the landing page should host an interactive spatial visualization where a user can select a data variable, such as snow cover or albedo, select a time period or relevant date, and zoom to a particular region of interest. This visualization should populate with North America, Greenland, and High Mountain Asia data. The landing page should also link to the data and tutorial pages to facilitate ease of access to the data and how to use it. The Group recommends adding a page dedicated to snow science research, which would provide a short background on snow hydrology, snow data variables, and the Snow Today researchers' SPIReS model. This page could also host additional static or interactive snow condition data visualizations. The Project recommends expanding the current data page content by adding general information on remote sensing data and the data Snow Today researchers are creating, including relevant metadata information. The Group recommends that the Clients change the existing metadata creation process to increase the data's geospatial interpretability. The Snow Today researchers could create a GitHub organization repository similar to this Project to facilitate ease of access to their environmental models and data processing repositories. Currently, these repositories are hosted on the researchers' personal GitHub accounts, which are not linked on the current website. A tutorial page was added to host the Python-based tutorials created by this Project and a potential future Snow Today YouTube channel that would host additional video-based tutorials, webinars, and training.

The current Snow Today website focuses on current snow conditions. We recommend additional features to easily allow users to view snow properties for a specific selected date or snow properties aggregated for monthly or annual timeframes. Similarly, we recommend additional spatial selection options. The current website only allows users to view the entire western US, specific states, or hydrologic unit code. We recommend that the updated Snow Today website include interactivity that allows users to zoom in and out on areas of interest. Another potentially useful feature would be a way for users to upload their own shapefiles to customize the area of interest further. For example, a water manager could be interested in viewing snow properties near specific reservoirs or for a specific watershed.

Real-time data integration is not within the scope of this Project. However, once developed, our workflow can be incorporated into the future Snow Today website and adapted to update the interactive visuals with real-time data continuously.

4.2 Interactive Visualizations

Visualizations include interactive charts and maps of snow cover and albedo to display the change in these parameters over space and time. All visualizations are presented on the Snow Today Shiny application, which can be found at https://shiny.snow.ucsb.edu/snow_today_shiny_app/. This app is a prototype of the suggestions included in the wireframe. Currently, the Shiny app only displays data for the Sierra Nevada region from water year 2001 through water year 2019. It allows users to select any date between October 1, 2000 (water year 2001) and September 30, 2019 (water year 2019) and visualize snow cover percent and albedo on that day. Users can zoom in/out of the maps to view specific regions. In addition, users are able to visualize annual and monthly means and anomalies. The Shiny app includes documentation on snow science definitions and the data used in this Project as well as links to the tutorials discussed below.

4.3 Tutorials

Tutorials based in Python were created to facilitate expanded use of snow cover and albedo HDF5 files from ERI's Snow Property Inversion From Remote Sensing (SPIReS) model (Bair 2021). The tutorials are intended to walk users through ways to comprehend and utilize the data used to make visualizations on the Snow Today website. The tutorials are for an audience with basic Python experience, but a previous understanding of multidimensional climate data is not required. The first tutorial focuses on walking users through the steps to open HDF5 files, explore metadata, and perform basic visualizations. The second tutorial provides instructions on calculating monthly and yearly means and anomalies of snow and albedo data, ways to convert data to GeoTIFF and NetCDF formats, and ways to create interactive maps. These GeoTIFF can be either individual files or raster stacks. The third tutorial focuses on calculating data statistics such as interquartile ranges and daily averages, then visualizing these values on interactive charts. While tutorials only use historic data from 2001 to 2019, the skills gained from the tutorials can be applied to present data.

5. Summary of Testing

The Snow Today Group completed an evaluation of our products and web application functionality through unit testing, sanity testing, and system testing. Unit testing was performed to ensure that the code ran as intended and that visualizations were appropriately rendered. Sanity testing was used to ensure our end-products were oriented and located in the correct position and logically made sense. System testing involved testing web-based and Binder environments' speed, stability, and operability.

5.1 Unit Testing

Unit testing ensured that each visualization was correctly rendered on the Shiny app website and that the interactive components' visualizations worked. We also confirmed that selection options return the desired outputs. Each tab was tested on its own before testing overall site navigation and operability. Group members tested individual code chunks and sections of the tutorials before finalizing them for end-users. Ultimately, the Project incorporated 19 years' worth of data contained within multiple datasets. We started by testing the app and tutorial functionality with a few years of data before deploying the full spatial, temporal, and historical snow cover and albedo records.

5.2 Sanity Testing

The Group ensured that our products produced realistic results. All Group members completed sanity testing. For example, did interactive visualizations display snow cover outside of the Sierra Nevada mountain range or during the summer months? Given that the Sierra Nevada region is not currently a selectable zone on the Snow Today website, our Group could not directly compare our results to Snow Today's findings. However, our Group compared relative values to overlapping and close-proximity locations, including California and the Pacific Northwest. Since accurately incorporating coordinate reference system and projection information was an essential component of this Project, sanity testing confirmed that no visualizations were rendered backward or upside down due to errors with coordinate system transformation. We also confirmed that visualizations and tutorials returned albedo values within realistic ranges. For example, early iterations of the albedo visualizations displayed a

smaller snow area than the snow cover percent visualizations. This alerted the Group to an error in the way “nan” values were addressed when calculating monthly and annual averages, and this issue was then resolved.

5.3 System Testing

Once the above tests were complete, system testing was conducted to ensure the operability of the web application and tutorials as a whole. System testing focused on navigation across the entire Shiny app to test the functionality of moving between visualizations and pages and from the Shiny app to the tutorials on the Snow Today organization’s public GitHub. A significant limitation to the Shiny app is the speed at which maps render.

Initially, the tutorials would be stored in a Binder notebook–a reproducible environment that makes tutorials immediately executable to any user. However, system testing determined that given Binder’s limited memory capacity, the tutorials could not render the notebooks successfully. Future developers interested in using Binder environments should consider researching additional methods to increase Binder’s memory capacity.

6. User Documentation

6.1 Overview

This user documentation aims to guide end users on how to properly install and use the Project’s snow data tutorials and navigate the data visualization web application.

6.2 Required Software and Packages

The Project was completed with open-source software. Python is used to read data files, complete spatial and statistical analysis, and visualize results. All code is stored in the MEDS Snow Today public GitHub repository. Deliverables are visualized in a R Shiny application platform.

Recommended software to install to run Project code: Anaconda-Navigator or Visual Studio Code (VS Code) (plus relevant extensions), and Conda, an open-source package management system (Anaconda 2017).

Python Packages

gdal	h5py	imageio
leafmap	matplotlib	numpy
pandas	plotly	rasterio
rioxarray	wget	xarray

6.3 Data and Repository Sources

The Project presents data on snow cover area and albedo. The Snow Today Group accessed data from ERI, which hosts a repository of historical snow condition data. These files were created using the SPIReS model and are outputted in an HDF5 format (.H5 files). The SPIReS HDF files contain 19 years of snow cover and albedo data. There is one file for each year, and this Project accessed the files from 2001 to 2019. All data used for the Project are publicly available, and there are no limitations to how others can use the data.

Metadata is documented on the Project's R Shiny application in an easy-to-find tab and a readme.txt file. This documentation explains the structure of the file types, timeframes, geographic extents, available variables, coordinate system, and units. The Client indicated that some Snow Today users prefer GeoTIFF files over the HDF5 file format. As such, the tutorials walk users through ways to convert the HDF5 files into GeoTIFFs and explain different aspects of the metadata, including projection information, cell size, projection type, and a variety of other variables. Doing so effectively increases the data's accessibility and reduces the time users need to comprehend and utilize the snow cover and albedo datasets.

Project deliverables and code are stored within the MEDS Snow Today GitHub organization and the UCSB Ylaipi GRIT server. The R Shiny web application is hosted on the UCSB Ylaipi GRIT server. Links to these resources are listed in the Archive Access section of this document.

6.4 Exploring the Data

6.4.1 Accessing Data and Metadata

Snow cover and albedo datasets are stored on UCSB's General Research IT (GRIT) server and can be accessed using a link within the tutorial notebooks.

Snow cover and albedo datasets are stored in a hierarchical data format, HDF5, which is designed to store and organize large amounts of data. HDF5 simplifies the file structure to include only two major types of objects: datasets and groups. As such, snow cover and albedo datasets are structured into "Grid"(group) –> "MODIS_GRID_500m"(group) –> variable(s)(dataset). The tutorial page includes ways to access the metadata and view the file structure using Python processes. In addition, links to external software are provided to view the dataset structure quickly and easily.

6.4.2 Convert Data Files and Visualize

Geospatial software and Python packages have trouble interpreting Snow Today's snow-related dataset's metadata, making it difficult to visualize the data spatially. As such, tutorials have been provided to subset, clean, reproject, and convert the snow-related datasets into GeoTIFFs and NetCDF file formats. Doing so allows the users to reproject the data into a more easily interpretable format by geospatial software and packages. The tutorials also include a method to visualize geospatially referenced raster data on an interactive map. A separate tutorial is included to visualize and compare yearly snow cover extent and albedo percentages.

6.4.3 Data Analysis

Users may be interested in using Snow Today's snow and albedo datasets to help answer scientific queries. As such, tutorials have been supplied to help users process and subset the datasets. The tutorials include ways to clean the data, calculate the monthly and annual average snow cover extent and albedo percentages, and steps to calculate monthly anomalies.

6.5 R Shiny Web Application

A prototype web application was developed to showcase our contributions to Snow Today data's more open-source workflow. The web application, which was developed with R Shiny, presents potential features for the new Snow Today website, interactive visualizations, and tutorials. The web application also presents documentation on snow science, links to Snow Today monthly newsletters, and information on the data sources, including metadata, MEDS capstone Project background, and team bios. Together, this content will minimize a barrier to working with Snow Today data. The deployed Shiny app can be found at https://shiny.snow.ucsb.edu/snow_today_shiny_app/.

The source data for the web application was the 19 years of snow cover and albedo data discussed above. These files were processed using Python in a Jupyter Notebook to calculate monthly and annual averages and anomalies for the period of record. These notebooks can be found on the MEDS Snow Today public GitHub repository. A challenge of this data was that the coordinate reference system metadata was not included in a standard format that mapping packages could easily recognize. Spatial information was specified when converting the processed data to GeoTIFF format to address this issue. Raster stacks of daily data for each water year and the processed GeoTIFFs served as inputs to the Shiny App.

Interactive visualizations presented on the Shiny app are for the Sierra Nevada region in the Western United States. The app's landing page, "Daily Snow Cover and Albedo," allows users to view snow properties for any day from October 1, 2000 through September 30, 2019 by selecting a date from the calendar widget. The top map shows snow cover percent, with brighter colors indicating more snow. The bottom map shows albedo for snow-covered areas with darker yellow indicating snow with lower albedo.

On the "Monthly Maps" page, users can select a water year (wy2001 through wy2019) from a drop-down menu, then snow cover percent or albedo from radio buttons. Here, the top map shows the averages of the selected variable for each month, and the bottom map shows the monthly anomaly. For the snow cover anomaly map, red indicates less snow than typical for that month, and blue represents areas with more snow than typical. For the albedo anomaly map, brown indicates lower than average albedo, while purple indicates higher than average albedo. The "Annual Maps" page shows the annual average and anomaly for the selected water year and variable.

6.6 Troubleshooting

If users experience issues in either the Shiny app or tutorials, they can submit an issue to the MEDS Snow Today Capstone Github Repository.

7. Archive Access

This Project was an analysis of existing data, which is openly available at the location cited in the reference section (Stillinger 2022). Further documentation about data processing is available on the MEDS Snow Today GitHub organization.

7.1 Data to Retain

Data Product	**Details**	**Location (link)**
Final output data	GeoTiff rasters with associated metadata for visualizations. Data is saved on the non-public UCSB Ylaipi GRIT server.	Github Organization repository: https://github.com/MEDSsnowtoday/data_processing
SPIReS data	Historic post-processed HDF5 snow data	UCSB ERI GRIT Server https://snow.ucsb.edu/index.php/remotely-sensed-products/
Technical Documentation	An open-source, digital version of this document was published using GitHub pages and the `bookdown` package.	Github Organization repository: https://github.com/MEDSsnowtoday/Technical_Documentation
Testing environment	Sandbox repositories for testing code in R and Python. These repositories are set to private and will not be accessible to end users.	Github Organization repositories: - https://github.com/MEDSsnowtoday/r_sandbox - https://github.com/MEDSsnowtoday/py_sandbox
Tutorial notebooks	Three Python-based tutorials created to help users through downloading, accessing, processing, and visualizing the National Snow and Ice Data Center's (NSIDC) Snow Today snow cover and albedo datasets.	Github Organization Tutorials repository: https://github.com/MEDSsnowtoday/Tutorials
Web application	R Shiny application that was developed to showcase Project's interactive visualization deliverables. Hosted on the UCSB Ylaipi GRIT server.	Github Organization Shiny app repository: https://github.com/MEDSsnowtoday/snow_today_shiny_app
Website Documentation	Documentation on website recommendations: architecture, wireframe, visualization palettes	Github Organization repository: https://github.com/MEDSsnowtoday/Technical_Documentation

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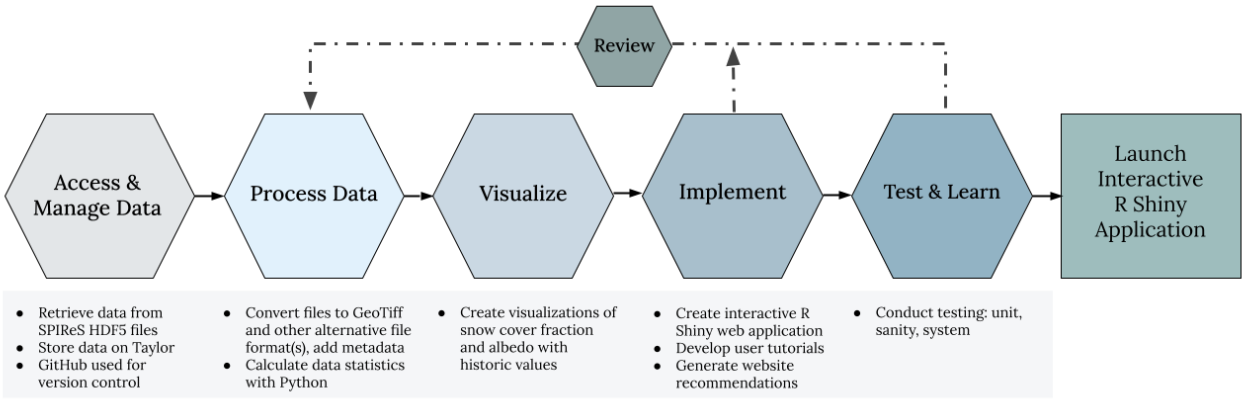
Appendix

Appendix A: Solution Design



Appendix B: Website Architecture

Figure 1: Current Snow Today Website Architecture

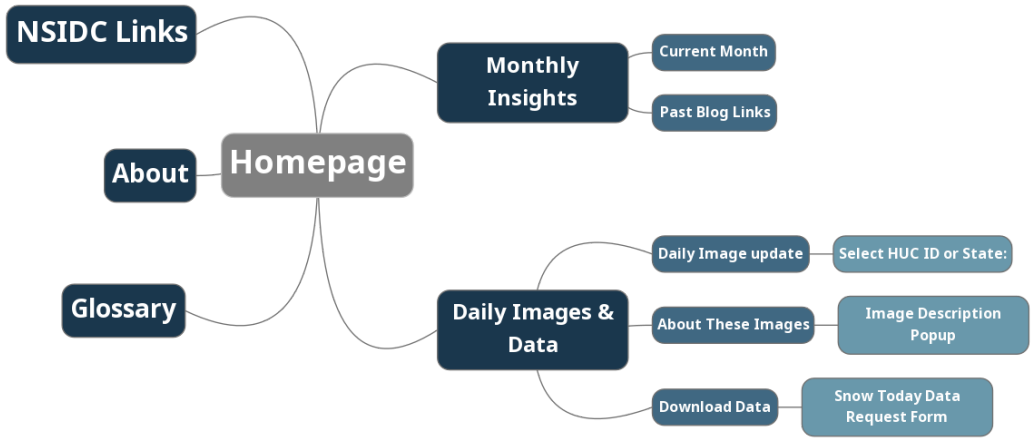
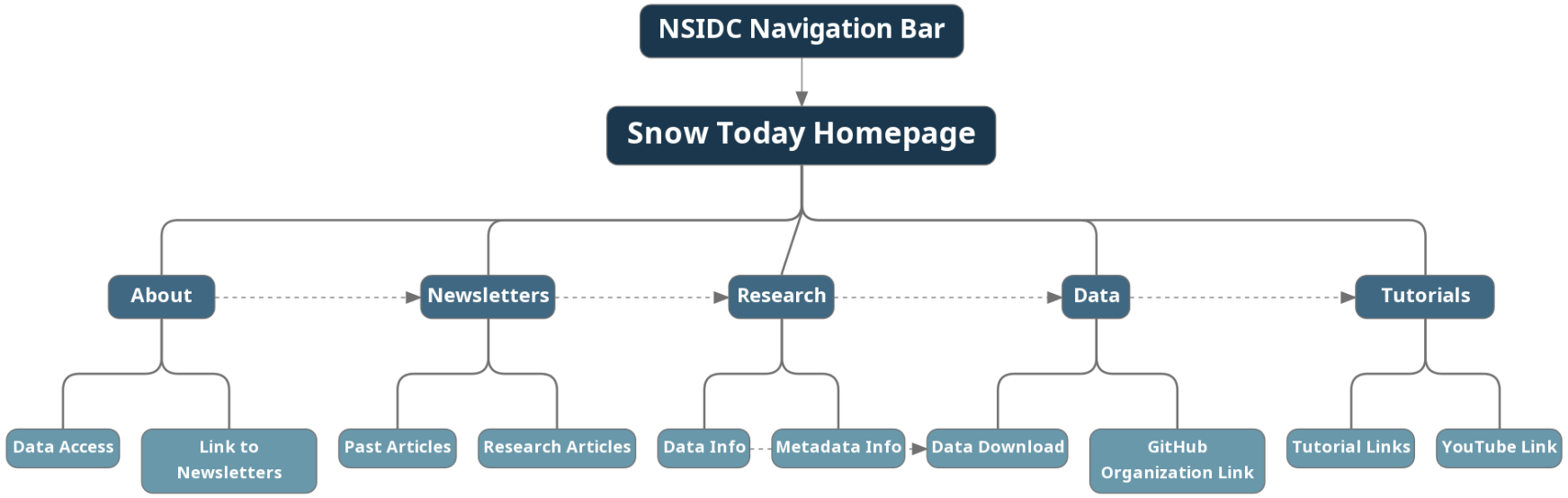
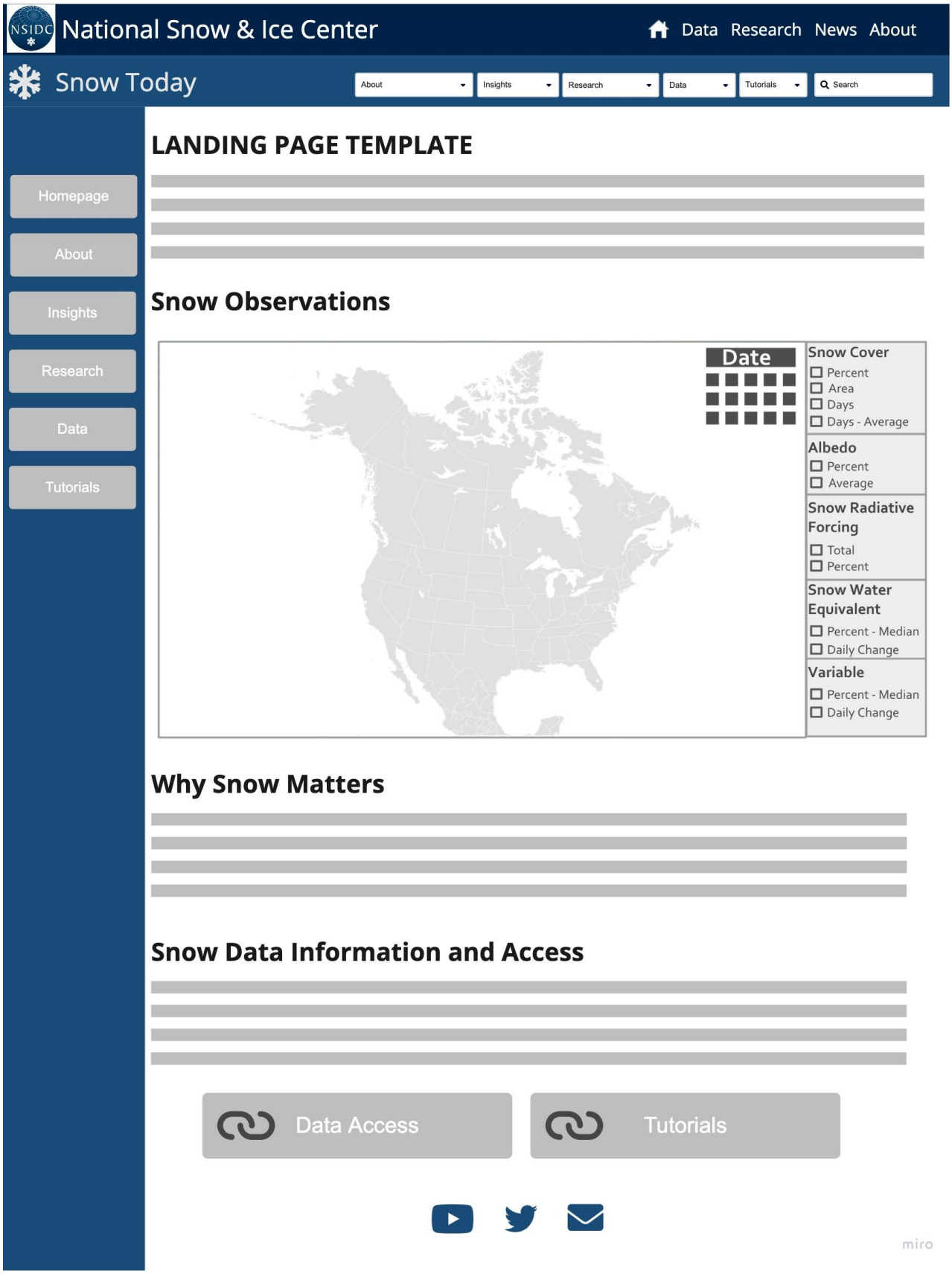


Figure 2: Recommended Snow Today Website Architecture



Appendix C: Recommended Snow Today Website Wireframe Mockup



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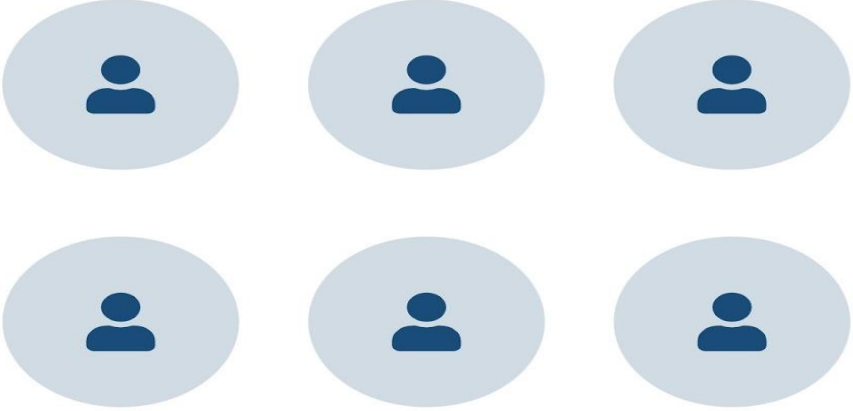

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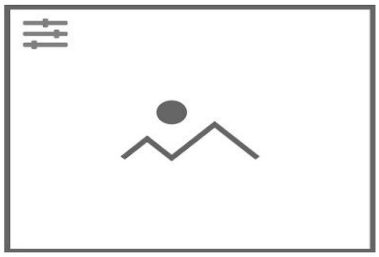

Snow Water Equivalent

SPIReS Model

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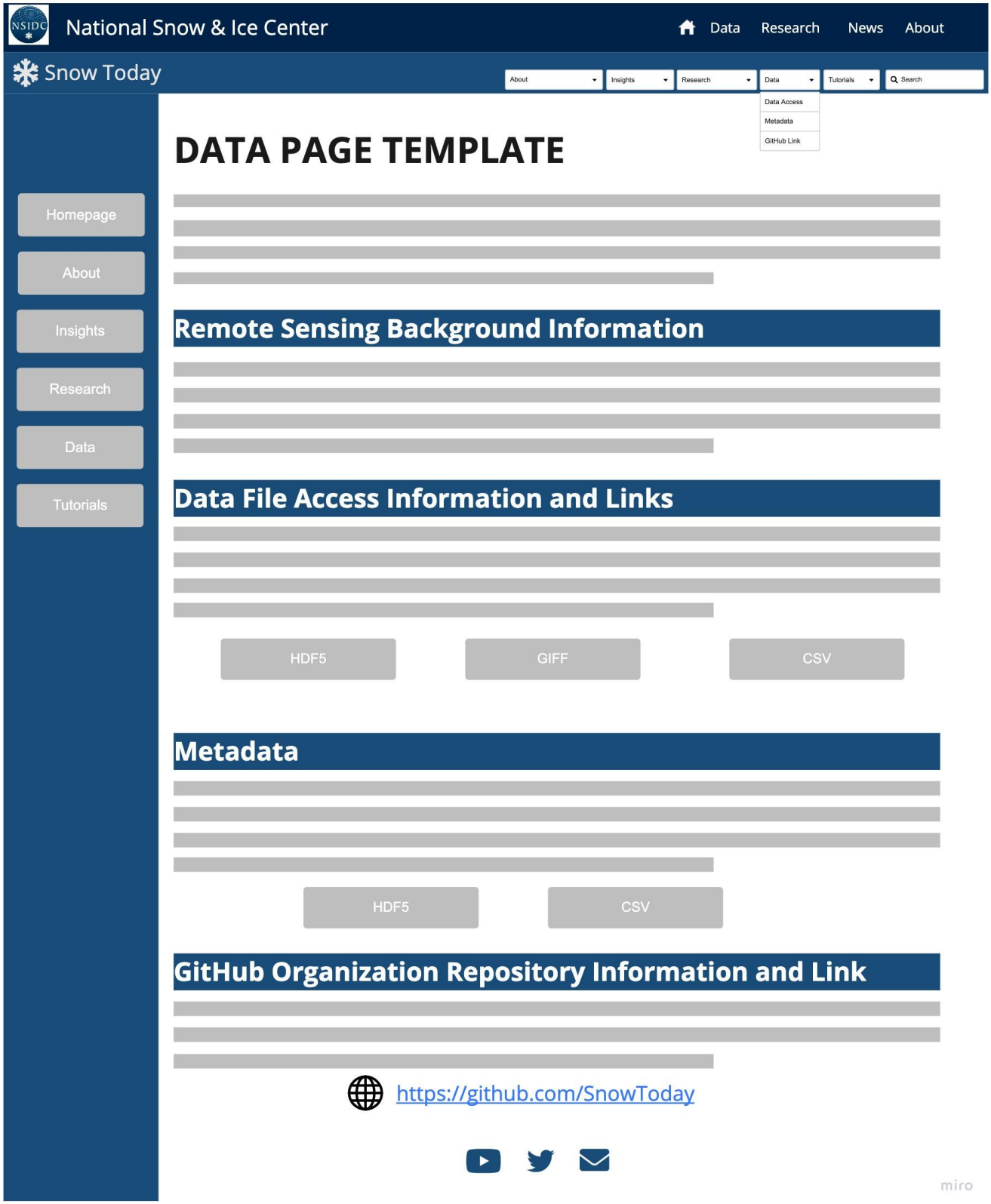
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