

Cross-validation of historical weather journals and downscaled climate estimates from a coastal Alaska watershed (#59360)

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I commend the authors for their extensive data set, compiled over many years of detailed fieldwork. In addition, the manuscript is clearly written in professional, unambiguous language. If there is a weakness, it is in the statistical analysis (as I have noted above) which should be improved upon before Acceptance.

Cross-validation of historical weather journals and downscaled climate estimates from a coastal Alaska watershed

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Downscaling coarse global and regional climate models allows researchers to access weather and climate data at finer temporal and spatial resolution, but there remains a need to compare these models with empirical data sources to assess model accuracy. Here, we cross-validate a widely used software for generating North American downscaled climate data, ClimateNA, with a novel empirical data source, 20th century weather journals kept by Admiralty Island, Alaska homesteader, Allen Hasselborg. Using Hasselborg's journals, we calculated monthly precipitation and monthly mean of the maximum daily air temperature across the years 1926 to 1954 and compared these to ClimateNA data generated from the Hasselborg homestead location and adjacent areas. To demonstrate the utility of this cross-validation to other disciplines such as hydrology, we also generated time series of 95% low duration flow estimates for the month of August using ClimateNA and Hasselborg data. Across 279 months, we found strong correlation between modeled and observed measurements of monthly precipitation ($\rho = 0.74$) and monthly mean of the maximum daily air temperature ($\rho = 0.98$). Monthly precipitation residuals (calculated as ClimateNA data - Hasselborg data) generally demonstrated heteroscedasticity around zero, but a negative trend in residual values starting during the last decade of observations may have been due to a shift to the cold-phase Pacific Decadal Oscillation. Air temperature residuals demonstrated a consistent but small positive bias, with ClimateNA tending to overestimate air temperature relative to Hasselborg's journals. The degree of correlation between weather patterns observed at the Hasselborg homestead site and ClimateNA data extracted from spatial grid cells across the region varied by wet and dry climate years. Monthly precipitation from both data sources tended to be more similar across a larger area during wet years (mean ρ across grid cells = 0.73) compared to dry years (mean ρ across grid cells = 0.65). The time series of annual 95% low duration flow estimates for the month of August generated using ClimateNA and Hasselborg data

were moderately correlated ($\rho = 0.55$). Our analysis supports previous research in other regions which also found ClimateNA to be a robust source for past climate data estimates.

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Abstract

Downscaling coarse global and regional climate models allows researchers to access weather and climate data at finer temporal and spatial resolution, but there remains a need to compare these models with empirical data sources to assess model accuracy. Here, we cross-validate a widely used software for generating North American downscaled climate data, ClimateNA, with a novel empirical data source, 20th century weather journals kept by Admiralty Island, Alaska homesteader, Allen Hasselborg. Using Hasselborg's journals, we calculated monthly precipitation and monthly mean of the maximum daily air temperature across the years 1926 to 1954 and compared these to ClimateNA data generated from the Hasselborg homestead location and adjacent areas. To demonstrate the utility of this cross-validation to other disciplines such as hydrology, we also generated time series of 95% low duration flow estimates for the month of August using ClimateNA and Hasselborg data. Across 279 months, we found strong correlation between modeled and observed measurements of monthly precipitation ($\rho = 0.74$) and monthly mean of the maximum daily air temperature ($\rho = 0.98$). Monthly precipitation residuals (calculated as ClimateNA data - Hasselborg data) generally demonstrated heteroscedasticity around zero, but a negative trend in residual values starting during the last decade of observations may have been due to a shift to the cold-phase Pacific Decadal Oscillation. Air temperature residuals demonstrated a consistent but small positive bias, with ClimateNA tending to overestimate air temperature relative to Hasselborg's journals. The degree of correlation between weather patterns observed at the Hasselborg homestead site and ClimateNA data extracted from spatial grid cells across the region varied by wet and dry climate years. Monthly precipitation from both data sources tended to be more similar across a larger area during wet

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Introduction

Across many scientific disciplines, researchers rely on the downscaling of coarse global and regional climate models to access weather and climate data at finer temporal and spatial resolution (Mote and Salathé 2010; Xu et al. 2019). While weather stations collect accurate local measurements, they are not evenly distributed and leave many empirical data gaps across the globe. Therefore, statistical, dynamical, or hybrid methods of downscaling weather measurements such as rainfall or air temperature, rather than empirical observations, often provide the foundation for analyzing climate and hydrologic response in remote regions where station maintenance is difficult and expensive. ClimateNA (Wang et al. 2016) is a widely used, publicly available, and user-friendly software that produces a suite of monthly and annual climate variables for point locations across North America. The software's simplicity and wide range of historical and future time ranges lends itself well to correlating climate patterns with questions related to many environmental science disciplines (Roberts et al. 2019). In this study, climate data generated by ClimateNA provide the basis for our cross-validation with a novel source of empirical weather data from sub-arctic Alaska.

In remote regions such as our study location in Southeast Alaska, USA, downscaled projections of temperature, precipitation, and snowfall are critical to understanding regional hydrology and ecology (Bieniek et al. 2016; Littell et al. 2018). For example, combining river basin topography with estimates of monthly precipitation allows for the calculation of various hydrologic metrics such as percentile flow magnitudes (Wiley and Curran 2003), which directly relate to the efficacy of burgeoning hydropower operations (Cherry et al. 2017) and the population dynamics of many aquatic organisms (Poff et al. 1997; Brown, 2016). The success of culturally and economically valuable fish populations in Alaska such as Pacific salmon (*Oncorhynchus* spp.) is inextricably tied to flow regimes (Schoen et al. 2017; Johnson et al. 2019); therefore, having access to high-quality climate information is critical for resource managers and users to assess habitat conditions over time and the potential for future change.

Climate change is occurring rapidly in Southeast Alaska. Regional experts predict increases in annual average air temperature and precipitation, with less precipitation falling as snow during the fall and winter (Shanley et al. 2015; Littell et al. 2018; Lader et al. 2020). A key challenge is determining the rate at which these changes are occurring, thus it is important to compare contemporary climate trends with historical data sets. Historical climate time series derived from direct measurement methods are often sparse in remote locations. In these instances, downscaled

data can be used to estimate climate metrics across large scales of time and space, but their accuracy is difficult to determine without cross-validation using empirical data. This is especially challenging in topographically complex areas like Southeast Alaska, where mountains rise from sea level to hundreds of m within a few km. A combination of mountains, glaciers, and narrow marine passages create dynamic micro-climates (Shanley et al. 2015), making it difficult to discern the accuracy of downscaled climate patterns relative to nearby weather stations. For example, in a cross-validation study of the North American arctic, modeled climate accuracy was variable across seasons and better at predicting air temperature than precipitation (Herzfeld et al. 2007).

Considering the difficulty in predicting climate patterns for a geographically complex region, the extent to which downscaled climate models can be corroborated with conventional weather measurements will improve the confidence of research and regional decision-making based mostly on modeling efforts. Here, we present a novel cross-validation of downscaled climate data from 1926 to 1954 using archived weather journals from Admiralty Island, Alaska homesteader, Allen Hasselborg. Our primary objective was to determine how closely weather observations from Hasselborg's journals correlated with monthly climate observations extracted from ClimateNA (Wang et al. 2016) at the same location and time periods. We then mapped the degree of correlation between the weather journals and modeled climate data across varying distances from the homestead site and elevations. We calculated residuals between observed and modeled values of monthly precipitation and monthly mean of the daily maximum air temperature to determine whether the accuracy of modeled data changed over time. To demonstrate the application of this research to other disciplines such as hydrology and fish biology, we compare streamflow metrics derived from the journals and modeled data.

Materials & Methods

Study area description

Daily weather observations were collected by Allen Hasselborg at his homestead adjacent to Mole Harbor and the Mole River, located on the eastern shoreline of Admiralty Island in Southeast Alaska (Figures 1 and 2). During the years 1926-1954 covered by his journals, only 6 weather stations existed in the region, with the nearest in Juneau approximately 77 km away. Mole Harbor remains uninhabited to the present day. Southeast Alaska is situated in the northern portion of the Pacific Coastal Temperate Rainforest, a generally mild and wet maritime landscape averaging 200 cm of precipitation per year (O'Neel et al. 2015). The maximum elevation for the Mole River watershed is 869 m while mean elevation is 272 m. With no glaciers present in its drainage area, the Mole River is a mostly forested watershed with discharge driven by a combination of rain and snow runoff (a "rain-snow-I" watershed as defined in Sergeant et al. 2020). Rain-snow-I watersheds are found throughout the coastal Gulf of Alaska, and while maximum discharge tends to occur in mid-March, the flow regime of the Mole River remains

unmeasured and maximum discharge could potentially occur during any day of the year (Sergeant et al. 2020).

Data acquisition

Data were acquired from an interactive climate model platform and Hasselborg's handwritten weather journals. The widely used software, ClimateNA (Wang et al. 2016), generates statistically downscaled climate estimates for any 4 x 4 km grid cell in North America, with customizable variables such as spatial coordinates, elevation, and date range. ClimateNA can generate precipitation and temperature data with monthly to annual resolution. The software incorporates and interpolates historical data spanning from 1901 to the present day, as well as a suite of general circulation models for future predictions. We obtained monthly precipitation and monthly mean of the daily maximum air temperature values from the approximate GPS coordinates for Mole Harbor (57.647541, -134.094391). We allowed ClimateNA to determine elevation automatically. This provided model estimates overlapping with all of Hasselborg's recorded years (1926-1954).

Hasselborg recorded daily temperature and precipitation between 1926 and 1954 at approximately sea-level near the mouth of the Mole River (Figures 1 and 2). Missing time periods spanned July-September 1931, August-September 1932, June 1933, and December 1933 to January 1938. Hasselborg's original handwritten weather journals are archived at the Alaska State Library and Archives in Juneau, Alaska, USA (Figure 2). Journals were scanned as images and manually transcribed into a Microsoft Excel spreadsheet. The lead author (ERW) transcribed daily maximum air temperature (converted from °F to °C) and monthly precipitation (converted from in to mm). Hasselborg recorded precipitation in 0.25 in fractions, and recorded even and odd integers for temperature in his journals until 1933. It is possible that after a break from journaling from 1933 to 1938, Hasselborg used a second thermometer or changed his protocol for temperature measurements as nearly all post-1938 temperatures are even integers. To our knowledge, Hasselborg did not provide notes on his temperature collection methods. We also do not know if his thermometer was shielded from sunlight. We hypothesized that he collected maximum daily air temperature because this is the most logical consistent measurement that could be collected from an analog thermometer without having to collect measurements at the exact same time each day. Subsequent analyses in the Results section support this hypothesis. We excluded unreadable journal days or entries with multiple measurements. We also do not know for certain whether Hasselborg included snow in his precipitation amounts, but based on journal pages where he makes separate notes for rain and snow, we believe he intended to only measure rain. This does not exclude the possibility of some error due to snow falling into the measurement tool along with rain during winter months.

Correlation analysis

For monthly precipitation and monthly mean of the maximum daily air temperature measurements, we trimmed the ClimateNA data to account for Hasselborg's data gaps (n=279 usable months for precipitation, n=274 usable months for temperature), and calculated a Spearman's rank correlation coefficient (ρ) for the complete time series of empirical and modeled data. To assess spatial correlation at increasing distances from the Mole River watershed, we mapped the correlation between Hasselborg's monthly precipitation data and ClimateNA datasets for the wettest year (1939) and the driest year (1951) found in his journals. Centroid coordinates for each grid cell in the spatial correlation map were spaced 0.2 decimal degrees longitude and 0.1 decimal degrees latitude apart and originated from the Hasselborg homestead.

To determine whether ClimateNA displayed seasonal or annual trends in estimating observed weather values, residuals were calculated across the entire time series by subtracting the monthly values for both precipitation and temperature measured by Hasselborg from those estimated by ClimateNA. Residuals were then averaged across the four meteorological seasons: winter (DJF), spring (MAM), summer (JJA), and fall (SON).

Application of climate data sources to estimating streamflow descriptors

Low-duration streamflow was estimated using precipitation, watershed basin area, and watershed elevation in a regression equation derived from streamflow gage data (Wiley and Curran 2003). To demonstrate the application of our cross-validation to useful hydrologic estimates, we calculated the annual 95th percentile low-duration flow for August (AUG95) in ft³/s using the following equation:

$$\text{AUG95} = (1.397 \times 10^{-9})(A^{1.16})(P^{1.367})(E^{1.896})$$

Where,

A = watershed drainage area (mi²)

P = mean annual precipitation (in)

E = mean basin elevation (ft)

AUG95 estimates in ft³/s were then converted to m³/s.

We did not estimate low-duration August flow during years where Hasselborg skipped >3 months of precipitation measurements. Hasselborg skipped one to three months per year for four of the included years in the data (1931, 1932, 1933, 1946).

Results

We found strong correlation (ρ) between the monthly precipitation time series generated from modeled (ClimateNA) and empirical (Hasselborg's journals) climate data ($\rho = 0.74$, $P \ll 0.001$; Figure 3). Residual values of modeled - observed monthly precipitation data ranged from 189 mm to -412 mm with a mean of -14.4 mm (Figure 4). In general, residuals demonstrated heteroscedasticity around the zero line for the vertical axis, but there was evidence of a negative trend in residual values starting during the last decade of data (Figure 4). Hasselborg's temperature values had a greater range than Climate NA, which consistently overestimated monthly precipitation when Hasselborg observed less than 50 mm and underestimated when observations were greater than 400 mm (Figure 3). When residuals were averaged across meteorological seasons, ClimateNA was more accurate in the spring and summer than the fall or winter, when precipitation was generally underestimated (Figure 5).

There was high correlation between monthly means of the maximum daily air temperature generated from ClimateNA and observed by Hasselborg ($\rho = 0.98$, $P \ll 0.001$; Figure 3). The residual values of modeled - observed monthly mean of the maximum daily temperature data ranged from -3.06 °C to 10.44 °C with a mean of 0.77 °C (Figure 4). Residuals demonstrate a consistent but small positive bias, with ClimateNA tending to overestimate air temperature relative to Hasselborg's journals (Figure 4). The averaged seasonal residuals of temperature demonstrate an opposite pattern to precipitation (Figure 5). ClimateNA overestimated the most during winter, while summer months were most closely correlated.

The degree of correlation between weather patterns observed at the Hasselborg homestead site and ClimateNA data extracted from spatial grid cells across the region varied by wet and dry climate years (Figures 6 and 7). Monthly precipitation from ClimateNA tended to be more similar to empirical data collected by Hasselborg across a larger area during wet years compared to dry years. During the wettest year recorded in Hasselborg's journals, 1939, mean $\rho = 0.73$ (SD = 0.11) across all grid cells (Figure 6). For the driest journal year, 1951, mean $\rho = 0.65$ (SD = 0.14) across all grid cells (Figure 7). For both years, correlations between ClimateNA and Hasselborg's data tended to be strongest in areas of low to mid-elevation. Correlations were weakest in high elevation areas and icefields across both years, but correlations were especially weak along the continental mainland during the dry year of 1951. During 1939, correlations were generally very high for grid cells south of the Hasselborg homestead.

The time series of annual 95% low duration flow estimates for the month of August generated using ClimateNA and Hasselborg data were moderately correlated ($\rho = 0.55$, $P = 0.007$; Figure 8). While the directional trends in both time series were comparable across time, similar to the spatial correlation maps (Figures 6 and 7), ClimateNA estimates of low duration flow tended to be further from estimates using Hasselborg observations during dry years such as 1951.

Discussion

With an ever-growing need to compare the changes in the earth's climate from historical times to present-day, cross-validation of climate models with empirical data will continue to be an essential aspect of environmental research. Historical weather measurements collected from remote locations have the potential to underestimate actual conditions (Baudouin 2020) and be of questionable quality. To our knowledge, Hasselborg's Mole River data set did not include a second observer or provide any methodological accounting. Despite these limitations, the corroboration of Hasselborg's data and downscaled estimates produced from ClimateNA suggests that both sources are generally reliable. Similar to the findings of Herzfeld et al. (2007) in the North American arctic, modeled air temperature data were more strongly correlated with observed data than precipitation. We also found support for the reliability of ClimateNA estimates in low-lying maritime environments throughout the northern portion of the Alaska Panhandle (Southeast Alaska), and correlations across space with Hasselborg's data were especially strong during a wet year.

The southern coastal region of Alaska is undergoing shifts in climate that impact the ecology of the region (Shanley et al. 2015). As a snow- and rain-driven system, the Mole River is representative of many low-lying watersheds throughout Southeast Alaska. Although adjacent watersheds should have similar climate patterns to the Mole River, we urge researchers to use caution when applying downscaled climate data to other ecological and physical estimates, especially in higher elevation watersheds with snow and glacier runoff patterns. While the August low streamflow descriptor we derived from empirical and modeled data followed the same general directional patterns over time, there were significant differences in the estimates of flow magnitude, especially during dry years such as 1951. This might be explained by long-range atmospheric drivers such as the Pacific Decadal Oscillation (PDO). The negative trend in modeled precipitation residuals during the final decade of data (1944-1954), correspond with a shift to a cold-phase PDO. In Southeast Alaska, this typically translates to more winter precipitation falling as snow than rain and resulting in higher-than-average summer discharge (Mantua et al. 1997; Neal et al. 2002). Patterns such as these are important context for researchers applying downscaled climate data and suggest that further cross-validation research is necessary across a broader range of elevational and latitudinal gradients.

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Figure 1

Study area.

The Mole River watershed (gray polygon) and the location of Allen Hasselborg's homestead (black dot).

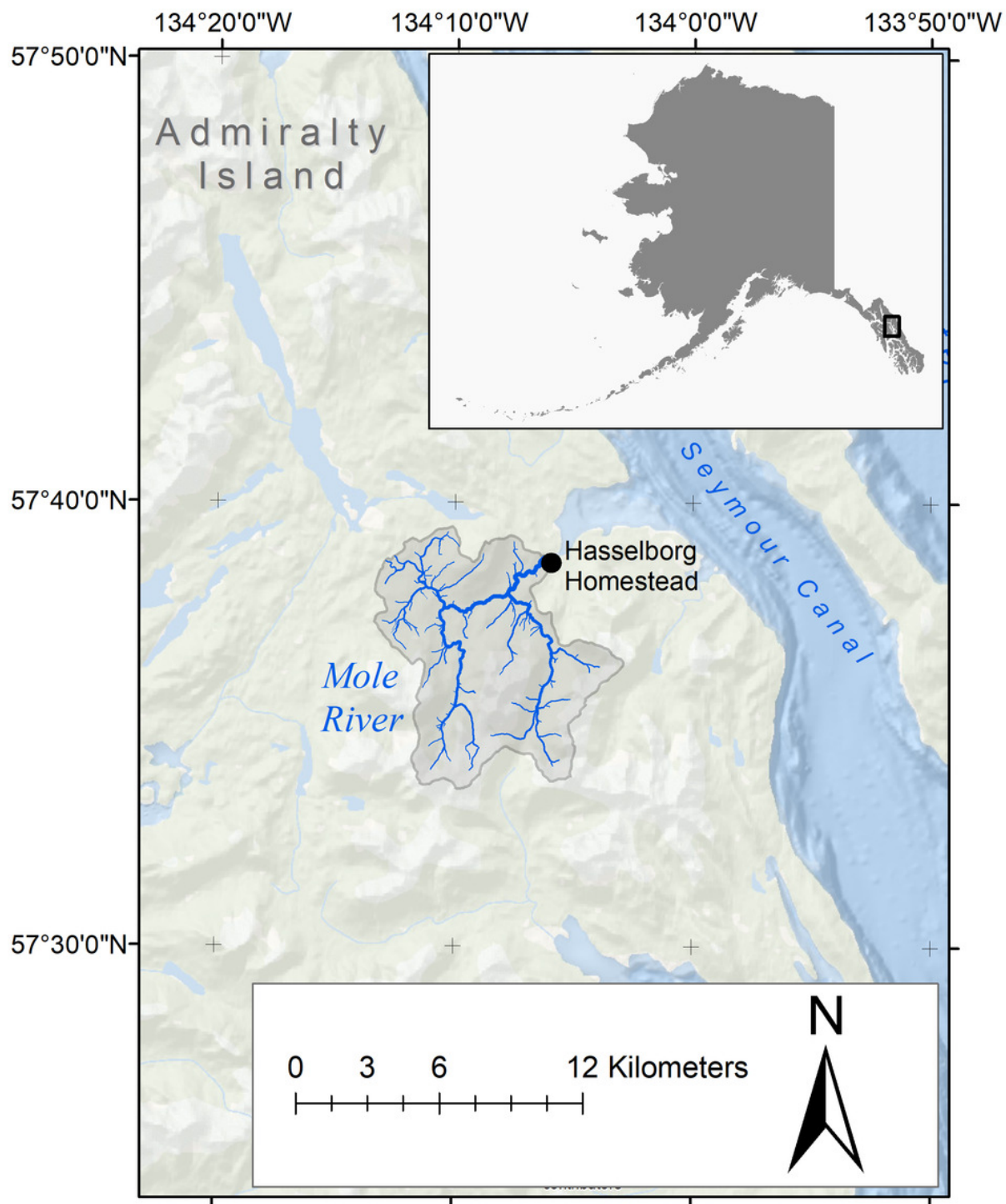


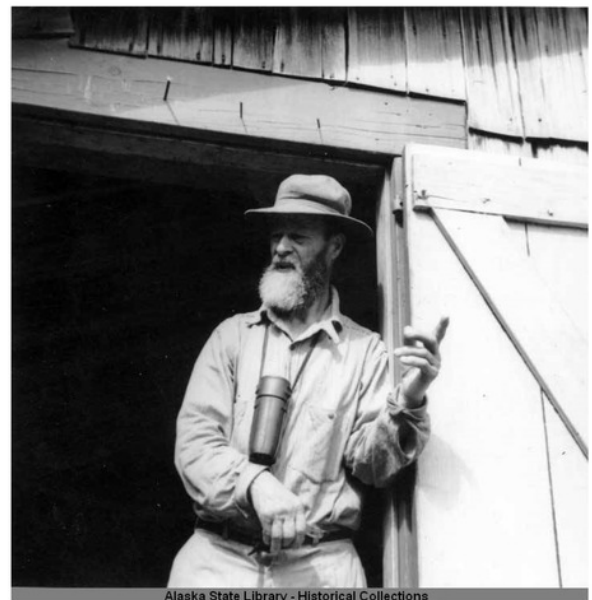
Figure 2

The journals of Allen Hasselborg.

(A) Example pages from Allen Hasselborg's weather journals. In the upper left corner of each page, note that Hasselborg summed total monthly precipitation in inches. In the third column of each page, Hasselborg provided a symbol describing weather conditions that day: clear (open circle), cloudy (cross), rain (upward facing arch), or snow (downward facing arch). (B) Hasselborg at his homestead next to Mole River in 1941 (Image accessed through the Alaska Digital Archives, <https://vilda.alaska.edu/digital/>).

A
B

2 nd MAY 1941			3 JUNE 1941		
1 50	+	c	1 74	0	c
2 50	+	c	2 64	+	c
3 56	⊕	c	3 60	+	c
4 60	0	c	4 68	0	c
5 64	0	c	5 70	⊕	c
6 52	+	c	6 60	⊕	c
7 54	⊕	c	7 66	0	c
8 54	+	c	8 60	+	c
9 54	⊕	c	9 50	0	c
10 60	0	c	10 60	0	c
11 60	0	c	11 64	⊕	c
12 62	0	c	12 64	⊕	c
13 56	+	c	13 60	⊕	c
14 56	0	c	14 62	⊕	c
15 54	+	c	15 62	⊕	c
16 52	0	c	16 70	0	c
17 50	+	c	17 70	0	c
18 46	0	c	18 58	0	c
19 48	0	c	19 60	+	c
20 48	0	c	20 60	0	c
21 52	0	c	21 70	0	c
22 46	0	c	22 74	0	c
23 52	⊕	c	23 62	⊕	c
24 56	⊕	c	24 60	+	c
25 54	+	c	25 64	+	c
26 54	⊕	c	26 54	0	c
27 64	0	c	27 56	0	c
28 70	0	c	28 62	0	c
29 72	0	c	29 60	0	c
30 68	0	c	30 64	+	c
31 74	0	c	31		



Alaska State Library - Historical Collections

Figure 3

Time series of modeled and observed climate data.

(A) Monthly precipitation estimated by ClimateNA (orange) compared with monthly precipitation measured by Hasselborg (blue). (B) Monthly mean of the daily maximum temperature estimated by ClimateNA (orange), compared to a monthly mean of Hasselborg's daily maximum temperature measurements (blue).

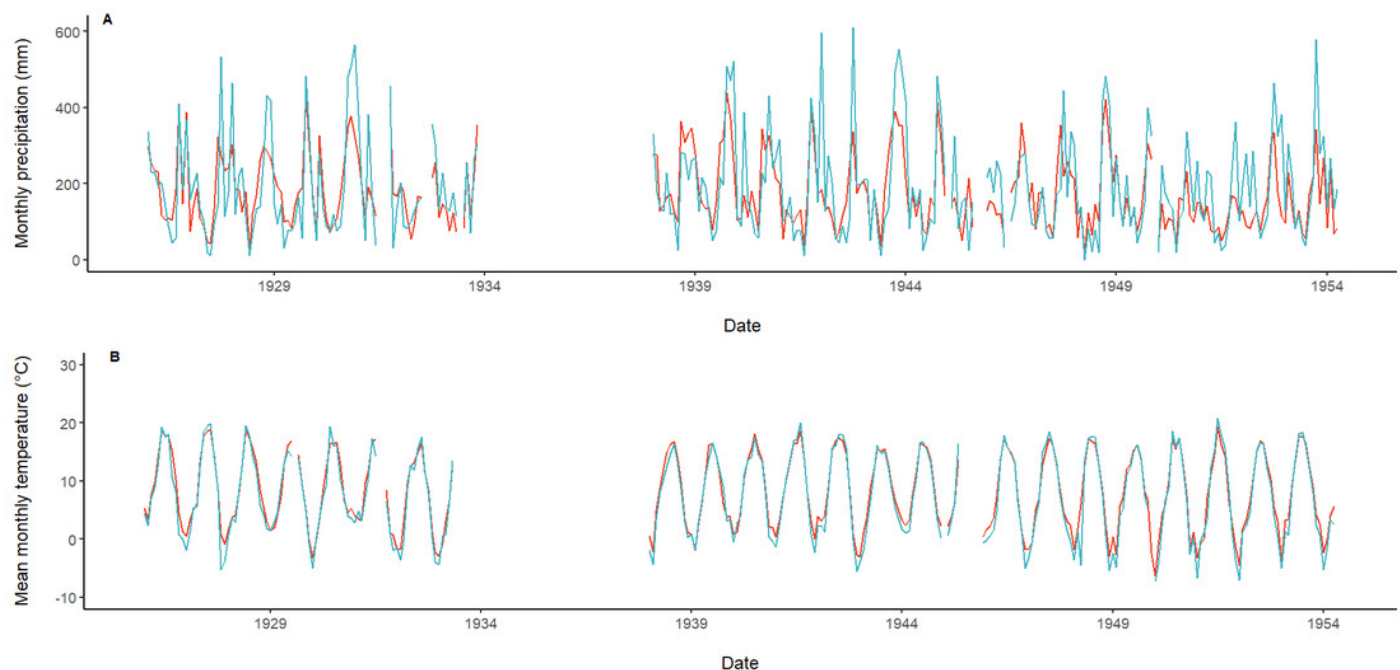


Figure 4

Residuals of modeled - observed climate data.

(A) Residuals of monthly precipitation and (B) monthly mean of the daily maximum temperature calculated as ClimateNA - Hasselborg. For each panel, a loess smoothed trend line with span = 0.75 (blue) is included along with a dotted reference line at $y = 0$.

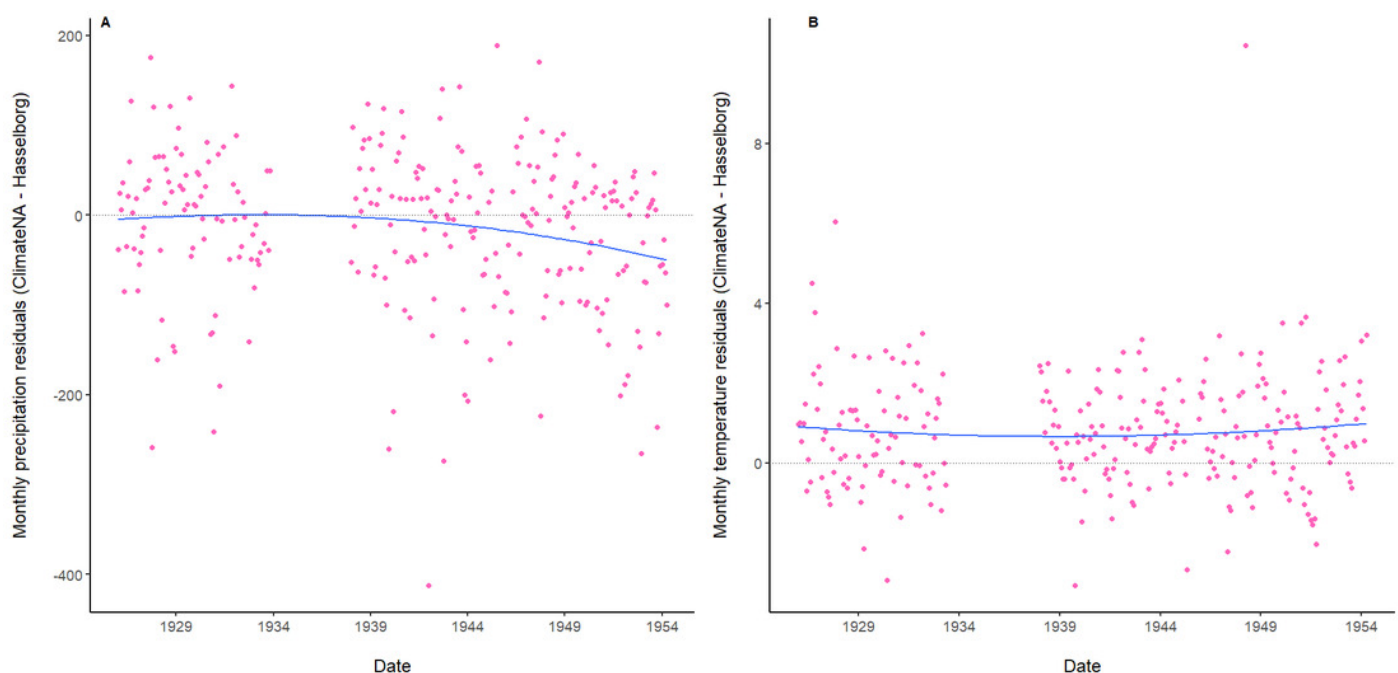


Figure 5

Seasonal residuals.

(A) Average residuals (± 1 SD) aggregated by meteorological season for monthly precipitation and (B) monthly mean of the daily maximum temperature calculated as ClimateNA - Hasselborg. Individual letters along the horizontal axis represent months of the year.

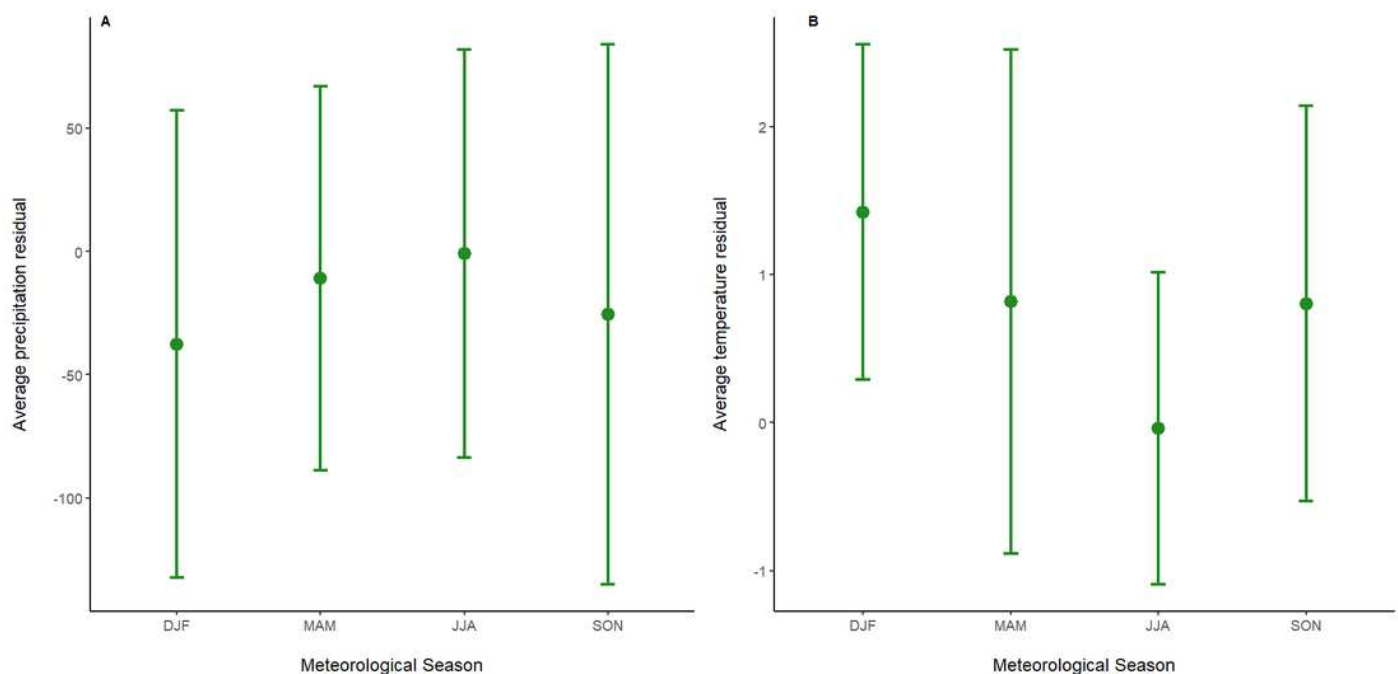


Figure 6

Spatial correlation of precipitation during a wet year.

Correlation between monthly precipitation values generated by ClimateNA and Hasselborg weather journals during 1939, the wettest year recorded in the journals. Grid cell colors correspond to the magnitude of correlation defined in the legend. Grid cells in the spatial correlation map were spaced 0.2 decimal degrees longitude and 0.1 decimal degrees latitude apart and originated from the Hasselborg homestead.

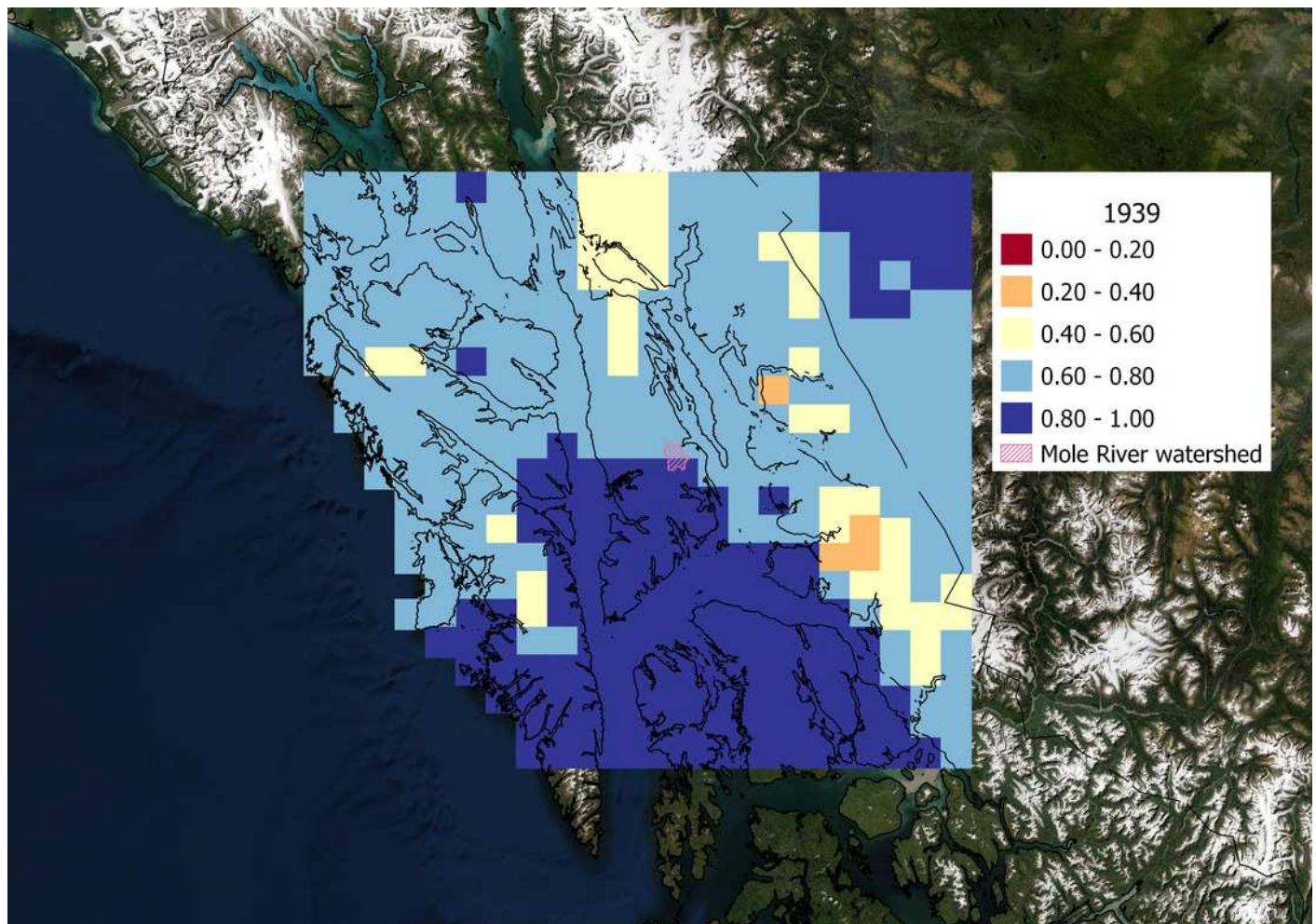


Figure 7

Spatial correlation of precipitation during a dry year.

Correlation between monthly precipitation values generated by ClimateNA and Hasselborg weather journals during 1951, the driest year recorded in the journals. Grid cell colors correspond to the magnitude of correlation defined in the legend. Grid cells in the spatial correlation map were spaced 0.2 decimal degrees longitude and 0.1 decimal degrees latitude apart and originated from the Hasselborg homestead.

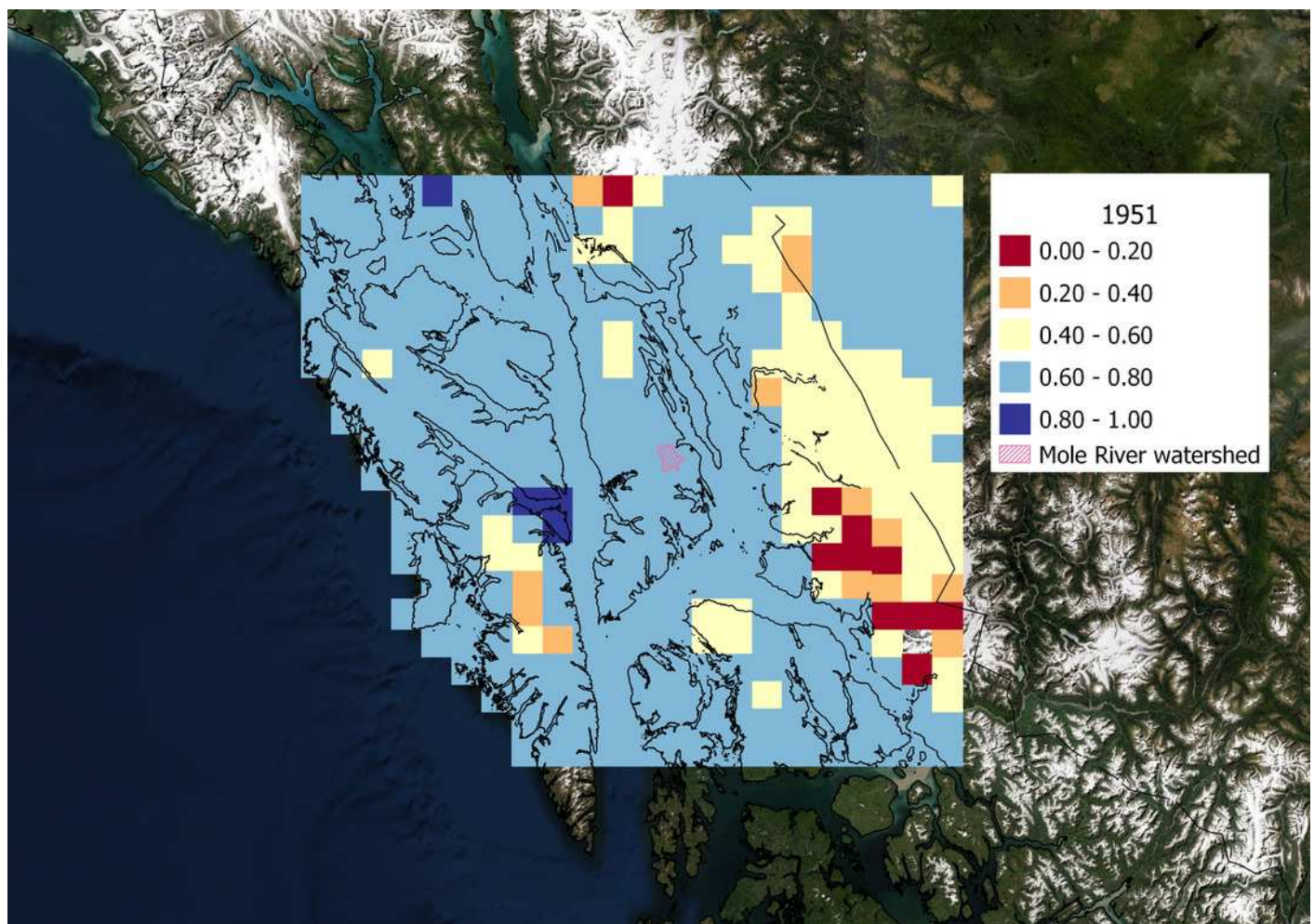


Figure 8

Using modeled and observed data to estimate low streamflow descriptors.

Annual estimates of 95% low duration flow in August using observed Hasselborg data (blue) and modeled ClimateNA data (orange).

