NASA DEVELOP National Program
2023 Spring Project Proposal

North Carolina – NCEI
Northeast Alaska Climate
Evaluating Snow Variability through a Climatological Analysis to Support Ecological Monitoring in Northeast Alaska

Project Overview

***Project Synopsis*:** Northeast Alaska encompasses the largest national wildlife refuge in the country and is home to a variety of migratory and resident wildlife. In recent decades, a warming climate has caused snow cover to become more variable, increased permafrost thaw, and altered the ability of the landscape to support dependent species in the region. Shifting patterns of snow depth affect the movement of caribou in the northeastern Alaskan landscape and, therefore, the food security of the communities that depend on these herds as a subsistence food source. Partnering with the US Fish and Wildlife Service and the Alaska Climate Adaptation Science Center, this project will evaluate historic snow variables including snow depth, normalized difference snow index (NDSI), snow albedo, snow cover, and snow water equivalent (SWE) to understand snow variability in a climatological context. Observations from AMSR-E, AMSR2, Terra/Aqua MODIS, ICESat-2 and NOAA Climate Data Records will be used to create snow variability maps and time series analyses across the Arctic National Wildlife Refuge (ANWR) and neighboring National Petroleum Reserve. This information can be used by refuge managers to monitor changes in snow conditions and proactively prepare for the ecological, cultural, and landscape impacts that changes in snow variability will cause in the future.

Study Location: Arctic National Wildlife Refuge and National Petroleum Reserve, AK
Study Period: January 1999 – January 2023

Advisors: Dr. Bob Bolton (International Arctic Research Center, University of Alaska Fairbanks) wrbolton@alaska.edu, Julian Dann (University of Alaska Fairbanks) jdann@alaska.edu, Jessie Cherry (NCEI Regional Climate Services Director, Alaska Region) jessica.cherry@noaa.gov, Ryan Theurer (Airborne Snow Observatories) ryantheur@gmail.com

Partner Overview

Partner Organizations:

Organization	POC (Name, Position/Title)	Partner Type	Sector
US Fish and Wildlife Service, Arctic National Wildlife Refuge	Dr. Paul Leonard, Supervisory Ecologist	End User	Federal Government
Alaska Climate Adaptation Science Center	Dr. Jessica Garron, Deputy University Director	Collaborator	Academic

End User Overview
End User's Current Decision-Making Process & Capacity to use Earth Observations:
The US Fish and Wildlife Service (USFWS) manages the Arctic National Wildlife Refuge. As a whole, its responsibilities focus on stewardship of wildlife and landscapes, preserving their wilderness values, and ensuring the public uses available at the refuge can continue. USFWS deploys

a host of management tools to address biological changes, including conducting surveys to determine distribution and population trends for a variety of wildlife species, studying plant communities and snow conditions to monitor changes over time associated with disturbance and climatic conditions. Currently, they do use some Earth observations in their monitoring activities.

Earth Observations Overview

Earth Observations:

Platform & Sensor	Parameters	Use
Aqua Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E)	Snow water equivalent (SWE)	Passive microwave data available from AMSR-E will be used to measure SWE from 2001–2011 at a 25km resolution.
Japan Aerospace Exploration Agency (JAXA) Global Change Observation Mission 1st-Water, "SHIZUKU" (GCOM-W1) Advanced Microwave Scanning Radiometer 2 (AMSR2)	SWE	AMSR2 serves as a continuation of AMSR-E for SWE and began collecting observations in 2012 at a 25km resolution.
ICESat-2	Ice sheet elevation	Ice sheet elevation data from 2018–2023 will be used for additional comparison to snow cover and snow depth.
Terra/Aqua Moderate Resolution Imaging Spectroradiometer (MODIS)	Normalized Difference Snow Index (NDSI), snow cover, fractional snow cover	NDSI, snow albedo, snow cover (snow present or not present), and fractional snow cover (estimated snow cover in percent) will be measured at a 500m resolution from 2002–present.

Ancillary Datasets:

- NOAA Climate Data Record (CDR) of Northern Hemisphere (NH) Snow Cover Extent (SCE), Version 1 – Snow cover extent from 1999-2023 will be used as inputs in the time series analysis, snow variability maps, and snow on and snow off maps.
- U.S. Geological Survey 5 Meter Alaska Digital Elevation Models (DEMs) – Topographic information provided from the DEM will be used in the snow variability and snow on and snow off maps to better understand snow changes in various topographic conditions.

Software & Scripting:

- Python 3.9 (Anaconda) – Data acquisition and processing
- Google Earth Engine API – Data acquisition, preprocessing, and analysis
- ESRI ArcGIS – Data visualization and map creation

Decision Support Tool & End Product Overview

End Products:

End Product	Partner Use	Datasets & Analyses
Snow Time Series Analyses	The snow time series analyses will highlight changes in NDSI, snow cover, and SWE over the study period. Project partners will use this product to quantify climate variables and temporal trends to understand historical snow fluctuations.	Measures of snow including snow cover extent, NSDI, and SWE derived from AMSR-E, AMSR2, Terra/Aqua MODIS, and NOAA CDR SCE will be used to create a time series analysis for each variable in the Arctic National Wildlife Refuge and National Petroleum Reserve.
Snow Variability Maps	This product will analyze NDSI, snow cover, and SWE normals and variability over the study period. This will provide partners with a holistic spatiotemporal assessment of snow conditions and can be used to identify regions historically susceptible to changes in snow availability.	Observations from AMSR-E, AMSR2, Terra/Aqua MODIS and NOAA CDR SCE for snow cover, NDSI, and SWE will be used to calculate climatological normals and variability of each snow measurement then mapped across the Arctic National Wildlife Refuge and National Petroleum Reserve. Ice sheet elevation will also be mapped in the study area using ICESAT-2 observations.
Snow on and Snow off Maps	Snow on and snow off maps will highlight changes in snow cover presence over the study period based on first and last days of snow cover and the median length of the continuous snow season. This will help partners better understand snow seasonality and quantify changes in snow cover presence across the study period.	Snow cover derived from Terra/Aqua MODIS and NOAA CDR SCE will be used to delineate snow cover before the snow season, during snow season, and after snow season across multiple years.

Project Timeline & Previous Related Work

Project Timeline: 1 Term: 2023 Spring

Similar Past DEVELOP Projects:

- Summer 2022 (CO) – Black Hills Wildfires: https://www.devpedia.developexchange.com/dp/index.php?title=Black_Hills_Wildfires_CO_Summer_2022
- Spring 2021 (NC) – Montana Water Resources II: https://www.devpedia.developexchange.com/dp/index.php?title=Montana_Water_Resources_II_NC_Spring_2021
- Spring 2018 (NC) – Alaska Disasters: https://www.devpedia.developexchange.com/dp/index.php?title=Alaska_Disasters_NC_Spring_2018
- Fall 2016 (MCHD) – Southeastern Arizona Water Resources: https://www.devpedia.developexchange.com/dp/index.php?title=Southeastern_Arizona_Water_Resources_MCHD_Fall_2016

Notes & References

***Notes*:** This proposal will be shared with Minority University Research and Education Project (MUERP) for American Indian and Alaska Native Science, Technology, Engineering and Math (STEM) Engagement (MAIANSE). Additionally, Dr. Jessica Garron with the Alaska Climate Adaptation Science Center has shared many potential DEVELOP project ideas with NC Fellow, Katie Lange, and AZ Fellow, Ryan Hammock. These ideas will be passed off to incoming NC Fellow, Katie Caruso to pursue in the future.

References:

Lievens, H., Demuzere, M., Marshall, HP., Reichle, R.H., Brucker, L., Brangers, I., de Rosnay, P., Dumont, M., Girotto, M., Immerzeel, WW., Jonas, T., Kim, EJ., Koch, I., Marty, C., Saloranta, T., Schober, J., & De Lannoy, GJM. (2019). Snow depth variability in the Northern Hemisphere mountains observed from space. *Nature Communications, 10*, 4629. https://doi.org/10.1038/s41467-019-12566-y

Pedersen, S.H., Bentzen, T.W., Reinking, A.K. Liston, G.E., Elder, K., Lenart, E.A., Prichard A.K., Welker, J.M. (2021). Quantifying effects of snow depth on caribou winter range selection and movement in Arctic Alaska. *Movement Ecology, 9*, 48. https://doi.org/10.1186/s40462-021-00276-4

Workplan Notes

Tutorials and Trainings

- NASA's Applied Remote Sensing Training Program (ARSET): Fundamentals of Remote Sensing
- Python:
  - Starting points:
    - Python for Beginners
    - Data Analysis and Visualization with Python (For Ecologists)
    - R vs. Python for Data Science
    - A Dramatic Tour through Python's Data Visualization Landscape
    - Google Colab allows you to write and execute Python in your browser
- Google Earth Engine Python API

Project Objectives

I. Investigate patterns in snow behavior (1999–2023) by analyzing trends in the following variables. Code for some metrics calculated with MODIS data are available in this GitHub repo https://github.com/gina-alaska/modis-snow-metrics (instructions for algorithm here https://github.com/gina-alaska/modis-snow-metrics/blob/master/docs/MODIS_derived_snow_metrics_ver1_0.pdf)

   a. *Snow depth* – Project partners are very interested in measuring snow depth using satellite data through this study. This could be a great place to begin literature review as well as a topic of discussion for initial science advising and partner meetings and a great thing to talk to Dr. Ross about during his visit to NCEI as well as during his office hours.. As a reminder, DEVELOP conducts "feasibility" studies, and it may not be feasible to complete this objective within the framework of this study! If that is the case, that finding along with information on additional resources that would support the completion of this objective to support future research would be an important finding of this study.

i. Snow depth is measured across ANWR, and ANWR can provide these data, particularly for validation
ii. Comment from Julian: Individual met stations are sparse. Snow depth data for small swath, eventual snow depth data for most of 1002 (likely coming after), Daymet model precipitation patterns, sparse icesat2 elevations. Where would we get reliable winter and summer elevation maps for differencing?
    1. Starting point for elevation: https://www.usgs.gov/faqs/where-can-i-get-global-elevation-data
iii. Here are a few starting points for looking into methodology for snow depth measurements:
    → Snow depth has been calculated using ICESAT-2 data (see Hu and Lu 2022)
    → Snow depth has been calculated using Sentinel-1 data (see Lievens et al. 2019)
    → Snow

b. *Normalized difference snow index* (NDSI)
c. *Snow cover* – snow present or not present
    i. Question from partners: Do bare spots in snow develop at different times of year? Do they move in the landscape?
    ii. Swanson_2014_SnowCoverMonitoringMODISArctic classified pixels as "snow covered" if they had >50% fractional snow cover and albedo >30% on the NSIDC raster
d. *Fractional snow cover* (estimated snow cover in percent) – variable for determining snow on/snow off metrics (see Lindsay_2015_SnowCoverMetricsAlaskaMODIS)
e. *Fractional snow cover* (estimated snow cover in percent) – variable for determining snow on/snow off metrics (see Lindsay_2015_SnowCoverMetricsAlaskaMODIS)
f. *Snow on/snow off* – As you conduct your literature review, begin looking into how snow on/snow off is defined across different studies to guide how it will be defined in this project. Determining definition for snow on/off metrics would also be a good starting point for science advising and partner discussions!
    - Here are two starting points with context on the snow season and snow metrics
        → Swanson_2014_SnowCoverMonitoringMODISArctic
            - Used the following metrics in their report:
                - First snow day – the first day of snow recorded in the snow year (i.e. after August 1).
                - Last snow day – the last day of snow recorded prior to the end of the snow year (July 31).
                - Snow-free periods can separate the last snow day from the end of CSS (below).
                - Start of CSS – the first day (in the fall) of the longest continuous snow season
                - End of CSS – the last day (in the spring) of the longest continuous snow season
        → Lindsay_2015_SnowCoverMetricsAlaskaMODIS
            - Defined the full snow season (FSS) as the interval between the first snow day (FSD) and the last snow day (LSD) of snow cover,
            - Defined the continuous snow season (CSS) as the longest interval of the season for which a pixel was snow covered. The CSS is a

period for which a pixel was snow covered for at least 14 days, with intervening snow-free periods limited to two days or less. If more than one uninterrupted 14-day snow covered event occurred, we selected the longest one of these as our CSS.

Table 1. Snow metrics, definitions, and band numbers.

Metrics Band Name	Metrics Description	Acronym	GeoTIFF Band
first_snow_day *	First snow day of the *full snow season*	FSD	1
last_snow_day *	Last snow day of the *full snow season*	LSD	2
first_last_snow_day_range	Duration of the *full snow season*	FLSDR	3
longest_css_first_day *	First snow day of the longest *continuous snow season*	LCFD	4
longest_css_last_day *	Last day of the longest *continuous snow season*	LCLD	5
longest_css_day_range	Duration of the longest *continuous snow season*	LCDR	6
snow_days	Number of days classified as snow after filtering	SD	7
no_snow_days	Number of days not classified as snow after filtering	NSD	8
css_segment_num	Number of segments within *continuous snow season*	CSN	9
mflag	Overall surface condition and snow-cover character for pixel		10
cloud_days	Number of days classified as cloud after filtering	CD	11
tot_css_days	Total number of days within all *continuous snow season* segments	TCD	12

* Values are day-of-snow-year (*i.e.*, day 213 of previous year—August 1, to day-of-snow-year 577—July 31).

II. Depict trends using the following end products:
- **Timeseries depicting change over time** (NDSI, snow cover, snow water equivalent)
  - Actionable decision: quantify historical trends to understand fluctuations across time
- **Maps delineating snow variability** (NDSI, snow cover, fractional snow cover, snow water equivalent)
  - Actionable decision: partners can identify regions that were susceptible to snow variability historically
  - Example snow variability/anomaly maps here
- **Maps delineating snow on/snow off** (first and last snow days, periods of continuous snow cover)
  - Previously identified questions that may be answered by snow on/off map:
    - → How variable are those conditions each year?
    - → When does the snow season start in the arctic?
      - How long does it last?
      - How variable is it over time?
  - Actionable decision: snow on/off impacts ecology (tundra-nesting birds on coastal plain, etc.)

Dataset Information and Links

After literature review, data acquisition is one of the first steps in a DEVELOP project, and tracking down and accessing datasets can be a time consuming process! Here are starting points for accessing datasets that will be used in this project:

- MODIS – see Cherry_2017_SnowCoverMODISAlaska for methods
  - MODIS Terra Snow Cover Daily L3 Global 500m Grid data (MOD10A1; NASA 2013) from the National Snow and Ice Data center (NSIDC: https://nsidc.org/data/modis)

- GINA MODIS - The National Park Service and the Geographic Information Network of Alaska (GINA) developed an algorithm to derive snow cover climatology for Alaska using the MODIS snow cover daily product.
    - Description of MODIS-derived snow metrics http://gina.alaska.edu/projects/modis-derived-snow-metrics
    - GitHub for MODIS Snow Metrics created through GINA (https://github.com/gina-alaska/modis-snow-metrics)
    - MODIS-derived Snow Metrics Algorithm (https://github.com/gina-alaska/modis-snow-metrics/raw/master/docs/MODIS_derived_snow_metrics_ver1_0.pdf)
- Code for calculating NDSI using MODIS data https://mbonnema.github.io/GoogleEarthEngine/05-time-series/
- The MOD10A1 V6 Snow Cover Daily Global 500m product contains snow cover, snow albedo, fractional snow cover, and quality assessment (QA) data https://developers.google.com/earth-engine/datasets/catalog/MODIS_006_MOD10A1
- MODIS Terra Daily NDSI https://developers.google.com/earth-engine/datasets/catalog/MODIS_MOD09GA_006_NDSI

- Imiq (https://imiq.portal.aoos.org/) – The Imiq Data Portal provides access to the Imiq Hydroclimate Database—a central repository containing historical hydrology and climate-related data in Alaska and nearby regions built by researchers at the University of Alaska Fairbanks.

Data Type	Sensor / Source	Data Product	Resolution	Parameter	Years
Climate data record	Snow Cover Extent (Northern Hemisphere) CDR	NOAA Climate Data Record (CDR) of Northern Hemisphere (NH) Snow Cover Extent (SCE), Version 1	88 x 88 (cells)	Snow cover extent	1999 – present
Model	DEM	U.S. Geological Survey 5 Meter Alaska Digital Elevation Models	5m	Elevation	2014 – present
Earth observation	Terra MODIS	1) NSIDC DAAC Snow cover 2) List of GINA MODIS-derived snow metrics	500m, daily	Snow cover, fractional snow cover	2000 – present

Wishlist Items

With 10 weeks to conduct our project, it is important to prioritize as there are many additional analyses we could consider. First, focus on the objectives outlined in this proposal and if there is additional time, here are other items to consider. Additionally, it is good practice to keep a running list of "future work" ideas; these will be great to mention in your presentation and technical report at the end of the term!

- Partners are interested in identifying locations where conditions may be reliable for supporting ice road construction based on locations with trends in snow variables through time
    - Would require an elevation layer because of dynamics in landscape due to heaving/thawing
        - NASA-based: SRTM (radar that mapped elevations across the world)
            - Roads would be best in places with less thawing, heaving, standing water
            - Is there water standing on the surface? - Sentinel-1 could tell you if there is water/times of year where there is melting
        - Land cover would be a great starting point!
            - National Land Cover Database
    - See Raynolds_2020_3D-SeismicSurveysANWR