ERA5 AND NCEI: AN ANALYSIS OF A JUNE MICROCLIMATE STUDY OF THE KENAI LOWLANDS

By

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ABSTRACT

ERA5 AND NCEI: AN ANALYSIS OF A JUNE

MICROCLIMATE STUDY OF THE KENAI LOWLANDS

Alaska is fraught with varied terrain, extensive coastline, and extreme terrestrial weather that makes areas conducive to microclimates. Given the challenges of climate modeling and weather forecasting, even some of the best technology struggles to resolve locations correctly. By assessing observed ambient temperatures using standard and non-standard observation systems from the National Centers for Environmental Information (NCEI) and comparing them to a well-respected climate model, the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5, microclimate conditions can be inferred across the Kenai Lowlands in southcentral Alaska. Amending meteorologists' perspective on climate conditions decreases errors introduced into the forecasting process and ultimately leads to a more correct representation of the environment. This study explores how the ERA5 reanalysis compares to observed conditions and how the difference between the two changes with the distance to the coastline and to elevation change. These results highlight how observed temperatures provide indication that terrain features cause microclimate conditions around the Kenai Lowlands. The coolest average temperatures were located near the coastline and the warmest average temperature was located the most inland. This information is valuable for an area of the state that is becoming more hospitable as climate change continues to shape the landscape. It will be imperative in shaping government and private industry in understanding the physical environment going forward.

Acknowledgements

I would like to voice my appreciation for the support I have received from the professors of Northern Arizona University Department of Geography, Planning, & Recreation for working with me during my graduate studies. Additional thanks go to my committee of Dr. Schiefer, Dr. Stan, and Gail Weaver. As someone who works full time and is a distance learner from far away, it is not easy to work with me in a timely manner. These individuals have shown great flexibility and assistance to meet my objectives and goals. Without their guidance and leadership, I could not possibly have completed these events with such success and for that I am grateful. Thank you also to my family and community for supporting me through this extended timeline with many long hours after work and on the weekends while I completed this program.

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1.0 INTRODUCTION

Large climate classification systems do not accurately depict places with incredible differences in topography and many climate influences (Lembrechts, 2023). Meteorologists approach creating a forecast through a process commonly referred to as the “forecast funnel” (Snellman, 1982). This technique involves looking at synoptic scale systems before moving onto mesoscale and finally microscale processes. The forecast funnel has a meteorologist looking at a larger area and deciphering how it influences a smaller area. In addition, they use a variety of tools, including numerical weather prediction, current observations, and climatology data before producing and publishing a forecast. Using knowledge from a large climate database or a climate classification system can become problematic when they are not entirely reflective of smaller areas within them. This means that some places are not accurately depicted in weather forecasting processes because meteorologists use climate information as a basis for understanding the current environment and because the climate representation is not accurate it incurs error into their forecast from the outset. In this study, I will examine the Kenai Lowlands in Alaska as a case study of one such area that has a unique climate profile and possible microclimate. Identifying the Kenai Lowlands, as a known microclimate region, will aid meteorologists in accurately forecasting weather conditions in this area. Furthermore, this designation can improve the safety of aviation flights as well as improve the protection of people and property in the surrounding area. This is especially crucial when considering the limitations of other weather forecasting aids in this area, with decreased atmospheric model resolution, lack of fixed-based weather sensors, and limited constellations of satellites overhead at such northerly latitudes impacting accurate forecasts (Swaszek et al., 2018).

Temperature is one of two variables used to determine the existence of a microclimate (Barry & Blanken, 2016). Analyzing and creating a temperature study of June, using sensors located within the Kenai Lowlands, I will compare the average temperature with a climate reanalysis to assess the difference between the two. I will then compare the distance between terrain influencing microclimate factors and see if there is a statistical indicator that these features are creating microclimate conditions around the designated area. As warmer or colder areas are indicated and compared with their proximity to topography, a microclimate will be identified. Knowledge of a microclimate will add value in the weather forecasting process which will result in greater lead times for weather warnings and a decrease in their “false alarm” rate. The global climate continues to change, and these microclimate areas will see exacerbated effects from it. Locations with a microclimate could be proven to be sites most suitable for agriculture within the Kenai Lowlands as the diversity of crops species can now expand to potentially more hospitable areas (Fresco et al., 2021). Not only would this result benefit the agricultural industry in the area, but it would also likely decrease the cost of goods in Alaska’s heavy import economy (Berman & Schmidt, 2019). Overall, the benefit to both governmental organizations and private industry shows the scope of how important this research could be for this state. Finally, this research will use a test case in the Kenai Lowlands to indicate if the proximity of terrain features to weather sensors in comparison to modeled conditions depict microclimate conditions in this area.

1.1 Research Questions

1. How will ECMWF ERA5 compare to observed conditions and to what extent do they differ?

2. Is there a difference between ERA5 and observations as they move in distance away from the coastline or increased elevation?

2.0 LITERATURE REVIEW

Alaska is known for its unique and varied topography, making microclimates abundant and likely in many areas throughout the state. Localized temperature differences can be an indication that a microclimate may exist (Maclean et al., 2021). Microclimates are caused by dynamic topography and can be subtle or very pronounced. An example of a microclimate can be seen in Figure 1. Understanding these small-scale processes is imperative for meteorologists, climatologists, related research fields, and other commercial industries when building plans or forecasts. Microclimates can range in height from a few centimeters in areas of tundra to 50 meters in tropical rainforests and they can range horizontally from a meter to several kilometers (Barry & Blanken, 2016). Understanding this spatial scale is imperative to understanding how microclimates work and the difficulty in identifying them.

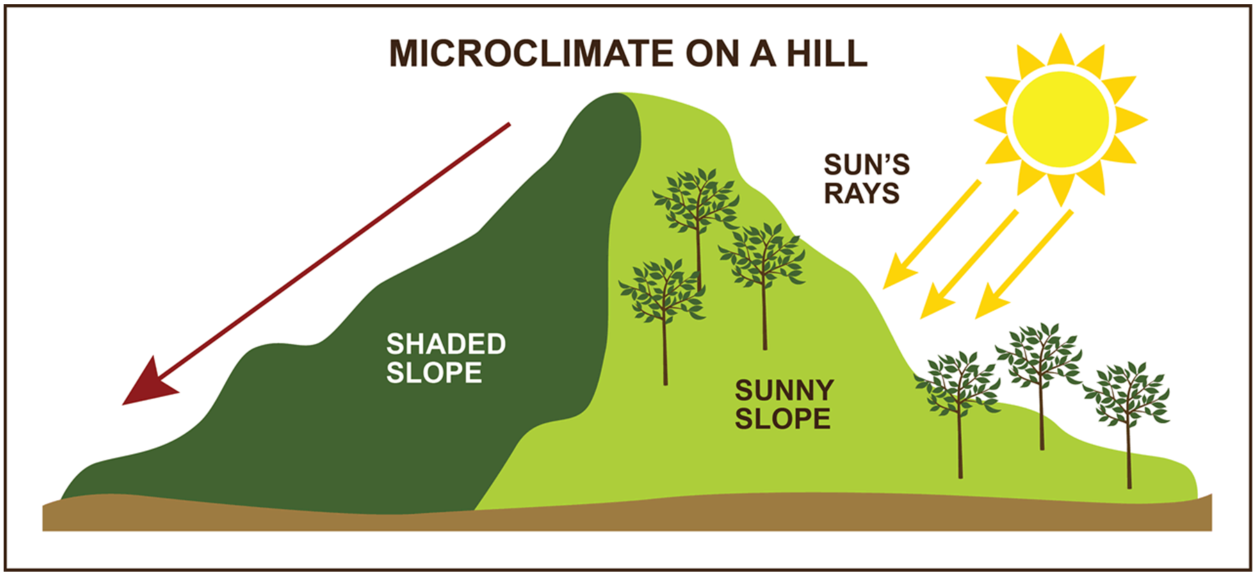


Figure 1: *An Example of a Microclimate*
This example shows how topography and elevation can cause localized conditions to differ with little difference between locations. Source: https://www.tomorrowsharvest.com/planting-and-care/climate-zones-chill-hours/

2.1 Microclimates in Mountainous Areas

Large climate classification can be thought of as the macroclimate. It is independent of topography, soil, and vegetation. It also occurs over at least a 30-year period. Measurements of this climate occur in a standardized way at a standardized location. Regional variations in climatology are caused by topography, vegetation, and human interaction (Stoutjesdijk & Barkman, 2015). These interactions also have additional influence from the soil surface based on its heat and moisture budget. It is important to note that to study both macroclimatology and microclimatology you must study both the horizontal and vertical gradient. The difference in magnitude of a microclimate is over a few meters whereas a macroclimate may exhibit the same over 5000 kilometers. If microclimates are overlayed onto their macroclimate they will show variations of the same theme; sometimes they deviate from each other so much they are hardly recognizable (Stoutjesdijk & Barkman, 2015).

A microclimates main difference with a macroclimate is the rate at which changes occur with elevation and with time (Rosenberg et al., 1983). Since mountainous areas have intense changes of elevation, they lend themselves to being highly susceptible to microclimate conditions. Additionally, surface temperatures between north and south facing mountainsides can vary as much as 20°C, equivalent to a latitudinal gradient of about 2000 kilometers (Zellweger et al., 2019). This means that the way the mountain is facing can also play a role in introducing microclimate conditions. Equatorial-facing slopes are drier and warmer, and polar-facing slopes are wetter and colder, than their regional macroclimates (Yin et al., 2023). The main interaction here is the flux of solar radiation, how much it hits an area, and at what intensity. At mid to high latitudes, the slope and aspect of the ground modifies the amount of solar radiation received by the surface (Bennie et al., 2008). Solar intensity directly affects species distribution as some may continue to persist in microclimates longer than they could in their macroclimate.

Describing microclimates is a valuable resource for many avenues of society. When predicting species range shifts for plants using macroclimatology, a large degree of error has been introduced. Many species have shown their ability to survive where their macroclimate shows it is no longer suitable (Lembrechts, 2023). While this is often thought of as wild plant and animal species, this also is the same for agriculture. Microclimates influence the dynamics of populations, communities, and ecosystems across biomes (Kemppinen et al., 2024). Driving how, when, and why species move. Thus, they are important in fields such as ecology and biogeography. Microclimates have also shown to directly impact the growth and survival of populations. This includes human populations and the use of the urban heat island effect in urban climatology (Hall et al., 2016). Microclimates can be shown in sections of cities and neighborhoods with causative factors causing individual heat islands (Mills et al., 2022). They can even be influenced by architectural styles of cities based on the materials used in construction and how airflow is directed (Mills, 2014). Studying microclimates is key to understanding not only meteorological processes, but in many ways how species are distributed in their macroclimate.

2.2 Microclimates in Coastal Areas

Incorporating coastal influences has been shown to depict more accurate microclimate boundaries (Ashcroft et al., 2008). Integrating coastal influences into temperature estimates can change the predicted spatial distribution of temperatures, and better explain the distribution of many plant species. (Ashcroft et al., 2008). This means that coastal influences must be considered for understanding microclimate conditions and to have a better understanding of the environment. Large bodies of water can moderate the temperature of nearby land masses and the proximity to a large water body can be a major determinant of climate regime of a region. (Daly et al., 2002). This location is surrounded by the Pacific Ocean on three sides and has a heavy maritime influence, so microclimate conditions receive this coastal temperature moderation effect. Coastal regions have been shown to have an immense moderation affect with temperature gradients during summer maximum temperatures exceeding 20°C within 5 to 20 kilometers (Daly et al., 2002). While small, a coastal microclimate still has notable influence from its proximity to the coast. In addition to this, coastal influences were also more important for the extreme temperatures such as during winter minimums and summer maximums (Ashcroft et al., 2008). This is also a factor for coastal microclimate conditions as the maritime influence is significantly warmer than the nearby landmass during much of winter. While not the focus of this study they can also affect precipitation patterns with these patterns lines of delineation becoming apparent by proximity to coastal moisture sources.

2.3 Temperature: a Key Variable in the Study of Microclimates

Temperature variations across small spatial scales could be indicative of a microclimate. The purpose of collecting air temperatures at non-standard locations is to quantify the difference from those that would be recorded by a standard weather station (Maclean et al., 2021), as it influences every aspect of the physical environment. Since it is the most important variable in determining a microclimate exists, it must be considered as critical in microclimate study. Because air temperature is the principal influence, the focus of microclimate study should be on air temperature and less on others, such as recorded precipitation. Showing that the conditions around the Kenai Lowlands are abnormal to these criteria, would indicate that there are highly localized effects that break from a coarse resolution climate classification, such as the Köppen system, would help indicate the presence of a microclimate. After a more in-depth study, to include ambient and dew point temperatures for all months of the year, one could then delineate the boundaries of a microclimate within the associated area.

2.4 Approaches Used in Microclimate Research

The challenge with standard weather stations capturing microclimatology effects is that they have been systematically placed in open landscapes, where the wind continuously mixes the air, and are shielded from direct solar radiation, ignoring many climate-forcing processes that operate near the ground. While this has made observations consistent, it has inadvertently made general climatology less resemblant to areas with high variability in terrain. Climatology has been shown to improve when orographic effects are included (Karger et al., 2017). Therefore, understanding microclimatic processes, which operate at fine spatial resolutions, will also improve more coarse climatological record keeping for the future. Microclimates also affect broad-scale ecological processes like species distributions and ecosystem functioning, important for secondary users of the study, such as biologists and ecologists, when mapping species distribution and measuring the health of an ecosystem.

Climatologists did their best to remove what they considered as 'noise' in climatology. Weather stations were set up to be standardized and reduce as many errors as possible. By designing a global network of standardized weather stations, they actually removed what ecologists would consider meaningful information to understand species distributions and ecosystem functioning (Lembrechts & Lenoir, 2020). Because of how standard weather stations were distributed across the United States, they inherently omit outliers in climatology that would be needed to distinguish localized conditions, making it especially problematic to define a microclimate when stations were designed to avoid them. To combat this, cooperative observers willing to record data in places that did not meet the initial criteria offer information needed to validate the existence of a microclimate. While observers introduce bias and are not as punctual as an automated system, the United States government has been running the Cooperative Observer Program for over 130 years, where experienced technicians have been providing data to fill the gaps between or augment automated systems.

The National Weather Service Cooperative Observer Program is a government run program that is not as regulated as official observations that are taken from airports or National Weather Service offices (Leeper et al., 2015). It does, however, provide a standardized collection method for a crowd-sourced pool of data that has some quality assurance already done to it.

When coupled with the U.S. Climate Reference Network, it on average, had less than 1°C temperature swing difference from other automated observing systems, with greater variability existing from station to station (Leeper et al., 2015). While this introduces known errors into the dataset and can be considered substantial when looking at long-term climate trends, it does offer a good network with a lengthy repository needed to interrogate and explain location specific in-situ data. It is also easily and freely accessible to the public, making the interrogation process a much easier barrier of entry to overcome.

2.5 Alaska and the Kenai Lowlands

Differentiating microclimates within a larger climate classification system can be difficult but is necessary when an area contains key indicators that microclimate conditions are present. The specific location of this study has many core influences that can indicate a microclimate, including variable terrain, air mass confluence, and other external factors such as proximity to glaciers. The Kenai Peninsula is a microcosm of Alaska with many key land-cover components in it: arctic, subarctic, boreal, and coastal ecosystems as well as relatively dense human population (Baughman et al., 2020). The dominant vegetation seen in the Kenai Lowlands before recent cover changes consisted of black spruce, muskegs, birch forest, Kenai birch, white spruce, and quaking aspen (Baughman et al., 2020). Land-cover is an important designator as it directly influences that albedo in the ecosystem and therefore influencing climate conditions. Diagnosing the predominant climate is also important to set as a baseline and understand when conditions are differing from what the climate normal is. Using the predominant macroclimate as a starting point is necessary when determining a microclimate because it is difficult to determine conditions differ without a reference of what is initially expected. Lastly, using available data sources to indicate statistical abnormalities in the area is key in differentiating between normal climatic conditions and microclimatic conditions.

Acknowledging the limitations of standardized weather stations and the need for another source of in-situ data is crucial in this validation process. Alaska does not benefit from the same robust data sensing capabilities available in the continental United States. Because of the complexity of microclimates, traditional physics laws may not accurately depict local variations in the environment (Zanchi et al., 2023). Non-traditional sources must be used to gather a fuller picture of the climate in the state. This is because the climate of these complex environments cannot be determined using standard meteorological equipment and so a combination of special observations and theory must be used to describe them (Barry & Blanken, 2016). Using a suite of data and approaches to study the climate in and around the Kenai Lowlands, a general understanding of potential existing microclimates here should materialize.

Mountains induce air mixing with orographic effects, to include temperature and precipitation variability from the windward to the leeward side of the terrain. The topography and terrain surrounding the Kenai Lowlands make the area very dynamic, with multiple air mass influences and significant elevation changes. Mountains cannot be defined by climatological criteria because a mountains climate is only a modified version of the climate that would exist if the orography was absent (Pepin et al., 2022). This area includes vast expanses of vegetation, large and small bodies of water, as well as 15 different glaciers within 100 miles of the area. Because glaciers cool the air temperatures around them and because most glaciers are currently in retreat, rates of climate change in glaciated valleys are being amplified by the retraction of these cold microclimates (Pearson et al., 2020). Conditions induced by local glaciers will lessen the effects upon the Kenai Lowlands with the continued regression of glaciers in the next century. As partial influence from local glaciers lessens, maritime or orographic effects are likely to become increasingly more dominant.

Snowpack continues to decrease with climate change in Alaska and will exacerbate microclimate conditions as historically snow-dominant conditions in mid-elevations shift to transitional or rain-dominant watersheds in the 2050's (Littell et al., 2018). With lessening interaction of snow albedo, air temperatures will exhibit a wider range of extremes from more rapid heating or cooling of the landmass of the central Kenai Lowlands. This is because warming is enhanced in the snow albedo feedback where the snowline is in retreat (Pepin et al., 2022). This region is at the confluence of dry, cold continental climate type and a wet and mild maritime climate where orographic effects from mountains induce a distinctive climatic zonation (Karlstrom, 1964). With these forcing mechanisms, unique confluence, and intensifying climate changes; the Kenai Lowlands are a prime location for microclimate existence and intensification. It will also be an area of increased interest as many of these factors will continue to change with the climate.

Understanding what normal climate conditions are lets an atmospheric scientist acknowledge that there is a differentiation from normal. Figure 2 shows the variability in temperature and precipitation for Kenai Municipal Airport, one of the stations used in the study. Note how the temperatures and precipitation change over the year as a generalization of what this study area sees in fluctuations.

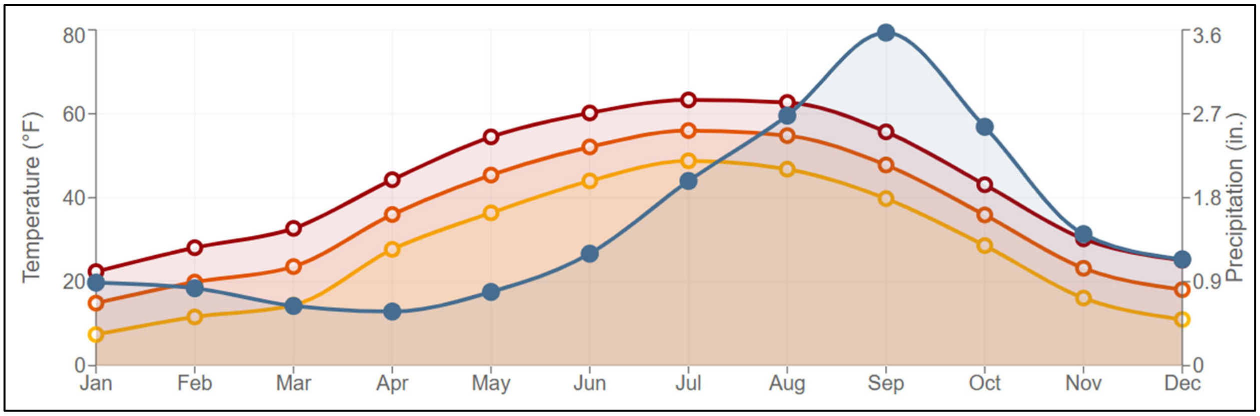


Figure 2: *Climograph of Kenai Municipal Airport 1991-2020*
Temperature and precipitation lines are shown for each month of the year. The red, orange, and yellow lines show the maximum, average, and minimum temperatures of each month respectively. The blue line shows average precipitation for each month of the year for the station. Source: https://www.ncei.noaa.gov/access/us-climate-normals/#dataset=normals-monthly&timeframe=30&station=USW00026523

The Köppen climate of the Kenai Lowlands is almost entirely designated as "Dsc" or a dry-summer subarctic climate as shown in Figure 3. This means the coldest month averages a temperature below 32°F and one to three months average above 50°F. It also receives at least three times as much precipitation in the wettest month of winter as it does in the driest month of the summer, where the driest summer month receives less than 1.2 inches of precipitation (*PRISM Group at Oregon State University*, n.d.).

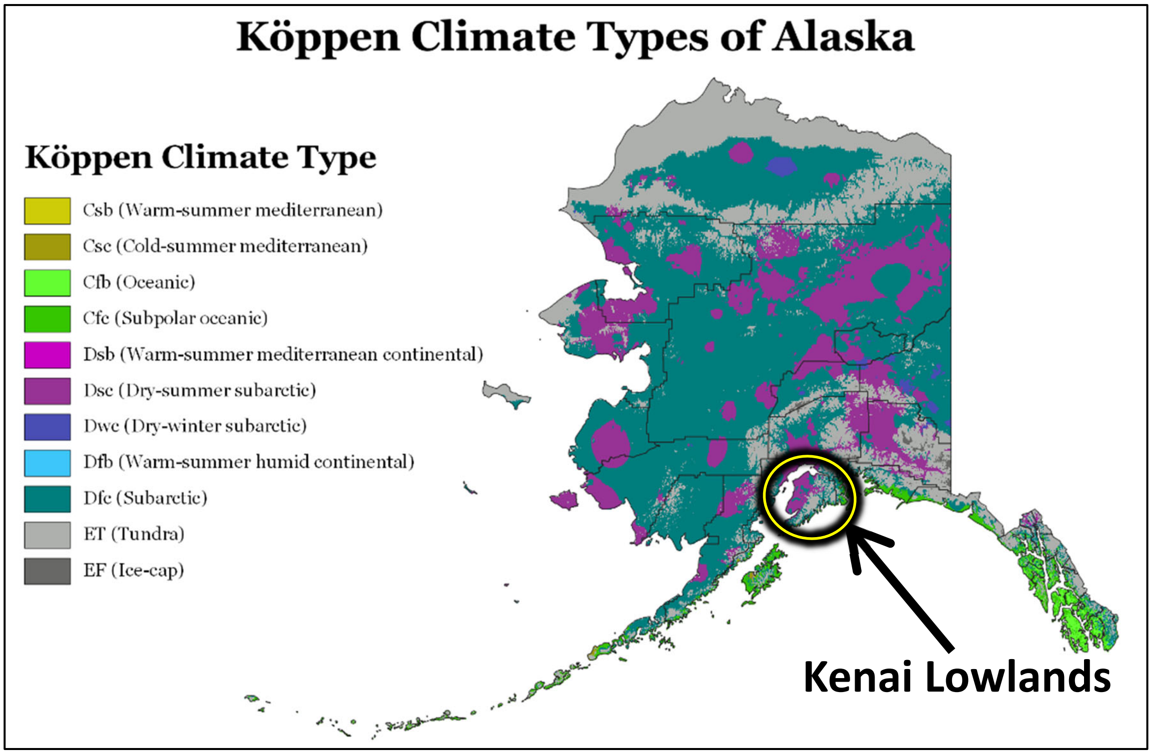


Figure 3: *Köppen (Macro) Climate Types in Alaska*
The climate classification is denoted by the color and three letter code. There are three climate types in the Kenai Lowlands. Source: 1981-2010 Climate normal from PRISM Climate Group, Oregon State University, https://prism.oregonstate.edu

The Kenai Lowlands, located next to the Cook Inlet and along the western Kenai Peninsula, are surrounded on three sides by mountains, but also experiences a moderating maritime influence that restricts the variability of temperature range (Shulski & Wendler, 2007). This allows the area to have much warmer conditions than other locations of the same latitude. Further inland into the Kenai Peninsula, diurnal temperature extremes grow from the more influential land mass. Denoting a microclimate can be done by analyzing temperature and dewpoint temperature, but only after interrogating differences from its macroclimate caused by terrain or proximity to large bodies of water. Elevation is the dominant control of temperature in mountains (Pepin et al., 2022). With significant terrain and a confluence of both continental and maritime airmasses, areas of temperature differentiation are likely to be common and increase the likelihood of identifying a microclimate.

Microclimates are denoted based on temperature and are highly influenced by terrain and topography. The location of the Kenai Lowlands at the confluence of continental and maritime air masses, coupled with the surrounding mountains, makes it a prime location for microclimates to exist. A single weather station will not accurately represent the thermal mosaic of microclimate (Mitchell et al., 2024). To combat this, looking at the National Weather Service Cooperative Observer program for data that is in less standardized locations can help meet the needs of a data source for proving microclimate existence, with the acknowledgement that the quality of this data is less than the optimal conditions provided by a standard weather station. This program however, has been recognized as the most authoritative source on United States climate trends for temperature (Wu et al., 2005). Further investigation into global climate models and other downscaling projects can also provide data and proof needed to validate this study. Because there are several downscaling projects that have occurred, it could provide a good source for expanding the knowledge of this subject area. Also worth noting is the climatic normal for the region based on the previous 30-year period. This is a way to increase the number of points in the study as there are few sites with long-term, continuous records. Using temperature to determine the existence of a microclimate is being done (Meyer et al., 2023), but an in-depth study of this area has not been. Several climate models cover the Kenai Lowlands and choosing one with the correct resolution to cover the intended area was a goal but notably was a challenge. The research will certainly expand the knowledge of the area and may present a starting point for further and more technical research methods to be conducted for validation.

2.6 ERA5 a Climate Reanalysis

The Copernicus Climate Change Service of ECMWF produces ERA5 a fifth-generation reanalysis combing observations and weather model together. This dataset from ECMWF covers a period from January 1940 to present. It is continuously updated to extend forward in real-time. This is part of the ECMWF's Integrated Forecast System (IFS) that divides the atmosphere into 137 pressure levels (Hersbach et al., 2020). It is coupled with a land surface model, the HTESSEL, which produces surface temperature data used in this study. The ERA5-Land component used in comparison to the observed data however, is not coupled to the IFS (Muñoz-Sabater et al., 2021). Instead it runs without assimilation of the ocean wave model of the IFS (Muñoz-Sabater et al., 2021). The dataset is in hourly increments and is no more than three months behind in real time. As a rule, the further back in time the analysis goes, there is more error and uncertainty because the observation system was not as accurate, especially pre-satellite technology. The number of observations included has drastically changed over time. In 1979, 750,000 per day on average were assimilated into ERA5 (Hersbach et al., 2020). By 2019 this had increased to 24 million per day. ERA5 uses observations from over 200 satellite instruments with in-situ data coming from 20 different sources.

This reanalysis is a good choice for this region as it has been show to perform well in the Arctic (Graham et al., 2019). It has also been shown to have a wide variety of applications and have been used as input to the World Meteorological Organization's (WMO) annual assessment of the State of the Climate and other assessments carried out by the Intergovernmental Panel on Climate Change (Hersbach et al., 2020). This proves the validity of this type of program as it is used by leaders within the climate area of study. A known challenge, however, is in mountainous regions above 1500 meters, which would include the mountains surrounding this study area. ERA5 has been shown to produce snow depth that is unrealistically large (Hersbach et al., 2020). This could also result in temperatures being predicted to be cooler in these regions due to the problems with resolving the snowpack. In-situ data for observations is provided by the WMO

Information System. The two most common observation inputs come from an automated surface observing system (ASOS) or an automated weather observing system (AWOS) (Organization (WMO), 2023.). The WMO conducts observations from a variety of sources that comprise the Global Observation System as seen in Figure 4 below.

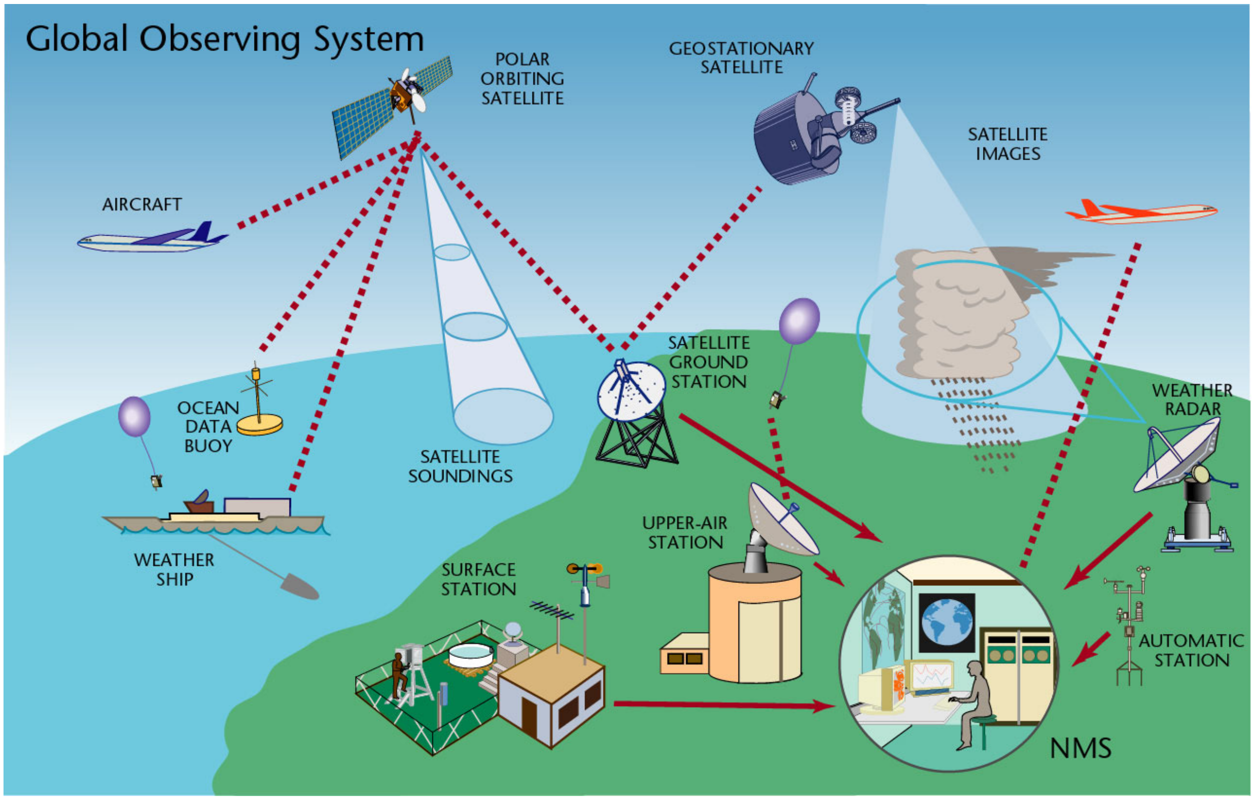


Figure 4: *WMO Global Observation System*
Each item shows one of many sensing nodes in the global observing system that feed directly into this study.

3.0 METHODS

This research was conducted using data from both ERA5 and observed data from the NCEI. To get this data, significant collection and analysis had to be done. I intended to look at a 30-year ambient temperature record equal to one climate period for all official weather observation stations, as well as those in the National Weather Service Cooperative Observer Network.

However, there was a significant limitation in finding stations that could meet these criteria. In fact, only one station out of the 33 active stations on the Kenai Peninsula fit this description. To get more spatial coverage of stations, I shortened this record period to those with a 10-year continuous record, save one station that had a lengthy record outside of the study period, but had omissions during the designated study period of 2013-2022. Climate classification seeks to group together locations with similar climates; so I then compiled this data and compared it to a ERA5, to determine if the temperature ranges in those differ from the observed and modeled conditions (Gomez & Jones III, 2010). My research was quantitative and focused on the compiling of data and comparing this output to expected conditions, making this approach a statistical analysis.

Physical geography is anchored in empirical observation and statistical analysis as the foundation of its research with secondary resources used to enhance credibility. The most common methods for evaluating spatial change are determining the mean pattern and patterns of departure from the mean (Nicholson, 2017). Climatology is a subsection of physical geography and lends itself to this method almost exclusively. This study is not based on a trend's departure from the normal over a period; therefore, the study of spatial variations from larger climate models is a valid technique in climatology classification methodology.

This study aimed to produce a microscale climate classification. Since a microclimate is on a smaller space and time scale as shown in Figure 5, it can be difficult to delineate it from the macroclimate. It can however be done using statistical analysis based on quantitative methods. Climate classification has two primary aims, to suggest why there are observed differences and to aid in forecasting weather (Gomez & Jones III, 2010). Because temperature influences every aspect of the physical environment (Maclean et al., 2021), I completed both in this study using this core climate variable. All information lends itself to being well within this research method.

This work was completed using open-source and freely available data that is procured using in-situ collection by weather stations.

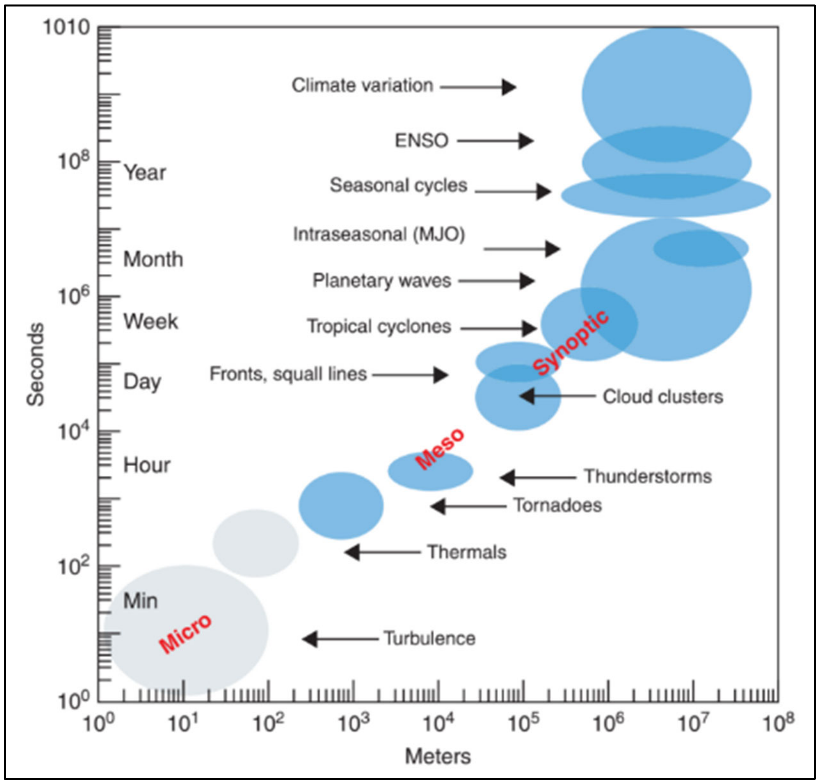


Figure 5: *Time and Space Scale of Meteorological Phenomena*
Microclimates exist in small spatial and temporal scales as indicated in the lower lefthand portion of this graph, much smaller than many other well-known meteorological features. Source: The COMET Program, UCAR

The study area was intended to be set in Kenai, Alaska with the usage of all applicable weather sensors located within a ten-statute mile radius of Kenai Municipal Airport. However, during my research, I confirmed my suspicions of limited data availability in Alaska. It was determined that to get a more robust sample size, I needed to increase the size of my study area. Kenai, Alaska was chosen for its extensive coastline and complex topography from mountain ranges that induce complex weather patterns as a result of a mixture of maritime and continental influences (Hayward et al., 2017). Expanding to include the Kenai Lowlands, a place with almost identical topography, was a necessary adjustment to gather more sensor data, but still have similar conditions to the original location. It has a dry-summer subarctic climate and is warm for a location at such a high latitude. The Kenai Lowlands were chosen as the new center point because it possessed a variety of standard operating weather stations and cooperative observer stations, some of which had lengthy climate records. Meteorologists generally consider a five-statue mile radius around a location to be representative for observations and forecasting purposes. By expanding the study, it does lower the specificity of one location containing a microclimate, but my intent was for more data sources to be included and compared to show microclimatic conditions exist in many places across the study area. When I expanded my study area to be the physiographic region of the Kenai Lowlands, this expanded my area to include all weather stations within 50 miles of Kenai, Alaska. This area encounters many variables that are known climate influencers and makes it a suitable location choice for researching the existence of a microclimate.

3.1 Study Area

The study area is bounded by the Cook Inlet, an entirely maritime environment to the west. The northern boundary is Island Lake located in Nikiski, Alaska. Much of the eastern boundary is confined to the public land extends to Sterling, Alaska at the confluence of Moose River and Kenai River, extending into the Kenai National Wildlife Refuge that was once a heavily forested area but is now the site of a burn scar from a recent wildfire. To the south, the area is bounded by Echo Lake located between Kasilof and Kalifornsky, Alaska. This area is characterized by lowlands with the Kenai Mountains to the east. Figure 6 shows the vast terrain bounds that surround the study area. Like most intense terrain, these mountains produce orographic effects. Because the study area is on the leeward side of the mountain, it is expected to see enhanced warming and less precipitation in the area. In this area, there are two typical atmospheric set-ups: a Low-Pressure system in the Gulf of Alaska or a Low-Pressure system that moves from Kodiak Island to the eastern side of the Kenai Peninsula. Kenai River is a major waterway and runs the length of the study area from east to west. Most of the western area is coastal running into forested or inhabited areas, so it receives a heavy climate influence from the ocean.

Figure 6: *Kenai Peninsula Borough Topographic Orientation*
The terrain and water bodies around the Kenai Peninsula show the immense differences in topography surrounding the study area. Source: Adapted from Kenai Peninsula Borough, 2019. (*Kenai Peninsula Borough*, 2019)

3.2 Data Collection

Data was compiled from existing resources, standard weather stations (to include ASOS/AWOS), National Weather Service cooperative observers, and United States Natural Resources Conservations Service Snowpack Telemetry (SNOTEL). This process of retrieving data required no direct interaction with the National Weather Service weather forecast office in Anchorage, however I did reach out to them to see if they had climate records not available online. They directed me to the NCEI website and advised me to ask any questions if I needed assistance. It was on the website of NCEI that I interfaced with the United States Historical Climate Network. This consists of records from these data sources because one station alone is not indicative of climate homogeneity within a region (Davey & Pielke, 2005). To enhance credibility, a wide range of sources must be used to get a more robust picture of this microclimate. No data required direct collection from the source as the timescale used for this research took place over a ten-year period in the past.

Data was pulled directly from NCEI's website (https://www.ncei.noaa.gov/access/search/index) and the database held within it. This is operated by the National Environmental Satellite, Data, and Information Service, an office of the National Oceanic and Atmospheric Administration. Appendix B lays out steps of imagery showing how to navigate the NCEI webpage. As an overview, I downloaded data from NCEI website. I navigated to the Global Summary of the Month listed under climate data tools. This dataset contains quality controlled monthly summaries of more than 50 elements (maximum temperature, snowfall, etc.) computed from stations in the Global Historical Climatology Network (GHCN)-Daily dataset. These include non-US stations, providing a global product from 1763 to present that is updated weekly. This is not to be confused with GHCN-Monthly, which only contains temperature and precipitation elements, and includes bias corrected data. However, for this study, only the average monthly temperature was used. Not all information is available immediately online but can be accessed by requesting information from the website and then data packages are disbursed after they have been processed.

All available data requested was compiled into Excel documents after they were received. In these documents I designated location, date, and the variable observed. The intended sample size was one climate period (each June from 1991 until 2020). However, after looking at active and historic sensors from the last 30 years, I determined that the period with the most sensors and least number of omissions was from 2013 until 2022. Figure 7 shows the current active sensors in the study area. Almost all targeted stations reported for the entire period, except for the Kenai NWR, which had reported every year since 1993 in my initial data download but had three years of omissions during the period I selected. There were other historical sensors located in this area with extensive records, however a study conducted at an earlier point in time (before 1990) would have significantly decreased the number of stations available for study.

There were 14 stations on Kenai Peninsula that met my criteria for being located within the Kenai Lowlands as shown in Table 1 and visually displayed in Figure 7. After downloading the data, I isolated temperatures in Microsoft Excel to include just the average June temperatures for each station for each year. I then combed the data and decided which stations would be included. I did this by highlighting the stations that would be included in green and highlighted stations that could be included in yellow if a larger sample size were needed. After determining whether a larger sample size was needed and changing both my spatial and temporal resolution, I ended up selecting 8 stations to be included. Imagery from each of the sites was also captured from Google Earth and the United State Department of Agriculture website. Each of these images was gathered to see if the site characteristics could have skewed the data. These images can be seen in Appendix D.

Table 1: *Information of Stations Selected Within the Kenai Lowlands*

Each active station in the study area is listed under the station name along with location, elevation, station type, the number of years it recorded data from 1993-2023, and the station identification.

Station Name	Station Type	Station ID	Elevation (ft)	Years	# of Years	Missing	Lat	Long
KENAI AIRPORT, AK US	WBAN (Weather Bureau Army Navy)	USW00026523	30.2	1993-2023	31	0	60.57909	-151.242
KENAI MOOSE PENS, AK US	U.S. Natural Resources Conservation Service SNOwpack TELemtry (SNOTEL)	USS0050L02S	91.4	1993-2023	26	1993,1997,1999,2000,2023	60.73	-150.48
STERLING 6 SW, AK US	U.S. Cooperative Network	USC00508731	89	2013-2023	11	0	60.4905	-150.919
SKILAK GUARD STATION ALASKA, AK US	U.S. Interagency Remote Automatic Weather Station	USR0000ASKI	179.8	2000-2023	24	0	60.4839	-150.461
KENAI NWR ALASKA, AK US	U.S. Interagency Remote Automatic Weather Station	USR0000AKEN	121.9	1993-2018, 2020, 2023	28	2019,2021,2022	60.5917	-150.317
SOLDOTNA 5 SSW, AK US	U.S. Cooperative Network	USC00508615	54.9	2004-2023	19	2005	60.4194	-151.134
SOLDOTNA AKKKS ALASKA, AK US	U.S. Interagency Remote Automatic Weather Station	USR0000ASAK	47.2	2013-2023	11	0	60.4967	-151.014
SWANSON RIVER ALASKA, AK US	U.S. Interagency Remote Automatic Weather Station	USR0000ASWA	85.3	1993-2000, 2002-2023	30	2001	60.7278	-150.872

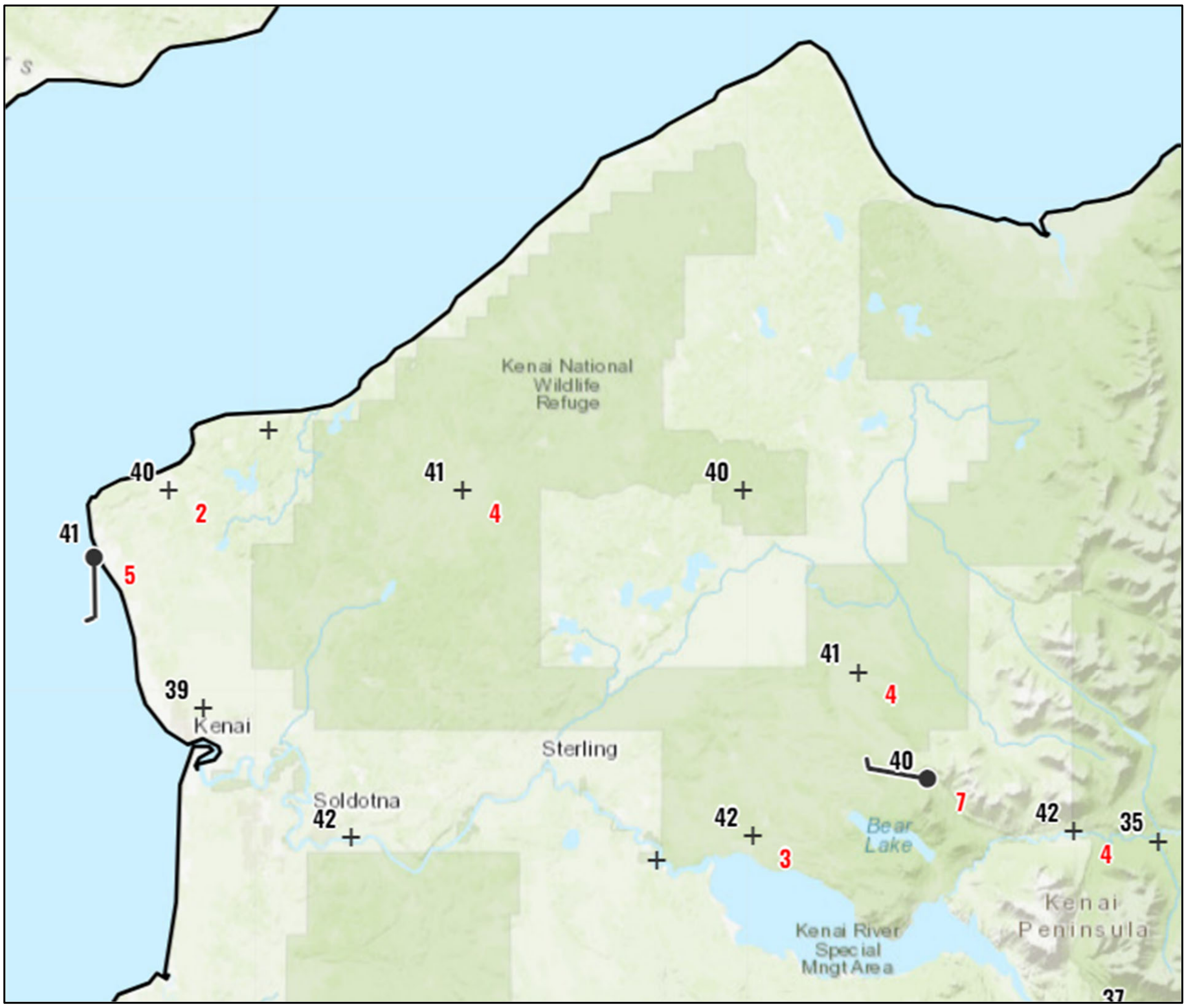


Figure 7: *Active Sensors in the Study Area*

The plus signed and filled in circles indicate an active station. This image is zoomed into the northwest portion of the Kenai Peninsula that encapsulates the study area. Source: Adapted from NWS Weather & Hazard Viewer, 2024. https://www.wrh.noaa.gov/map/?obs=true&wfo=sto&basemap=OpenStreetMap&boundaries=true,false&obs_popup=true

All data had some quality assurance already done to it, according to the NCEI guidelines. It is notable that automated observing systems have limitations, but temperature is one of the least complex variables to observe, being scalar and not vector. The data for each station consisted of the mean temperature observed on one calendar day. Those numbers were averaged for the entire month of June and then noted again for each year in Microsoft Excel. There was no difference in compiling or averaging procedures, with the exception being Kenai NWR, which had three missing June temperature reports. The station with missing daily data was marked as not available so as to not skew the data and ensure a more straightforward comparison (Leeper et al., 2015). Overall, there was limited potential for inconsistencies and bias to be introduced due to the nature of this study with all data already compiled by a trusted source, NCEI, and the collection method having strict criteria as outlined by the World Meteorological Organization.

Similarly, the ERA5 data needed to be collected. Appendix C shows a step-by-step process of how this is done. Overall, the information was retrieved through Google Earth Engine. It was opened in the programs code editor where I added additional lines of coding to change the color palette, center point, and aspect ratio. Markers were added for each station to make selecting that site easier and clearer to the viewer. The Inspector tool was used to then gain the temperature information for each station for each year of the study. This information was then transcribed into Microsoft Excel where it could be compared and plotted more easily to the observed data from NCEI.

3.3 Data Analysis

I analyzed the data by finding the mean monthly temperatures from the daily mean temperature derived from all designated sensors located within the Kenai Lowlands (Karger et al., 2017). I then compared each sensor individually for June of each year for the selected period to the expected temperature conditions of the ERA5 to determine if the temperature ranges in those differ between the observed and modelled conditions. I also calculated the mean value of all sensors together and repeated the same process. After determining the findings, interrogation was done based on the location of the sensor to local topography. I determined the distance from each point to the coastline in Google Earth Engine. Using standard atmospheric lapse rates for the area and the listed elevations provided by each sensor in the Global Summary of the Month, a general approximation of change in temperature could be done additionally and compared to the temperature changes of each station by their elevation. Lapse rates are generally used to describe the effects of orographic lifting and elevation change on the environment (Minder et al., 2010). However, lapse rates vary from actual surface conditions in specific regions, during seasonal cycles, diurnal variability, spatial variability of the slope, or location relative to valleys. The mountain peaks of the Kenai Mountains surrounding the Kenai Lowlands range from 3,000-5,000 feet above mean sea level. While these are not significant mountains, temperature can change drastically in just the first few millimeters off the surface (Rosenberg et al., 1983). If major differences are observed between these sensors, I can infer that the proximity to the feature influenced the local conditions more or less than other locations.

The ERA5 data was changed to have a color palette that aligned with increments of two degrees in temperature change. Additionally, the opacity was changed and a terrain layer added to help understand the topography of the area. A screen capture was taken for each year to show the change in temperature resolution throughout the study period. After retrieving the temperature data from each station, I then compared it to the observed data from NCEI.

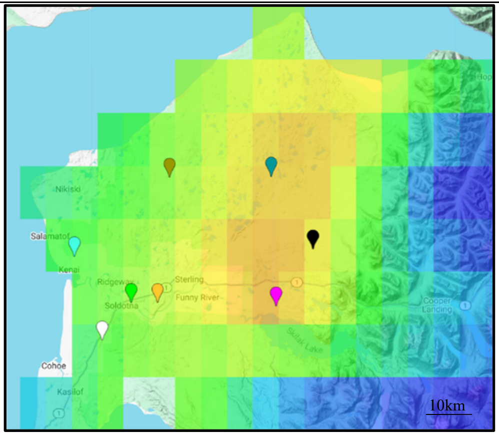
Using Microsoft Excel, data was compiled, and mathematical computations were utilized to process the data. The software was able to create charts as necessary. With there being more than two sensors and more than two external topographical factors influencing the temperature, an analysis of variance test between the data of each sensor is a statistical test that could be run. While they record the same data, not all the locations are the same type of reporting system, and each has varying distances to known temperature influences. A regression test was done between each sensor to see if microclimate influences, such as proximity to water and mountains, are directly related to temperature changes. Climate is a complex system. It is usually best described by a nonlinear regression function (Mudelsee, 2019). This is a commonly used statistical test employed in climatology classification and one that may be employed based on distance to features and differences in temperature itself.

4.0 RESULTS

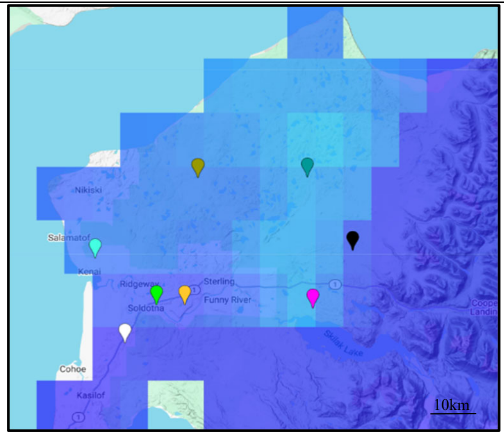
The findings from the ERA5 analysis on Google Earth Engine are displayed below in Figures 8a-8j with a legend indicating the location of each station shown in Figure 9. The color scheme has shades of green indicating cooler temperatures moving to shades of yellow that indicate warmer temperatures. Being a temperature environment in the summer, there was no major fluctuation to indicate two extremes on the spectrum (red as hot and blue as cold). The work completed is shown in both chart and table format describing ERA5 temperatures, observed temperatures, and station information.

4.1 ERA5 Temperature Maps

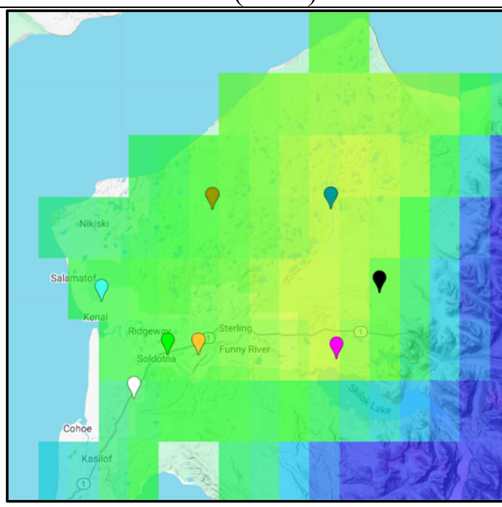
The ECMWF ERA5 climate model is a well-respected climate reanalysis that covers the globe. It also has an enhanced version, ERA5-Land that has a series of improvements, to include an improved resolution of 9 kilometers (Muñoz-Sabater et al., 2021). This land component of ERA5 is the where the temperature data comes from and is compared in this study. Quality climate data is usually obtained from the ERA5 database, however the spatial scale may not be sufficient for things that operate on a smaller scale resolution (Zanchi et al., 2023). This becomes problematic when microclimates are highly localized conditions that can provide different areas in areas less than two kilometers apart. The coastline and mountains run from south-southwest to north-northeast through the study area. Interrogating the temperature gradient in relation to the mountains, it runs from west-northwest to east-southeast. In relation to the coast, there is a less intense temperature gradient that is slightly warming through the Swanson River and Kenai NWR stations before it reverses direction and a more intense gradient cools with elevation as it goes into the mountains.



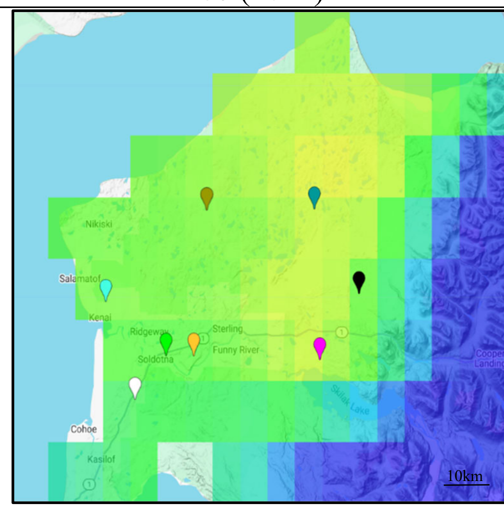
8a (2013)



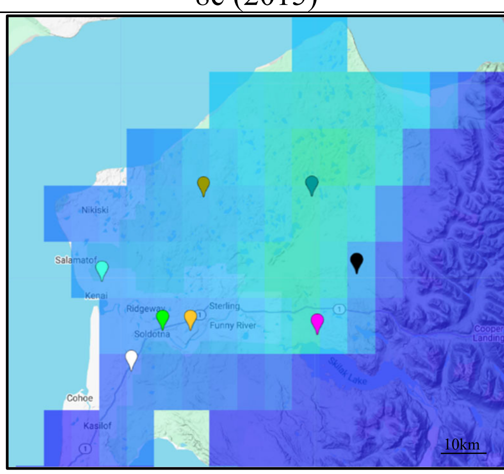
8b (2014)



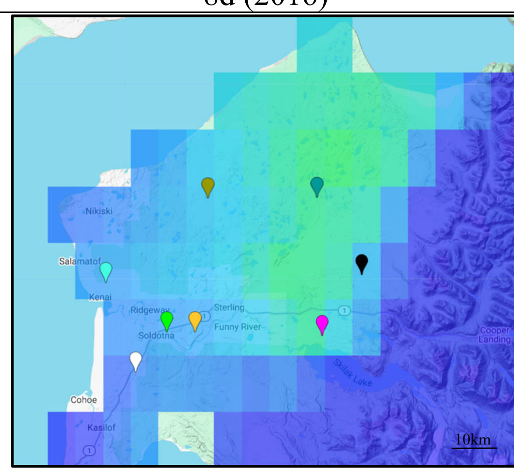
8c (2015)



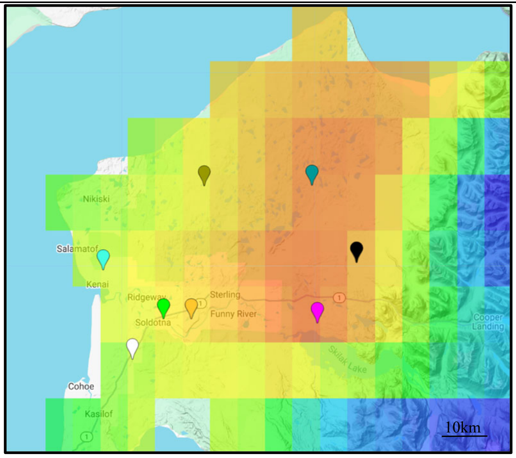
8d (2016)



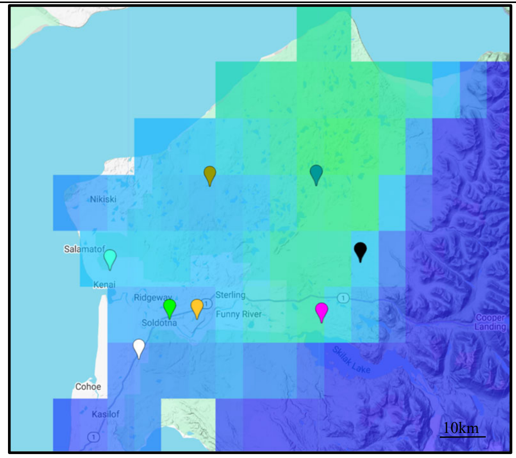
8e (2017)



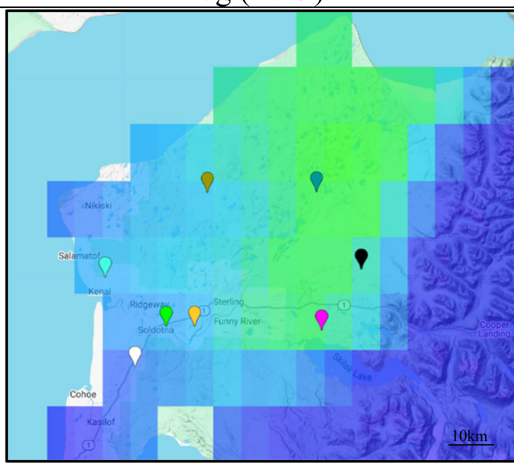
8f (2018)



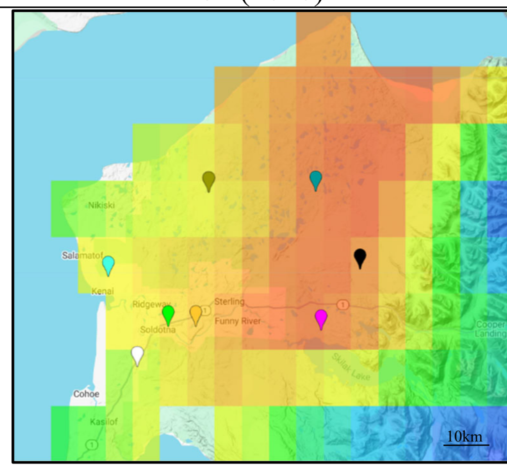
8g (2019)



8h (2020)



8i (2021)



8j (2022)

Figures 8a-8j are ERA5 Temperature Maps by year.
All use the same temperature legend, which is included in Figure 9. Data sourced from Copernicus Climate Change Service ERA5.

Figure 8a shows Swanson River, Soldotna AKKKS, and Skilak Guard Station were the only three stations in which the observed temperature was warmer than the ERA5 output. Kenai Airport saw the largest difference between observed temperature and the ERA5 reanalysis, with observed temperatures 2.44°F cooler than ERA5. Figure 8b indicates Swanson River, Soldotna AKKKS, and Skilak Guard Station were once again the only three stations in which the observed temperature was warmer than the ERA5 output. Kenai Moose Pens saw the largest difference between observed temperature and the ERA5 reanalysis, with observed temperatures 2.14°F cooler than ERA5. Figure 8c shows that Kenai NWR, Swanson River, Soldotna AKKKS, and

Skilak Guard Station were the four stations in which the observed temperature was warmer than the ERA5 output. Swanson River saw the largest difference between observed temperature and the ERA5 reanalysis, with observed temperatures 1.71°F warmer than ERA5. Figure 8d shows Sterling 6 SW, Kenai NWR, Swanson River, Soldotna AKKKS, and Skilak Guard Station were the stations in which the observed temperature was warmer than the ERA5 output. Skilak Guard Station saw the largest difference between observed temperature and the ERA5 reanalysis, with observed temperatures 1.49°F warmer than ERA5.

Figure 8e indicates Swanson River, Soldotna AKKKS, and Skilak Guard Station were the only stations in which the observed temperature was warmer than the ERA5 output. Skilak Guard Station saw the largest difference between observed temperature and the ERA5 reanalysis, with observed temperatures 1.32°F warmer than ERA5. Figure 8f shows Sterling 6 SW, Kenai NWR, Swanson River, Soldotna AKKKS, and Skilak Guard Station were the stations in which the observed temperature was warmer than the ERA5 output. Soldotna 5 SSW saw the largest difference between observed temperature and the ERA5 reanalysis, with observed temperatures 1.79°F cooler than ERA5. Figure 8g shows Sterling 6 SW and Swanson River were the only stations in which the observed temperature was warmer than the ERA5 output. Soldotna 5 SSW saw the largest difference between observed temperature and the ERA5 reanalysis, with observed temperatures 3.06°F cooler than ERA5. Figure 8h indicates that Sterling 6 SW, Swanson River, Soldotna AKKKS, and Skilak Guard Station were the stations in which the observed temperature was warmer than the ERA5 output. Swanson River saw the largest difference between observed temperature and the ERA5 reanalysis, with observed temperatures 2.38°F cooler than ERA5. Figure 8i indicates Sterling 6 SW, Swanson River, Soldotna AKKKS, and Skilak Guard Station were the stations in which the observed temperature was warmer than the ERA5 output. The Swanson River site saw the largest difference between observed temperature and the ERA5 reanalysis, with observed temperatures 2.44°F cooler than ERA5. Figure 8j shows Swanson River and Skilak Guard Station were the two stations in which the observed temperature was warmer than the ERA5 output. Soldotna 5 SSW saw the largest difference between the observed temperature and the ERA5 reanalysis, with observed temperatures 4.96°F cooler than ERA5. Figure 8 (below) is the exact same image as Figure 8j but is enlarged to show the temperature scale as well as the labels for each station.

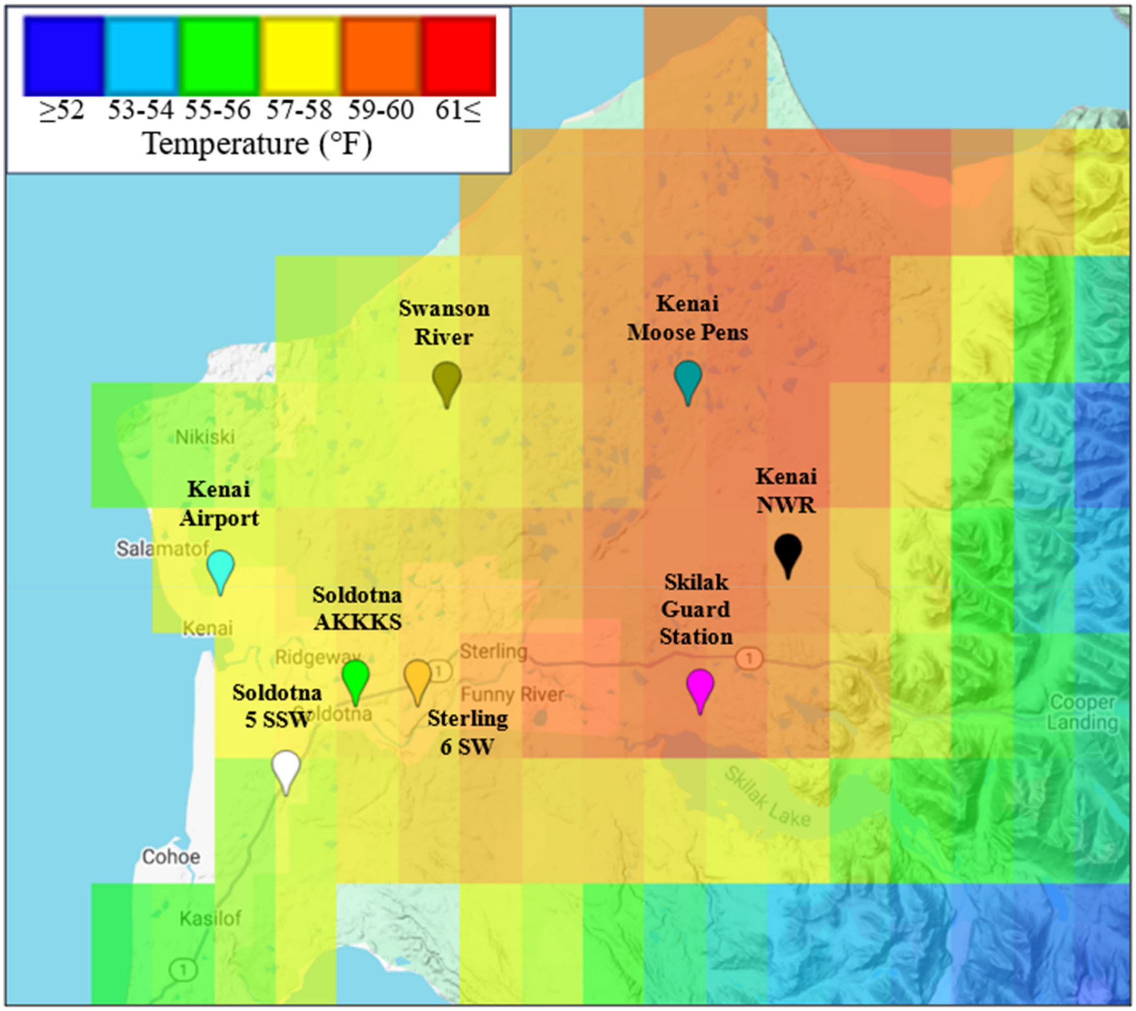


Figure 9: *ERA5 Temperature Map, 2022 Enlarged*
Study area stations are indicated with a marker. This image has been blown up to better show the temperature resolution and allow for easier station identification. Each station is indicated with markers with the ERA5 temperatures overlaid.

The ERA5 temperature maps consistently resolved the east central part of the study area with the warmest temperatures as indicated in Figure 9, this warm temperature trend runs north northeast from Skilak Lake to the Turnagain Arm. The coolest temperatures were always indicated over the mountains to the east with the next coolest temperatures from Nikiski to Kasilof. Each color on map was scaled to two degrees Fahrenheit with a general range of 52 to 61 degrees Fahrenheit to best match the temperature output of the study area. Kenai Airport, Kenai Moose Pens, and Soldotna 5 SSW were difficult for ERA5 to resolve as observed temperatures were cooler in every year of the study at those locations. Swanson River was another difficult place for ERA5 to resolve as observed temperatures were warmer here in every year of the study. This is noteworthy in that these stations are comprised of the three stations closest to the coastline and have the most maritime influence. It also represents two of the three stations with the lowest elevation. This could indicate that the climate reanalysis has difficulty in resolving these conditions or the observed conditions indicate that these observations are from the highly localized conditions found in a microclimate.

4.2 Station Temperature Trends

ERA5 temperatures were warmer than the observed temperatures at five of the eight stations. These stations were: Kenai Airport, Kenai Moose Pens, Sterling 6 SW, Skilak Guard Station, Kenai NWR, and Soldotna 5 SSW (see Table 2). Observed temperatures were on average 0.24°F cooler than the ERA5 reanalysis, however observed conditions ranged from 1.7°F cooler to 1.77°F warmer than the ERA5 reanalysis. The stations observed average temperatures ranges from 52-57°F, with minimal diurnal fluctuations, which is typical in coastal Alaska due to the longevity of the sunlight and the moderating influence of coastal waters on land temperatures.

Some observations worth noting are that the two stations closest to the coastline showed the coolest observed temperatures compared to the ERA5 reanalysis. The two locations furthest from the coast were close in temperature to ERA5 or warmer than the reanalysis. Although the location with the lowest elevation showed cooler observed temperatures than ERA5 and the station with the highest elevation showed warmer observed temperatures than ERA5, there does not seem to be a correlation to the stations in-between.

Table 2: *Station Distance, Elevation, and Temperature Difference Between Observed and ERA5*. Tobs is the average observed temperature during the research period. TERA5 is the output temperature of ERA5 during the research period.

Station Name	Distance to Coast (mi)	Elevation (ft above MSL)	Average (Tobs-TERA5)	Tobs	TERA5
KENAI AIRPORT	2.17	30.20	-1.401	53.06	54.46
KENAI MOOSE PENS	15.81	91.40	-1.691	54.60	56.29
STERLING 6 SW	12.38	89.00	-0.025	54.67	54.69
SKILAK GUARD STATION	27.74	179.80	1.059	57.37	56.31
KENAI NWR	21.85	121.90	-0.149	54.07	54.22
SOLDOTNA 5 SSW	5.34	54.90	-1.869	52.09	53.95
SOLDOTNA AKKKS	9.13	47.20	0.354	54.88	54.52
SWANSON RIVER	7.04	85.30	1.769	56.49	54.72

Figure 10 shows that observed temperatures were warmer on average at Skilak Guard Station, Soldotna AKKKS, and Swanson River. The greatest difference between observed and ERA5 temperatures was at Soldotna 5 SSW and the least difference at Sterling 6 SW.

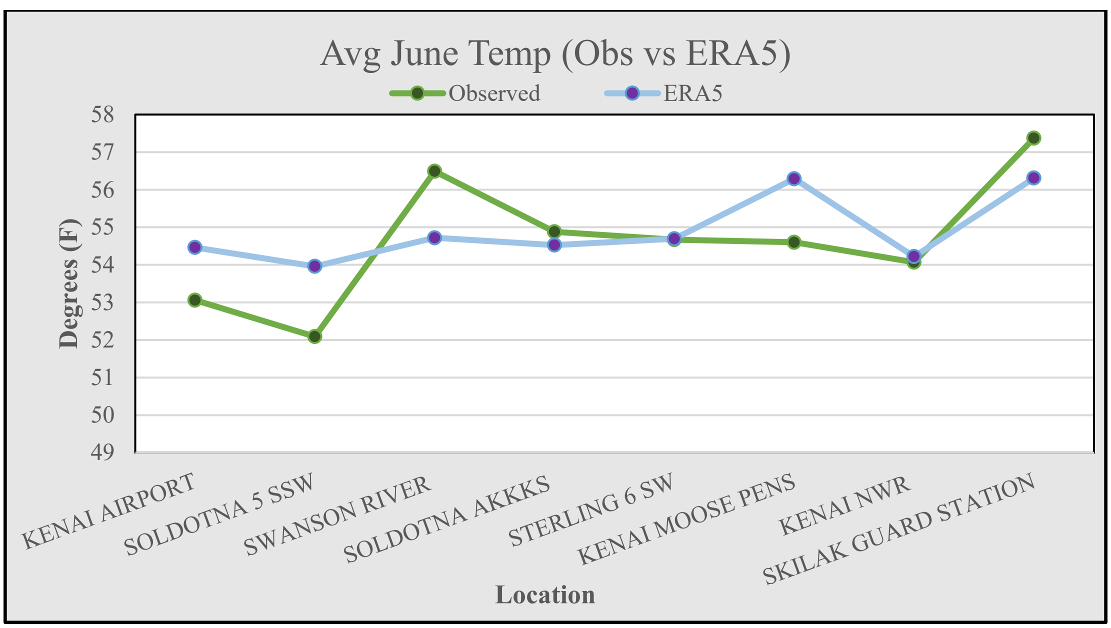


Figure 10: *Station Observed and ERA5 Temperatures During Research Period* Stations are plotted by distance from coastline with Kenai Airport being closest to the coast and Skilak Guard Station being the furthest away from the coast.

ERA5 temperatures were warmer every year of the study for Kenai Airport as seen in Figure 11. Observed temperatures were on average 1.4°F cooler than the ERA5 reanalysis. This was the closest station to the ocean and the lowest in elevation. ERA5 temperatures were warmer every year of the study as well for Kenai Moose Pens (see Figure 11). Observed temperatures were on average 1.7°F cooler than the ERA5 reanalysis. This location was 15.8 miles from the ocean and 91.4 feet above mean sea level. ERA5 temperatures were nearly identical to observed temperatures throughout the study for Sterling 6 SW (See Figure 11). Observed temperatures were on average 0.03°F cooler than the ERA5 reanalysis. This location was 12.4 miles from the ocean and 89 feet above mean sea level. Skilak Guard Station ERA5 temperatures were generally cooler than observed temperatures throughout the study (see Figure 11). Observed temperatures were on average 1.1°F warmer than the ERA5 reanalysis. This location was 27.7 miles from the ocean and 179.8 feet above mean sea level, making it both the highest in elevation and farthest from the ocean of any station.

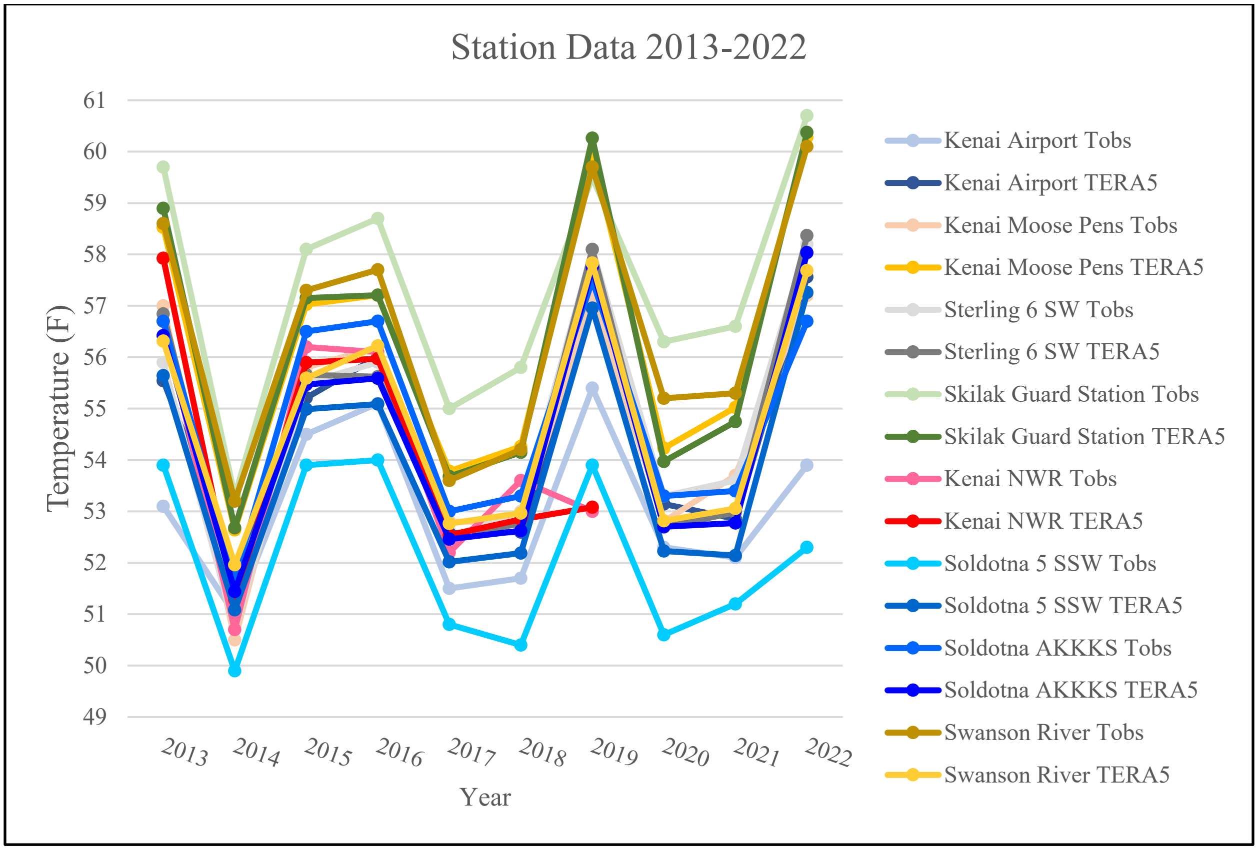


Figure 11: *All Stations Observed and ERA5 Temperatures During Research Period.* Tobs is the observed temperature and TERA5 represents the temperature output of ERA5.

ERA5 temperatures were nearly identical to observed temperatures throughout the study for Kenai NWR (see Figure 11). Observed temperatures were on average 0.15°F warmer than the ERA5 reanalysis. This location was 21.9 miles from the ocean and 121.9 feet above mean sea level. Soldotna 5 SSW ERA5 temperatures were warmer than observed temperatures in each year of the study (see Figure 11). Observed temperatures were on average 1.87°F cooler than the ERA5 reanalysis. This location was 5.3 miles from the ocean and 54.9 feet above mean sea level. ERA5 temperatures were cooler than observed temperatures in most years of the study for Soldotna AKKKS (see Figure 11). Observed temperatures were on average 0.35°F warmer than the ERA5 reanalysis. This location was 9.1 miles from the ocean and 47.2 feet above mean sea level. Swanson River ERA5 temperatures were cooler than observed temperatures in every year of the study (see Figure 11). Observed temperatures were on average 1.77°F warmer than the ERA5 reanalysis. This location was 7.0 miles from the ocean and 85.3 feet above mean sea level.

4.3 Station Temperatures and the Pacific Decadal Oscillation

The Pacific Decadal Oscillation (PDO) index is an empirical orthogonal function based on monthly seas surface temperature anomalies in the North Pacific from 20°N to 70°N (Wang et al., 2012). Like the El Niño-Southern Oscillation (ENSO), it is defined by positive and negative phases that produce opposite patterns. The amplitude of the PDO increases from winter to spring, reaching peak values from May through June, before declining in summer, with a secondary peak again in the fall (Wang et al., 2012). For the PDO, a positive phase generally means above average temperatures in Alaska and a negative phase means below average temperatures in Alaska (Heuer et al., 2023), however the effects are most pronounced during the winter and for southern coastal and Panhandle regions of the state.

While the PDO is a teleconnection across a vast spatial and temporal scale, it is worth acknowledging this larger pattern in relation to the surface temperatures observed during this study. While this temperature study did not match the expected PDO indices throughout, every station saw its lowest average temperature in 2014 as the PDO began to switch to a warm phase and saw an increase in temperatures in 2015 and through 2016. Note in Table 3 that the PDO hovered around neutral in 2019, which likely contributed to the stations observing one of their warmest years during the study. This however contrasts with 2022, when the negative phase should have indicated below average temperatures for the region, but most stations saw one of their warmest years in the observation period. Overall, there was found to be no significant statistical relation with station temperatures and the PDO, but this may be due to the relatively short period of time for this study compared to the temporal scale of variations in this oscillation.

Table 3: *Pacific Decadal Oscillation Index by Year*
PDO denotes the Pacific Decadal Oscillation. In the header of the table each station has been given an identifier: KA is Kenai Airport, KMP is Kenai Moose Pens, S6S is Sterling 6 SW, SGS is Skilak Guard Station, KNWR is Kenai NWR, S5S is Soldotna 5 SSW, SA is Soldotna AKKKS, SR is Swanson River. Each of these identifiers is accompanied by either an "O" or an "E." An "O" represents the average observed temperature, and the "E" represents the temperature output for ERA5. Within the data, there were three years that were not reported for Kenai NWR. These years are denoted as NR. The corresponding ERA 5 temperature to those years is omitted because there is nothing to compare them to. These instances are denoted with a hyphen (-).

Year	PDO Index	KA O	KA E	KMP O	KMP E	S6S O	S6S E	SGS O	SGS E	KNWR O	KNWR E	S5S O	S5S E	SA O	SA E	SR O	SR E
2013	-1.19	53.1	55.5	57	58.5	55.9	56.8	59.7	58.9	56.7	57.9	53.9	55.6	56.7	56.4	58.6	56.3
2014	-0.28	51	51.9	50.5	52.6	50.7	51.4	53.3	52.7	50.7	51.3	49.9	51.1	51.7	51.4	53.2	52.0
2015	0.82	54.5	55.2	55.8	57.0	55.5	55.7	58.1	57.1	56.2	55.9	53.9	55.0	56.5	55.5	57.3	55.6
2016	0.87	55.1	56.0	56.2	57.2	55.9	55.6	58.7	57.2	56.1	56	54	55.1	56.7	55.6	57.7	56.2
2017	0.35	51.5	52.5	52.8	53.8	52.5	52.5	55	53.7	52.2	52.5	50.8	52.0	53	52.5	53.6	52.8
2018	-0.66	51.7	52.5	52.8	54.3	53	52.8	55.8	54.1	53.6	52.8	50.4	52.2	53.3	52.6	54.2	53.0
2019	-0.06	55.4	57.1	57.2	59.9	58.1	58.1	59.5	60.3	NR	-	53.9	57.0	57.5	57.8	59.7	57.8
2020	-0.75	52.3	53.1	52.8	54.2	53.3	52.7	56.3	54.0	53.0	53.1	50.6	52.2	53.3	52.7	55.2	52.8
2021	-1.81	52.1	52.8	53.7	55.0	53.6	53.0	56.6	54.7	NR	-	51.2	52.1	53.4	52.8	55.3	53.1
2022	-1.33	53.9	57.5	57.2	60.3	58.2	58.4	60.7	60.4	NR	-	52.3	57.3	56.7	58.0	60.1	57.7

When comparing the PDO to ENSO, studies suggest that when the PDO is positive the likelihood of an El Niño occurring is higher and its impacts are additionally amplified, with the same result for a negative PDO and La Niña (Maher et al., 2022). It should however be noted that the largest correlation between the two was shown during winter and spring (Maher et al., 2022). In addition, ENSO correlation to Alaska is not high, but still substantial. In general, La Niña summers mean cooler temperatures and El Niño summers mean warmer temperatures. During this study, the Oceanic Niño Index had La Niña conditions in 2015 and 2019 with El

Niño conditions in 2022. The remaining years were neutral in between these phases. Only 2019 had PDO and ENSO in-phase with each other and these results did not align with the overall understanding of how these teleconnections impact Alaska. While microclimates are dependent on their direct surroundings to cause their variation from the macroclimate classification, it should be acknowledged that global circulation plays a role in driving all climate conditions.

5.0 DISCUSSION

The trend line on Figure 12 above indicates observed temperatures, while cooler closer to the coastline becoming warmer than the ERA5 reanalysis with increased distance from the coastline and therefore lessening the effect of the maritime environment and increasing the temperature variability of the land. This could in part be from systematic bias that ERA5 has been shown to exhibit due to land cover and vegetation (Lopes et al., 2024). The average observed temperature increased by 0.11°F per mile moving inland while the average modeled temperature increased 0.06°F per mile moving inland. Maritime airmass influences moderate nearby land surface temperatures as the water heats up and cools down at a slower rate than land does. This allows the airmass above nearby land to mix and maintain a steadier temperature than one further away from a maritime influence. It is interesting to note that ERA5 did not resolve the temperatures at the three locations closest to the ocean. These places without any other influences should theoretically have been the most stable in temperature. ERA5, with its current resolution limit and spatially limited data station inputs did not have the ability to see this small historical variation and resolved more appropriately. The three locations that had the least variability between observed temperatures and ERA5 temperatures were between nine and 22 miles from the coast.

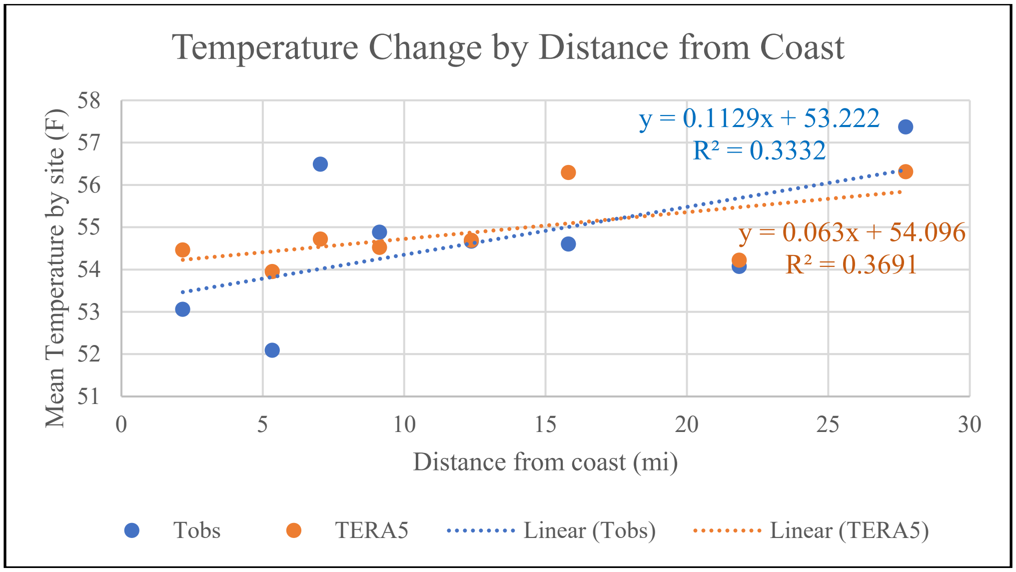


Figure 12: *Temperature Difference by Distance to Coastline*

Slope lines are indicated with the blue and orange dotted lines. These lines correspond to the observed and ERA5 temperatures indicated in the same color, but as points for each station.

The trend line on Figure 13 indicates observed temperatures, while cooler at lower elevations becomes warmer than the ERA5 reanalysis with increased elevation and therefore increasing the likelihood of terrain and orographic principles affecting the temperature. The average observed temperature increased 2.5°F per 100 feet of elevation gain and the average modeled temperature increased 1.2°F per 100 feet of elevation gain. Distance and elevation were shown to have a high degree of correlation, so they essentially presented the same information as seen in Figures 12 and 13. The observed temperatures slope is almost double the slope of the model temperature for both distance inland and elevation, so warming inland was more pronounced than what ERA5 temperature suggests. It must be acknowledged however that these slope lines showed a low degree of statistical significance as indicated in Appendix A.

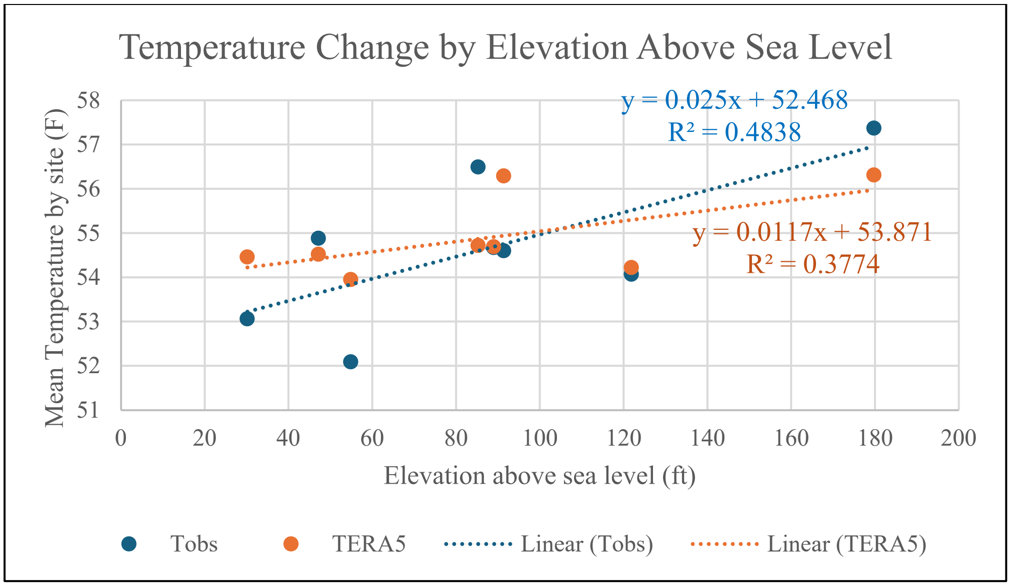


Figure 13: *Temperature Difference by Station Elevation*

Slope lines are indicated with the blue and orange dotted lines. These lines correspond to the observed and ERA5 temperatures indicated in the same color, but as points for each station.

The average observed temperature of the stations generally increases as it moves further from the coastline (see Figure 14). Stations closer to the ocean are likely being moderated by the cooler ocean waters while the more inland locations are warmer due to the faster warming land surface.

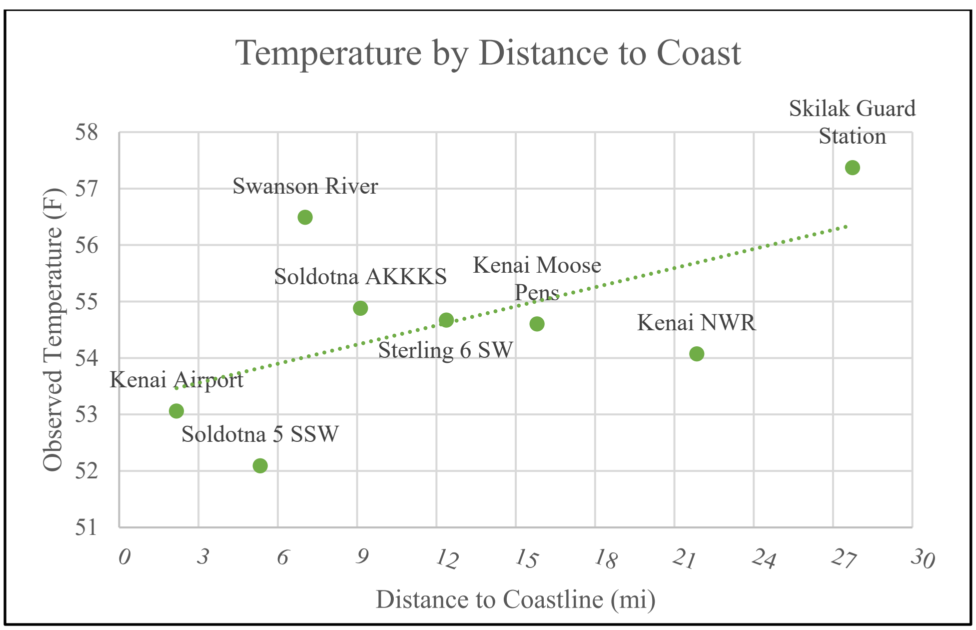


Figure 14: *Observed Temperature by Station Distance to Coastline*

Figure 15 shows observed temperatures have a warming trend as they increase in elevation. This is not a standard principle as temperatures generally decrease with an increase in elevation gain. The ERA5 model also consistently showed cooler temperatures with increased elevation gain but did show the warmest temperatures in the lowlands immediately preceding more intense elevation gain. However, there was only a relatively small elevation gain so it is unsurprising to think this could mean that other factors have been influencing the temperature more than the elevation is at these stations. Oceans have a higher heat capacity than nearby land surfaces (Lambert et al., 2011). This could also explain an inland warming trend since land heats up faster than the ocean. The more coastal stations received a more moderate effect from the deep ocean waters, while inland stations benefitted from the more rapidly heating land surface or shallow water bodies that surrounded them.

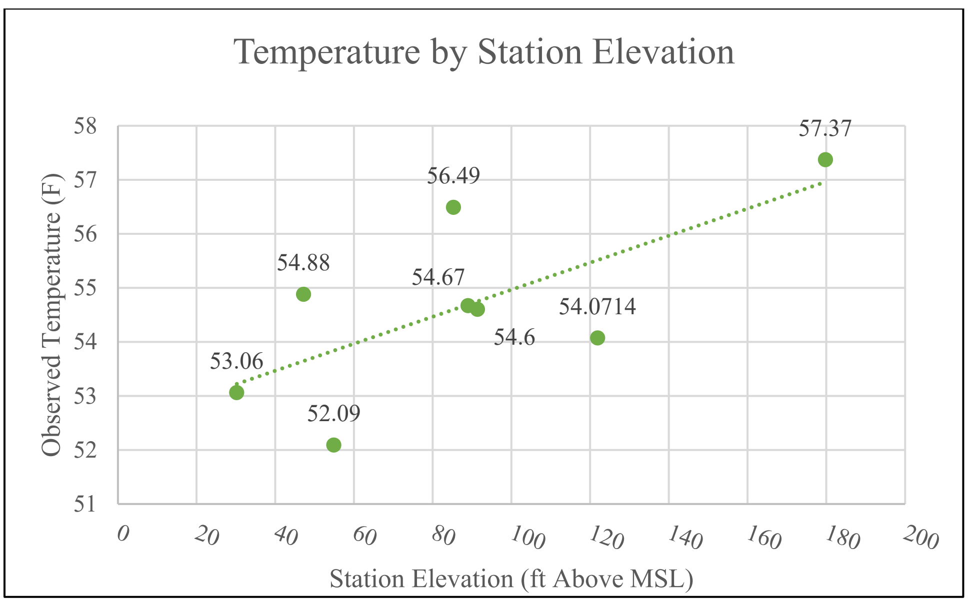


Figure 15: *Observed Temperature by Station Elevation*

The stations highly localized site selection may have played a part in this. When reviewing Appendix D, the Kenai Airport is the most open station and would allow for the most mixing of air but also be affected by significantly more manmade surfaces. Localized air circulation could be more of a factor in this location since it is more open, allowing for easier mixing of warm and cold air. The Sterling, Soldotna 5 SSW, and Soldotna AKKKS are all sites that could also have been impacted as these look to be placed near buildings. While this in itself is not a cause, the localized dynamics of temperature affecting those stations could be partially blocked by buildings and not allowing for consistent air flow from all directions (Wright et al., 2010). The remaining locations are different than the rest of the stations as they reside in mostly wooded areas. The land cover in these wooded areas is likely shading the site and impeding wind flow. This results in less radiation being received by the site (Wright et al., 2010). With less radiation reaching the site, the area remains cooler and could potentially skew the data being recorded in this manner.

Over the last 50 years, the Kenai Lowlands has undergone significant land-cover change. Although deforestation events such as the spruce bark beetle outbreaks, wildfires, and timber harvest have occurred, studies show that this area has actually become more forested (Baughman et al., 2020). This is a result of forest loss in the southern half of the Kenai Lowlands, but significant regrowth in the northern half. There has been a noted observation of transition areas from wetland to forest and/or shrub (Baughman et al., 2020). It has also been shown that mixed-forest classification has transitioned to broadleaf in the northern half of the Kenai Lowlands, which makes up the study area for this microclimate analysis. Because northern latitudes are warming at twice the rate of the global average and warming temperatures increase drought and beetle attacks, an amplification of climate change is likely to happen over the coming decades (Baughman et al., 2020). This will lead to changes in land-cover and albedo that will reduce or enhance the effects of microclimates in this area. With less snow cover expected in the future, the exchange of a high albedo for a lower one is also likely to increase the warming of this area as less radiation is reflected into the atmosphere.

Agriculture in this area will likely see changes from land-cover impacts in the future. This industry could benefit in selecting locations to meet their business needs if temperatures are found to be more hospitable in one area of the study versus another (King et al., 2018). This could include new varieties of crops or larger yields from the harvest. The Kenai Peninsula has seen a 60% increase in the number of farms in the borough since 2007 (*Agriculture | Kenai Peninsula Economic Development District (KPEDD)*, 2024). This makes up 9% of the state's agriculture and 21% of it goes directly to the consumer. With increased warming from climate change increasing the growing season and overall temperature, this trend is likely to continue. While the northern Kenai Lowlands are likely to remain forested (Baughman et al., 2020), the impact of species distribution will be highlighted as areas transition in the type of forest cover. Skilak Guard Station had the warmest average observed temperature in the month of June during this study period with Swanson River having the second highest average temperature (see Figure 16). Soldotna 5 SSW had the coolest average observed temperature during the study period.

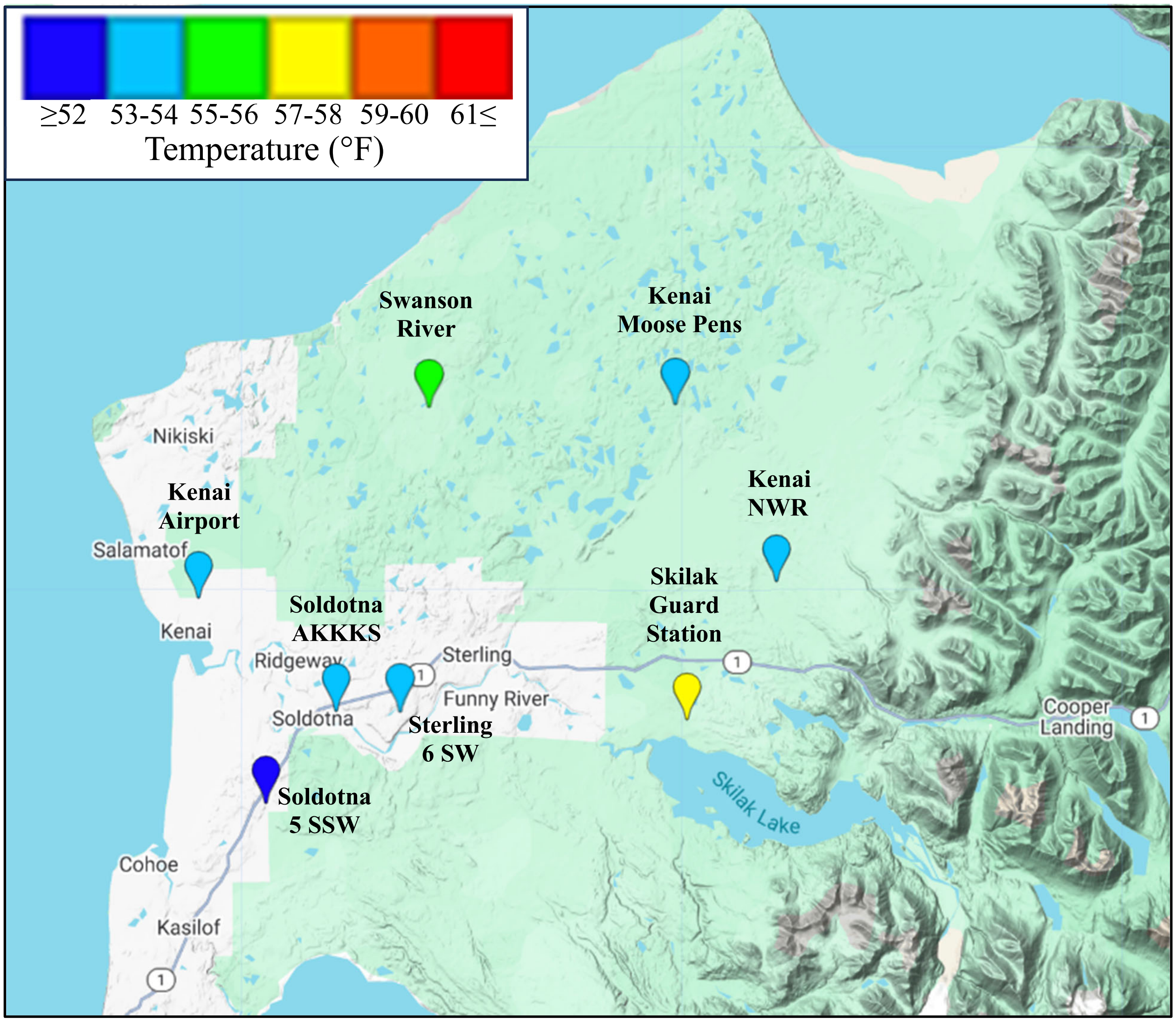


Figure 16: *Observed Average Temperature*
Each station marker is color coded to the temperature legend in the map to indicate the average observed temperature during the study period at each station.

ERA5 had Skilak Guard Station and Kenai Moose Pens as the two warmest stations, resolving all other stations similarly as seen in Figure 17.

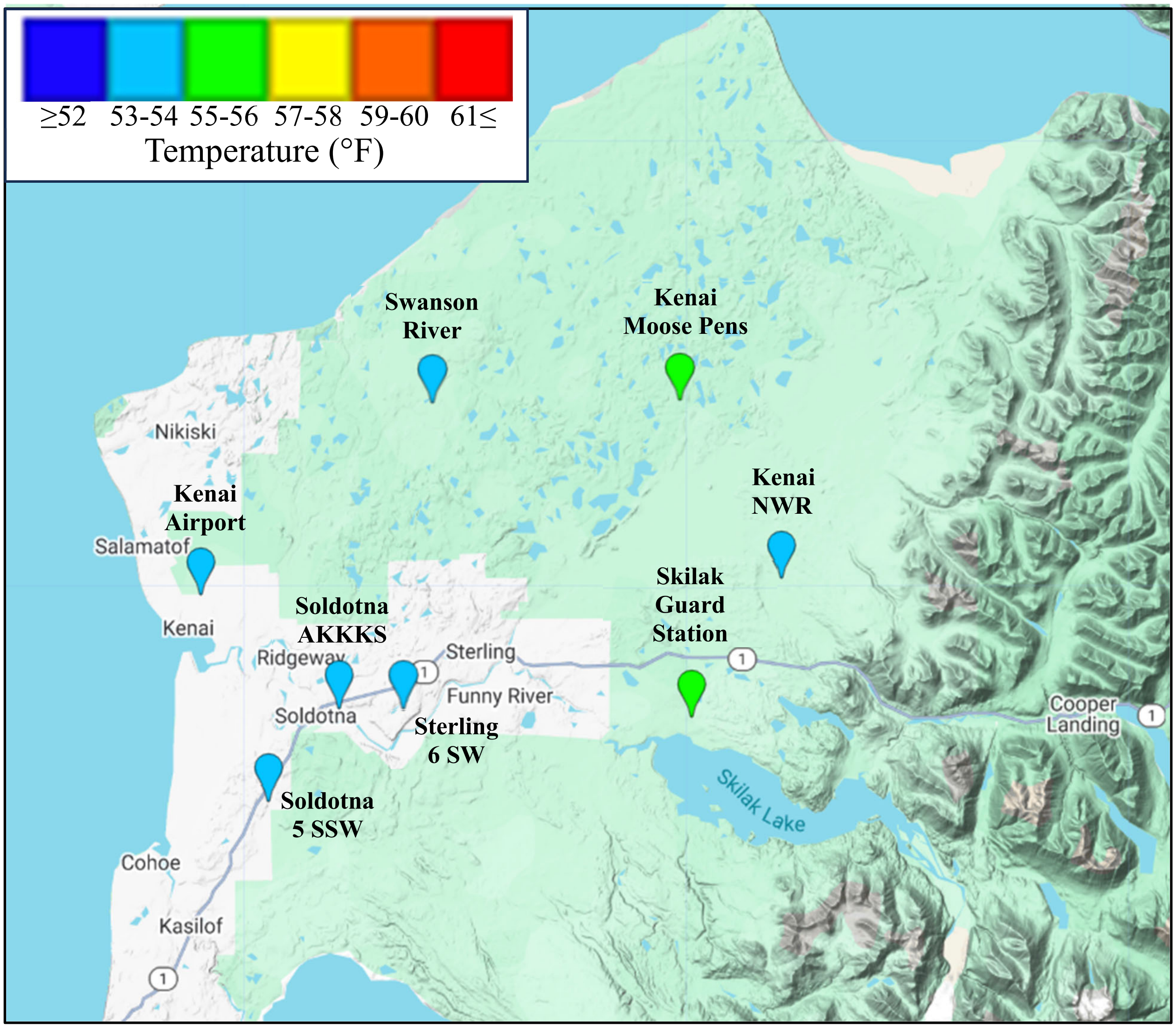


Figure 17: *ERA5 Average Temperature*
Each station marker is color coded to the temperature legend in the map to indicate the average ERA5 temperature during the study period at each station.

6.0 CONCLUSIONS

Observed temperatures provide some indication that terrain features cause microclimate conditions around the Kenai Lowlands. The coolest average temperatures were located near the water and the warmest average temperature was located the most inland. This makes sense with the knowledge of how land and water heat and cool. An interesting finding was that the station with the highest elevation was also the warmest, which is against typical understanding as temperature usually decreases with an increase in height. This could indicate a localized circulation providing this deviation or the presence of cold pooling in other areas of the study area at lower elevations.

ERA5 is a well-respected reanalysis and was within a few degrees of each station. While this does not sound like much, remembering that this study was done in an extremely temperate environment with little diurnal temperature fluctuation leads me to believe that in more extreme months the difference between observed temperatures and model temperatures would be much greater. Further studies should be done to verify how well ERA5 would do in this area in different months of the year.

This study will increase our understanding of localized weather conditions and microclimates in the Kenai Lowlands. It will address the knowledge gaps that exist due to the immense land area of Alaska. There is a lack of ground truth data available, so forecasters often use pattern recognition to improve their accuracy. The research will expand knowledge of the area and may present a starting point for further and more technical research methods to be conducted. Local meteorologists in this area and other areas with varied topography can appreciate the value of data on local microclimates to aid in better, more accurate forecasts. Many governmental organizations will benefit from this study. Most new members of these organizations are not familiar with Alaska when they are assigned to be meteorologists in the state. Having sound climate information and weather forecasting processes is imperative to make these individuals as effective as possible when taking these jobs.

This study provides a more accurate depiction of the state and awareness of the intense topography of its landscape. While the Kenai Lowlands are only a small portion of Alaska, it does have some of the most hospitable weather conditions for people to live and work in. Private industry will continue to benefit, especially the agricultural industry as precision agriculture has relied on microclimate monitoring systems in recent years (Zanchi et al., 2023). Enhancing industry knowledge of microclimate conditions could include the expansion of the growing season and region, as well as prevent disease outbreaks. This will only be exacerbated with increasing climate change in the state.

In a state so sparse with meteorological data, it is important to continue to study the environment and provide weather forecasters with the ability to accurately relay timely information for public safety and mission success. This study provides aid for meteorologists in their forecasting processes, giving them a better understanding of the climatic normal for the Kenai Lowlands. Additionally, it benefits aviators traversing through the area, increasing their awareness of localized conditions. With a state so dependent on aviation, this is paramount to the safety and success of flight operations as well as the impact aviation has on the local economy. Having sound climate information and weather forecasting processes is imperative to the safety of both public and private industry as it improves their effectiveness. This study serves as a benchmark for other research to be done across the state and provides new opportunities and safer conditions in those locations as well. Further investigation should be carried out to include precipitation measurements. It should also be extended across the entirety of the year, especially in months with the greatest degree of variability to see how climate models compare to observed temperatures.

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8.0 Appendix A: Statistical Summary from R

```
> summary(lm(Tobs~Dist,data=dataT))

Call:
lm(formula = (Tobs) ~ Dist, data = dataT)

Residuals:
    Min      1Q  Median      3Q     Max
-1.7347 -0.7099 -0.1782  0.7246  2.4733

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  53.2218     0.9824  54.173 2.66e-09 ***
Dist          0.1129     0.0652   1.732    0.134
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.5 on 6 degrees of freedom
                                                Adjusted R-squared:
Multiple R-squared:  0.3332,                    0.2221
F-statistic: 2.999 on 1 and 6 DF,  p-value: 0.134
```

```
> summary(lm(TERA5~Dist,data=dataT))

Call:
lm(formula = (TERA5) ~ Dist, data = dataT)

Residuals:
     Min       1Q   Median       3Q      Max
-1.25280 -0.26001  0.01477  0.28717  1.19788

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 54.09566    0.50691 106.716 4.56e-11 ***
Dist         0.06303    0.03364   1.873     0.11
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.7742 on 6 degrees of freedom
                                                Adjusted R-squared:
Multiple R-squared:  0.3691,                    0.2639
F-statistic:  3.51 on 1 and 6 DF,  p-value: 0.1102
```

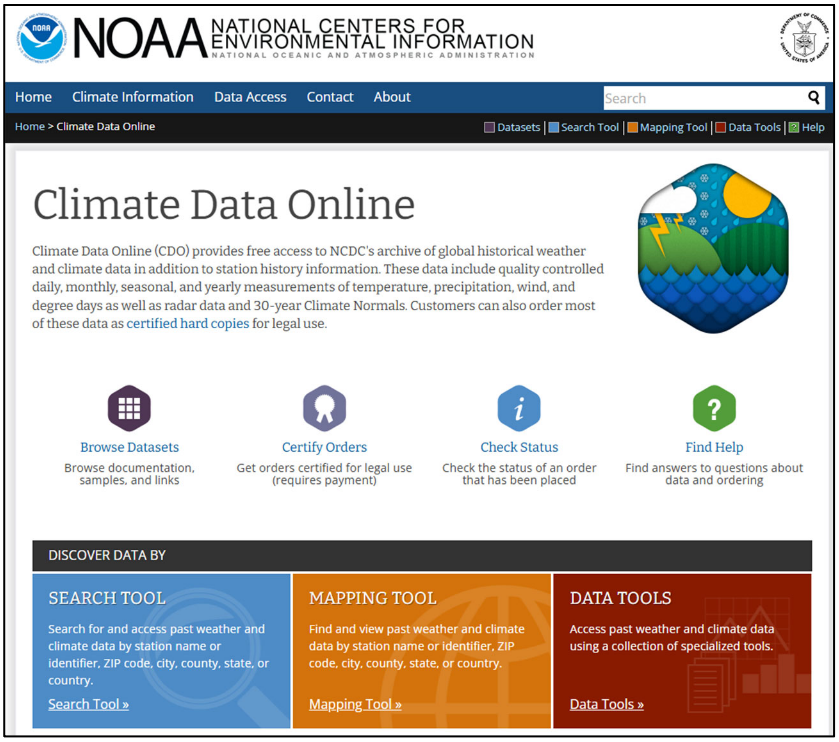
```
> summary(lm(Tobs~Elev,data=dataT))

Call:
```

```
lm(formula = (Tobs) ~ Elev, data = dataT)

Residuals:
     Min       1Q   Median       3Q      Max 
-1.75008 -0.48323 -0.08715  0.61478  1.89029 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 52.46825    1.03315  50.785 3.91e-09 ***
Elev         0.02499    0.01054   2.371   0.0554 .  
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 

Residual standard error: 1.32 on 6 degrees of freedom
                                 Adjusted R-squared:
Multiple R-squared:  0.4838,      0.3977 
F-statistic: 5.622 on 1 and 6 DF,  p-value: 0.05543
```

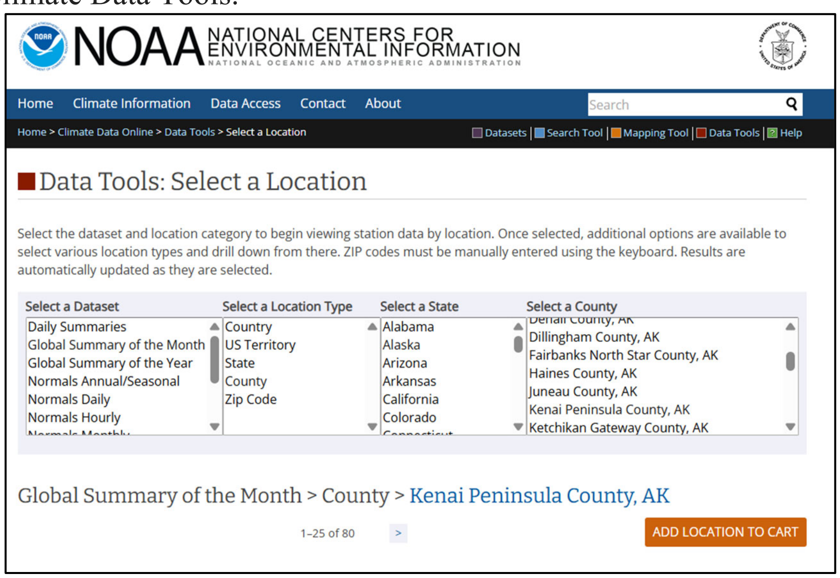
```
> summary(lm(TERA5~Elev,data=dataT))

Call:
lm(formula = (TERA5) ~ Elev, data = dataT)

Residuals:
     Min       1Q   Median       3Q      Max 
-1.07817 -0.30820 -0.02666  0.26004  1.34890 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 53.871047   0.601789  89.518 1.31e-10 ***
Elev         0.011707   0.006138   1.907    0.105    
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 

Residual standard error: 0.769 on 6 degrees of freedom
                                        Adjusted R-squared:
Multiple R-squared:  0.3774,            0.2737 
F-statistic: 3.638 on 1 and 6 DF,  p-value: 0.1051
```

8.1 Appendix B: NCEI Data Retrieval

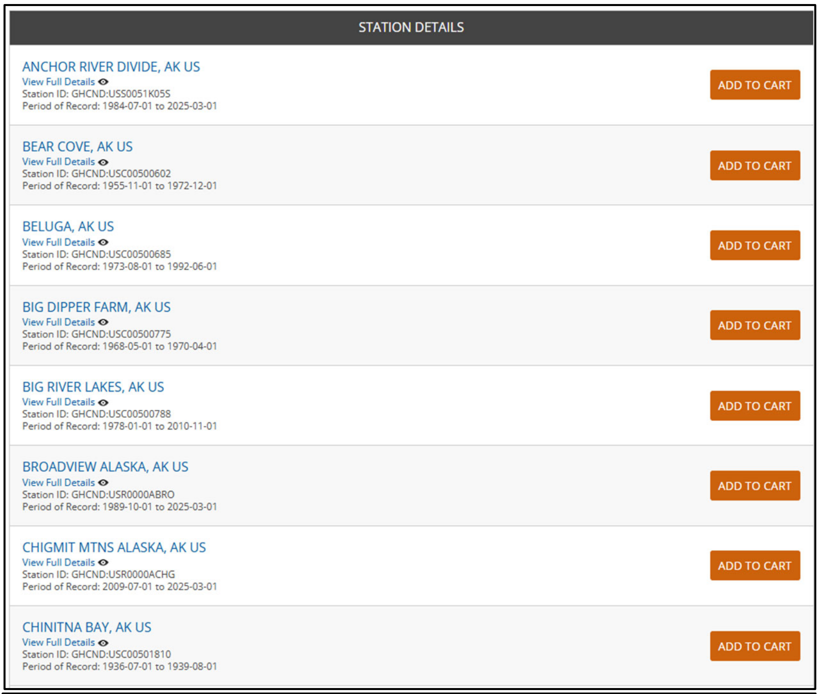
<u>Step 1:</u> Navigate to NCEI Climate Data Online.

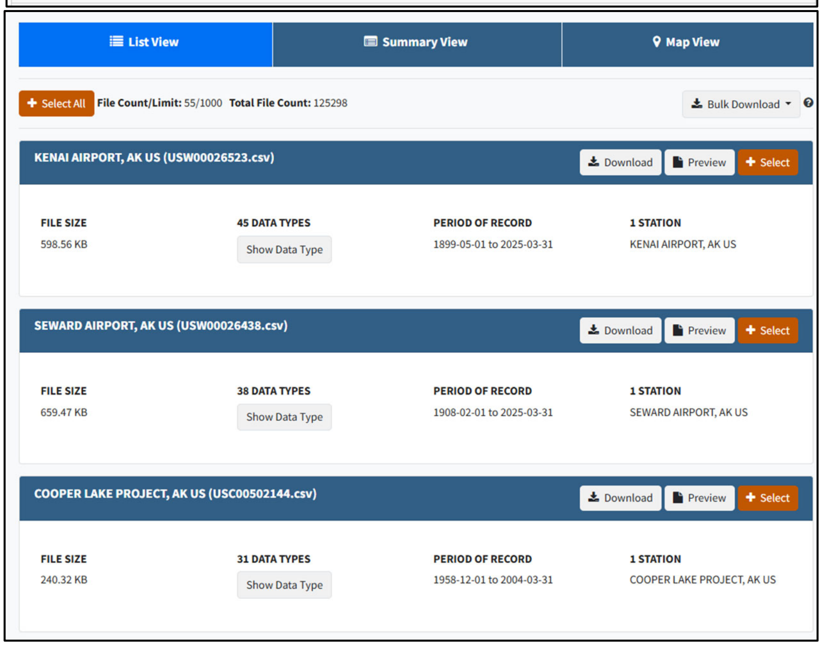


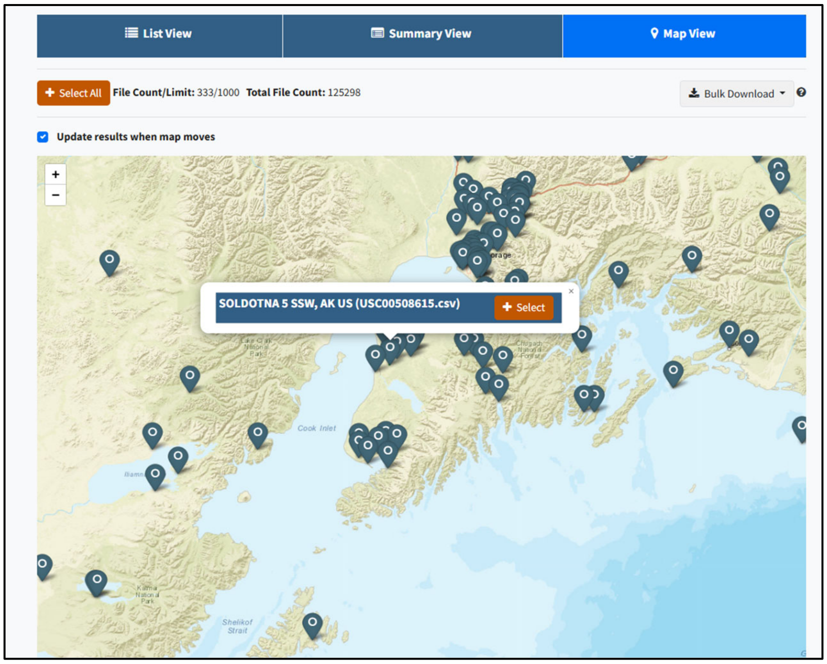
<u>Step 2:</u> Select Climate Data Tools.



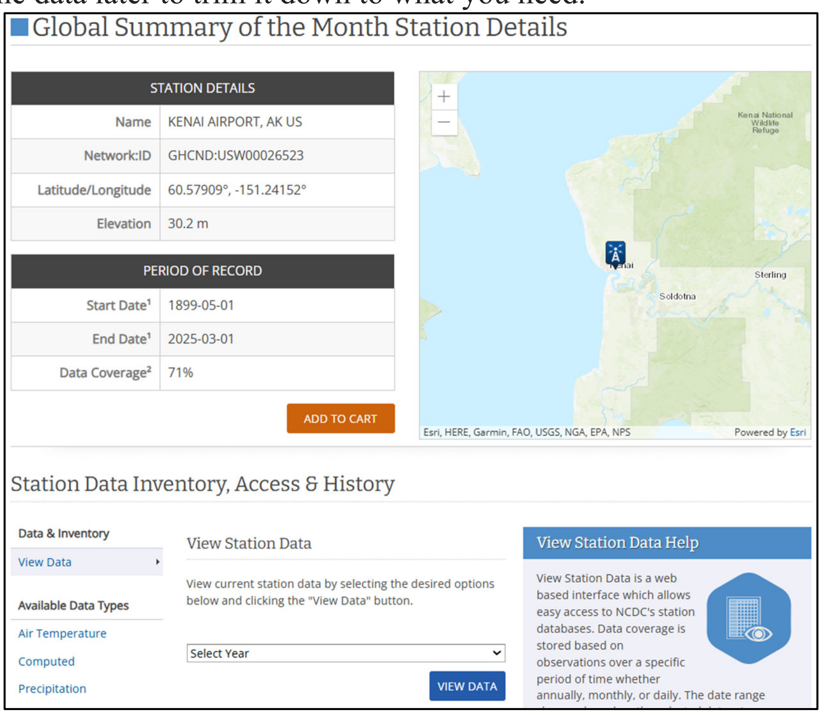
<u>Step 3:</u> Choose how you would like to view the data. It can be viewed in a list, map, or summary. Edit additional details to narrow your date range. You will also need to select the parameter that you are trying to view and whether you want to receive the data in csv or pdf form.


STATION DETAILS
ANCHOR RIVER DIVIDE, AK US
View Full Details
Station ID: GHCND:USS0051K05S
Period of Record: 1984-07-01 to 2025-03-01
ADD TO CART
BEAR COVE, AK US
View Full Details
Station ID: GHCND:USC00500602
Period of Record: 1955-11-01 to 1972-12-01
ADD TO CART
BELUGA, AK US
View Full Details
Station ID: GHCND:USC00500685
Period of Record: 1973-08-01 to 1992-06-01
ADD TO CART
BIG DIPPER FARM, AK US
View Full Details
Station ID: GHCND:USC00500775
Period of Record: 1968-05-01 to 1970-04-01
ADD TO CART
BIG RIVER LAKES, AK US
View Full Details
Station ID: GHCND:USC00500788
Period of Record: 1978-01-01 to 2010-11-01
ADD TO CART
BROADVIEW ALASKA, AK US
View Full Details
Station ID: GHCND:USR0000ABRO
Period of Record: 1989-10-01 to 2025-03-01
ADD TO CART
CHIGMIT MTNS ALASKA, AK US
View Full Details
Station ID: GHCND:USR0000ACHG
Period of Record: 2009-07-01 to 2025-03-01
ADD TO CART
CHINITNA BAY, AK US
View Full Details
Station ID: GHCND:USC00501810
Period of Record: 1936-07-01 to 1939-08-01
ADD TO CART

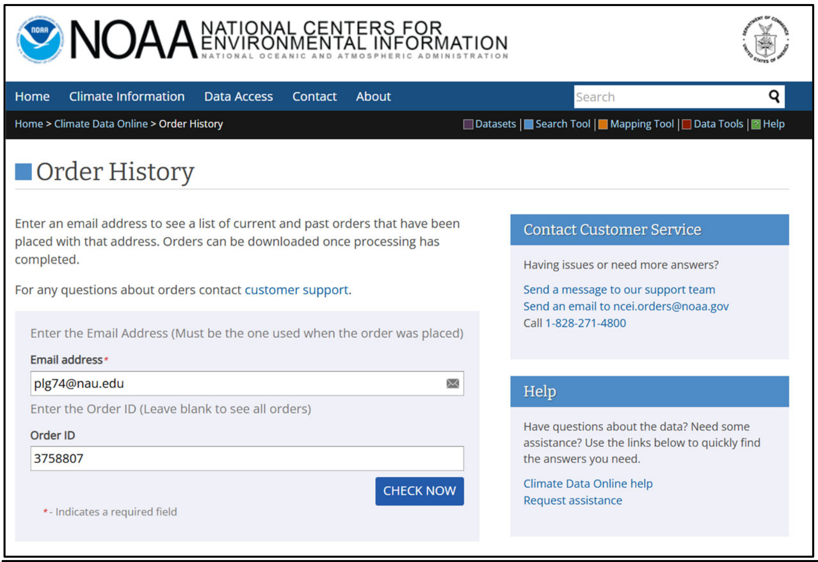

List View
Summary View
Map View
Select All
File Count/Limit: 55/1000 Total File Count: 125298
Bulk Download
KENAI AIRPORT, AK US (USW00026523.csv)
Download
Preview
Select
FILE SIZE
598.56 KB
45 DATA TYPES
Show Data Type
PERIOD OF RECORD
1899-05-01 to 2025-03-31
1 STATION
KENAI AIRPORT, AK US
SEWARD AIRPORT, AK US (USW00026438.csv)
Download
Preview
Select
FILE SIZE
659.47 KB
38 DATA TYPES
Show Data Type
PERIOD OF RECORD
1908-02-01 to 2025-03-31
1 STATION
SEWARD AIRPORT, AK US
COOPER LAKE PROJECT, AK US (USC00502144.csv)
Download
Preview
Select
FILE SIZE
240.32 KB
31 DATA TYPES
Show Data Type
PERIOD OF RECORD
1958-12-01 to 2004-03-31
1 STATION
COOPER LAKE PROJECT, AK US

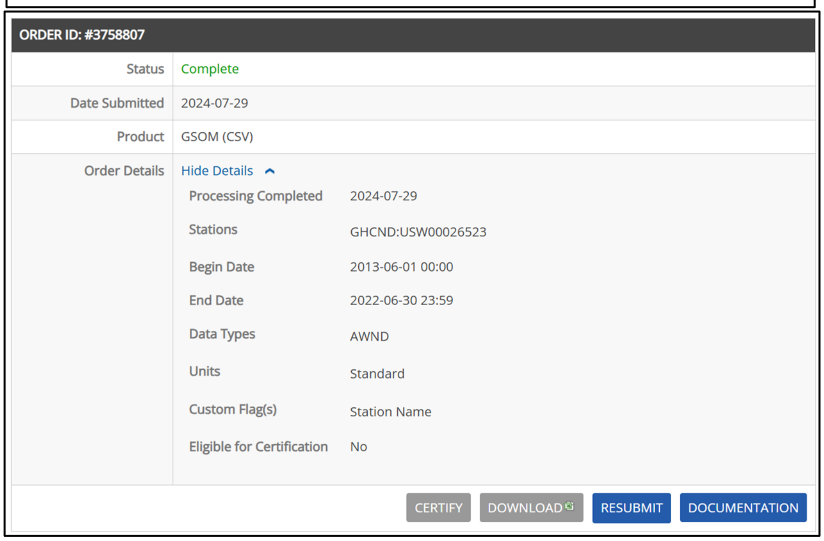


Step 4: Choose the station you would like to request data from or select the bulk download option if you are trying to select many stations within the study area. Note, you will need to further process the data later to trim it down to what you need.



Step 5: Submit your order and wait to receive notification from NCEI that it is ready.





Step 6: View the data and begin processing it to meet the criteria being analyzed. I opened my csv file in Microsoft Excel. It comes with a pdf file of documentation that explains more about the data.

GLOBAL SUMMARY OF THE MONTH (GSOM) DATA FILES

v1.0.3 Last Updated: 5/15/2023

1. INTRODUCTION

1.1 OVERVIEW

The Global Summary Of The Month (GSOM) Data Files contain quality controlled monthly summaries of more than 50 elements (max temp, snow, etc.) computed from stations in the Global Historical Climatology Network (GHCN)-Daily dataset. These include non-US stations, providing a global product from 1763 to present that is updated weekly. This is not to be confused with GHCN-Monthly, which only contains temperature and precipitation elements and which include bias corrected data (which are not available in the first release of GSOM/GSOY). A description of the files are included below in Section 1.3.

1.2 ACCESS

The GSOM Data Files can be accessed at the following location:

https://www.ncei.noaa.gov/data/global-summary-of-the-month/

1.3 DOWNLOADING

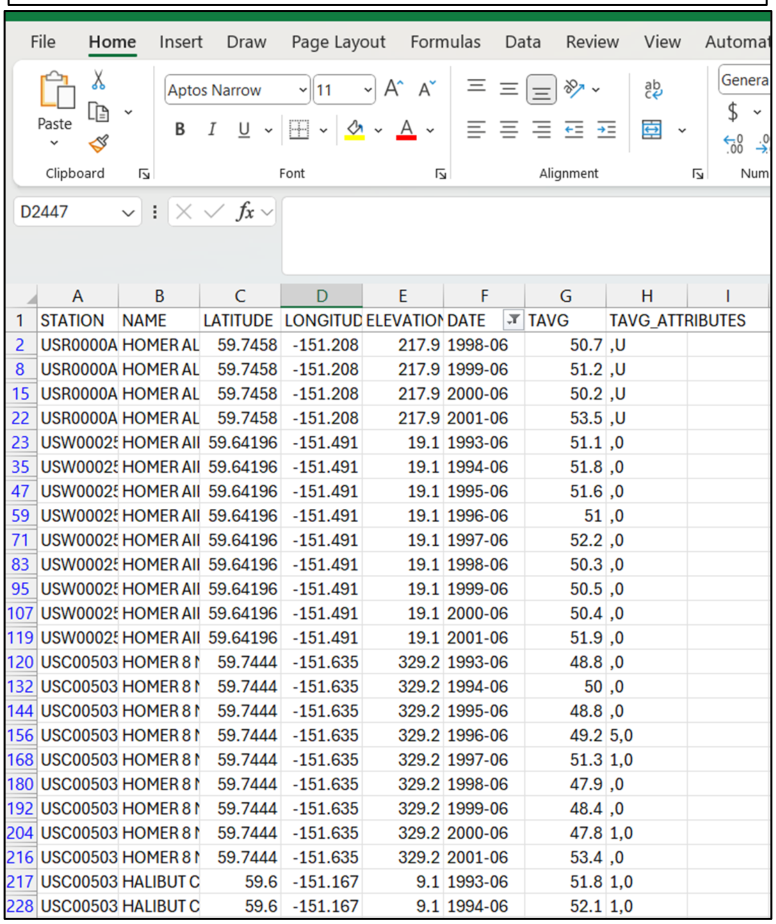
There are three sets of individual files that are included as part of the HPD Digital Inventory Reports:

a. XXY########.csv (GSOM Station Data File Name)

XXY######## is the GHCN ID for the station in question, where:

XX = FIPS Country Code Two-Letter Identifier
Y = Station Network Code (Identifies The Station Numbering System Used)

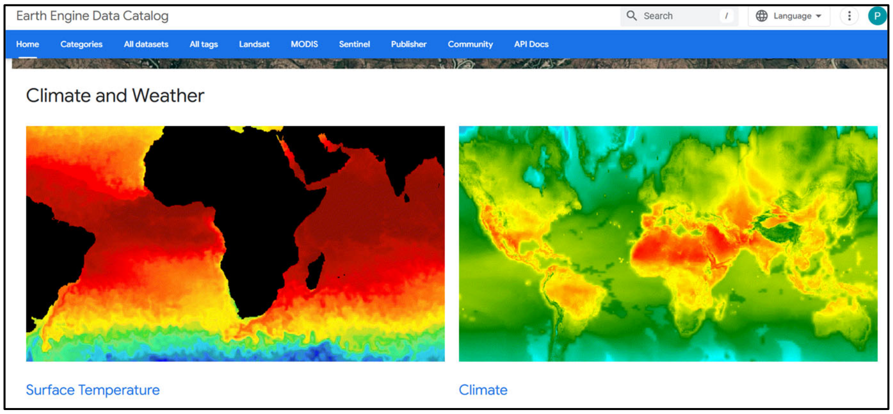
Valid Station Network Codes:



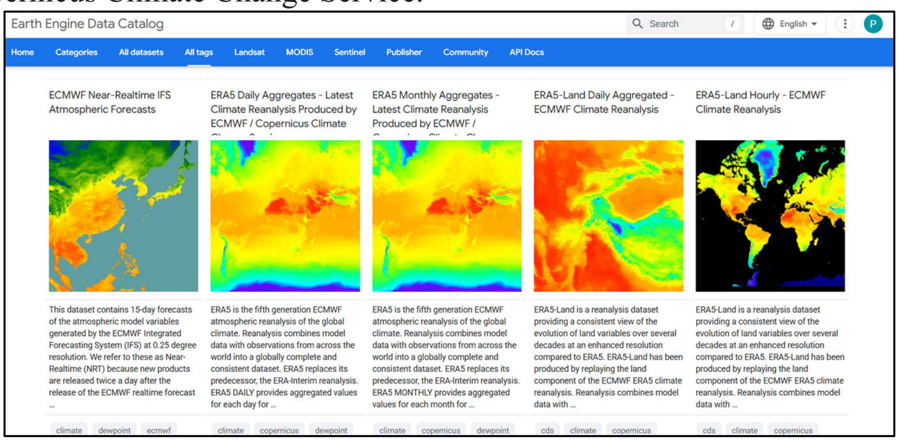
	A	B	C	D	E	F	G	H	I
1	STATION	NAME	LATITUDE	LONGITUD	ELEVATIOI	DATE	TAVG	TAVG_ATTRIBUTES	
2	USR0000A	HOMER AL	59.7458	-151.208	217.9	1998-06	50.7	,U	
8	USR0000A	HOMER AL	59.7458	-151.208	217.9	1999-06	51.2	,U	
15	USR0000A	HOMER AL	59.7458	-151.208	217.9	2000-06	50.2	,U	
22	USR0000A	HOMER AL	59.7458	-151.208	217.9	2001-06	53.5	,U	
23	USW0002!	HOMER AII	59.64196	-151.491	19.1	1993-06	51.1	,0	
35	USW0002!	HOMER AII	59.64196	-151.491	19.1	1994-06	51.8	,0	
47	USW0002!	HOMER AII	59.64196	-151.491	19.1	1995-06	51.6	,0	
59	USW0002!	HOMER AII	59.64196	-151.491	19.1	1996-06	51	,0	
71	USW0002!	HOMER AII	59.64196	-151.491	19.1	1997-06	52.2	,0	
83	USW0002!	HOMER AII	59.64196	-151.491	19.1	1998-06	50.3	,0	
95	USW0002!	HOMER AII	59.64196	-151.491	19.1	1999-06	50.5	,0	
107	USW0002!	HOMER AII	59.64196	-151.491	19.1	2000-06	50.4	,0	
119	USW0002!	HOMER AII	59.64196	-151.491	19.1	2001-06	51.9	,0	
120	USC00503	HOMER 8 I	59.7444	-151.635	329.2	1993-06	48.8	,0	
132	USC00503	HOMER 8 I	59.7444	-151.635	329.2	1994-06	50	,0	
144	USC00503	HOMER 8 I	59.7444	-151.635	329.2	1995-06	48.8	,0	
156	USC00503	HOMER 8 I	59.7444	-151.635	329.2	1996-06	49.2	5,0	
168	USC00503	HOMER 8 I	59.7444	-151.635	329.2	1997-06	51.3	1,0	
180	USC00503	HOMER 8 I	59.7444	-151.635	329.2	1998-06	47.9	,0	
192	USC00503	HOMER 8 I	59.7444	-151.635	329.2	1999-06	48.4	,0	
204	USC00503	HOMER 8 I	59.7444	-151.635	329.2	2000-06	47.8	1,0	
216	USC00503	HOMER 8 I	59.7444	-151.635	329.2	2001-06	53.4	,0	
217	USC00503	HALIBUT C	59.6	-151.167	9.1	1993-06	51.8	1,0	
228	USC00503	HALIBUT C	59.6	-151.167	9.1	1994-06	52.1	1,0	

8.2 Appendix C: ERA5 Data Retrieval

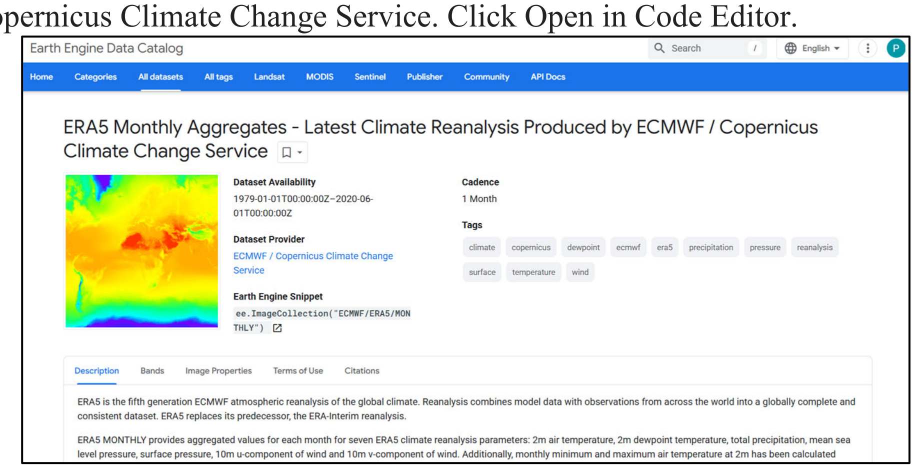
Step 1: Navigate to Google Earth Engine Data Catalog. Select the Climate section under Climate and Weather.



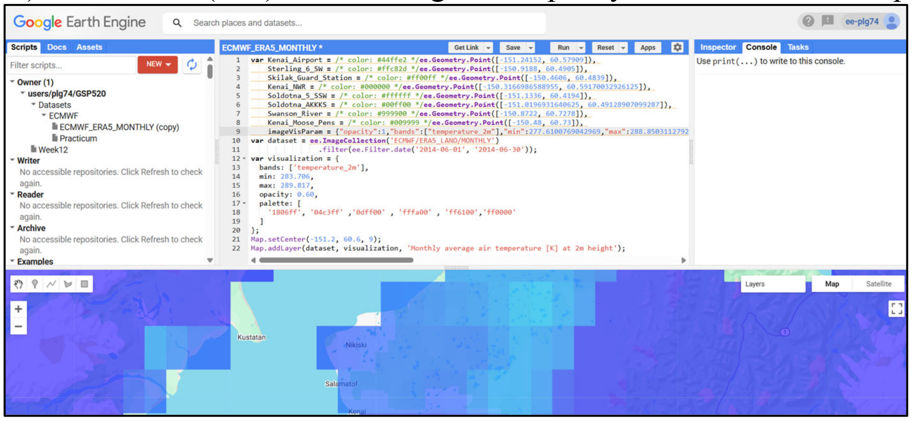
Step 2: Choose the ERA5 Monthly Aggregates – Latest Climate Reanalysis Produced by ECMWF Copernicus Climate Change Service.

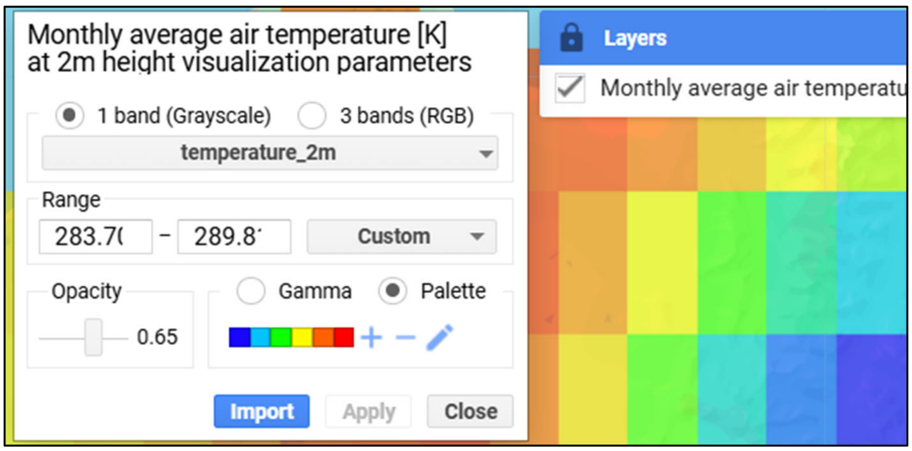


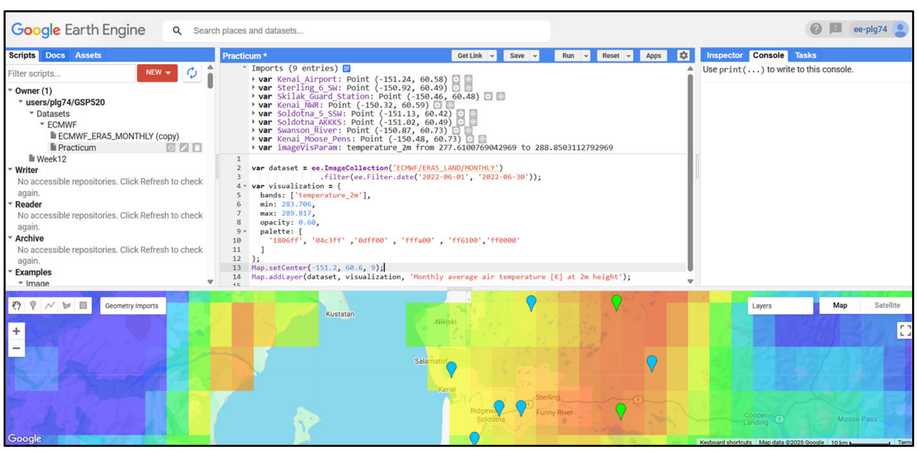
Step 3: Choose the ERA5 Monthly Aggregates – Latest Climate Reanalysis Produced by ECMWF Copernicus Climate Change Service. Click Open in Code Editor.



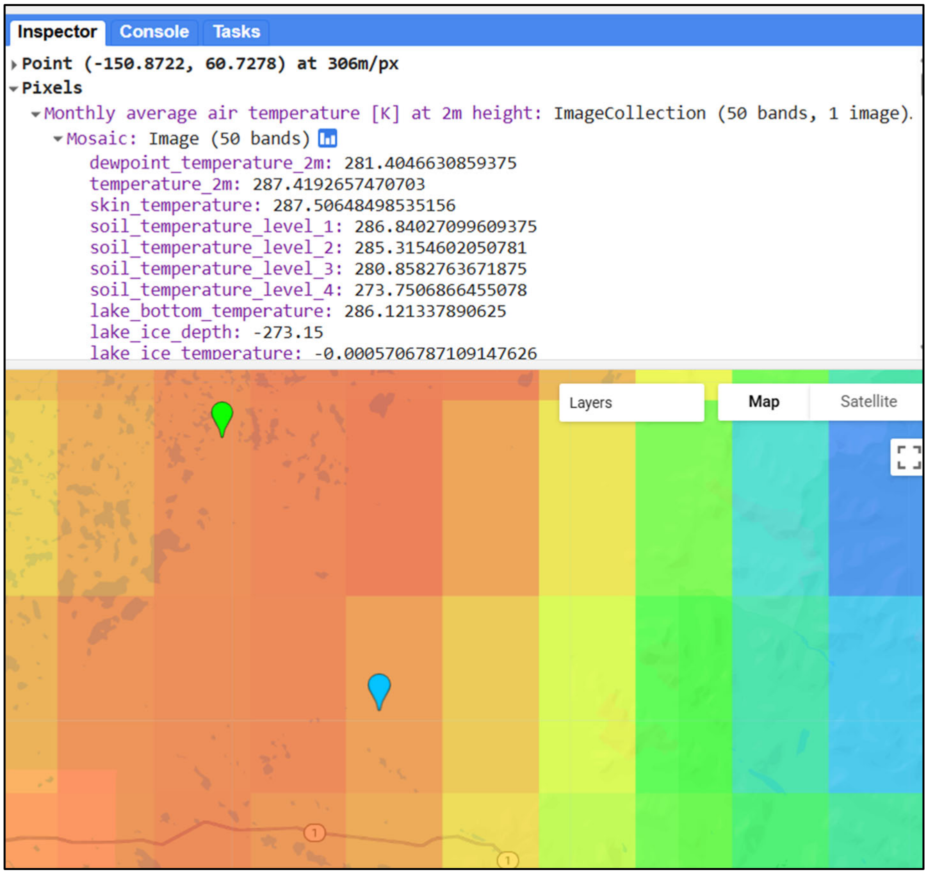
Step 4: Code this analysis by adding points and markers. I also changed the pallet to 1806ff, 04c3ff, 0dff00, fffa00, ff6100, ff0000 to spread the temperature range to 2 degrees per color 283.706K (51F) – 289.817K (62F). I also changed the opacity to see the terrain map below it.







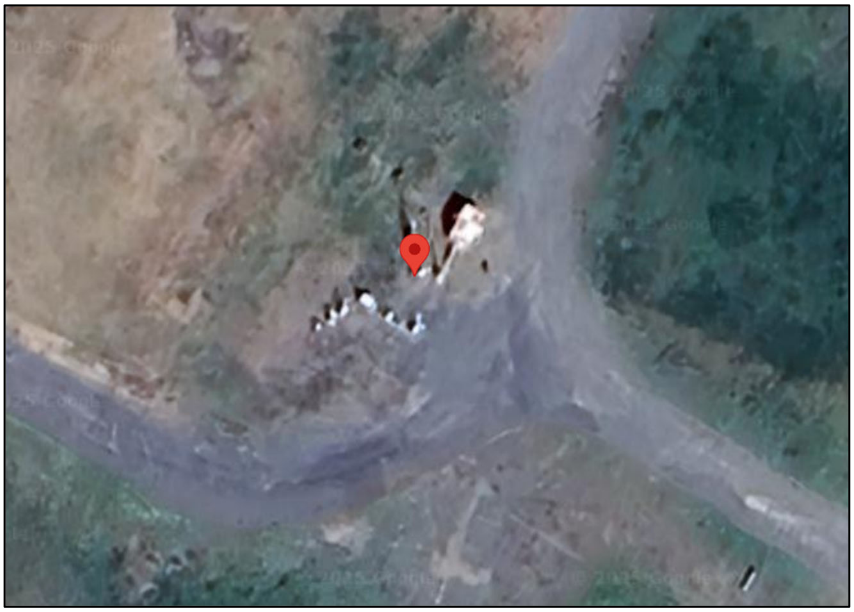
Step 5: Change the year in the coding and then click on the map using the Inspector tool on the right. If you click the drop down and view the values, you can see the 2m temperature for the month. I did this for every location every year until I had retrieved all the average temperatures for each station for the study period.


Inspector
Console
Tasks
Point (-150.8722, 60.7278) at 306m/px
Pixels
Monthly average air temperature [K] at 2m height: ImageCollection (50 bands, 1 image).
Mosaic: Image (50 bands)
dewpoint_temperature_2m: 281.4046630859375
temperature_2m: 287.4192657470703
skin_temperature: 287.50648498535156
soil_temperature_level_1: 286.84027099609375
soil_temperature_level_2: 285.3154602050781
soil_temperature_level_3: 280.8582763671875
soil_temperature_level_4: 273.7506866455078
lake_bottom_temperature: 286.121337890625
lake_ice_depth: -273.15
lake_ice_temperature: -0.0005706787109147626
Layers
Map
Satellite

8.3 Appendix D: Observation Site Imagery

Kenai Airport (Station ID: USW00026523)

60°34'44.7"N, 151°14'29.5"W



Kenai Moose Pens (Station ID: USS0050L02S)

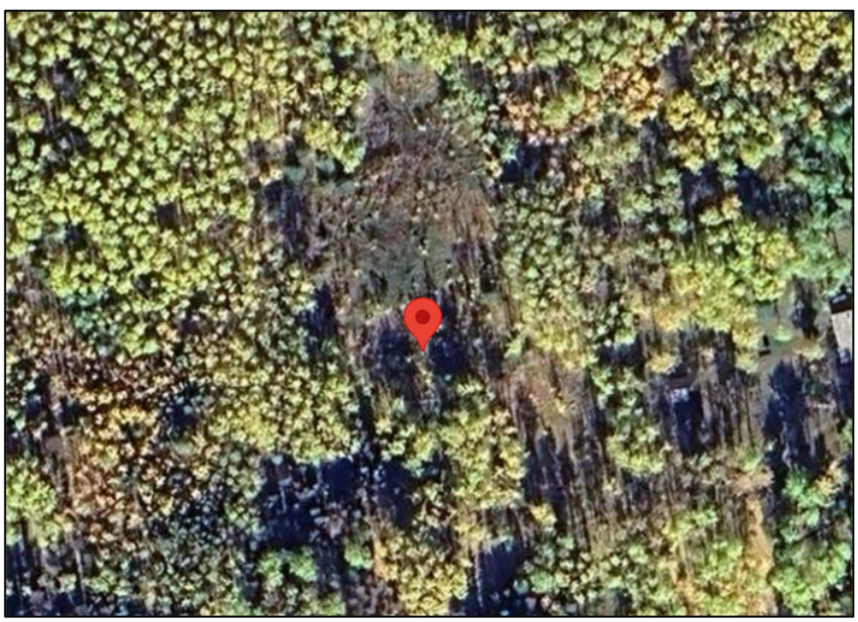
60°43'48.0"N, 150°28'48.0"W

Sterling 6 SW (Station ID: USC00508731)

60°29'25.8"N, 150°55'07.7"W

Skilak Guard Station (Station ID: USR0000ASKI)

60°29'02.0"N, 150°27'38.2"W



Kenai NWR (Station ID: USR0000AKEN)

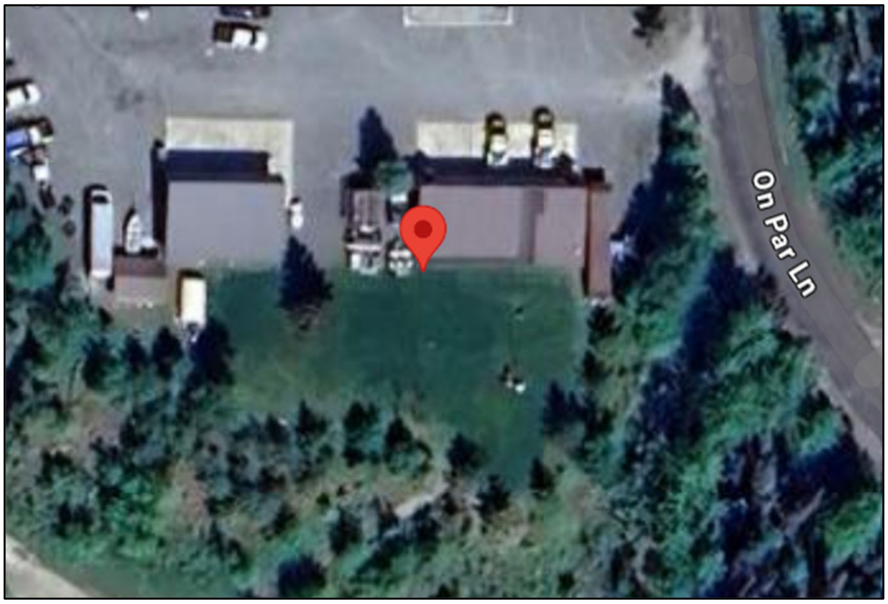
60°35'30.1"N, 150°19'00.1"W

Soldotna 5 SSW (Station ID: USC00508615)

60°25'09.8"N, 151°08'01.0"W

Soldotna AKKKS (Station ID: USR0000ASAK)

60°29'48.1"N, 151°00'51.1"W



Swanson River (Station ID: USR0000ASWA)

60°43'40.1"N, 150°52'19.9"W