TOWARDS A TTOP-MODEL OF PERMAFROST DISTRIBUTION FOR THREE AREAS IN YUKON AND NORTHERN BRITISH COLUMBIA

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A thesis submitted to

the Faculty of Graduate and Postdoctoral Studies

in partial fulfillment of

the requirements for the degree of

Master of Science in Geography

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Abstract

Air, ground surface and top of permafrost temperatures (TTOP) were measured at 58 sites in three areas of Yukon and northern British Columbia in order to: (1) explore relationships between climate-permafrost transfer functions and environmental variables, (2) assess and validate the TTOP-model, and (3) attempt the first implementation of the TTOP-model (Smith and Riseborough, 1996, 2002) for these regions with complex terrain. The strongest factors controlling climate-permafrost transfer functions are elevation and land cover, though slope, aspect, topographic position and surficial geology were also investigated. In 1000 iterations of the model using random equally possible scenarios, 64% of the TTOP-model predictions were within ±1°C of measured values, a result that is 6% better than applying a simple 3°C "total offset" to the mean annual air temperature. A sensitivity analysis confirmed that the TTOP-model is most sensitive to changes in snow, thermal conductivity of the ground and summer air temperatures. A land cover driven TTOP-model was then developed and implemented. The model correctly predicts high likelihoods of permafrost (> 0.8) for sites with permafrost present and low likelihoods (< 0.4) for non-permafrost sites.

Acknowledgements

This thesis, the year and a half spent in Whitehorse, the more than 8 months of cumulative fieldwork in all seasons and all conditions, the multiple conferences and the endless unique research opportunities would not have been possible without the mentorship and friendship of my supervisor, Dr. Antoni Lewkowicz. I like to say that we deserve each other: my steadfast independence and your many hats meant that we had to trust one another. There was Toni the dean, Toni the supervisor, Toni the scientist, Toni the family man, Toni in the field, etc. This has truly been a transformative experience for me, and I would not change any aspect of it.

Financial assistance was provided by the W. Garfield Weston Foundation Award for Northern Research, the Natural Science and Engineering Research Council Discovery Grant and a University of Ottawa research grant to Dr. Lewkowicz, the Yukon Research Centre Northern Endowment Fund, the Northern Scientific Training Program and the National Geographic Young Explorer Grant. More than monetary value, these funds were a tip of the hat that inspired confidence and encouragement to a young researcher keen to explore and discover.

Field assistance for this thesis is not to be overlooked. These stations are often located in hard to reach locations, and field crews need to manage multiple field priorities (i.e. ERT!). First, I would like to thank Max Duguay for his tireless support and for his (truly) unique skillset in the field – just please turn off the country music! Tyler (Tyrel des Bois) DeJong deserves a hearty acknowledgement for helping me cope with Max and for great banjo jams in the back of the pickup truck on the Haines Pass, at Summit Lake, and beyond. Thank you to Anna Schmidt and the Taku River Tlingit First Nation in Atlin for their in kind support by providing flights through the most spectacular scenery imaginable.

My thesis committee is also to be recognized for their steadfast support throughout this thesis. Dr. Mike Sawada had many of the initial ideas that inspired the multiple iterations and random sampling schemes used in the TTOP-model and Dr. Denis Lacelle was always keenly interested in discussing our respective research projects, be it in the department or chance meetings at the Whitehorse airport. Thought provoking conversations with Karen McKenna, Panya Lipovsky, Philip Bonnaventure, Stephan Gruber, Christopher Burn, Kumari Karunaratne, David Murray, Fabrice Calmels and Sebastian Jones also helped shape this thesis.

My dearest friends, some of you must be from the circus, some from the mountains, some the library and some the symphony. Life would be dull without you, without risk and without passion. My thanks for not abandoning me throughout this ordeal and thanks for taking me seriously when I say: "No, I can't go skiing this weekend because I need to work on my thesis." (Yeah right! You knew I would come!) Thanks to the young researcher community that have provided me with travel funding, training opportunities, international partners, a vote of confidence and thanks for too many hours on skype and not enough in person! I'm looking at you ehPECS-Canada and PYRN, I look forward to maintaining these networks in our continuing paths in life!

And to my family, I say a most heartfelt thank you. Thank you for the encouragement, for the inspiration, for the honesty, for the acceptance. To my step sisters, step brothers, brother, mothers and fathers, my grandparents, my niece, nephews and soon to be niece, you all bring richness to my life. To my father, who always asks about my research, and then reiterates it to me in the simplest of words. To my mother, for her love, and for repeating: "There is a perfect thesis, and there is a submitted thesis."

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CHAPTER 1: Permafrost and climate monitoring

1.1. Research objectives

The three objectives of this research are (1) to investigate relationships between climate-permafrost transfer functions and environmental variables, (2) to test the temperature at the top of permafrost model (TTOP-model) developed by Smith and Riseborough (1996, 2002), and (3) to predict the spatial distribution of equilibrium permafrost by implementing the TTOP-model. The three study areas are Atlin in northern B.C. and Dawson and Whitehorse, both in Yukon.

The five chapters of this thesis address these research objectives. The first chapter introduces the project by summarizing previous research and describing the three study areas. The second chapter addresses the first research objective through a statistical analysis of climate-permafrost transfer functions in relation to environmental variables. The third chapter addresses the second research question by comparing the results of the TTOP-model to a large field dataset. The fourth chapter addresses the third research question by implementing the TTOP-model throughout the study areas. Finally, the fifth chapter discusses the results in relation to the literature and concludes the thesis.

1.2. Background

1.2.1. Permafrost and climate

Permafrost is any earth material that remains at or below 0ºC for two or more consecutive years and it is responsible for unique geomorphic processes and features both at and below the ground surface (ACGR, 1988). At a regional scale, permafrost is controlled by climate and it is generally present only where the mean annual air temperature (MAAT) is at or below -2ºC (Lewkowicz et al., 2012; Smith and Riseborough, 1996; Throop et al., 2012). Locally, other factors such as snow cover, vegetation, soil moisture and topography control its distribution (Williams and Smith, 1989). Higher latitudes generally have deeper, colder and more extensive permafrost due to colder air temperatures, although permafrost may also be found at lower latitudes in suitable mountain environments (Figure 1). The spatial distribution of permafrost varies from continuous (>90%), through extensive discontinuous (50-90%) and sporadic discontinuous (10-50%) to isolated patches (<10%) (Brown et al., 1997). Other characteristics of permafrost include, for example, its thermal regime (*i.e.* warm vs. cold), ice content (*i.e.* ice-rich vs. ice-poor), depth (*i.e.* deep vs. shallow) and location (*i.e.* terrestrial vs. marine) (French, 2007). Permafrost terrain generally has an active layer that freezes and thaws annually due to the seasonal fluctuation of air temperature and a deeper base layer that remains perennially frozen. A *talik* may form a residual thaw zone when the seasonal freezing of the ground does not reach the permafrost. The thermal regime of the ground is transient in nature and the depth of the active layer varies. The permafrost surface, or the top of permafrost, is an equilibrium concept between the active and base layer of permafrost that is used to simplify the influence of climate on permafrost. Lachenbruch et al. (1988) define the climate-permafrost relationship as the difference between the MAAT, the mean annual ground surface temperature (MAGST) and the top of permafrost temperature (TTOP). Smith and Riseborough (2002) demonstrated that TTOP ranges from 1 to 6°C warmer than MAAT in the Arctic and the typical southern limit of discontinuous permafrost in Canada corresponds to the -1°C MAAT isotherm, while the southern limit for the continuous zone is the -8°C MAAT isotherm. Smith and Riseborough (2002) showed that in theory, the southern limit of the discontinuous zone is controlled by the thermal conductivity of ground materials and the northern limit is controlled by snow cover.

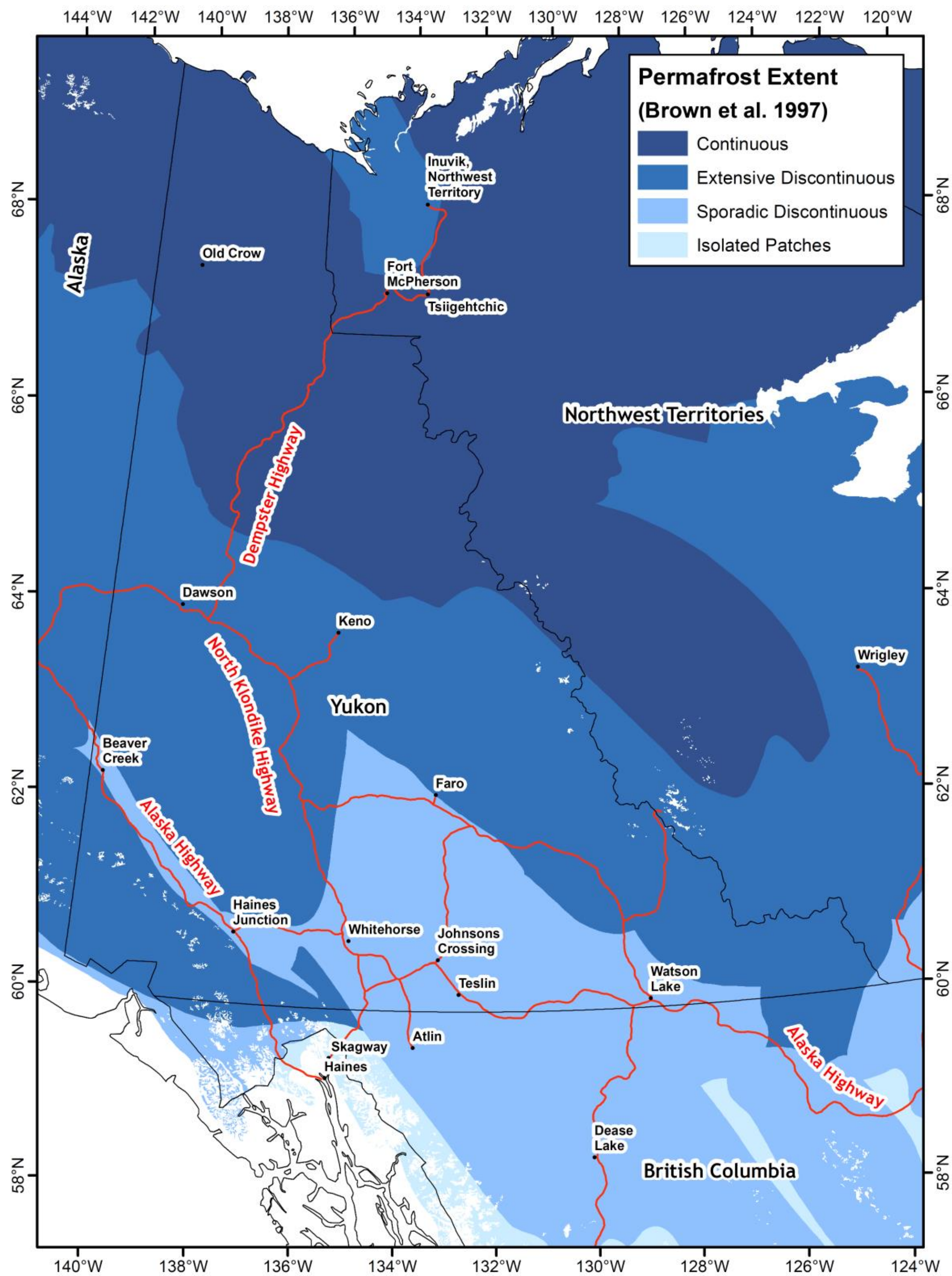

Figure 1: Permafrost distribution in northwestern Canada, see legend (Modified from Brown et al. 1997). Major roads are shown in red and towns with black points.

Zones with perennially cryotic conditions encompass roughly 24% of the exposed land area of the Northern Hemisphere (Tingjun Zhang et al., 2000) and about 50% of the Canadian landmass (Figure 1; Brown et al. 1997; Henry and Smith 2001). Projected climate warming in the near future is expected to be more significant at high latitudes due to feedback processes that occur in polar environments (Arctic Climate Impact Assessment [ACIA], 2005; Intergovernmental Panel on Climate Change [IPCC], 2013; Arctic Monitoring and Assessment Programme [AMAP], 2012). Permafrost is expected to warm and to decrease in spatial extent due to its strong coupling with climate (AMAP, 2012; IPCC, 2007). In the Northern Hemisphere, warming permafrost has been observed in Alaska, Canada, Asia, and Europe (Heginbottom et al., 2012; IPCC, 2007). Nearly all permafrost being monitored in North America has warmed during the past 20-30 years (Smith et al. 2010). Regional climate models project that by 2080 the total area occupied by near-surface permafrost worldwide will be reduced by between 65 and 81% (Arctic Climate Impact Assessment (ACIA), 2005). The consequences of changes in permafrost conditions include changes to the magnitude and frequency of geohazards, such as rock falls (Gruber et al., 2004; Isaksen et al., 2011), infrastructure challenges caused by thaw settlement and a deepening active layer (Gavrilova, 1993; Nelson et al., 2002), and a positive feedback to the global climate system due to the release of greenhouse gasses from thawing organic materials (Schuur et al., 2009). Globally, there is increasing interest towards understanding the human-permafrost system and how it may change in the future.

1.2.2. TTOP modelling

Spatial predictions of permafrost conditions are generally achieved through direct or indirect observations, robust thermal models (e.g., the Stephan Model or the Kudryavtsev

Model), and geospatial datasets (Riseborough et al., 2008). The two broad modelling frameworks are empirical-statistical models and process-based numerical models.

Empirical-statistical models are steady-state models that use regression functions to associate the presence of permafrost to topo-climatic factors such as elevation, slope and aspect (Harris et al., 2009; Hoelzle et al., 2001). This type of modelling omits the complexities of ground surface exchanges (e.g., latent heat exchanges during the freeze-back period, heat flow through the snowpack, etc.) resulting in relatively simple models requiring limited inputs. These models generate permafrost probability or mean ground temperature values in the form of a gridded surface output (Bonnaventure and Lamoureux, 2013; Riseborough et al., 2008). While they are relatively simple to compute and generally accurate, empirical-statistical models need to be recalibrated for different environments (Riseborough et al., 2008). For example, the basal temperature of snow (BTS) model was first conceived for modelling permafrost in the Swiss Alps, and has since been adapted for central Europe, Japan, Scandinavia, and North America (Riseborough et al., 2008).

Process-oriented numerical models are more complex and incorporate modelled energy fluxes between the atmosphere and permafrost (e.g., solar radiation, turbulent heat fluxes, surface albedo, and heat conduction). These models require large amounts of data, and data permitting, they allow modelling through space and time. Process-oriented models enable surface temperatures to be computed, and thermal conditions at depth to be estimated (D. Riseborough et al., 2008).

Empirical-statistical modelling has been undertaken for Yukon and northern British Columbia (Bonnaventure et al., 2012) but process-oriented modelling has no. These models are not yet practical for areas with limited data availability like Yukon and northern British-Columbia. One of the goals of this thesis is to fill this gap.

The TTOP-model (Equation 1.1) is a physically-based equilibrium model that predicts TTOP based on air temperature and two offsets that account for surface and subsurface site characteristics (Figure 2; Smith and Riseborough 1996, 2002). First, a *surface offset* links air temperature to ground surface temperature by applying freezing and thawing *n*-factors to the climate indices of the air. Second, a *thermal offset* links ground surface temperature to the TTOP by applying the thermal conductivity ratio of the active layer to the climate indices at the ground surface (Romanovsky and Osterkamp, 1995). TTOP can therefore be expressed as the sum of air temperature, the surface offset and the thermal offsets:

$$TTOP = MAAT + Surface\ Offset + Thermal\ Offset \quad [1.1]$$

The TTOP-model has been used to assess the impacts of climate change on permafrost (Smith and Riseborough, 1996), to map permafrost at a continental scale (Henry and Smith, 2001), and to assess the climate limits of permafrost in (Smith and Riseborough, 2002). In addition, the TTOP-model has been used to map permafrost distribution in Colorado (Janke et al., 2012), Norway (Gisnås et al., 2013; Juliussen and Humlum, 2007), Alaska (Kerkering, 2008), and the Mackenzie region (Stevens et al., 2010; Wright et al., 2003).

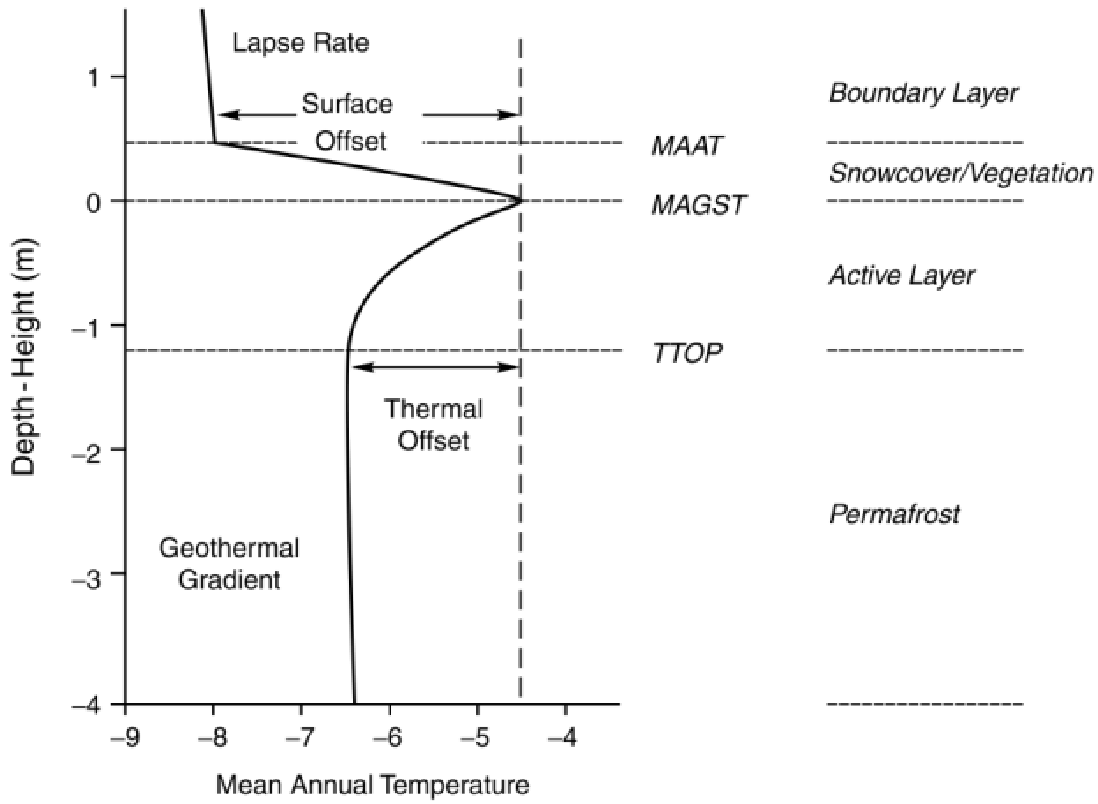

Figure 2: The mean annual temperature profile of the near-surface and of the subsurface showing the relationship between air, ground surface and permafrost temperatures (Smith and Riseborough 2002).

Surface offset

The surface offset represents the net difference between the mean annual temperature of the air and of the ground surface (Smith and Riseborough, 2002), and is calculated as follows:

$$Surface\ Offset = MAGST - MAAT \quad [1.2]$$

In the Arctic, the surface offset is generally positive (MAGST > MAAT) although negative offsets may exist where snow and vegetation is minimal or absent or in very arid conditions (Guglielmin, 2006). Influences on the surface offset include the winter snow cover, shading by vegetation in summer and the presence or absence of permafrost. At a local scale, land cover and snow cover both strongly influence the ground thermal regime. For example, a well-developed vegetation canopy can cool the ground surface relative to the air in summer by blocking incoming solar radiation whereas a deep/long snow cover can warm the ground surface by insulating it from the cold winter air and reducing the transfer of heat between the ground and the atmosphere (Goodrich, 1982; Smith and Riseborough, 1996). These relationships can vary greatly within similar ground surface conditions. Klene et al. (2001) suggest that these types of variations may be attributed to the micro-scale variations of soil moisture. For example, Gubler et al. (2011) measured variations of more than 2.5°C within distances of less than 14 m in homogenous terrain.

Seasonal freezing and thawing degree-days (F/TDD) are used to quantify the intensity of positive and negative temperature variations in the air ($_A$) and at the ground surface ($_S$) (Karunaratne and Burn, 2004). These indices have long been recognised as important controls on permafrost and were used in the past to estimate the depth of permafrost when ground temperatures were not available (Crawford and Boyd, 1956). F/TDD are calculated as the sum of the absolute values of the measured negative and positive mean daily temperatures (MDT) during the freezing and thawing seasons. These can also be expressed as time-temperature integrals when temperature measurements are sparse or incomplete (Klene et al., 2001; D. W. Riseborough, 2003):

$$FDD = \sum_{F_{START}}^{T_{START}} abs(MDT < 0°C) \quad ; \quad TDD = \sum_{T_{START}}^{F_{START}} abs(MDT > 0°C) \qquad [1.3]$$

Where: T_{START} and F_{START} represent the beginning of the thawing and freezing seasons and MDT represents the mean daily temperature. Currently, there is no universally-accepted definition to distinguish the transition between freezing and thawing seasons (Gisnås, 2011). Air temperatures often oscillate above and below 0°C for a number of days during the shoulder seasons with relatively small amplitudes. During this time the ground surface can remain near 0°C due to the release of latent heat from the ground during freeze-up in the fall, or due to melt water percolation through the snowpack in the spring. Some have used the ground surface temperature to define the seasons (e.g., Klene et al. 2001; Juliussen and Humlum 2007) and others have fit sinusoidal waves to air temperature data in order to predict the transition between seasons (e.g., Wright et al. 2003). The impact on the TTOP model results of these differing definitions has not been assessed, but it is not likely to play a significant role due to the small amplitude of oscillations in the shoulder seasons. In this study, we define the start of the thawing and freezing seasons as follows: in the spring, thaw starts on the first day of a group of consecutive positive MDAT that when summed outweigh the sum of all future negative MDAT for that season. The opposite logic is used to define the start of the freezing season in the fall.

Transfer functions, termed *n*-factors, enable a numeric parameterization between F/TDD_S and F/TDD_A (Jorgenson and Kreig, 1988; Lunardini, 1978; US-Army, 1950). The seasonal freezing (N_F) and thawing (N_T) *n*-factors are calculated as the ratio between degree-days at the ground surface and in the air and can therefore be multiplied respectively by F/TDD_A to obtain values of F/TDD_S (Karunaratne and Burn, 2004):

$$N_F = \frac{FDD_S}{FDD_A} \quad ; \quad N_T = \frac{TDD_S}{TDD_A} \qquad [1.4]$$

Thermal offset

In equilibrium conditions TTOP is measured at the bottom of the seasonally active layer. The thermal conductivities of seasonally thawed and frozen ground materials influence the heat flow upward or downward through the active layer. The thermal conductivity ratio (R_K) is the ratio between the conductivity of thawed (K_T) and frozen (K_F) materials. If TTOP is not known at a given location, it can be calculated using the MAGST and the thermal conductivities of the ground. The thermal offset describes the difference between MAGST and TTOP due to the cumulative effect of K_T and K_F, and is negative when the conductivity of frozen ground materials is higher than that of the thawed values (Goodrich, 1982). In solid bedrock, there is little to no thermal offset (and no latent heat exchange), which means that the difference between MAGST and TTOP approaches zero (D. W. Riseborough and Smith, 1998; Throop et al., 2012). Positive thermal offsets have been measured in dry areas of Antarctica (Guglielmin, 2006). The thermal offset is therefore calculated as the difference between TTOP and MAGST:

$$Thermal\ Offset = TTOP - MAGST = \frac{N_T TDD_A (R_K - 1)}{P} \qquad [1.5]$$

TTOP summary

The advantage of the TTOP model is that it bundles complex processes into simple offsets and indices. Surface interactions are summarized as *n*-factors and the ground thermal conductivity of the active layer is summarized in the R_K value. The disadvantages of the TTOP model are that it oversimplifies complex site parameters and consequently, for example, it does not account for the spatial or temporal variability of ground ice and unfrozen moisture. Notwithstanding these drawbacks, the TTOP model was chosen for this project because a physical model of permafrost distribution has not previously been developed for the Yukon and because TTOP is the most complex model that can be used given the limited data available. It should be underlined that this is a steady-state model and only works for permafrost that is in thermal equilibrium with climate. The TTOP-model can therefore be expressed as (Smith and Riseborough 2002):

$$TTOP = \frac{R_K N_T TDD_A - N_F FDD_A}{P} \qquad [1.6]$$

1.2.3. Permafrost and the landscape

Permafrost can be found in diverse parts of the landscape, ranging from exposed mountain tops to peat plateaus in lowland regions. Permafrost is controlled by the landscape in many ways and in turn it plays an active role in shaping the landscape. Polygonal networks in Arctic lowlands are a good example of this. Other examples include pingo development in fine grained materials, thermokarst development in degrading ice-rich permafrost, and slope processes in mountain environments. In this way, topographic attributes, land cover and surficial geology have a combined influence on permafrost distribution and characteristics. Topographic attributes and land cover work together to control the surface offset because of their influence on shading and snow distribution, and topographic parameters and surficial geology control the thermal offset because of their influence on the thermal conductivity of ground materials and on active layer hydrology.

Mountain permafrost is permafrost in mountain areas and can be characterised by the intense local heterogeneity of environmental variables (Gruber and Haeberli, 2009). Topography influences snow cover and snow distribution, vegetation growth, soil hydrology and soil type. More specifically, topographic attributes such as aspect, slope, terrain curvature and incoming solar radiation are expected to influence permafrost temperature and distribution. For example, south-facing slopes in the northern hemisphere receive more solar radiation, especially in winter, and steep slopes accumulate less snow because of snow shedding due to snowpack instability.

Vegetation, or land cover, has a non-linear relationship with the presence of permafrost and it is better understood when combined with topography (Kremer et al., 2011). Natural and anthropogenic environmental change (e.g., forest fire and infrastructure development) also have widespread impacts on the thermal regime of permafrost (Shur and Jorgenson, 2007). For example, forest fires typically cause degradation because of the sudden change in surface conditions, i.e. changes in vegetation, incoming solar radiation, and snow cover (Burn, 1998). The response of permafrost to environmental change depends on the type of permafrost affected and the type of change that has occurred. Shur and Jorgenson (2007) proposed a classification system of permafrost that incorporates the complex influences of climate, ecology and time (e.g., climate-driven permafrost, ecosystem-protected permafrost, etc.). This classification highlights the diversity of permafrost environments in terms of vegetation, organic mat, ground ice, etc., and that classifying permafrost by extent ignores, for example, the characteristics of the ground thermal regime and its sensitivity to change (e.g., environmental, climatic, etc.).

Near-surface air temperature lapse-rates (SLR) are critical to the spatial modelling of air temperature from weather stations in mountainous terrain. It is often assumed that the mean annual SLR is -0.65°C / 100 m (Glickman, 2000; Minder et al., 2010) though seasonal and spatial variations such as winter inversions and continentality are not represented by this annual average. Cold air drainage in valley bottoms causes positive, or inverted, SLR during cold nights (Rolland, 2003) or during the winter season (Janowicz, 1999; Lewkowicz and Bonnaventure, 2011; Lewkowicz and Ednie, 2004; Li et al., 2013). Clear skies lead to less intense radiative cooling that results in a stable stratification with the dense cold air sitting below warmer air (Kattel et al., 2012). Below treeline, the strength of winter inversions in the Yukon is well correlated with the degree of continentality measured as the difference between the mean monthly air temperature in January and in July (Lewkowicz and Bonnaventure, 2011). Similarly, inversions in China were well correlated with relative humidity (Li et al., 2013). Inversions were documented in many parts of the world: in the northwest Xinjiang Province of China inverted winter SLR are +0.3°C / 100 m (Li et al., 2013); in south-central Idaho, winter inversions can be +0.1°C / 100 m in cold and dry regions (Blandford et al., 2008); and in the Dawson region in northwestern Canada annual SLR below treeline are +0.07°C / 100 m (Lewkowicz and Bonnaventure, 2011). More extreme values exist on the John Evans Glacier on the east coast of Ellesmere Island where daily inversions were measured to be +1.5°C / 100 m (Gardner et al., 2009). A good understanding of the behaviour of surface lapse rates above and below treeline during all months of the year allows predictions of mean annual air temperatures to be made for unmonitored sites (e.g., Lewkowicz et al. 2012).

1.3. Study areas

Three study areas between 8.1 and 9.5 thousand square kilometres were selected for this thesis: Atlin in northern British Columbia, and Whitehorse and Dawson in Yukon (Figure 3). In addition to having at least one long-standing Environment Canada weather station and multiple University of Ottawa climate stations (see Section 1.4 for meteorological data), the study areas are distributed along a north-south transect from roughly 59°N to 64°N and also along a continentality gradient, with Atlin being the least continental and Dawson being the most. This results in differing climatic and permafrost conditions in addition to unique physiographic characteristics.

The Atlin study area is a mountainous environment with the highest probability of permafrost found above treeline. The Whitehorse study area borders the transition between the Coast Mountains and the Yukon Plateau and is on the boundary between sporadic and extensive discontinuous permafrost. The Dawson study area is characterized by a large range of temperatures throughout the year, strong winter inversions, and extensive discontinuous permafrost. Mean monthly air temperature normals from 1981-2010 show that the Environment Canada weather stations in each area experience similar air temperatures in the July with Dawson as the warmest (15.7°C) then Whitehorse (14.3°C) and Atlin (13.4°C). In January, Dawson is the coldest (-26.0°C), then Whitehorse (-15.2°C) and Atlin (-12.8°C) (Figure 4).

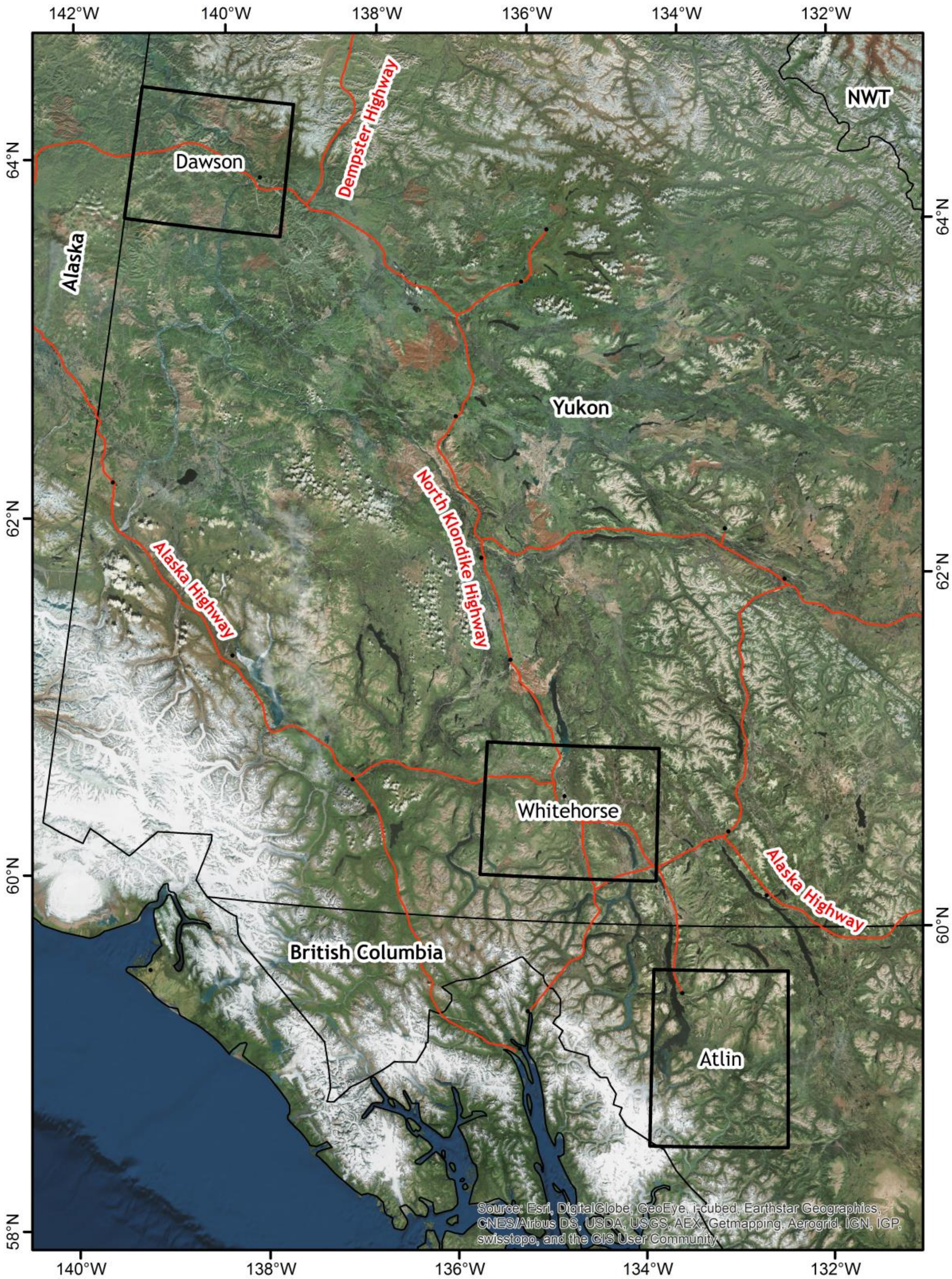

Figure 3: Location map of southern Yukon and northern British Columbia with study areas outlined in black, they are: Atlin, Whitehorse and Dawson. Map projection is Yukon Albers. Basemap: ESRI World Imagery, 2014.

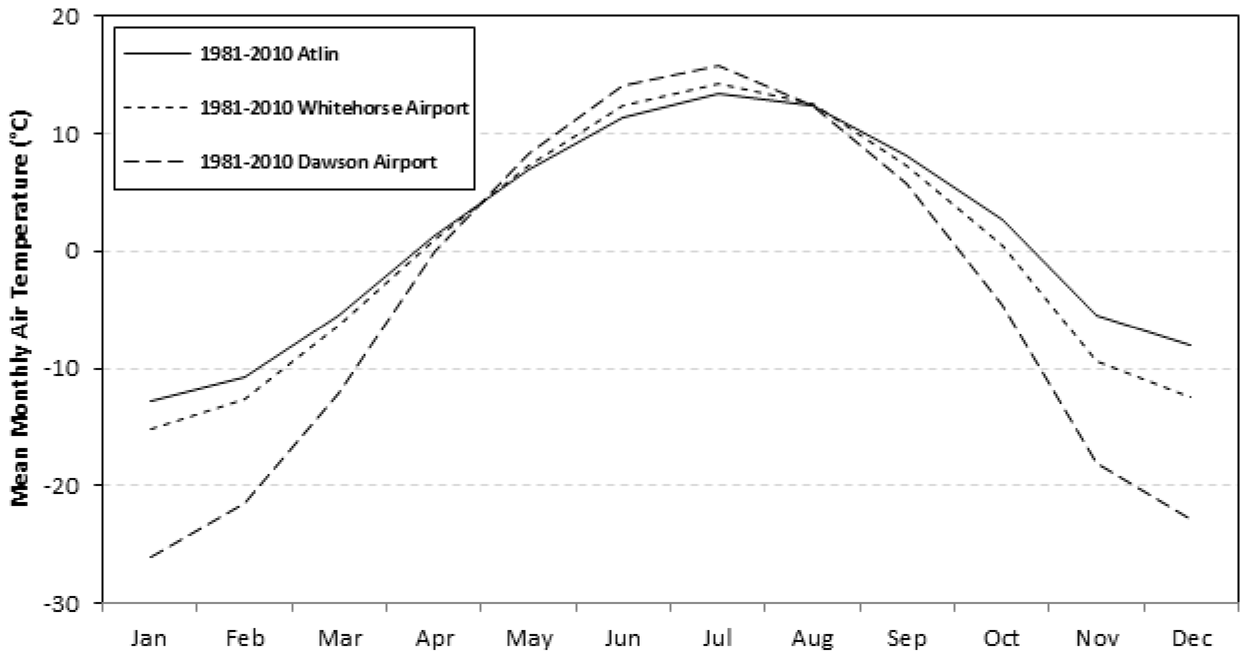

Figure 4: Mean monthly air temperatures for the three study areas. Source: Environment Canada 1981-2010 Climate Normals (Environment Canada, 2014).

1.3.1. Atlin, BC

The Atlin study area (9,535 km^2; centred on 59.6°N, 133.7°W) is located in northern British-Columbia and borders Yukon to the north and Alaska to the southwest (Figure 3; Figure 5). The study area is a mountainous environment that ranges between 37 and 2516 m above sea level (a.s.l.). This region is broadly characterized as having sporadic discontinuous permafrost and isolated patches of permafrost towards the Pacific Ocean in the southwest (Brown et al., 1997). Bonnaventure et al. (2012) predict a similar distribution with BTS modelling with the exception that permafrost can be extensive discontinuous or continuous above treeline (roughly 1300-1400 m a.s.l.). In addition, ground ice was observed in the past in a palsa located in a valley bottom at approximately 1000 m a.s.l. (Seppälä, 1980). The Atlin area was glaciated at the time of the last glacial maximum (~21 ka) but only a small portion of the study area still has glaciers (Figure 5). This area is a part of the Coast Mountains ecoregion in the southwest and the Teslin Plateau ecoregion in the northeast. Land cover is dominated by coniferous forest and isolated patches of deciduous and mixed forests up to about 1300-1400 m a.sl., shrubs are generally present between 1000 and 1400 m a.s.l., and above the shrubs an alpine zone is present (Figure 5). The transition to the alpine environment is rapid in the Coast Mountains as slopes are generally steep, whereas the transition is slow in the Teslin Plateau due to gentler slopes (Figure 5). Consequently shrubs occupy a larger portion of the landscape in the northeast of the region.

There are twelve University of Ottawa climate stations in the Atlin study area. They are described in the following section. Figure 6 displays photographs of the Chikoida Mountain climate station (CHK-MNT) and of the Kuthai Lake climate station (KUT-LAK). The only Environment Canada weather station is at Atlin (59°34' N, 133°42' W, 673.6 m a.s.l.) and it is also described below.

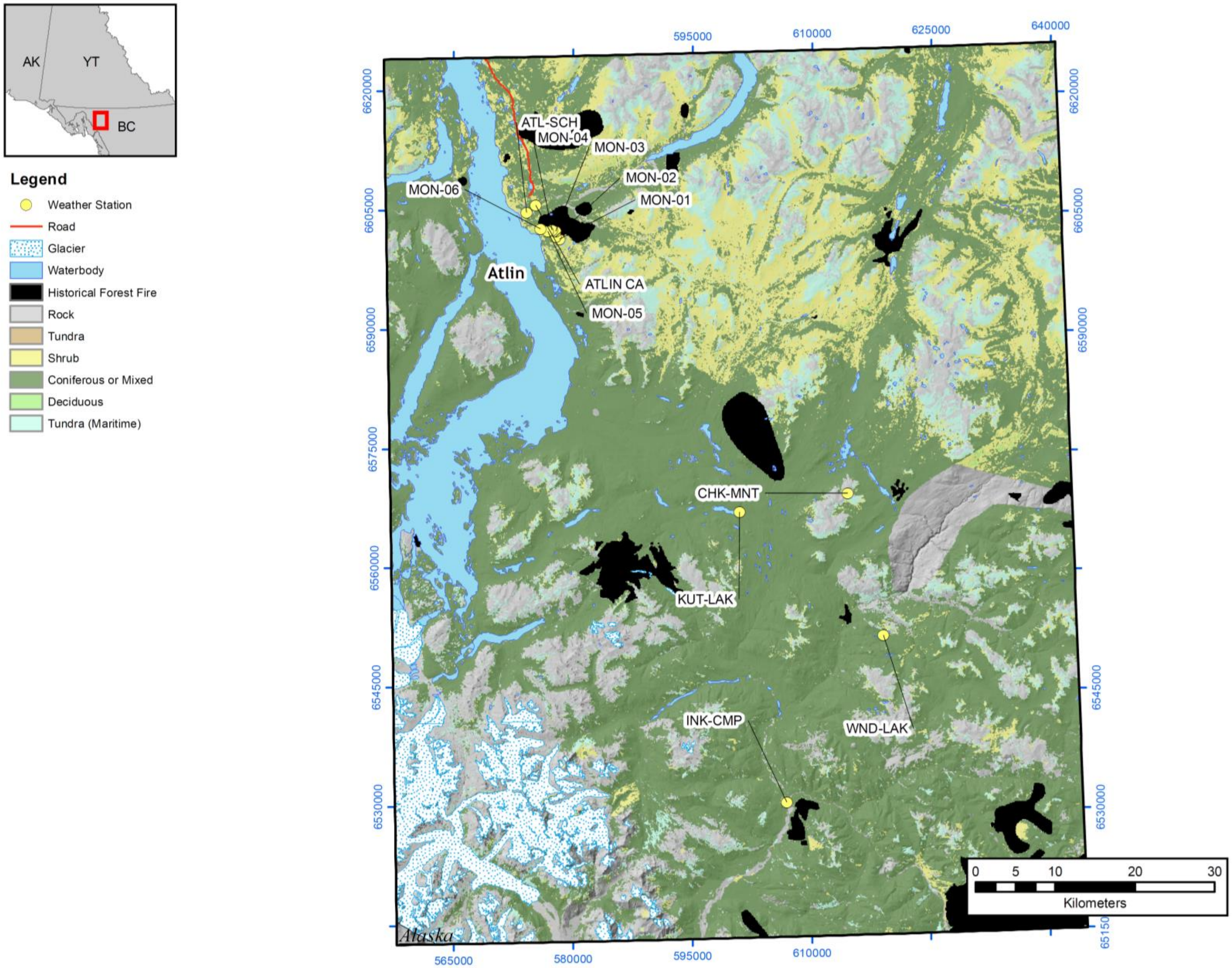

Figure 5: Map of the Atlin study area showing climate stations locations (see section 1.4), large lakes and glaciers from the CanVec dataset, historical forest fires from the Canadian National Fire Database (see section 2.2), topography from the Canadian Digital Elevation Dataset (Geobase, 2011) and land cover classes from the EOSD classification (see section 2.2). Coordinate system: NAD83, UTM08.

Figure 6: Top panel, photograph of the Chikoida Mountain climate station (CHK-MNT). Bottom panel, photograph of the Kuthai Lake climate station (KUT-LAK). See Figure 5 for site locations. These photographs demonstrate the variability of the land cover due to the range of elevations found in this region.

1.3.2. Whitehorse, YT

The Whitehorse study area (9,150 km^2; 60.6°N, 135.0°W) is located in southern Yukon (Figure 3; Figure 7). The study area is mountainous with large U-shaped valleys and numerous large lakes. It extends across part of the Yukon Plateau ecoregion in the northeast to the Coast Mountain ecoregion in the southwest (Figure 7). Elevations range from 614 to 2234 m a.s.l. This region is broadly characterized as being within the sporadic discontinuous permafrost zone with areas of extensive discontinuous permafrost in the Coast Mountains (Brown et al., 1997). Bonnaventure et al. (2012) predict sporadic discontinuous permafrost throughout the landscape with extensive discontinuous and continuous permafrost occurring above treeline using BTS modeling. Lewkowicz & Ednie (2004) modelled very low probabilities of permafrost occurrence below treeline in the Wolf Creek Basin (completely within the Whitehorse study area) and high probabilities above treeline. The entire study area was glaciated at the time of the last glacial maximum (~21 ka) but none of the region remains glaciated at present. However, perennial snow patches are present at a number of locations in this landscape (Dove et al., 2005; Farnell et al., 2004).

There are twenty eight University of Ottawa climate stations in the Whitehorse study area. They are described below. Figure 8 displays photographs of the Mount Granger climate station (MtGR) and of the Sima Trail climate station (WC-T1). The Whitehorse Airport Environment Canada weather station (60°42' N, 135°04' W, 706 m a.s.l.) was also used in the Whitehorse area analyses.

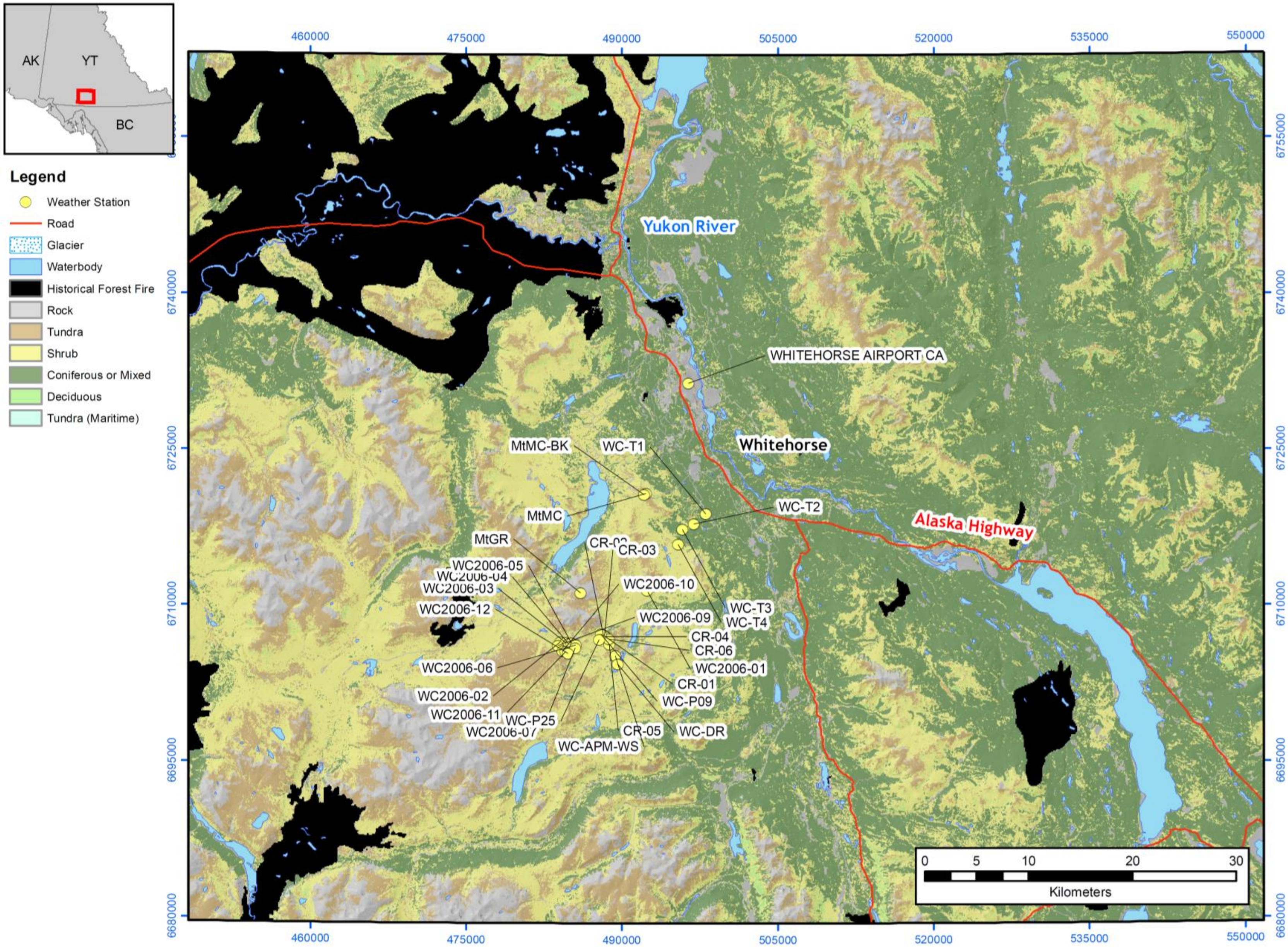

Figure 7: Map of the Whitehorse study area showing climate stations locations (see section 1.4), large lakes and glaciers from the CanVec dataset, historical forest fires from the Canadian National Fire Database (see section 2.2), topography from the Canadian Digital Elevation Dataset (Geobase, 2011) and Land cover classes from the EOSD classification (see section 2.2). Coordinate system: NAD83, UTM08.

Figure 8: Top panel, photograph of the Mount Granger climate station (MtGR). Bottom panel, photograph of the Sima Trail 01 climate station (WC-T1). See Figure 7 for site locations. These photographs demonstrate the range of surface cover that may be found near Whitehorse.

1.3.3. Dawson, YT

The Dawson study area (8,146 km^2; 64.0°N, 139.1°W) is located in central Yukon and is bordered by Alaska to the west (Figure 3; Figure 9). The area is mountainous, ranging in elevation from 251 to 1981 m a.s.l. This area falls within the extensive discontinuous permafrost zone (Brown et al., 1997). It is a part of the Klondike Plateau with the Tintina Trench crossing through the northeast sector (Figure 9). Land cover is dominated by shrubs on south-facing slopes and coniferous forest on slopes with northerly aspects (Figure 9). Bonnaventure et al. (2012) predict from BTS modeling the presence of extensive discontinuous permafrost throughout the landscape including valley bottoms, with patches of sporadic discontinuous permafrost near treeline and continuous permafrost on high peaks above treeline. Forest fires were identified in this region as having a significant influence on detachment failure activity on permafrost slopes (Calmels et al., 2012; Coates, 2008). Only a small portion of the southwest sector and a larger part of the northeast sector of the region were glaciated during early- and mid-Pleistocene glaciations. During the late Pleistocene glaciation, the region remained unglaciated, permafrost was widespread, and it was part of eastern Beringia. Ice wedges, which formed during either the Reid (MIS 4) or McConnell (MIS 2) glaciations, were observed in valley bottoms. They may have thawed during a warming period since the last glacial maximum to then refreeze during the Holocene (Naldrett, 1981), or they may have persisted throughout, as is suggested by the preserved Gold Run tephra deposits overlying the ice wedges dated 740,000 ± 60,000 years before the present (Froese et al., 2008).

There are fourteen University of Ottawa climate stations in the Dawson study area. They are described in the next chapter. Figure 10 displays photographs of the Top of the World 02 climate station (TOW-02) and of the Top of the World 10 climate station (TOW-10). The only

EC weather station within the study area is the Dawson Airport station (64°02' N, 139°07' W, 370 m a.s.l.) and it is also be described in the next chapter.

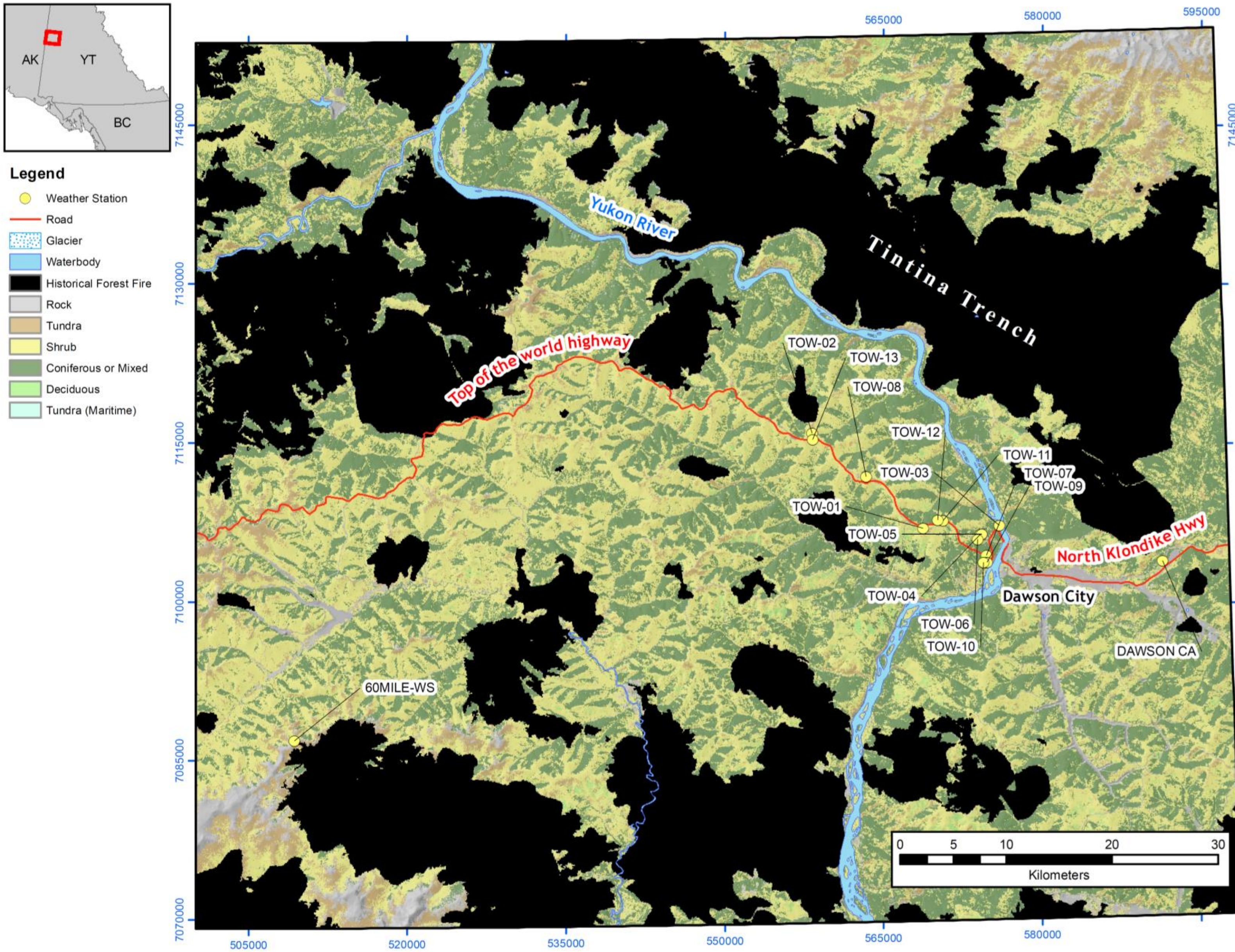

Figure 9: Map of the Dawson study area showing climate stations locations (see section 1.4), large lakes and glaciers from the CanVec dataset, historical forest fires from the Canadian National Fire Database (see section 2.2), topography from the Canadian Digital Elevation Dataset (Geobase, 2011) and land cover classes from the EOSD classification (see section 2.2). Coordinate system: NAD83, UTM07.

Figure 10: Top panel, photograph of the Top of the World 02 climate station (TOW-02). Bottom panel, photograph of the Top of the World 10 climate station (TOW-10). See Figure 9 for site locations. These photographs demonstrate the variable land covers found in the Dawson region, from shrub dominated mountain slopes to deciduous forest in the river valley.

1.4. Meteorological data

Meteorological data collected at a total of 58 climate stations between 2007 and 2014 are used in this thesis. Of these, three are Environment Canada (EC) weather stations (Environment Canada 2014) and 55 are University of Ottawa (UO) stations operated by Dr. Antoni Lewkowicz. The EC stations were selected based on two criteria: that they are located within the study areas and have hourly weather data between 2007 and 2014. The latter criterion meant that data from Mayo Road and Whitehorse Riverdale Environment Canada stations could not be used. Climate normals are calculated from near-complete 30 year EC datasets following standards set by the World Meteorological Organisation (WMO). They are available for 1961-1990, 1971-2000 and 1981-2010, with the exception that 1961-1990 normals are not available for Dawson A (Table 1, Figure 4). Between the 1961-90 and 1981-10 normal periods, Atlin and Whitehorse A experienced a net rise in mean annual air temperature of 1.1°C and 0.9°C, respectively, while Dawson A experienced a 0.3°C increase between the 1971-00 and 1981-10 normal periods. Both the mean annual daily minimums and maximums increased over these periods. Rainfall and snowfall remained nearly unchanged except at Atlin where they increased by 5-10% (Table 1). This suggests that the greatest changes in regional climate have occurred in the Atlin area and that the smallest occurred near Dawson, although this conclusion might have been different if the 1961-1990 normals had been available for the latter.

Table 1: Climate normals 1961-1990, 1971-2000 and 1981-2010 (Environment Canada, 2014). Datum for the coordinates provided is WGS84.

	ATLIN			WHITEHORSE A			DAWSON A		
Latitude	59.58300°N			60.71700°N			64.05000°N		
Longitude	133.66700°W			135.06700°W			139.13000°W		
Elevation	716 m a.s.l.			703 m a.s.l.			370 m a.s.l.		
Normal period	1961-90	1971-00	1981-10	1961-90	1971-00	1981-10	1961-90	1971-00	1981-10
MAAT (°C)	0.0	0.5	1.1	-1.0	-0.7	-0.1	-	-4.4	-4.1
Rainfall (mm)	192	193	201	160	163	161	-	200	201
Snowfall (cm)	145	155	164	145	145	142	-	160	166

The UO stations installed by Dr. Antoni Lewkowicz are equipped with Onset HOBO Pro data-loggers that record hourly air, ground surface and ground temperatures. The temperature range of the HOBO sensors ranges from -50° to 100°C and the sensor-logger assembly is accurate to about ±0.2°C within the centre of the range, with greater potential errors at extreme values (Onset, 2014). The air temperature sensor is located about 1.5 m above the ground at most sites and is always covered by a radiation shield. The ground surface sensor is located just below the ground surface (e.g., in moss or other surface vegetation mat) in order to be shaded from direct solar radiation. Where permafrost is present and was reached during installation, the ground temperature sensor is located at the bottom of the active layer generally between 0.5 m and 1.5 m beneath the surface. Where permafrost is absent, the sensor is usually at a depth of 1 m unless clasts or bedrock prevented installation at this depth in which case a shallower depth was used.

Due to the intermittent failure of the University of Ottawa loggers over this time period (e.g. due to water damage, animal damage or user errors) and owing to the relatively short (<10 years) duration of the UO station records, a *blended-year* was calculated for each site in order to characterize the current climate (between 2003 and 2013). The blended-year creates a single year of data based on the mean of all months that are more than 90% complete. The blended-year approximates the climate at each site based on as much of the available data as possible. It is explicitly mentioned when blended-year statistics are used in this thesis.

Values calculated for a single year, such as annual mean air temperature (AMAT), annual mean ground surface temperature (AMGST) or annual TTOP are calculated using a hydrological year that uses the calculated start of the freeze season at the ground surface until the start of the following freeze season (Equation 1.3). When FDD or TDD of the air or ground surface are calculated for a single year, they use the calculated beginning and end of the freeze season and the calculated beginning and end of the thaw season at the ground surface (Equation 1.3).

Blended-year statistics for all UO stations are shown in Table 2. The northernmost and southernmost stations are Top of the World 02 (TOW-02) at 64.16°N and King Salmon Camp (KSAL-CMP) at 58.72°N, respectively. The highest and lowest stations are Mount Granger (MtGR) at 2066 m a.s.l. and Inklin Camp (INK-CMP) at 85 m a.s.l. The coldest blended-year MAAT values were for MtGR and 60-Mile at -7.0°C and -6.1°C, respectively. All of the Top of the World (TOW) sites, MtGR and 60-Mile have more than 2500 air freezing degree days (FDD_A). The maximum blended-year FDD_A was measured at TOW-04 (484 m a.s.l.) with 3617 FDD_A. Annual means for complete years can be found in ANNEX 1: Annual Means and complete station metadata can be found in ANNEX 2: Station Metadata.

Table 2: Summary of blended-year statistics for University of Ottawa climate stations. Coordinates are in WGS84.

Station Name **Abbreviation** **Study Area**	**Lat (°N)** **Long (°W** **m a.s.l.**	**MAAT (°C)** **n=months**	**FDD_A** **TDD_A** **(°C-days)**	**MAGST (°C)** **n=months**	**FDD_S** **TDD_S** **(°C-days)**	**TTOP (°C)** **n=months**	**N_T**	**N_F**	**R_K**	**S_{OFF}**	**T_{OFF}**
Atlin School	59.5747	0.2	1557	2.3	716	2.3	0.9	0.5	1.0	1.7	-0.1
ATL-SCH	133.6874	37	1648	37	1558	37					
Atlin	705										
Chikoida Mountain	59.2494	-4.4	2342	-0.3	787	-	1.2	0.3	-	4.8	-
CHK-MNT	132.9937	29	626	33	714	15					
Atlin	1650										
Inklin Camp	58.9022	-	1059	6.3	641	4.5	1.2	0.3	-	4.8	-
INK-CMP	133.1463	12	2136	40	1855	33					
Atlin	85										
King Salmon Camp	58.7167	0.6	1383	2.8	178	-	0.8	0.1	-	2.4	-
KSAL-CMP	132.9441	32	1593	26	1223	4					
Atlin	537										
Kuthai Lake	59.2311	-0.3	1485	2.9	295	3.6	0.9	0.2	1.2	2.9	0.8
KUT-LAK	133.2326	33	1378	40	1346	36					
Atlin	742										
Monarch Mountain 1	59.544	-3.3	2060	1.6	422	1.6	1.0	0.2	1.0	4.6	0.0
MON-01	133.6167	35	865	35	1006	35					
Atlin	1410										
Monarch Mountain 2	59.5464	-2.0	1673	0	923	0.8	0.9	0.5	1.2	2.0	0.7
MON-02	133.6242	33	969	33	966	29					
Atlin	1347										
Monarch Mountain 3	59.5528	-1.5	1532	0.1	758	0.1	0.8	0.5	1.0	1.5	0.0
MON-03	133.6245	33	1007	33	813	33					
Atlin	1238										
Monarch Mountain 4	59.5543	-1.3	1783	2.3	163	2.4	0.7	0.2	1.0	2.9	0.1
MON-04	133.6325	12	1313	33	999	33					
Atlin	1103										
Monarch Mountain 5	59.5533	0.1	1502	3.2	244	3.1	0.8	0.1	1.0	2.6	-0.1
MON-05	133.6415	33	1574	40	1394	29					
Atlin	954										
Monarch Mountain 6	59.5557	0.0	1493	2.1	360	1.7	0.6	0.4	1.0	0.9	0.0
MON-06	133.6577	22	1497	26	1003	26					
Atlin	731										
Windy Lake	59.0877	-1.8	1843	1.8	193	-	0.7	0.2	-	3.1	-
WND-LAK	132.9246	33	1205	33	854	14					
Atlin	895										

Station Name **Abbreviation** **Study Area**	**Lat (°N)** **Long (°W** **m a.s.l.**	**MAAT (°C)** **n=months**	**FDD_A** **TDD_A** **(°C-days)**	**MAGST (°C)** **n=months**	**FDD_S** **TDD_S** **(°C-days)**	**TTOP (°C)** **n=months**	**N_T**	**N_F**	**R_K**	**S_{OFF}**	**T_{OFF}**
Coal Ridge 01 CR-01 Whitehorse	60.4996 135.2162 1260	-3.1 58	2191 1077	0.7 69	660 911	0.1 66	0.8	0.3	0.8	3.5	-0.6
Coal Ridge 02 CR-02 Whitehorse	60.4994 135.2153 1271	-3.2 61	2229 1086	0.3 75	863 988	-0.4 63	0.9	0.4	0.7	3.2	-0.7
Coal Ridge 03 CR-03 Whitehorse	60.4988 135.2134 1363	-2.9 66	2083 1035	-0.5 75	1171 991	-0.6 50	1.0	0.6	1.0	2.2	-0.1
Coal Ridge 04 CR-04 Whitehorse	60.4979 135.2121 1457	-3.3 63	2067 884	- -	1044 838	-0.8 57	0.9	0.6	0.9	2.3	-0.3
Coal Ridge 05 CR-05 Whitehorse	60.491 135.2047 1495	-2.9 43	1917 877	-2.4 50	1818 970	-2.5 31	1.1	1.0	0.9	0.4	-0.2
Coal Ridge 06 CR-06 Whitehorse	60.4959 135.2052 1555	-3.9 62	2310 905	0.1 74	620 675	-0.2 62	0.7	0.3	0.8	3.8	-0.4
Mount McIntyre MtMC Whitehorse	60.6217 135.1414 1567	-3.9 56	2263 875	-2.4 59	1982 1134	-1.8 55	1.3	0.8	1.2	1.7	0.6
Mount McIntyre Backup MtMC-BK Whitehorse	60.6204 135.1445 1565	-4.1 46	2320 845	-1.4 46	1152 676	- 9	0.7	0.5	-	2.6	-
Inversion Valley 01 WC2006-01 Whitehorse	60.538 135.1384 1266	-2.5 52	2032 1123	1.9 78	582 1296	1.4 36	1.1	0.3	0.9	4.1	-0.5
Inversion Valley 02 WC2006-02 Whitehorse	60.4932 135.2902 1349	-3.5 32	2276 1016	0.3 36	840 953	0.7 33	1.0	0.4	1.1	3.6	0.4
Inversion Valley 03 WC2006-03 Whitehorse	60.4927 135.2808 1387	-2.9 25	2128 1096	0.3 36	975 1105	0.7 36	1.0	0.5	1.1	3.1	0.4
Inversion Valley 04 WC2006-04 Whitehorse	60.4918 135.2756 1386	 10	2169 508	0 0	731 1245	1.3 12	1.3	0.4	1.0	4.1	-0.1
Inversion Valley 05	60.4922	-2.9	2153	0.6	721	0.7	0.9	0.4	1.0	3.5	0.0

Station Name **Abbreviation** **Study Area**	**Lat (°N)** **Long (°W** **m a.s.l.**	**MAAT (°C)** **n=months**	**FDD_A** **TDD_A** **(°C-days)**	**MAGST (°C)** **n=months**	**FDD_S** **TDD_S** **(°C-days)**	**TTOP (°C)** **n=months**	**N_T**	**N_F**	**R_K**	**S_{OFF}**	**T_{OFF}**
WC2006-05 Whitehorse	135.2705 1390	32	1113	36	956	25					
Inversion Valley 06 WC2006-06 Whitehorse	60.4903 135.2628 1426	-3.0 36	2142 1054	0.9 36	795 1147	0.4 13	1.2	0.4	0.8	4.0	-0.5
Inversion Valley 07 WC2006-07 Whitehorse	60.4879 135.2645 1288	-3.5 36	2345 1108	0.9 36	683 1037	1.0 36	1.0	0.3	1.0	4.3	0.0
Mount Granger WC2006-08-MtGR Whitehorse	60.5354 135.2554 2066	-7 62	2950 420	-5.4 71	2468 523	-5.8 49	1.3	0.9	0.7	1.6	-0.5
Inversion Valley 09 WC2006-09 Whitehorse	60.4902 135.2951 1378	-3.1 36	2152 1046	0.4 36	954 1103	0.1 36	1.1	0.5	0.9	3.3	-0.3
Inversion Valley 10 WC2006-10 Whitehorse	60.4854 135.2865 1373	- -	- -	-0.4 36	991 846	-0.7 21	-	-	0.9	-	-0.3
Inversion Valley 11 WC2006-11 Whitehorse	60.485 135.2813 1376	-2.8 26	2067 1059	-0.6 36	1038 820	-0.8 36	0.8	0.6	0.9	1.8	-0.2
Inversion Valley 12 WC2006-12 Whitehorse	60.4835 135.2765 1373	-3.1 35	2172 1075	0.2 36	830 897	-0.6 36	0.8	0.4	0.7	2.9	-0.8
Permafrost Mound WC-APM-WS Whitehorse	60.4814 135.1935 1202	-3.3 59	2270 1096	1.6 72	469 1057	0.9 41	0.9	0.2	0.7	4.4	-0.7
Drained Lake WC-DR Whitehorse	60.474 135.1894 1225	-3.9 25	2517 1119	1.9 46	489 1185	1.4 30	1.1	0.2	0.8	5.7	-0.5
Palsa 09 WC-P09 Whitehorse	60.5 135.2192 1241	-3.4 17	2144 923	-0.2 65	940 897	-0.7 50	1.1	0.5	0.8	3.1	-0.6
Palsa 25 WC-P25 Whitehorse	60.4952 135.2228 1235	- -	- -	0.9 81	789 1146	3.6 81	-	-	1.8	-	2.6
Sima Trail 01 WC-T1	60.6044 135.0354	-1.9 72	2174 1520	0.7 72	1005 1294	1.1 72	0.9	0.5	1.1	2.1	0.3

Station Name Abbreviation Study Area	Lat (°N) Long (°W m a.s.l.	MAAT (°C) n=months	FDD_A TDD_A (°C-days)	MAGST (°C) n=months	FDD_S TDD_S (°C-days)	TTOP (°C) n=months	N_T	N_F	R_K	S_{OFF}	T_{OFF}
Whitehorse	868										
Sima Trail 02	60.5955	-1.9	2092	1.8	604	0.7	0.9	0.3	0.7	3.3	-1.1
WC-T2	135.0569	80	1406	80	1267	50	-	-	-	-	-
Whitehorse	1011										
Sima Trail 03	60.5904	-2.6	2160	2.2	421	1.3	0.9	0.2	0.7	4.2	-1.0
WC-T3	135.0769	58	1249	72	1246	59					
Whitehorse	1145										
Sima Trail 04	60.5778	-3.3	2270	1.6	469	0.9	0.9	0.2	0.7	4.4	-0.7
WC-T4	135.0844	59	1096	72	1057	41					
Whitehorse	1290										
Sixty Mile	63.9095	-5.8	3030	-4	2388	-4.1	1.0	0.8	1.0	1.7	-0.1
60MILE-WS	140.8104	48	955	48	933	73					
Dawson	1447										
Sixty Mile Backup	63.9095	-3.2	2229	0.3	863	-0.4	0.9	0.4	0.7	3.2	-0.7
60MILE-BK	140.8104	61	1086	75	988	63					
Dawson	1440										
Top of the World 01	64.0827	-5.4	2921	-2.8	1611	-2.9	0.6	0.6	0.9	2.4	-0.1
TOW-01	139.5917	83	961	83	603	83					
Dawson	1010										
Top of the World 02	64.1651	-5	2982	-	2394	-4.1	0.9	0.8	0.9	1.1	-0.4
TOW-02	139.8029	24	1178	-	1060	24					
Dawson	1223										
Top of the World 03	64.0836	-4.7	3441	0.1	1412	-2.4	0.8	0.5	0.4	3.9	-2.5
TOW-03	139.4431	83	1770	83	1447	83					
Dawson	331										
Top of the World 04	64.0766	-5.3	3617	0.2	1170	-1.6	0.7	0.4	0.5	4.9	-1.8
TOW-04	139.4808	69	1690	72	1247	72					
Dawson	484										
Top of the World 05	64.0768	-3.9	3242	-0.1	1282	0	0.7	0.5	1.0	3.2	0.0
TOW-05	139.4784	59	1846	59	1267	59					
Dawson	503										
Top of the World 06	64.0721	-4.3	3250	-1.5	1719	-1.1	0.7	0.6	1.1	2.2	0.3
TOW-06	139.4864	69	1697	72	1196	72					
Dawson	570										
Top of the World 07	64.0588	-3.4	2920	1.2	772	0.8	0.6	0.3	0.9	4.2	-0.4
TOW-07	139.4696	56	1694	72	1200	49					
Dawson	701										

Station Name Abbreviation Study Area	Lat (°N) Long (°W m a.s.l.	MAAT (°C) n=months	FDD_A TDD_A (°C-days)	MAGST (°C) n=months	FDD_S TDD_S (°C-days)	TTOP (°C) n=months	N_T	N_F	R_K	S_{OFF}	T_{OFF}
Top of the World 08	64.1274	-3.7	2665	-0.7	1096	-0.4	0.6	0.5	1.1	2.6	0.2
TOW-08	139.6993	59	1339	62	872	57					
Dawson	1119										
Top of the World 09	64.0525	-4.2	3385	2.0	836	1.8	0.9	0.3	1.0	6.0	-0.2
TOW-09	139.469	45	1858	70	1573	70					
Dawson	477										
Top of the World 10	64.0528	-3.4	3137	1.2	1194	1.9	0.8	0.4	1.1	4.3	0.6
TOW-10	139.4758	54	1937	74	1650	74					
Dawson	490										
Top of the World 11	64.0888	-3.6	2864	2.0	519	1.8	0.8	0.2	0.9	5.4	-0.3
TOW-11	139.5522	72	1578	72	1265	47					
Dawson	842										
Top of the World 12	64.0894	-3.5	2875	0.9	658	0.5	0.6	0.3	0.8	4.1	-0.5
TOW-12	139.5622	72	1610	72	1008	70					
Dawson	858										
Top of the World 13	64.1597	-4.1	2823	1.5	596	-	0.9	0.2	-	5.6	-
TOW-13	139.8019	48	1346	71	1139	-					
Dawson	1116										

MAAT = Mean annual air temperature; MAGST = Mean annual ground surface temperature; TTOP = Temperature at the top of permafrost (or shallower); NF = Freezing n-factor; NT = Thawing n-factor; RK = Thermal conductivity ratio; SOFF = Surface offset; TOFF = Thermal offset.

1.4.1. Temperatures

Blended year mean annual air temperatures (MAAT) measured at climate stations in the three study regions vary between -4.4°C and 0.6°C in Atlin, -7.0°C and -1.9°C in Whitehorse, and -5.8°C and -3.1°C in Dawson (Table 2). Annual mean air temperatures (AMAT) for individual years (n = 138) have a mean of -3.3 ± 1.5°C (Figure 11A). The range of AMAT values is 9.3°C, between -8.0°C and 1.3°C. Forested sites are generally warmer than shrubs, which are warmer than tundra and bare rock sites (see Figure 11 A). The coldest station in each study area is Chikoida Mountain in Atlin (blended MAAT = -4.4°C), Mount Granger in Whitehorse (blended MAAT = -7.0°C), and 60-mile in Dawson (blended MAAT = -5.8°C). AMAT is not normally distributed (p-value = 0.044, n = 138), however within land cover classifications AMAT is normally distributed in all cases (Figure 11 A). The distribution of AMAT is normal in Atlin (p value = 0.89, n = 17) and Dawson (p value = 0.28, n = 55), but not in Whitehorse (p value = 0.008, n = 66) (Figure 11B). Elevation is an important control on air temperature and is examined further in Chapter 4.

Blended year mean annual ground surface temperatures (MAGST) in the three study regions vary between 0.2°C and 5.0°C in Atlin, -5.4°C and 1.9°C in Whitehorse, and -4.0°C and 2.0°C in Dawson (Table 2). Annual mean ground surface temperatures (AMGST) for individual years (n = 138) have a mean of 0.42 ± 1.9°C (Figure 11 C). The range of measured AMGST is 13°C, almost 4°C greater than the AMAT range, with variations between -6.6°C and 6.4°C. Forested sites are generally warmer than shrubs, which are warmer than tundra and bare rock sites (see Figure 11 C). The coldest station in each study area is Monarch 3 in Atlin (blended MAGST = 0.2°C), Mount Granger in Whitehorse (blended MAGST = -5.4°C), and 60-mile in Dawson (blended MAGST = -4.0°C). AMGST is not normally distributed overall (p-value =

0.006, n = 197) nor is it normally distributed within individual land cover classes (Figure 11C). The distribution of AMGST is normal in Atlin (p value = 0.39, n = 28) and but not in Dawson or Whitehorse (Figure 11D).

Blended year TTOP temperatures in the three study regions vary between 0.1°C and 4.5°C in Atlin, -5.8°C and 1.4°C in Whitehorse, and -4.1°C and 1.9°C in Dawson (Table 2). TTOP temperatures that are above zero represent ground temperatures at comparable depths in non-permafrost environments. Annual TTOP values for individual years (n = 166) have a mean of -0.14 ± 2.1°C (Figure 11E). The range of measured annual TTOP values is 11.2°C and varies between -6.4°C and 4.8°C. Forested sites are generally warmer than shrubs, which are warmer than tundra and bare rock sites (see Figure 11E). The coldest station in each study area is Monarch 3 in Atlin (blended TTOP = 0.1°C), Mount Granger in Whitehorse (blended TTOP = -5.8°C), and 60-mile in Dawson (blended TTOP = -4.1°C). Annual TTOP is not normally distributed (p-value = 0.013, n = 166) (Figure 11E). The distribution of annual TTOP values is normal in Atlin (p value = 0.8, n = 27) but not in Dawson or Whitehorse (Figure 11F).

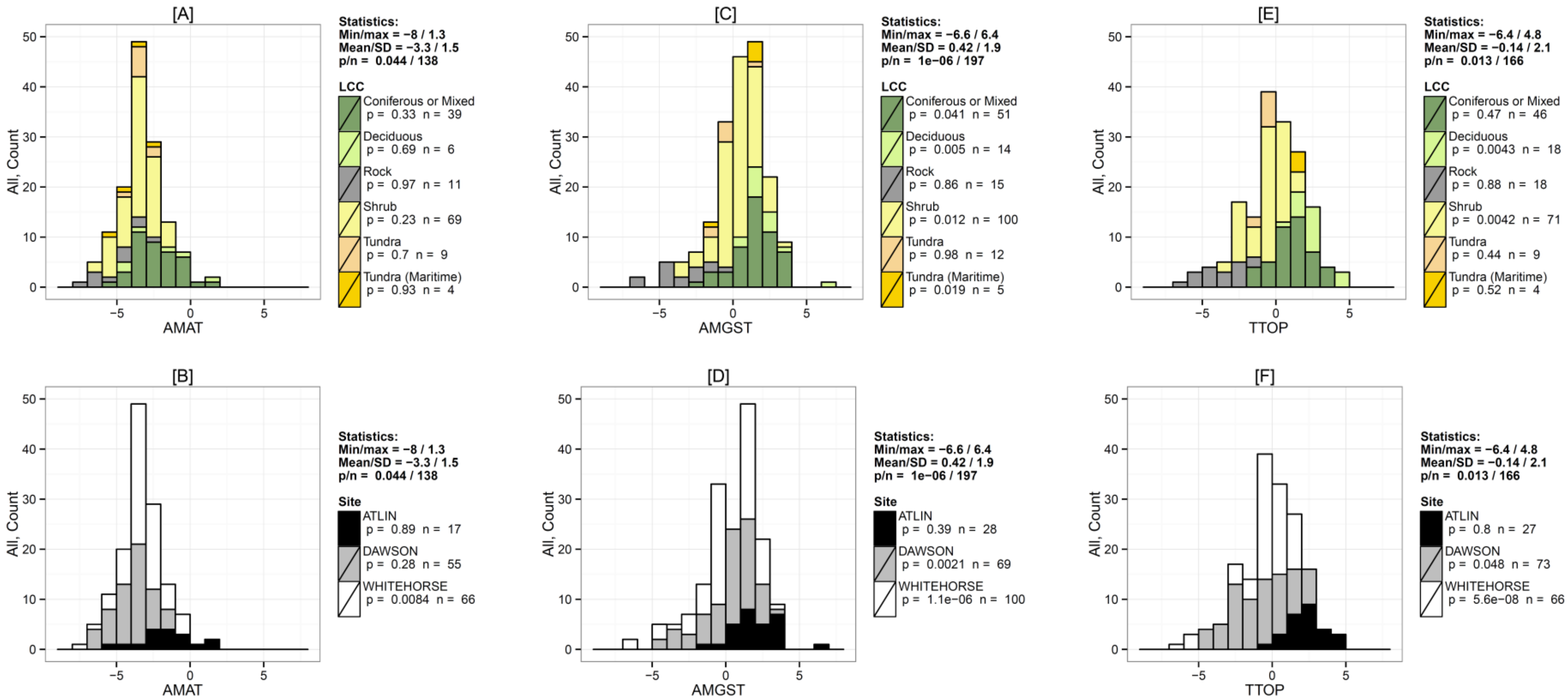

Figure 11: Measured values of annual mean air temperature (AMAT) [A,B], annual mean ground surface temperature (AMGST) [C,D] and annual top of permafrost temperatures (TTOP) [E,F] in °C. Histograms are colored by land cover classification [A,C,E] and by study area [B,D,F]. TTOP greater than 0°C indicates ground temperatures.

1.4.2. *N*-factors and R_K values

N_F is not normally distributed within the overall dataset (p value = <0.001, n = 188) and has a range between 0.01 and 0.98. The freezing n-factor has a slightly bimodal distribution because the rock land cover classification produces a group of distinctly higher values (Figure 12A). N_F is however normally distributed for nearly all individual land cover classifications per study area (Figure 12B-D). Overall most N_F values are between 0.3 and 0.4. The range of values in Atlin is between 0.01 and 0.56, the range of values in Whitehorse is between 0.06 and 0.97 and the range of values in Dawson is between 0.09 and 0.81. The Atlin stations characteristically get more snow and generally do not have permafrost, causing N_F values to be closer to zero.

N_T is also not normally distributed within the overall dataset (p value = 0.002, n = 135). However the distribution is normal within the overall land cover classes (Figure 12E). The range of values in Atlin is between 0.64 and 1.32, the range of values in Whitehorse is between 0.73 and 1.53, and the range of values in Dawson is between 0.59 and 1.20. The greatest class of N_T values lie between 0.9 and 1 in Atlin and Whitehorse, and between 0.7 and 0.8 in Dawson suggesting that there is more shading or a less conductive surface organic mat in Dawson. Maximum N_T values are quite high in the rock class in Whitehorse. This may be due to the nature of the Mount Granger and Mount McIntyre station sites that behave more like blockfields than bedrock.

R_K is not normally distributed, overall (p value = 0.005, n = 126) and has a range between 0.30 and 1.96. R_K is normally distributed within land cover classifications (Figure 12I). The most common values are between 0.9 and 1 in all regions. R_K-values in Whitehorse can reach nearly 2 (Figure 12K).

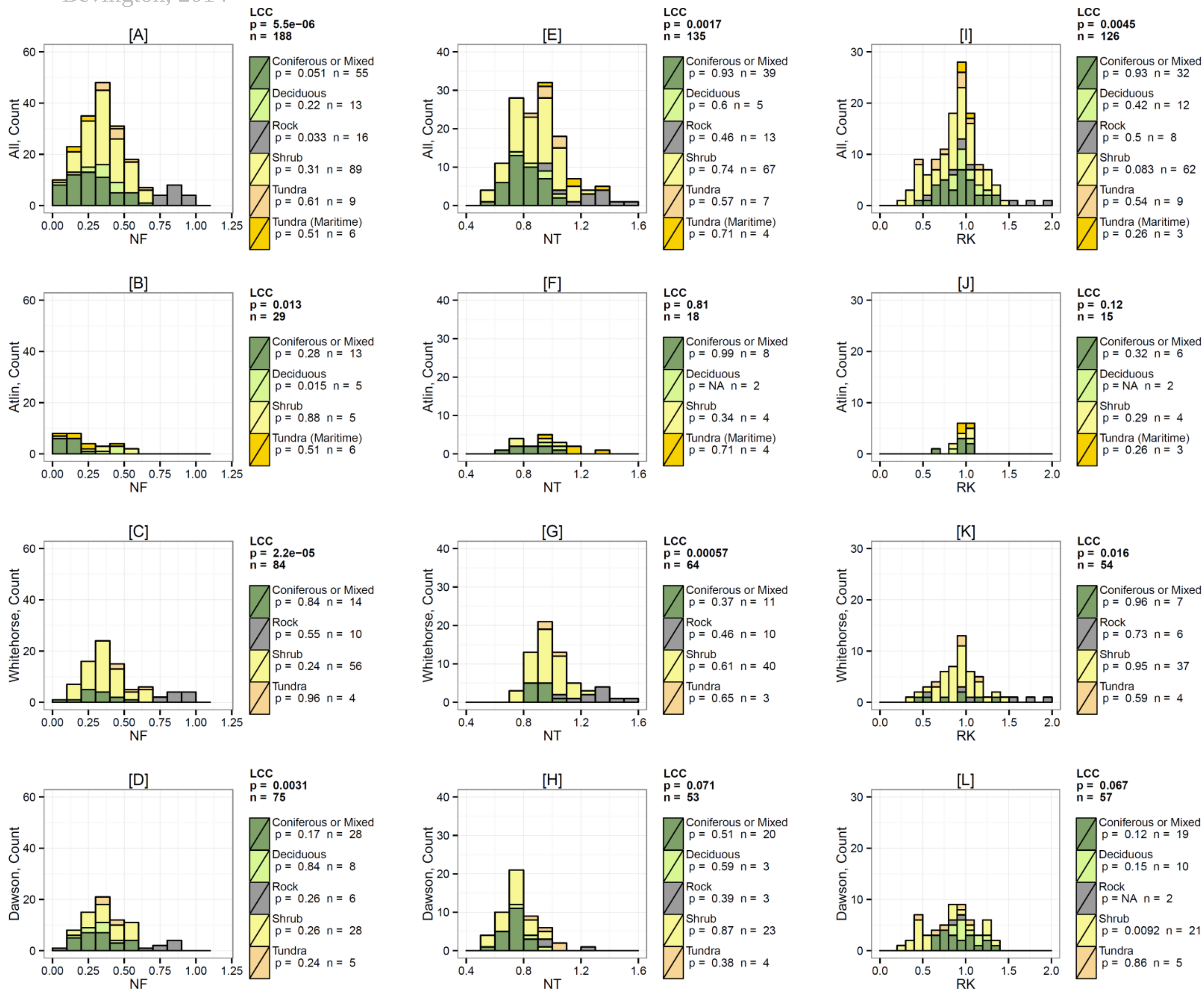

Figure 12: Histogram of N_F, N_T and R_K by study area and land cover: All sites [A, E, I], Atlin [B, F, J], Whitehorse [C, G, K] and Dawson[D, H, L].

1.4.3. Offsets

The surface offset (SO) is normally distributed overall (p value = 0.24, n = 132 with over half of all offsets between 2°C and 4°C. The range of values is between 0.59°C and 6.59°C. The SO is also normally distributed within land cover classifications (Figure 13A). All surface offsets are positive indicating that MAGST is warmer than MAAT. Rock sites have characteristically low surface offsets between 0.5°C and 2°C. Coniferous and mixed forests, deciduous forests and shrubs have similar surface offsets, whereas continental tundra has much lower offsets than maritime tundra (Figure 13A).

The thermal offset (TO) is not normally distributed overall (p value < 0.05, n = 135) but it is within all land cover classes except shrubs (Figure 13E). The TO ranges between -2.8°C and 1.9°C. Negative TOs indicate TTOP values that are colder than MAGST and positive values indicate TTOP values that are warmer than MAGST. Positive TOs do not occur according to traditional conceptions of Arctic permafrost (Smith and Riseborough, 1996, 2002). Though, recent findings in the dry environments of Antarctica yield positive TOs (Guglielmin, 2006). Negative offsets may be caused by: moist summer soils have a higher thermal conductivity than dry winter soils or the thermal dependency of the thermal conductivity of the gas phase in the soil (though not in bedrock). Larger TO values are harder to explain, but may be the result of representing a transient system with a steady state model, because the lag between TTOP and MAGST could influence the thermal offset.

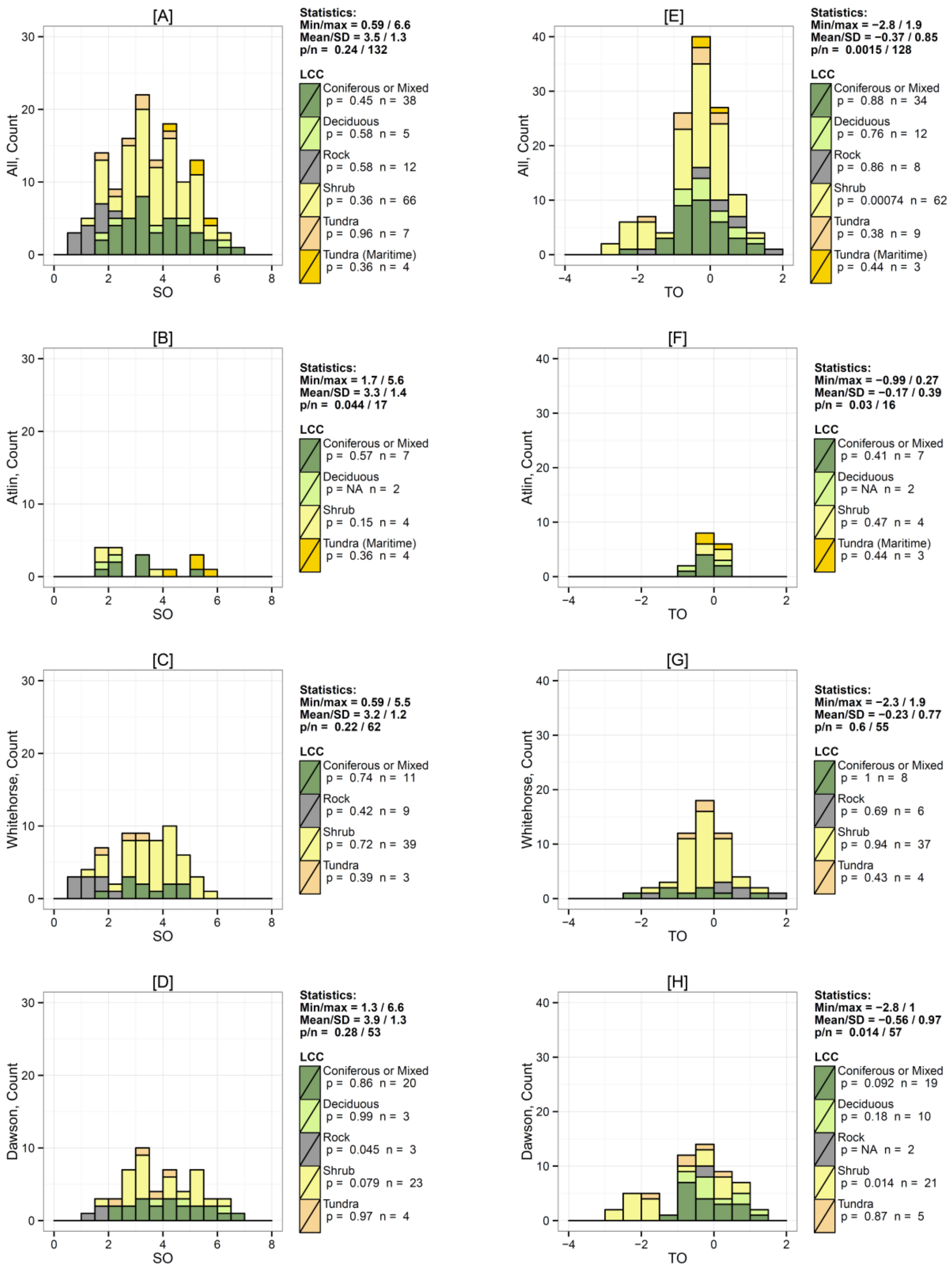

Figure 13: Histogram of the surface offset (SO) and the thermal offset (TO) by study area and land cover: All sites [A, E], Atlin [B, F], Whitehorse [C, G] and Dawson [D, H].

1.4.4. The "total offset"

A first order approximation at the complexity involved in understanding ground temperature conditions at a given location can be obtained by looking at the differences between MAAT and TTOP, or the "total offset". From field measurements, TTOP is between 0.5 and 6.5°C warmer than MAAT (Figure 14A-C). The total offset is normally distributed (p value = 0.22, n = 406) and is also normally distributed for each land cover class (Figure 14A). The mean measured total offset is 3.0°C. The presence of permafrost seems to change the limits of the total offset. Total offset values where permafrost is present vary between 0.5°C and 4.0°C degrees, whereas they vary between 0.5°C and 6.5°C where permafrost is not present (Figure 14B). The range of thermal offset values appears to be similar across the three study areas (Figure 14C).

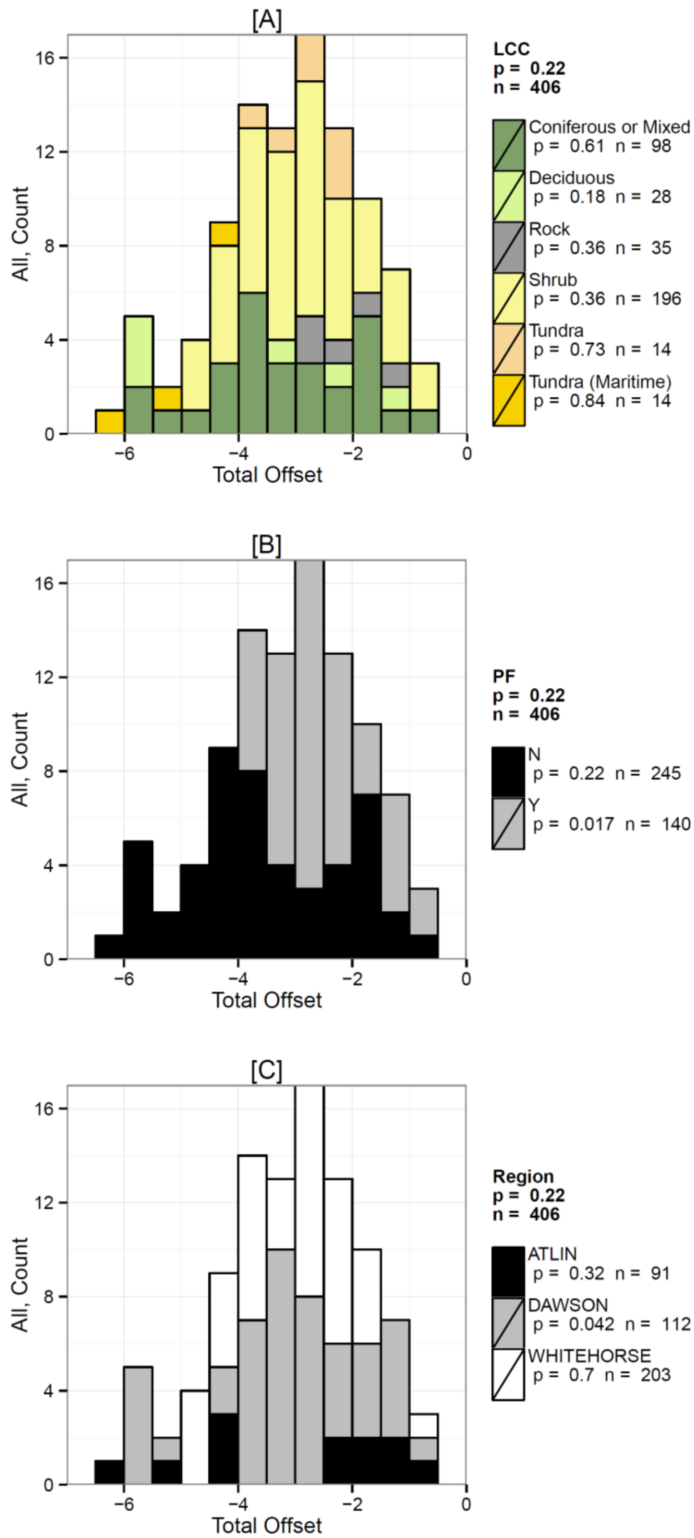

Figure 14: Histogram of the "total offset", or the difference between MAAT and TTOP by land cover [A], presence of permafrost [B] and region [C].

1.5. Summary and concluding remarks

We have presented a large dataset from 58 climate stations between 2007 and 2014. Most of these stations do not have continuous records due to logistic limitations and instrument failures. Consequently, we use both individual yearly mean values and blended year means to analyse the data. Yearly values use calculated seasons freeze and thaw seasons at the ground surface, as opposed to the usual 365 day year.

AMAP in the three study regions varies between -8.0°C and 1.3°C and has a mean of -3.3 ± 1.5°C (Figure 11A). AMGST has a greater range of values, from -6.6°C to 6.4°C and has a mean of 0.42 ± 1.9°C (Figure 11C). Annual TTOP values are similar to the ground surface values and vary between -6.4°C and 4.8°C with a mean of -0.14 ± 2.1°C (Figure 11D). The surface offset from these annual values is +3.7°C, the thermal offset is -0.6°C and the total offset is +3.2°C.

N_F, N_T and R_K are normally distributed for nearly all individual land cover classifications for each study area and can be assumed to be normal in future work. The surface offset (SO) is also normally distributed overall (p value = 0.24, n = 132) with most offsets between 3°C and 4°C. All surface offsets are positive indicating that MAGST is warmer than MAAT. The thermal offset is between -3°C and 2°C, with most values ±1°C. Positive TOs may be caused by the application of an equilibrium model to a transient system.

Finally, the total offset, or the difference between MAAT and TTOP, varies between 0.5°C and 6.5°C with a mean of 3°C. TTOP values in the rock class are most similar to MAAT whereas TTOP values in maritime tundra are much warmer than MAAT. It may be reasonable to assume a 3°C offset for almost all vegetation classes, with a smaller offset for rock and a larger one for maritime tundra.

CHAPTER 2: Climate-permafrost transfer functions and environmental variables

2.1. Introduction

The surface and thermal offsets are transfer functions that encapsulate the complex energy exchanges between the atmosphere, ground surface and permafrost. This chapter investigates the use of environmental variables such as topographic attributes, land cover and surficial geology as predictors for these transfer functions. The following research questions are explicitly addressed in this chapter: First, what are the relationships between the three parameters of the climate-permafrost transfer functions (N_F, N_T and R_K), and topographic attributes, land cover and surficial geology? Second, how do climate-permafrost transfer functions vary together and what are their limits?

2.2. Methodology

2.2.1. Topographic attributes

In order to investigate the relationships between topographic attributes and climate-permafrost transfer functions (see Section 1.2.3) a 30 x 30 m resolution digital elevation model (DEM) was obtained for each of the study areas from the Canadian Digital Elevation Dataset (Geobase, 2010). The slope and aspect of the DEM were calculated in ArcGIS 10.1 Spatial Analyst (Table 3). Whitehorse is on average the highest region (1423 m a.s.l.), and Dawson is on average the lowest (1116 m a.s.l.). Atlin has the greatest range of elevations, calculated from the minimum and the maximum elevation points (2479 m).

The topographic position index (TPI) that was originally proposed by Weiss (2001) was calculated for the three study areas using the Land Facet Corridor Designer toolset in ArcGIS 10.1 developed by Jenness et al., (2013). The tool classifies the landscape using the difference between the elevation of a cell in a DEM and the average elevation of a neighbourhood of surrounding cells. High TPI values may be near the top of a hill or ridge and low values may be closer to the bottom of a valley. A null TPI could be a flat area within the search radius or a mid-slope area and the slope can help solve this (Jenness et al., 2013). The magnitude of the value depends in part on the size of the neighbourhood used.

TPI values using search neighbourhoods of 50, 200, and 700 m were generated for each of the study areas in order to explore the effect of topographic position at different scales on climate-permafrost interactions (Table 3). Ridge tops, slopes and valleys were classified from the raw TPI values as being greater than 1 standard deviation above the mean, within 1 standard deviation of the mean, and greater than 1 standard deviation below the mean, respectively. Note that the toolset removes a distance equal to the size of the neighbourhood from the edge of the raster. A larger search radius (e.g., 700 m) will classify locations as mountain tops and valley bottoms whereas a smaller search radius (e.g., 50 m) will classify locations as gullies or mounds, for example.

Table 3: Digital elevation model statistics

Variable	Statistic	Atlin	Whitehorse	Dawson
Elevation (m a.s.l.)	Min	37	614	251
	Mean	1276	1423	1116
	Max	2516	2234	1981
	Range	2479	1620	1730
TPI 50 (m)	Min	-98	-48	-67
	Mean	0	0	0
	Max	99	124	96
	Std. Dev.	2.6	1.1	1.4
TPI 200 (m)	Min	-154	-75	-188
	Mean	0	0	0
	Max	235	168	91
	Std. Dev.	11.9	7.1	9.2
TPI 700 (m)	Min	-359	-168	-184
	Mean	0	0	0
	Max	557	255	246
	Std. Dev.	45.4	31.3	38.6

2.2.2. Land cover

Two land cover datasets were used to investigate the relationships between land cover and climate-permafrost transfer functions: (1) the Earth Observation for Sustainable Development of Forests (EOSD) land cover classification dataset, and (2) the Canadian National Fire Database (CNFDB; http://cwfis.cfs.nrcan.gc.ca/ha/nfdb).

The EOSD dataset is publicly available from the Canadian Geobase website (http://www.geobase.ca). This dataset was created by the Canadian Centre of Remote Sensing by converting raster thematic land cover data, originating from classified Landsat 5 and 7 ortho-images, to vectors (Geobase, 2010). The dataset classifies land cover in Canada into 44 classes, far more than was found necessary by Kremer et al. (2011) for associating land cover with permafrost probability. Kremer et al. (2011) used seven classes of land cover to model permafrost: water, bare ground, tundra, shrubs, broadleaf trees, needle-leaf trees and undefined areas. Their analysis showed that not all of these were significant in predicting the presence of permafrost (Kremer et al. 2011). In order to have multiple climate stations in each land cover classification, the dataset was reclassified into the following six categories: (1) coniferous or mixed forest, (2) deciduous forest, (3) rock, (4) shrubs, (5) tundra, and (6) tundra (maritime).

Land areas affected by historic forest fire were not modelled owing to insufficient field data and a poor understanding of forest fire impacts on climate-permafrost interactions over time. Only two climate stations are located within known burn areas: UO stations Monarch 1 & 4 (1926 fire). The CNFDB is compiled and maintained by the Canadian Forest Service from data provided by provincial, territorial and Parks Canada fire management agencies (CNFDB, 2013). The CNFDB is not complete nor is it entirely accurate but it is the most comprehensive dataset available, extending as far back as 1917. The database provides point locations and polygon outlines of fires and metadata such as the date, size, mapping agency, mapping data source and mapping method of the burn. More than150 fires have occurred annually in Yukon and British-Columbia since 1980, each with an average burn size of about 1500 hectares, totalling 8.3 million hectares of burn-affected land. Of these fires, 77 occurred in the study areas: 11 in Atlin, 6 in Whitehorse and 60 in Dawson. These numbers represent 4%, 11% and 38% of the study areas, respectively. The total burn area is greatest in the Dawson area where more than one-third of the terrain has been subject to historic fire.

2.2.3. Surficial geology

Surficial geology maps exist for parts of the Yukon at scales between 1:20,000 and 1:250,000 (Lipovsky and Bond, 2014). They use a five class system that includes texture, surficial material, surface expression, age and geomorphological process. The Yukon Geological Survey adopted this classification from the British Columbia Terrain Classification System by (Howes and Kenk, 1997), with only minor modifications (Lipovsky and Bond, 2014). Twelve surficial geology maps were obtained in the form of geodatabases from the Yukon Geological Survey (Table 4). There is no surficial geology mapping available for the Atlin study area.

Table 4: Surficial geology map metadata for the Dawson and Whitehorse study areas

Study area	Title (NTS)	Scale	Reference	Publication
Dawson	Crag Mountain (115N/15)	1:50K	(Jackson Jr., 2005a)	GSC Open File 4579
	Enchantment Creek (115N/16)	1:50K	(Jackson Jr., 2005b)	GSC Open File 4580
	Garner Creek (115O/13)	1:50K	(Jackson Jr. et al., 2005)	GSC Open File 4590
	Grand Forks (115O/14)	1:50K	(Froese and Jackson Jr., 2005)	GSC Open File 4591
	Dawson (116B-C)	1:250K	(Duk-Rodkin, 1996)	GSC Open File 3288
Whitehorse	Upper Laberge (105D/14)	1:50K	(Bond et al., 2005d)	YGS Geoscience Map 2005-8
	Whitehorse (105D/11)	1:50K	(Bond et al., 2005e)	YGS Geoscience Map 2005-7
	MacRae (105D/10)	1:50K	(Bond et al., 2005b)	YGS Geoscience Map 2005-6
	Robinson (105D/07)	1:50K	(Bond et al., 2005c)	YGS Geoscience Map 2005-5
	Alligator Lake (105D/06)	1:50K	(Bond et al., 2005a).	YGS Geoscience Map 2005-4
	Southern Lakes (105D/01-14)	1:100K	(Morison et al., 1982)	YTG unpublished
	Whitehorse (105D)	1:250K	(Morison and Klassen, 1991)	GSC Map 12-1990

Note: No surficial geology data is available for Atlin.

2.2.4. Covariance

Conceptually, *n*-factors characterize the thermal effect on ground surface temperatures of the presence or the absence of snow cover and shading. Low N_T values represent a relatively cool summer ground surface due to the shading effect provided by the vegetation canopy whereas low N_F values represents a relatively warm winter ground surface due to thermal insulation of the snowpack (Throop et al., 2012). These two variables were studied extensively, though their covariance is not well documented. Figure 15A illustrates the combined effect of N_F and N_T resulting in intermediate, warm, and cold ground surface temperatures.

n-factors can also be combined with R_K values to characterize top of permafrost temperatures. Figure 15B illustrates the intermediate, warm and cold combinations of N_T and R_K. Higher R_K values indicate equal (or greater) apparent thermally conductivity of the active layer in summer (Kt) and winter (Kf) – or even more thermally conductive. It means that, for example, the ground is wet and conductive in the summer but dries out before fall and becomes dry and non-conductive in the winter. Figure 15C illustrates the intermediate, warm and cold combinations N_F and R_K. These inter-relationships have not yet been explored previously in the literature.

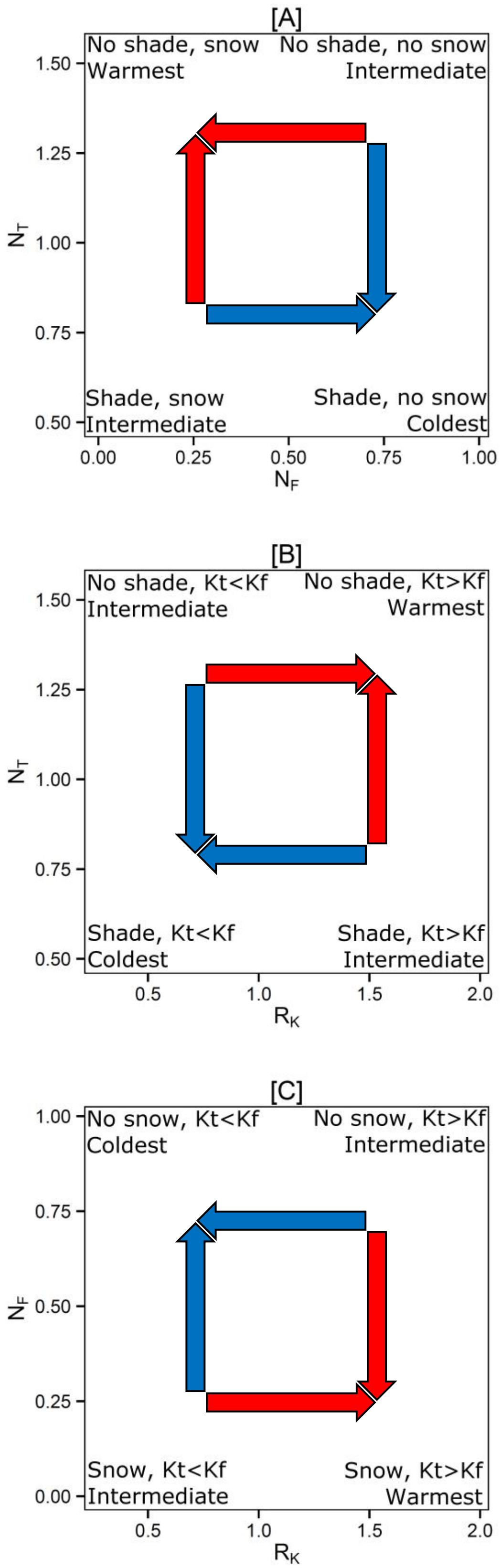

Figure 15: Conceptual diagram of the combined effects of freezing and thawing n-factors and R_K values on TTOP, assuming a consistent number of thawing and freezing degree days in the air. The red arrows show the warming direction and the blue arrows show the cooling direction on the ground surface.

2.3. Results

2.3.1. Topographic attributes

Topographic attributes were examined as potential controls for N_F, N_T and R_K at the instrumented sites using linear regression analysis. Elevation, slope, aspect and TPI were calculated for each site using the 30 x 30 m DEM as previously described.

The strength (r) and the 95% significance (p-value) of linear regression models were obtained for N_F, N_T and R_K with elevation and slope (Figure 16). Aspect influence was also visualised using polar diagrams (Figure 16).

N_F and elevation have a positive correlation ($r = 0.36$) that is statistically significant (p-value < 0.05, $n = 173$) indicating that higher N_F values are found at higher elevations (Figure 16A). N_T and elevation have a positive linear correlation ($r = 0.65$) that is also statistically significant (p-value < 0.05, $n = 123$) indicating that higher N_T values are also found at higher elevations (Figure 16B). R_K and elevation have a positive linear correlation ($r = 0.31$) that is statistically significant (p-value < 0.05, $n = 124$) indicating that higher R_K values are found at higher elevations (Figure 16C). The graphs show a high degree of scatter. This may be why the 3 models are yielding a range of permafrost probabilities, the variations around the linear relation is high.

None of N_F, N_T or R_K has statistically significant relationships with slope (Figure 19 D-F). It should be noted, however, that the steepest slopes monitored are less than 35°. The results might have been different, for N_F in particular, if sites which shed snow by avalanche in the winter had been sampled.

Aspect also does not show a strong relationship with N_F, N_T or R_K (Figure 16 G-I). The maximum values of N_F, N_T and R_K are highest in the northeast and slightly lower in the southwest. The northwest has low values in all three and there is a gap in the southeast. The minimum values for the three variables are similar for all aspects.

Polynomial models were attempted for elevation and slope, but there was no significant improvement in the results. Some scatterplots appear to show a polynomial distribution (e.g., Figure 16A), but closer inspection suggests that there is a step change between forests and shrubs at lower elevations, and tundra and bare rock sites at higher elevations.

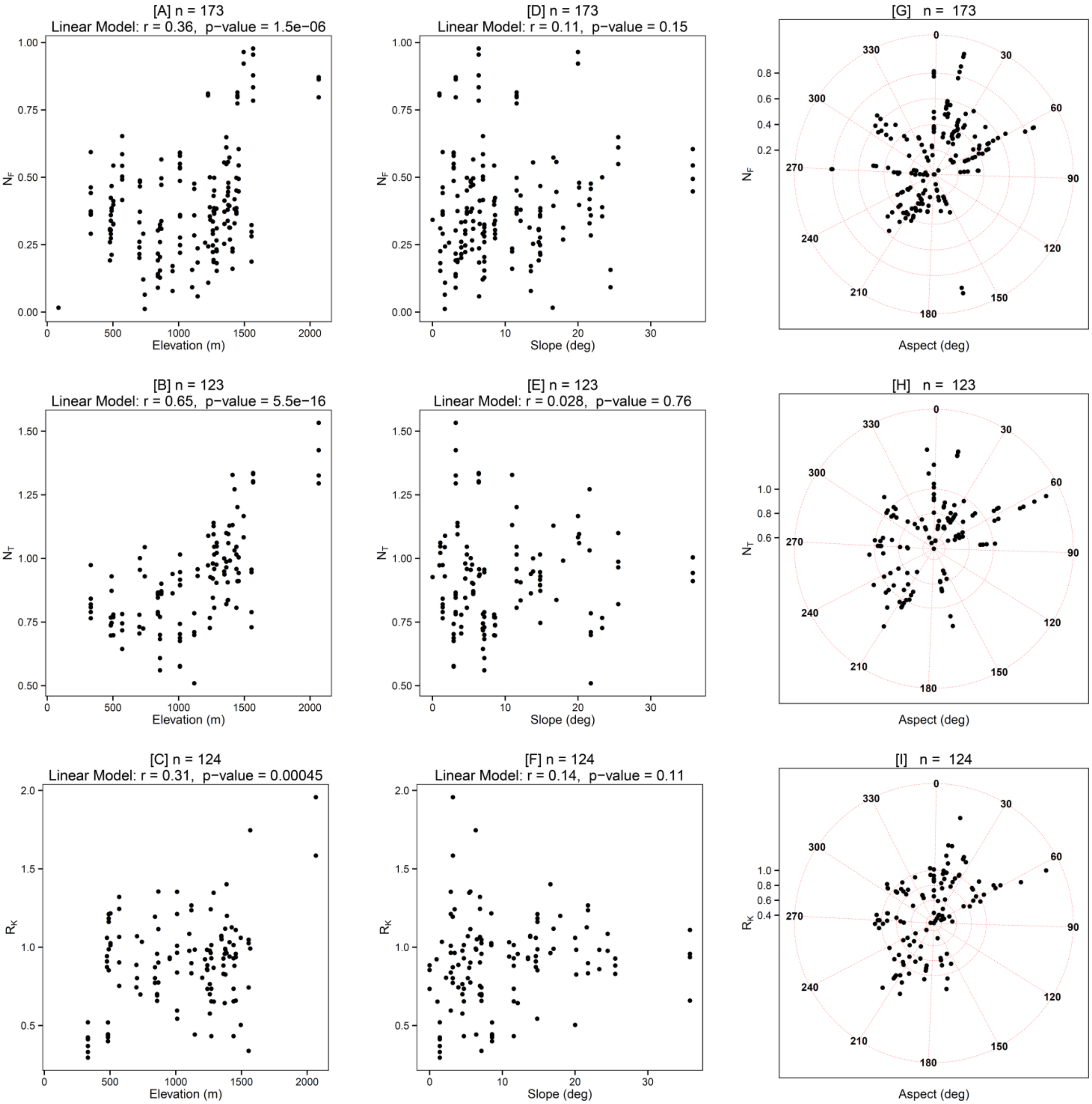

Figure 16: Scatterplot of N_F, N_T and R_K by elevation (m a.s.l.) [A, B, C]; by slope (deg) [D, E, F]; and by aspect (deg) [G, H, I]. The number of station-years is indicated above the individual plots. The values of the circular rings are given on the side of plots G-I. The strength of the linear relationship (correlation coefficient *r*) and the significance of the relationship (*p*-value) are only shown for elevation and slope.

Figure 17 presents scatter plots of TPI values (explained in section 2.2.1) with N_F, N_T and R_K using 700, 200 and 50 m search radii. The TPI (700 m) represents topographic positions relative to a 700 m search radius, thus encapsulating broad landscape features such as valleys and mountains. TPI (700 m) and N_F have a positive linear correlation (r = 0.2) that is statistically significant (p-value < 0.05, n = 173) suggesting that higher N_F values tend to be found in more convex terrain (Figure 17A). However, high N_F values are also present in both flat and very concave terrain (Figure 17A). TPI (700 m) and N_T also have a positive linear correlation (r = 0.19) that is statistically significant (p-value < 0.05, n = 123) suggesting that higher N_T values tend to be found in more convex terrain (Figure 17B). TPI (700 m) and R_K have a positive linear correlation (r = 0.31) that is statistically significant (p-value < 0.05, n = 124) suggesting that higher R_K values are associated with more convex terrain (Figure 17C).

The positive associations between TPI and N_F, N_T and R_K are maintained at smaller search radii (200 m and 50 m) (Figure 17D-I). In the case of N_T the correlation is strongest for a 200 m search radius (Figure 17E) while for the other parameters the highest correlation is for a 700 m search radius and the r value declines as the radius shrinks. In the case of N_F, the smaller TPI radii produce non-significant correlations.

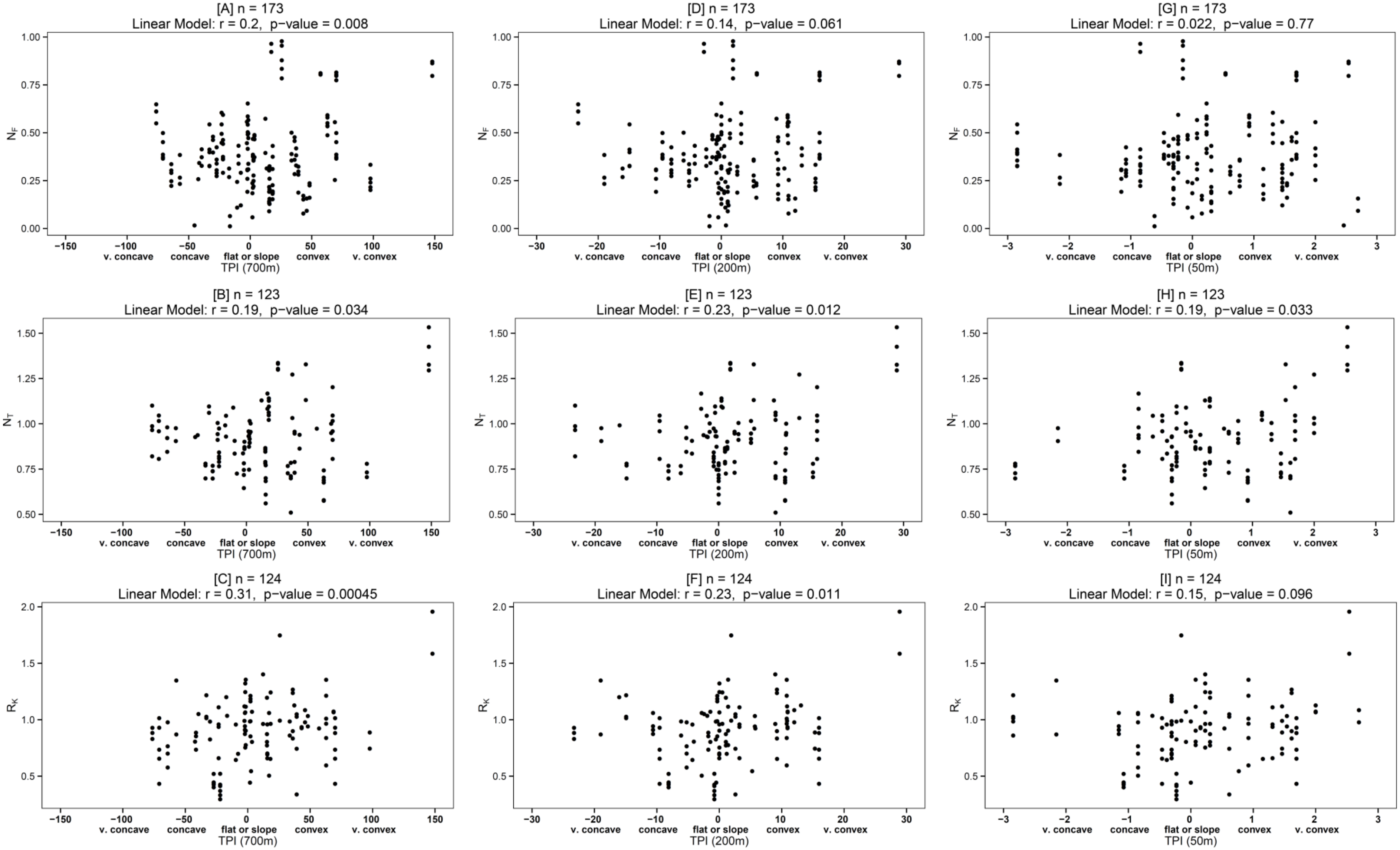

Figure 17: Scatterplot of N_F, N_T and R_K by TPI 700 (m) [A, B, C]; by TPI 200 (m) [D, E, F]; and by TPI 50 (m) [G, H, I]. The number of station-years is indicated above the individual plots. The strength of the linear relationship (correlation coefficient *r*) and the significance of the relationship (*p*-value) are given above the plot.

The results show that N_F is higher in more convex terrain and lower in more concave terrain, presumably because snow is deflated from the former and accumulates in the latter. Since only the TPI (700 m) is significant, broader landscape features influence N_F more than local features. However, it is probable that a 700 m TPI is also capturing elevation as well as convexity/concavity so the high N_F values are being affected by land cover associations (i.e. tundra and bare rock) with high elevations. Overall, N_T is higher in more convex terrain and lower in more concave terrain. This suggests that the ground surface receives more direct sunlight in convex terrain than concave terrain. The relationship is similar at all scales of TPI. Overall, R_K is higher in more convex terrain and lower in more concave terrain. This suggests that active layer materials are more thermally conductive in summer in convex terrain than concave slopes. There is likely to be drier soil and more bedrock exposed in convex terrain.

2.3.2. Land cover

The mean of the median N_F values for each land cover classification is 0.41 (Table 5). The two forested classes, the shrub and the maritime tundra classes have median N_F values below the mean and both rock and tundra are above it (Figure 18A). Table 6A is a matrix that tests the difference in means between each land cover class for N_F. The rock class is the most significantly different from all other classes (p-values < 0.000). The maritime tundra class appears to be different in the boxplot, though similarities exist between it and the coniferous and mixed class (p-value > 0.05). The two forested classes are not significantly different from each other, and shrubs have no significant difference from deciduous forests.

Table 5: Descriptive statistics of N_F, N_T and R_K by land cover classification, surficial geology texture and surficial geology materials.

			Percentile					
N_F	Land Cover	n	5th	25th	50th	75th	95th	S.D.
	Con. or Mixed	51	0.06	0.15	0.25	0.35	0.55	0.15
	Deciduous	13	0.12	0.26	0.37	0.47	0.48	0.14
	Rock	16	0.78	0.8	0.82	0.89	0.97	0.07
	Shrub	81	0.18	0.29	0.37	0.46	0.60	0.12
	Tundra	9	0.37	0.39	0.45	0.50	0.58	0.08
	Tundra (Maritime)	3	0.08	0.15	0.19	0.23	0.39	0.04
	Mean				0.41			
N_T	Land Cover							
	Con. or Mixed	36	0.64	0.73	0.79	0.9	0.96	0.11
	Deciduous	5	0.77	0.87	0.93	0.96	0.99	0.10
	Rock	13	0.95	1.17	1.30	1.33	1.47	0.17
	Shrub	60	0.66	0.77	0.85	0.99	1.12	0.16
	Tundra	7	0.84	0.93	0.96	1.01	1.04	0.08
	Tundra (Maritime)	2	1.00	1.08	1.12	1.18	1.30	0.14
	Mean				0.99			
R_K	Land Cover							
	Con. or Mixed	32	0.61	0.75	0.91	1.04	1.28	0.22
	Deciduous	12	0.83	0.90	0.96	1.09	1.20	0.14
	Rock	8	0.64	0.91	1.03	1.63	1.88	0.50
	Shrub	61	0.37	0.64	0.87	1.01	1.27	0.29
	Tundra	9	0.52	0.66	0.93	0.96	1.07	0.22
	Tundra (Maritime)	2	0.95	0.96	0.99	1.01	1.03	0.06
	Mean				0.95			
R_K	Surficial Texture							
	Gravel	4	0.75	0.82	0.87	0.93	1.03	0.13
	Mixed Fragments	90	0.44	0.74	0.93	1.06	1.30	0.26
	Sand	8	0.31	0.36	0.42	0.61	1.18	0.36
	Mean				0.74			
R_K	Surficial Materials							
	Rock	20	0.43	0.72	0.91	0.97	1.6	0.35
	Colluvium	50	0.44	0.71	0.9	1.05	1.26	0.25
	Fluvial	10	0.31	0.38	0.47	0.82	0.98	0.27
	Lacustrine	2	0.89	0.99	1.11	1.23	1.32	0.34
	Till	28	0.46	0.80	0.98	1.12	1.39	0.30
	Mean				0.87			

The mean of the median N_T values for each land cover classification is 0.99 (Table 5). The two forested classes, the shrub and the tundra classes have median values below the mean and both rock and maritime tundra are above it (Figure 18B). Table 6B is a matrix that tests the difference in means between each land cover class for N_T. The rock class is the most significantly different from all other classes (p-values < 0.000), except it is similar to the maritime tundra class (p-value > 0.05). The maritime tundra class appears to be different in the boxplot, though similarities exist between all classes except tundra (p-value > 0.05). The two forested classes are not significantly different from each other, and shrubs have no significant difference from deciduous forests. 28% of N_T values are above 1, indicating warmer ground surface temperatures than air temperatures in the thawing season.

A pattern is present where relatively low N_F values tend to be associated with relatively low N_T values (Figure 18A-B). Maritime tundra, however, has the opposite relationship between N_F and N_T. It has relatively low N_F values and high N_T values.

The mean of the median R_K values for each land cover classification is 0.95 (Table 5). Medians for individual land cover classes are all similar to 0.95, though the range of values in each class varies considerably (Figure 18C). Table 6C is a matrix that tests the difference in means between each land cover class for R_K. The only significant difference is between shrubs and deciduous forest. R_K values that are above unity indicate that measured TTOP is warmer than measured MAGST, an unexpected result that occurs in 32% of the measurements. This could be a measurement error introduced by the improper placement of TTOP loggers or ground surface temperature loggers or it may be indicative of net positive heat flux on an annual basis that is not captured by an equilibrium statistic.

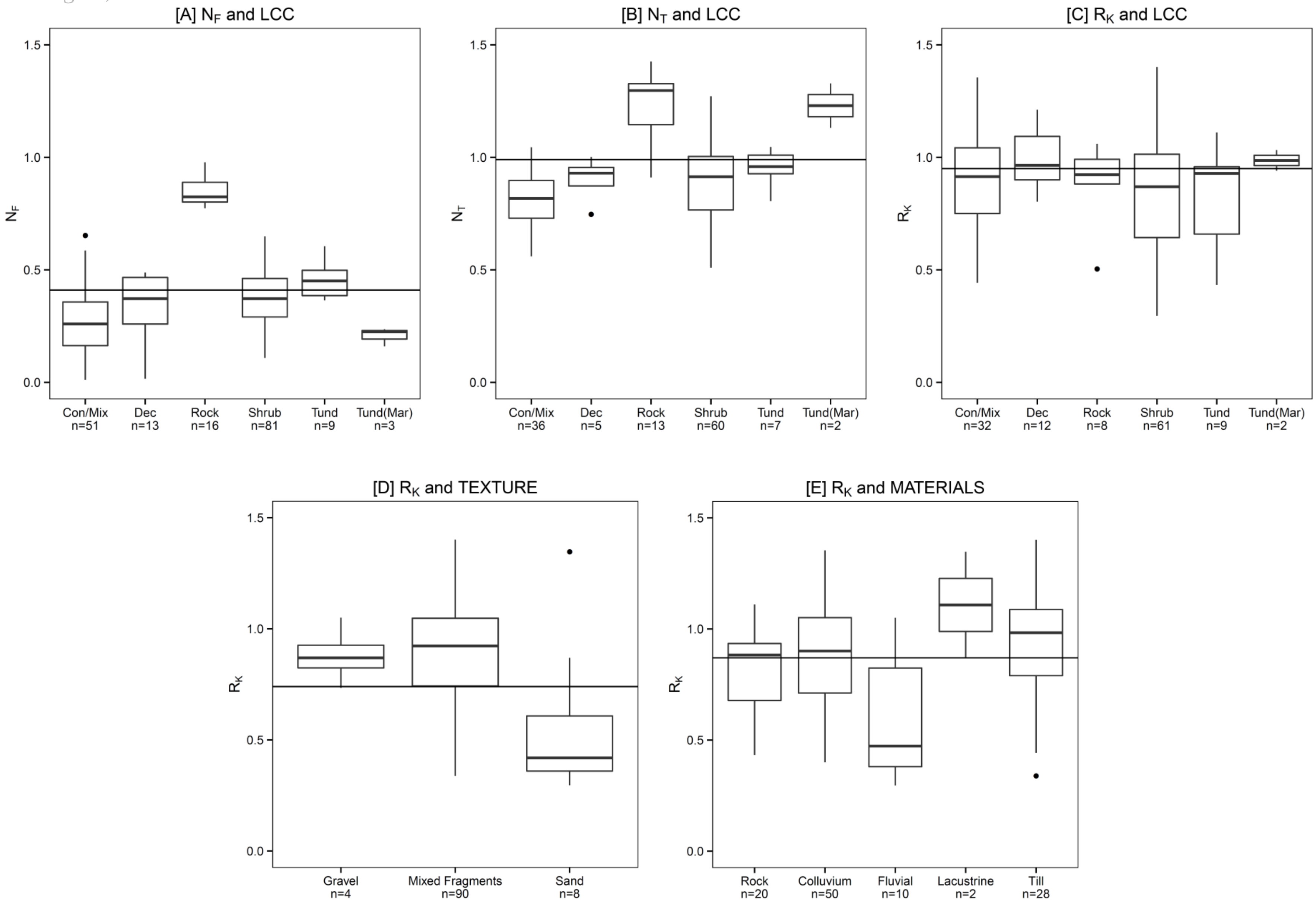

Figure 18: Boxplot distributions of N_F [A], N_T [B] and R_K [C] by land cover classification. R_K is also shown in relation to surficial geology texture [D] and materials [E]. The boxplot edges of the box represents the 25th and 75th percentiles, the whiskers represent the 5th and 95th percentiles and the black line represents the median. The mean of the medians of all of the classed is represented by a horizontal black line. Outliers are black points outside of these limits. The sample size (n) is given below each category.

Table 6: Significance levels (p-values) for difference of mean *t*-tests for N_F, N_T and R_K grouped by land cover classification [A-C] and by surficial geology texture [D] and materials [E].

	[A]	Con/Mix.	Decidu.	Rock	Shrub	Tundra
N_F	Decidu.	0.265				
	Rock	0.000*	0.000*			
	Shrub	0.000*	0.260	0.000*		
	Tundra	0.000*	0.013*	0.000*	0.019*	
	Tun. (Mar.)	0.051	0.016*	0.000*	0.004*	0.000*

	[B]	Con/Mix.	Decidu.	Rock	Shrub	Tundra
N_T	Decidu.	0.127				
	Rock	0.000*	0.000*			
	Shrub	0.011*	0.803	0.000*		
	Tundra	0.002*	0.345	0.000*	0.095	
	Tun. (Mar.)	0.138	0.139	0.905	0.166	0.194

	[C]	Con/Mix.	Decidu.	Rock	Shrub	Tundra
R_K	Decidu.	0.152				
	Rock	0.148	0.283			
	Shrub	0.140	0.005*	0.076		
	Tundra	0.294	0.059	0.076	0.904	
	Tun. (Mar.)	0.324	0.873	0.264	0.092	0.103

	[D]	Gravel	MixFrag
R_K	MixFrag	0.743	
	Sand	0.057	0.034*

	[E]	Rock	Colluv.	Fluv.	Lacus.
R_K	Colluv.	0.816			
	Fluv.	0.010*	0.006*		
	Lacus.	0.559	0.531	0.240	
	Till	0.653	0.344	0.000*	0.640

* indicates that a relationship is significant

2.3.3. Surficial geology

Active layer properties can be expected to be linked to the characteristics of surficial geology mapping products. Classification systems for surficial geology mapping use a variety of qualifiers such as texture, age, and materials (Howes and Kenk, 1997). The most important shortcoming of associating surficial geology classes with thermal conductivity values of the active layer is the omission of the organic mat and measurements of moisture content. It should be noted that there is no surficial geology map available for the Atlin study area. The Dawson and Whitehorse areas have surficial products at a variety of scales, though not all surficial classes that are present in the study areas are represented by instrumented climate stations. Two surficial qualifiers were extracted for the instrumented sites in the Dawson and Whitehorse regions. R_K was measured in three classes of texture and five classes of materials.

The mean of the median R_K values for each surficial texture is 0.74 (Table 5). Gravel and mixed fragments have median values above the mean and sand is below it (Figure 18D). Table 6D is a matrix that tests the difference in means between each surficial texture for R_K. These tests reveal that the only significant difference between classes is between sand and mixed fragments (p-values < 0.05).

The mean of the median R_K values for each surficial material is 0.87 (Table 5). Rock, colluvium, lacustrine and till classes have median values above the mean and fluvial material is below it (Figure 18E). Table 6E is a matrix that tests the difference in means between each surficial material for R_K. The only significantly different class is the fluvial class. It is different from all other classes, except the lacustrine class (p-value > 0.05).

2.3.4. Covariance

N_F, N_T and R_K are often studied independently (e.g., Henry and Smith 2001; Janke et al. 2012; Juliussen and Humlum 2007) and their covariance is not well documented or understood. N_F, N_T and R_K work together to have combined effects that result in the warming or the cooling of the ground surface and of TTOP (Figure 15). The three combinations of N_F, N_T and R_K are examined in Figure 19 linear best fit models are performed on all sites, on permafrost sites, and on non-permafrost sites.

Figure 15A demonstrates that the top left quadrant of the N_T to N_F scatterplot is associated with warmer ground temperatures and the bottom right is associated with colder ground surface temperatures. Three zones are identified in the N_T and N_F scatterplot with red dashed lines (Figure 19A). The first zone is found to the bottom right and contains only permafrost sites, the second is to the upper left and contains only seasonally frozen sites, and the third is a zone located in the middle that contains both. The mixed zone exists because of differences in R_K, FDD_A and TDD_A. Positive correlations exist between these two variables. Permafrost sites have the strongest correlation ($r = 0.66$, p-value < 0.05) and non-permafrost sites are weaker (r = 0.17) and not significant (p-value > 0.05).

Figure 19B investigates the relationship between N_T and R_K. Overall, there is no zonation in this plot and the correlation is positive ($r = 0.22$, p-value < 0.05).

Figure 15C shows that the top left of the N_F to R_K scatterplot is associated with colder ground temperatures and the bottom right is associated with warmer ground temperatures. Three zones are identified in the N_F and R_K scatterplot with red dashed lines (Figure 19C). The first zone is found to the top left and contains only permafrost sites, the second is to the bottom right and contains only seasonally frozen sites, and the third is a zone located in the middle that contains both. The mixed zone exists because of differences in FDD_A and TDD_A. Strong positive correlations exist between these two variables. Seasonally frozen sites have the strongest correlation ($r = 0.55$, p-value < 0.05) and permafrost sites are only slightly weaker (r = 0.52, p-value < 0.05). The cold zone has high N_F values (i.e. less snow) and low R_K values (i.e. less conductive active layer) resulting in less heat transferred to TTOP in summer and in winter. The warm zone has low N_F values (i.e. more snow) and higher R_K values (i.e. more conductive active layer) resulting in more heat transferred to TTOP in summer and less heat loss from the ground surface in winter.

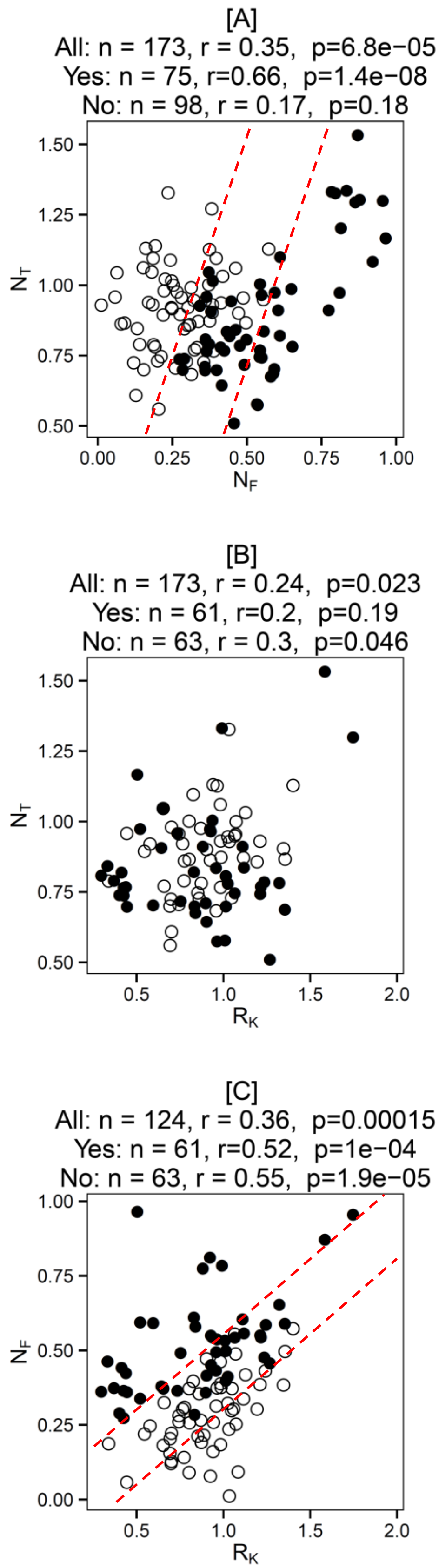

Figure 19: Scattereplots of the relationships among N_F, N_T and R_K. Filled and empty circles represent presence or absence of permafrost, respectively.

2.4. Concluding remarks

The two research questions of this chapter were: First, what are the relationships between climate-permafrost transfer functions (N_F, N_T and R_K), and topographic attributes, land cover and surficial geology? Second, how do climate-permafrost transfer functions vary together and what are their limits? The unique dataset described in Chapter 1 allows for a large number of sites to be analysed from the three study areas in Yukon and northern British Columbia.

The strongest relationships were obtained between N_F, N_T and R_K and elevation. They have positive linear correlations, respectively, of r = 0.36 (Figure 16A), r = 0.65 (Figure 16B), r = 0.31 (Figure 16C). The strongest correlation coefficient, N_T, reflects the thinning and eventual disappearance of the vegetation canopy with elevation. Lower elevations sites have more complete canopies and thicker understory vegetation that provides shade to the ground surface.

Slope is a biased statistic in this study as no sites are instrumented above 35° and the range of slope angles in the study areas is from 0° to 81°. N_F, N_T and R_K have positive linear correlations with slope, albeit weaker than those with elevation. These suggest that less shade, less snow and active layers with equal seasonal conductivities are found on steeper slopes. Values of N_F, N_T and R_K are highest for northeastern aspects, though minimums are similar for all aspects. Polynomial models did not improve these findings.

The three scales of TPI analysed with linear regression represent landscape features on the order of 700, 200 and 50 m. The largest of them, the 700 m radius, has positive correlations with N_F, N_T and R_K of r = 0.2 (Figure 17A), r = 0.19 (Figure 17B) and r = 0.31 (Figure 17C). The 200 m and 50 m radii resulted in similar correlations, except at the 50 m scale a weak correlation of r = 0.022 was obtained with N_F (Figure 17G). This indicates that snow cover is most variable at the 50 m scale. These results suggest that snow is transported from convex slopes and accumulates in concave slopes, that positive relief features are more exposed to incoming solar radiation and have less shade, and that convexities have more thermally conductive active layers in summer.

Boxplots classed by land cover have revealed a pattern whereby relatively low N_F values are typically associated with relatively low N_T values (Figure 18A-B). Maritime tundra, however, has the opposite relationship between N_F and N_T because of the deeper snow found in this environment. 32% of the measured R_K values are above unity, indicating that measured TTOP is warmer than measured MAGST. This could be a measurement error introduced by the improper placement of TTOP loggers or ground surface temperature loggers or it may be indicative of net positive heat flux on an annual basis that is not captured by an equilibrium statistic. Two surficial geology qualifiers are compared to climate permafrost transfer functions for Dawson and Whitehorse. Surficial geology texture classes only have significantly different means between sand and mixed fragments, whereas surficial geology material classes have significantly different means between fluvial and all other classes, except the lacustrine class.

Three zones can be identified in the N_F and N_T scatterplot (Figure 19A). The first zone is found to the bottom right and contains only permafrost sites, the second is to the upper left and contains only seasonally frozen sites, and the third is a zone located in the middle that contains both. The mixed zone exists because of differences in R_K, FDD and TDD. Three zones can also be identified in the N_F and R_K scatterplot (Figure 19C). The first zone is found to the top left and contains only permafrost sites, the second is to the bottom right and contains only seasonally frozen sites, and the third is a zone located in the middle that contains both.

Higher resolution spatial data may improve this type of analysis in the future. Land cover classifications were identified as an important control on climate-permafrost transfer functions and will therefore be used in following chapters to create a vegetation-driven TTOP-model. The strongest correlations are between elevation and N_T and between elevation and N_F.

CHAPTER 3: TTOP-model assessment and validation

3.1. Introduction

The TTOP-model has multiple parameters that collectively account for both surface and subsurface processes and conditions. These are often computed using single values of N_F, N_T, and R_K for each of the land cover and surficial geology classifications (see Section 1.2.2). In this chapter, a quantitative modelling approach is used to assess and validate the TTOP-model. Given the large field dataset available in the three study areas (see Chapter 1), this chapter explores the following two research questions: (1) how well does the TTOP-model predict measured TTOP temperatures and the presence of permafrost and, (2) how sensitive is the TTOP-model to changes in input parameters?

3.2. Methodology

In order to investigate the predictive ability of the TTOP-model, the model was implemented in R, a statistical software package that allows, among other things, iterative modelling and conditional programing (http://www.r-project.org/). The TTOP-model compiles all individual station-years that have complete records for FDD_A, TDD_A, N_F, N_T, R_K and TTOP. The model then divides the data using a random sampling scheme into testing and training datasets. The sampling is done five times to create training datasets of 5%, 25%, 50%, 75% and 95% of the original data, and is tested against the entire dataset (i.e. test dataset = 100%). The entire dataset is used as a test dataset because when training is 95%, the test dataset is inconclusive (only 5%). These are referred to below as the “random sampling schemes”. The sampling is done for each land cover classification individually to ensure that all land cover classes are included in each random sampling scheme.

The training datasets are used to determine the input values (N_F, N_T and R_K) for the calculation of the TTOP-model. In order to model a variety of equally likely scenarios, seven values (the 1st, 5th, 25th, 50th, 75th, 95th, and 99th percentiles) of each input variable are calculated from the training dataset. These 21 values are assigned to the testing dataset based on land cover. The data (N_F, N_T, R_K) are assumed to be normally distributed within each land cover classification (see Chapter 1) and the percentiles are calculated from the distribution curve.

The model is then iterated 1000 times for each random sampling scheme using the measured values of FDD_A and TDD_A for each station year. TTOP is calculated using the pairs of low and high percentile values of N_F, N_T and R_K (*e.g.*, 1st and 99th, 5th and 95th, and 25th and 75th percentiles). Cold scenarios of TTOP are calculated using low R_K and N_T values and high N_F values (Equation 1.6), whereas warm scenarios are calculated in the opposite way (Equation 1.7). The mean value for each pair of high and low percentiles is calculated as the mean of the warm and cold scenarios. In addition, the 50th percentile values are used to calculate the median TTOP prediction. In total seven TTOP predictions are made for each of the five random sampling schemes, they are: extremely cold, very cold, cold, median, warm, very warm and extremely warm predictions.

$$TTOP_{cold} = \frac{R_K^{low} N_T^{low} TDD_A - N_F^{high} FDD_A}{P} \quad [1.6]$$

$$TTOP_{warm} = \frac{R_K^{high} N_T^{high} TDD_A - N_F^{low} FDD_A}{P} \quad [1.7]$$

3.2.1. TTOP assessment

Four methods are used to assess how well the TTOP-model predicts measured TTOP values. The first method assesses a baseline model of applying a standard “total offset” to

MAAT regardless of environmental variables (see Section 1.4.4). The second method compares both mean and median TTOP predictions with the measured TTOP values. The third method calculates a rate of success (in percent) if the measured TTOP value is within the limits of the warm and cold scenarios for each pair of percentiles described previously. Finally, the fourth method investigates the presence of permafrost and calculates a rate of success if both the measurement and the prediction of TTOP are below zero.

3.2.2. Model Sensitivity

The sensitivity of the TTOP-model is assessed by iterating the model using all of the measured values for a single station-year, except for one. The model is iterated 1000 times using all measured values except the 5th, 25th, 50th, 75th, and 95th percentiles of N_F, N_T and R_K. In addition, changes in FDD_A and TDD_A are explored by modifying FDD_A and TDD_A by ±100°C-days and ±500°C-days.

3.3. Results

3.3.1. TTOP assessment

The quantitative model incorporates 89 station-years that have complete values of N_F, N_T, R_K, FDD_A and TDD_A. The model was iterated 1000 times. Five sets of 89 000 predictions were calculated using training datasets of 5% (n=9), 25% (n=25), 50% (n=47), 75% (n=68) and 95% (n=82). Eight TTOP predictions were made for each random sampling scheme using the 1st, 5th, 25th, 50th, 75th, 95th, and 99th percentiles of N_F, N_T, and R_K, and a mean scenario (total 3.56 million predictions). Note that the sample size (n) of station-years per set of predictions is not directly a percentage of the total sample population because the percentage of inputs is calculated for each land cover classification and results in rounding errors (*i.e.* the 50% random sampling scheme uses 47 out of 89 station years = 53%).

As a first approximation of TTOP, we used the "total offset" (see Figure 14). This approach ignores all environmental variables and simply applies an offset between MAAT and TTOP, with TTOP being warmer than MAAT (see Figure 2). Three scenarios are compared with measured TTOP-values. The first uses the 5^{th} percentile of the "total offset", or MAAT + 5.6°C (Figure 20A): 8% of predictions are within ±1°C of the measured values and 31% are within ±2°C. The second uses the 50^{th} percentile of the "total offset", or MAAT + 3.0°C (Figure 20B): 58% of predictions are within ±1°C of the measured values and 89% are within ±2°C.The third uses the 95^{th} percentile of the "total offset", or MAAT + 1.0°C (Figure 20C): 22% of predictions are within ±1°C of the measured values and 52% are within ±2°C.

Mean and median TTOP scenarios were modelled using average and median values of N_F, N_T and R_K. When comparing the mean model with the measured TTOP values (Figure 20D), 64% of predictions are within ±1°C of the measured values and 85% are within ±2°C. When comparing the median model and the measured TTOP values (Figure 20E), 63% are within ±1°C and 92% are within ±2°C.

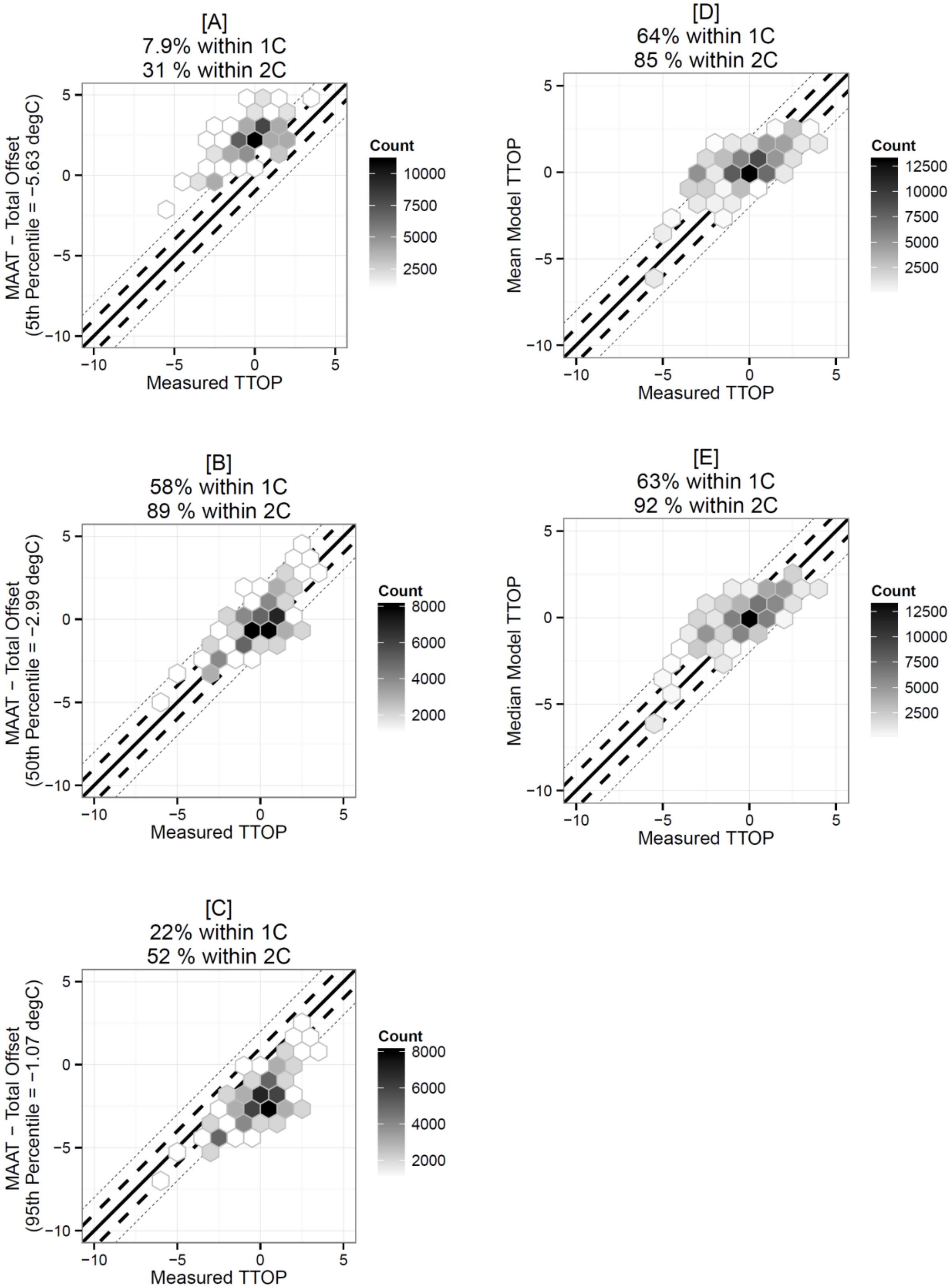

Figure 20: Hexbin plots of TTOP predictions compared to measurements using the 5th, 50th and 95th percentiles of the "total offset"-model [A,B,C] and the mean and median TTOP-models [D,E].

Examining the impact of sample size on prediction success, we determine if measured TTOP values are within the limits of the predicted extreme warm/cold scenarios (1st and 99th percentiles), the very warm/cold scenarios(5th and 95th percentiles), and the warm/cold scenarios(25th and 75th percentiles).

Smaller training datasets are less successful than larger training datasets (Figure 21). Naturally, because their range is greater, the extreme scenarios are more successful at including measured values within their limits. 84% of predicted TTOP temperatures are within the limits of the 25thth and 75th percentile predictions using a training sample size of 95% (n = 82) of the input data (Figure 21). This percentage falls relatively slowly until the training sample size drops below 50% (n = 47; Figure 21). With a 25% (n = 25) training sample size only 66% of the predicted TTOP temperatures are within the limits of the 25th and 75th percentile predictions. For the 5% (n = 9) training sample size only 36% of the predicted TTOP temperatures are within the limits of the 25th and 75th percentile predictions (Figure 21).

Overall the more narrow limits of the 25th to 75th percentile predictions have the least success in predicting TTOP values. As the limits increase to a wider range, the measured TTOP values will be more likely to be within the prediction limits. The training sample size is also important. Using only 5% of the input data (n = 9 station-years) achieves low success rates (<61%) whereas increasing to 50% of the input data (n = 47 station years) increases success by 40% or more. Increasing beyond 50% of the input data yields improvements of 5% or less (Figure 21).

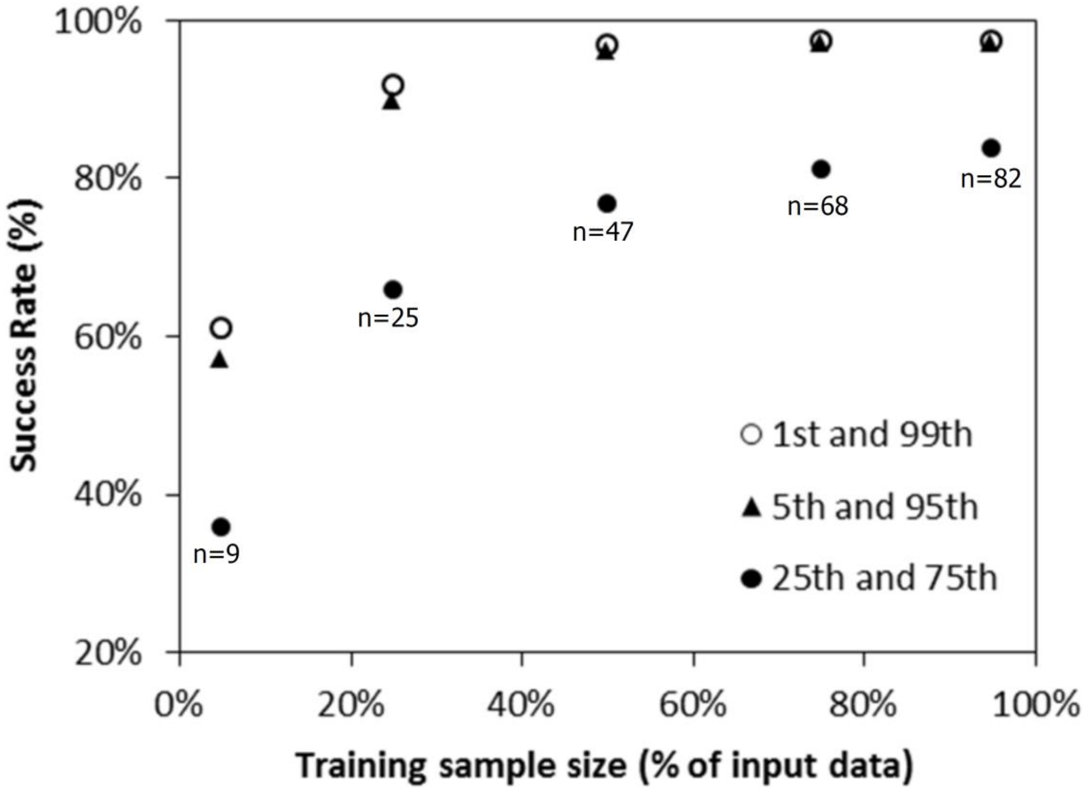

Figure 21: Plot of the percentage of measured TTOP values that are within the limits of cold and warm predictions using the 1st and 99th percentiles, the 5th and 95th percentiles and the 25th and 75th percentiles of the input variables N_F, N_T and R_K.

3.3.2. Model Sensitivity

The sensitivity of the TTOP-model has yet to be explored in the literature. Here we present results from a random iteration of the model, following the same methodology as the previous section, except only one variable at a time is iterated and all other values are measured.

Considerable scatter results when we iterate through all scenarios of N_F (Figure 22A): 59% of TTOP predictions are within ±1°C of measured values and 88% of are within ±2°C. Much less scatter develops when we iterate through all scenarios of N_T (Figure 22B): 92% of TTOP predictions are within ±1°C of measured values and 100% of are within ±2°C. Moderate scatter is achieved when we iterate through all scenarios of R_K (Figure 22C): 64% of TTOP predictions are within ±1°C of measured values and 91% of are within ±2°C.

The TTOP predictions using TDD_A ±100 and ±500°C-days (i.e. 4 scenarios) are compared with TTOP measurements (Figure 22D): 97% of TTOP predictions are within ±1°C of measured values and 100% of are within ±2°C. The TTOP predictions using FDD_A ±100 and ±500°C-days (i.e. 4 scenarios) are compared with TTOP measurements in Figure 22E: 77% of TTOP predictions are within ±1°C of measured values and 98% of are within ±2°C.

The TTOP model is more sensitive to N_F than N_T as the iterations produce more scatter. This is likely has two causes: the first is that FDD_A values are greater than TDD_A values in the three study areas, and the second is that N_F has a greater range of values than N_T. Similarly, the TTOP model is more sensitive to TDD_A than FDD_A because FDD_A is dampened by snow cover (N_F values are lower than 1) and TDD_A is often amplified by N_T (values near 1 or greater). The model is also sensitive to R_K because R_K values above and below 1 serve to amplify TDD_A.

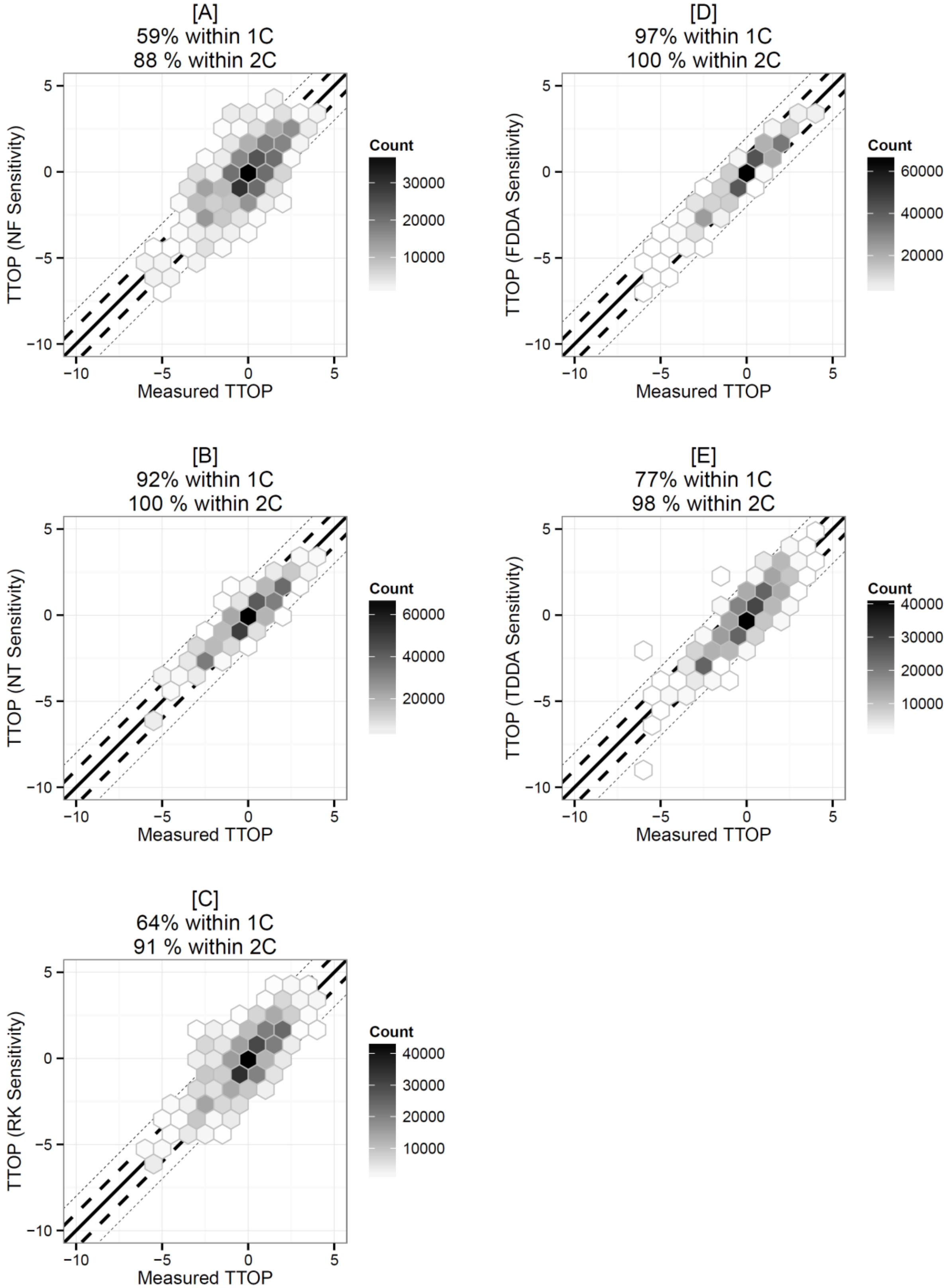

Figure 22: Hexbin plots of TTOP predictions compared to measurements to assess the model sensitivity to changes in N_F, N_T and R_K [A,B,C] and to changes in FDD_A and TDD_A [D,E]. The lines represent 1:1, ±1°C and ±2°C.

3.4. Concluding remarks

As a first approximation of TTOP we have used a “total offset”-model that ignores environmental variables altogether. Running the “total offset”-model with + 3.0°C offset yields 58% of predictions within ±1°C and 89% within ±2°C of measured values. Using the land cover driven TTOP-model, explained throughout the entirety of this thesis, with mean input values, we obtain 64% of predictions within ±1°C and 85% within ±2°C of measured values. The TTOP model with median values is slightly superior with 63% of predictions within ±1°C and 92% within ±2°C of measured values. Moving from a total offset to a TTOP model increases the amount of predictions that are within ±1°C by 5% and within ±2°C by 3%. This demonstrates that the TTOP-model yields only slightly better results than a very simple “total offset”-model using a +3°C offset for the study sites.

To assess how well the predictions reflect measured values, we observed how many of the measured values are within the limits of warm and cold model predictions. Using only 5% of the input data (n = 9 station-years) achieves low success rates (<61%) whereas increasing to 25% of the input data (n = 25 station years) increases success by 30% or more. Increasing beyond 25% of the input data also yields improvements, but of 10% or less. The mean model predicts the frozen/un-frozen state of the ground correctly in 72% of cases and is much less sensitive to changes in sample size.

The TTOP model is most sensitive to variations in N_F, R_K and TDD_A and less sensitive to differences in N_T and FDD_A. Snow cover, through N_F, is very important to the TTOP-model because it has a dramatic effect on the freezing degree-days at the ground surface. N_F varies from nearly 0 to nearly 1 and FDD_A is larger than TDD_A in these areas. R_K also has a large range of values and is still poorly understood because of a lack of appropriate site descriptions and among other factors, spatial datasets of active layer hydrology. R_K values are above and below 1, and can in some cases amplify the effect of TDD_A. TDD_A is a sensitive parameter because TDD_A can be amplified by both N_T and R_K. Differences in FDD_A are buffered by snow cover and exert relatively small effects on the TTOP values. Differences in N_T are less important because TDD_A is less than FDD_A at almost all sites in the three study areas.

CHAPTER 4: Spatial distribution of permafrost using the TTOP-model

4.1. Introduction

The TTOP-model (Smith and Riseborough, 1996, 2002) has been used to predict the spatial distribution of top of permafrost temperatures at a variety scales (e.g., Gisnås et al. 2013; Henry and Smith 2001; Janke et al. 2012; Juliussen and Humlum 2007; Wright et al. 2003). This chapter investigates the implementation of a land cover driven TTOP-model to predict permafrost distribution in three study areas within southern Yukon and northern British-Columbia. The following research questions are explicitly addressed in this chapter: (1) what are the predicted patterns of permafrost distribution in the three study areas, and (2) how does the TTOP-model compare to other predictions of permafrost distribution in these areas?

4.2. Methodology

The TTOP-model is thoroughly described in Chapter 1. The spatial implementation of this model was undertaken using ESRI ArcGIS 10.2 software. The model has three steps: the first is a prediction of seasonal air temperatures, the second is a prediction of ground surface temperatures and the third is a prediction of top of permafrost or ground temperatures. The methodology used is explained in the following three sections.

4.2.1. Air temperature

The TTOP-model requires gridded predictions of F/TDD_A in order to predict ground surface and top of permafrost temperatures. Freezing and thawing degree-day lapse-rates of the air (F/TDD_A-LR) were calculated for each study area in order to incorporate topographic impacts. Linear and polynomial regression analysis was undertaken to understand how F/TDD_A change with elevation in each of the areas. A 30 x 30 m resolution F/TDD_A prediction was developed for each study area by applying the individual measured F/TDD-LR to the DEM described earlier in Section 2.2.1. In this model, therefore, near-surface air temperatures are entirely controlled by elevation.

4.2.2. Ground surface temperature

The F/TDD_A predictions were transformed into F/TDD_S predictions using a range of N_F and N_T values. As no meaningful correlation was found between environmental variables beyond the use of a simple land cover classification for *n*-factors (see Chapter 2), the very cold, cold, mean, warm and very warm scenarios of N_F and N_T for the six land cover classes were used to bracket the model (see Figure 23). The classes are: coniferous or mixed, deciduous, rock, shrub, tundra and maritime tundra. These five scenarios, from very cold to very warm, use the 5^{th}, 25^{th}, 50^{th}, 75^{th} and 95^{th} percentiles of the N_F and N_T data in order to calculate ground surface temperatures (similar to Section 3.2).

The EOSD dataset was used to assign *n*-factors in the three study areas. This dataset uses a very detailed classification scheme (see Section 2.2.2) that was simplified to only six classes: coniferous and mixed forest, deciduous forest, shrubs, maritime tundra, tundra, and bare rock. This simplification was required to have sufficient data points in each class. The model was not used to predict permafrost conditions beneath lakes, glaciers or developed areas which were masked out by removing the “Snow and Ice”, the “Water” and the “Developed” land cover classifications. Major roads were also masked from the model by creating a buffer region of 100 m and clipping the output raster. Historical forest fires were masked from this analysis by using the CNFDB dataset described in Chapter 2. F/TDD_S predictions were output in a gridded raster dataset for each of the five scenarios of ground surface temperatures.

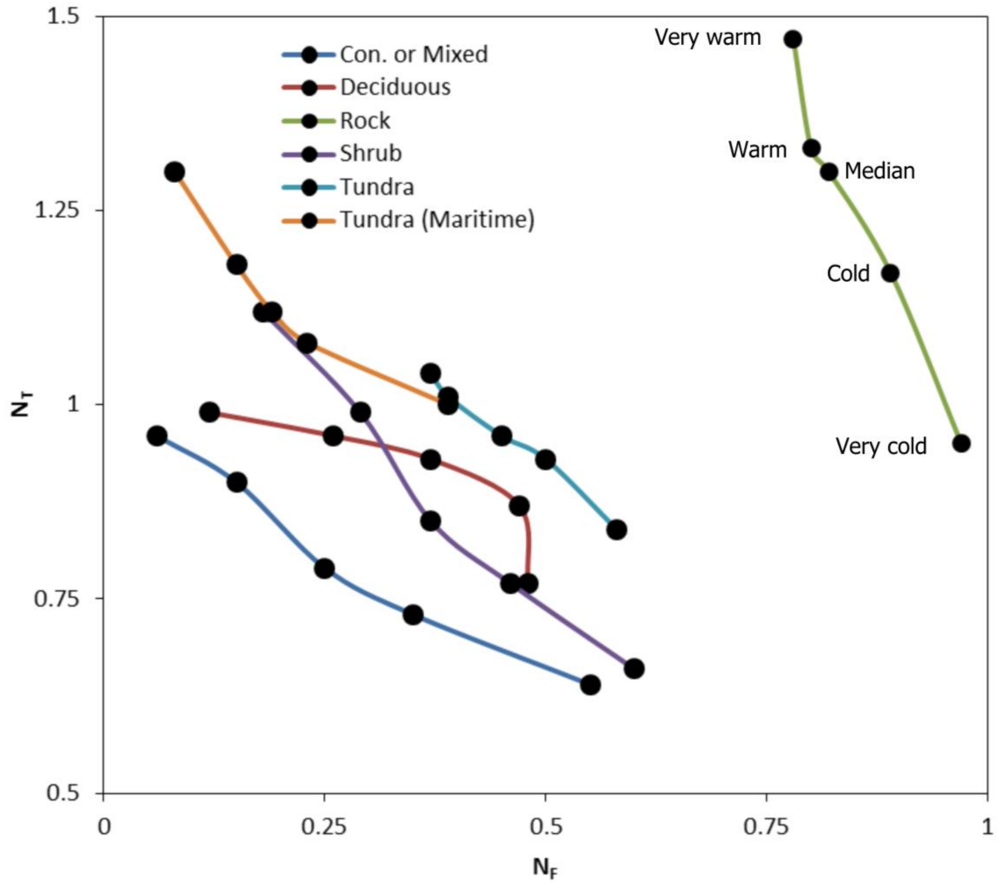

Figure 23: Schematic representation of the five scenarios (very warm, warm, median, cold and very cold) calculated for each land cover classification. Data from Table 5 and used in the spatial implementation of the TTOP-model.

4.2.3. Top of permafrost

The F/TDD$_S$ predictions were transformed into predicted TTOP values using R_K. As no meaningful correlation was found between environmental variables and the thermal offset parameters (Chapter 2), very cold, cold, median, warm and very warm scenarios of R_K were used. The EOSD dataset was used to assign R_K values to each grid cell in each study area (see Figure 18C).

Five scenarios of gridded TTOP predictions were obtained using Equation 1.6. The five TTOP-model predictions were used to calculate a likelihood of permafrost. The likelihood ranges from 0 indicating no permafrost in any of the five scenarios to 1 indicating permafrost in all scenarios.

4.2.4. Model comparison

Two other models of permafrost probability were compared with the outputs from the TTOP-model: (1) a “total offset”-model (TOFF-model; Section 1.4.4), and (2) a “basal temperature of snow” model (BTS-model; Section 1.2.2). The TOFF-model used a fixed offset from MAAT.

Five scenarios were used to rank the probability of permafrost in the landscape. The values of the TOFF used, termed very cold, cold, median, warm and very warm scenarios, are obtained from the 5th, 25th, 50th, 75th and 95th percentiles of the measured offset (Section 1.4.4), which respectively are: 5.6, 3.7, 3.0, 2.4, and 1.1°C. The BTS model of permafrost distribution in these areas is available for download from the Yukon Permafrost Network (http://permafrost.gov.yk.ca/) and is described in Bonnaventure et al. (2012).

4.3. Results

4.3.1. F/TDD$_A$ predictions

A 30 x 30 m resolution spatial model of F/TDD$_A$ is presented for each study area. The F/TDD$_A$ predictions rely on F/TDD$_A$-LR obtained from regression analysis of station elevation and measured values of F/TDD$_A$. A linear regression model produces a strong relationship between TDD$_A$ and elevation (n = 135; r = 0.92; Figure 24) indicating that elevation is the main control on TDD$_A$. The slope of the linear model is negative so that TDD$_A$ decreases with elevation by 1273°C-days per vertical kilometer. This model estimates 2123°C-days at sea level and estimates 0°C-days at 2497 m a.s.l. Many of the regions of the Yukon are above this elevation and may have positive thawing degree days in the air. Climate station data from above 2500 m a.s.l. would be needed to better understand air temperature trends above treeline.

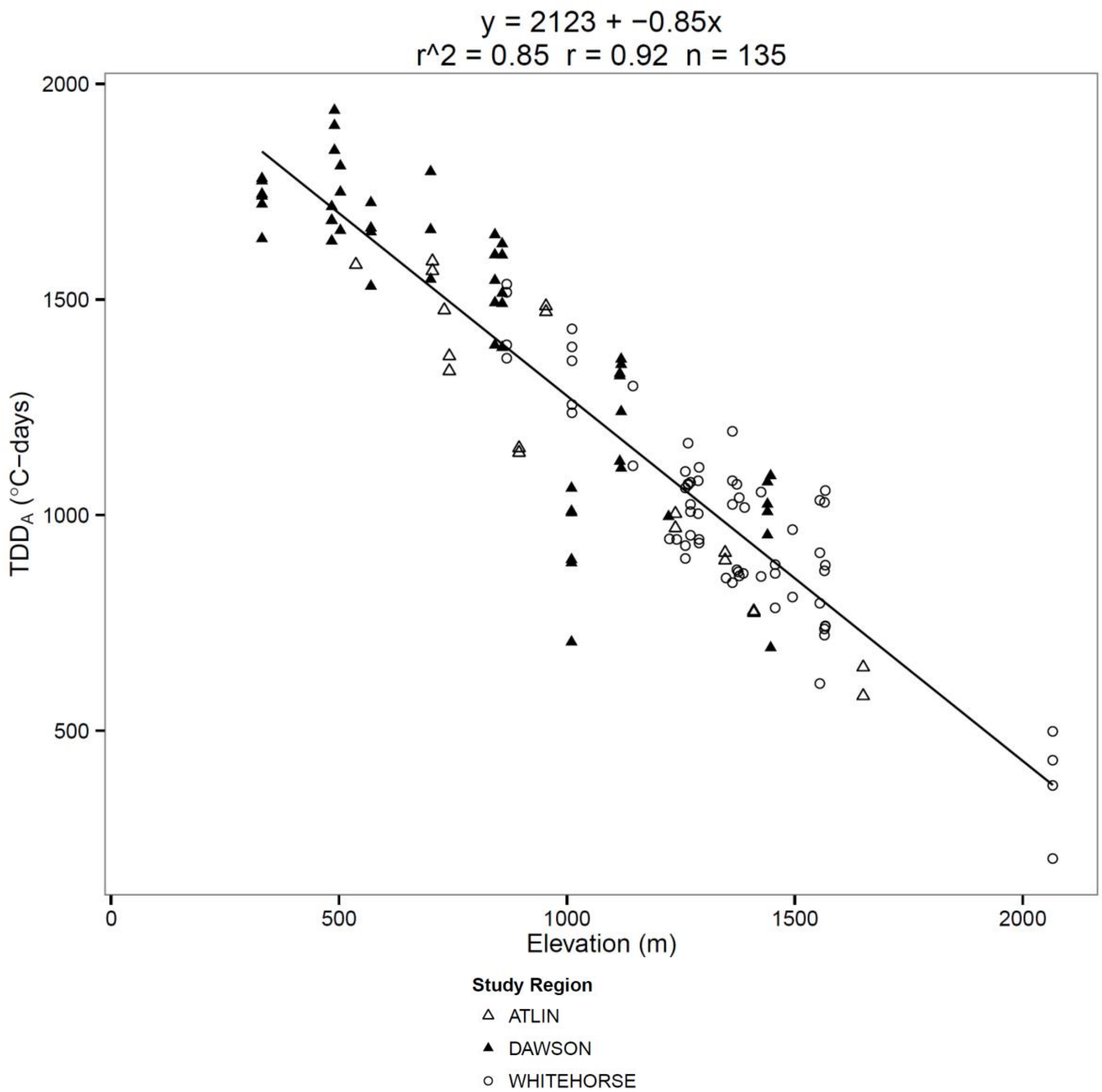

Figure 24: Scatter plot of TDD_A vs. station elevation. The shape of the data point identifies the region. The black line is a linear model for all station-years.

A polynomial regression model produces strong relationships between FDD_A and elevation for each study region, but a weak relationship for the entire area. This suggests that elevation is a significant influence on FDD_A within each study region. In Atlin (Figure 25), the relationship is positive with FDD_A increasing with elevation by about 600°C-days/km. In fact a linear model could sufficiently describe this relationship. The Atlin model estimates about 1100°C-days at sea-level. In Whitehorse (Figure 25), the relationship between elevation and FDD_A changes at treeline. Below treeline slightly inverted lapse-rates of about -100°C-days/km were measured between 700 and 1200 m a.s.l. Above treeline, more normal lapse-rates of about 700°C-days/km were measured between 1400 and 1900 m a.s.l. At sea level the Whitehorse model estimates about 2700°C-days whereas at the elevation of Whitehorse itself, the model estimates about 2100°C-days. Lapse rates above and below the highest and lowest measurement sites may not be accurate as a polynomial function cannot be verified. In Dawson (Figure 25), the relationship between elevation and FDD_A is mostly negative. Below treeline inverted lapse-rates averaging about -1100°C-days/km were measured between 300 and 800 m a.s.l., above treeline, the trend line flattens but is still inverted at about -450°C-days/km between 1000 and 1500 m a.s.l.

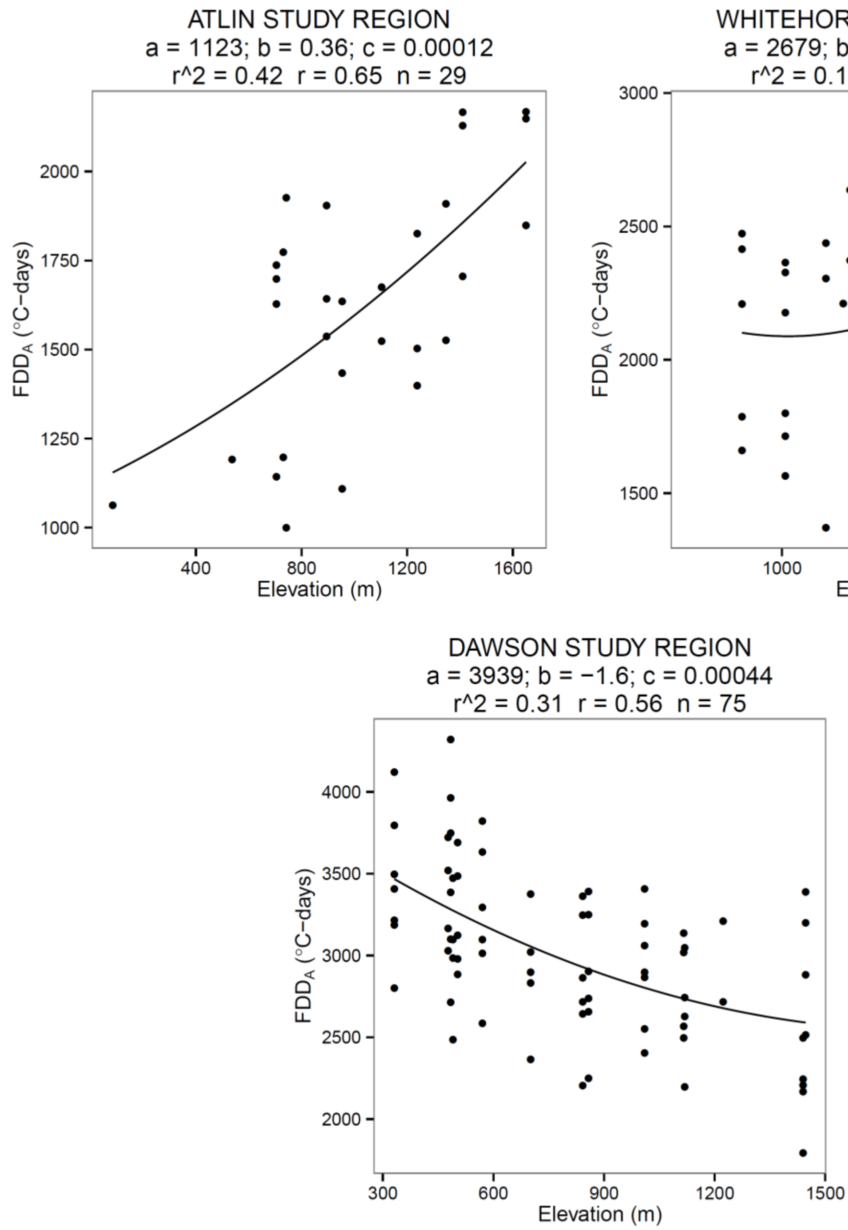

Figure 25: Scatter plot of FDD_A and station elevation for Atlin, Whitehorse and Dawson. Second order polynomial fits were plotted (dark line) and the parameters shown are from the equation: $y = cx^2 + bx + a$.

Gridded degree-day predictions were made using the general linear model for TDD_A and the three individual polynomial models of FDD_A and were combined to calculate MAAT. In Atlin, MAAT ranges from positive values in the valley bottoms to cold mean temperatures in the alpine (Figure 26). MAAT predictions in the Atlin region represent a linear SLR of -4.6°C/km both above and below treeline. The entire Whitehorse study area is predicted to be below zero with the warmest temperatures of about -1°C in valley bottoms (Figure 27). The Whitehorse region has a SLR of -4.9°C/km above treeline and a SLR of -2.8°C/km below treeline. The Dawson region is quite uniform in temperature with the exception of the mountainous areas in the southwest and the northeast (Figure 28). The Dawson region has a SLR of -2.7°C/km above treeline and a SLR of -0.1°C/km below treeline.

Dawson is the coldest study area, on average (-4.1°C) but the coldest calculated MAAT is in the alpine zone of Atlin. The warmest study area is Atlin (mean of -1.3°C) with a maximum MAAT of 3.2°C. The range of MAAT in Atlin, Whitehorse and Dawson is 11.6, 6.7, and 3.1°C, respectively. Atlin has the largest contrasts in MAAT owing to the large range of elevations and the complementary nature of normal seasonal lapse-rates. Dawson is fairly uniform in its climate as the SLR is near zero below treeline and is gentle above treeline.

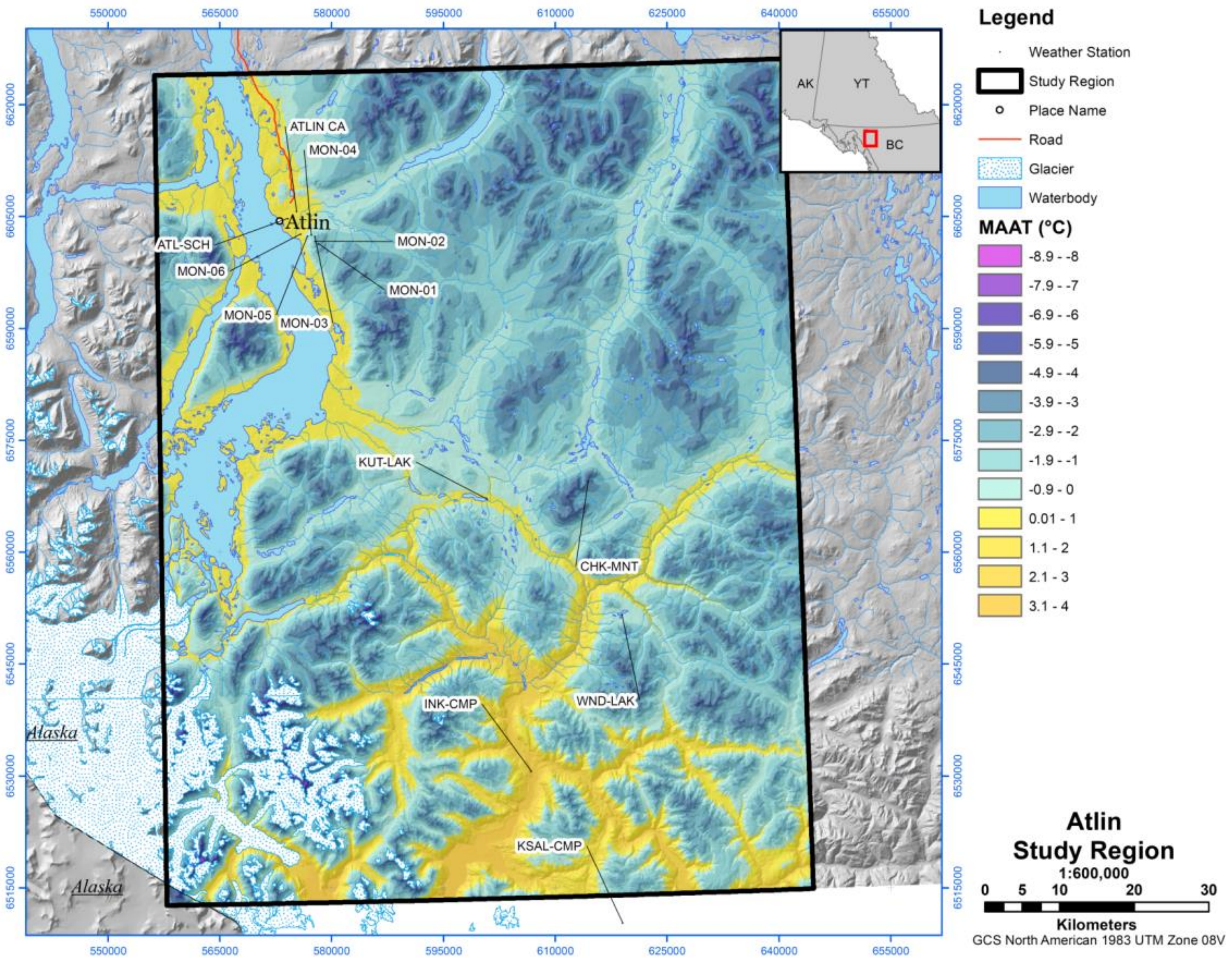

Figure 26: Predicted mean annual air temperature for the Atlin Study area using measured climate data.

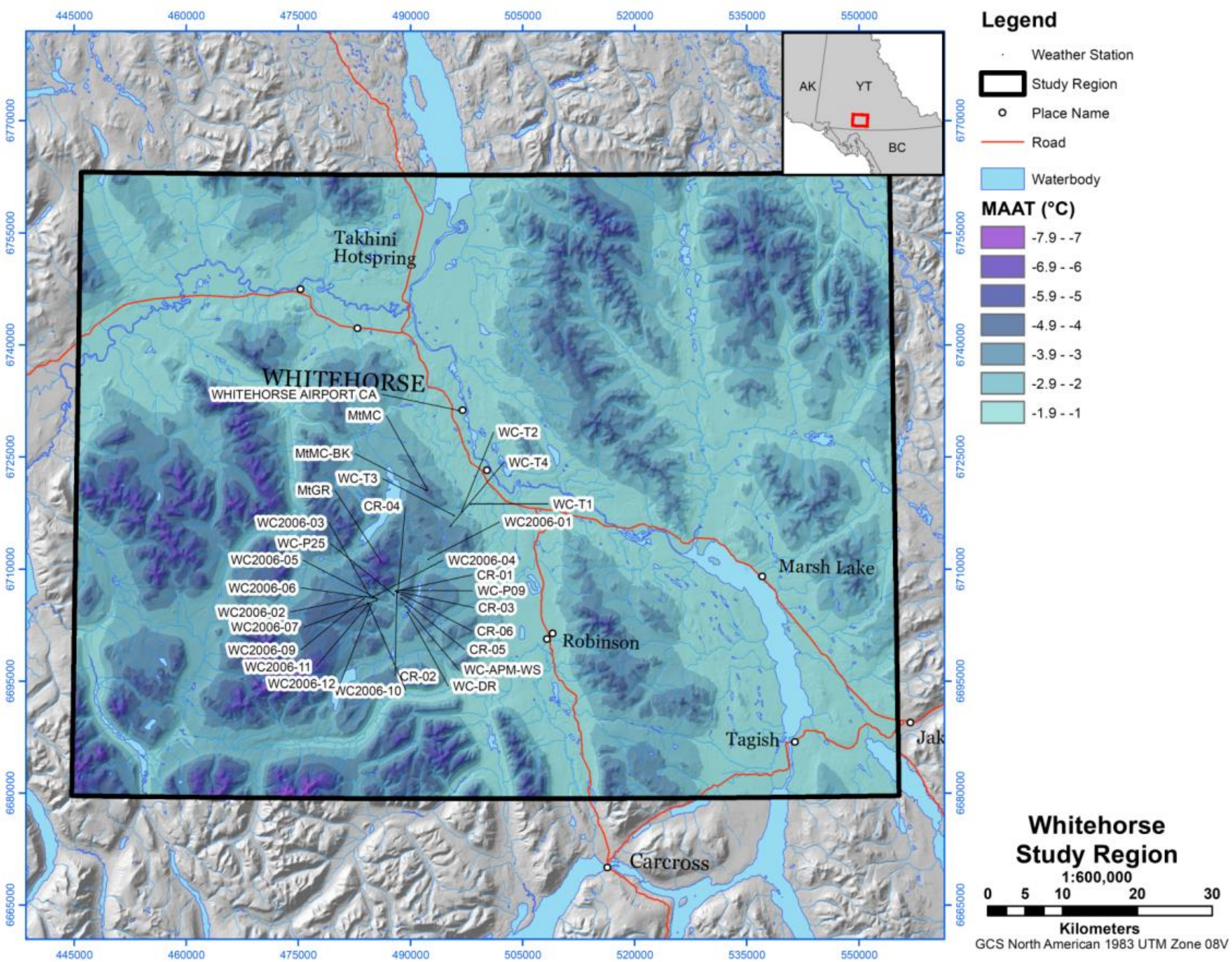

Figure 27: Predicted mean annual air temperature for the Whitehorse Study area using measured climate data.

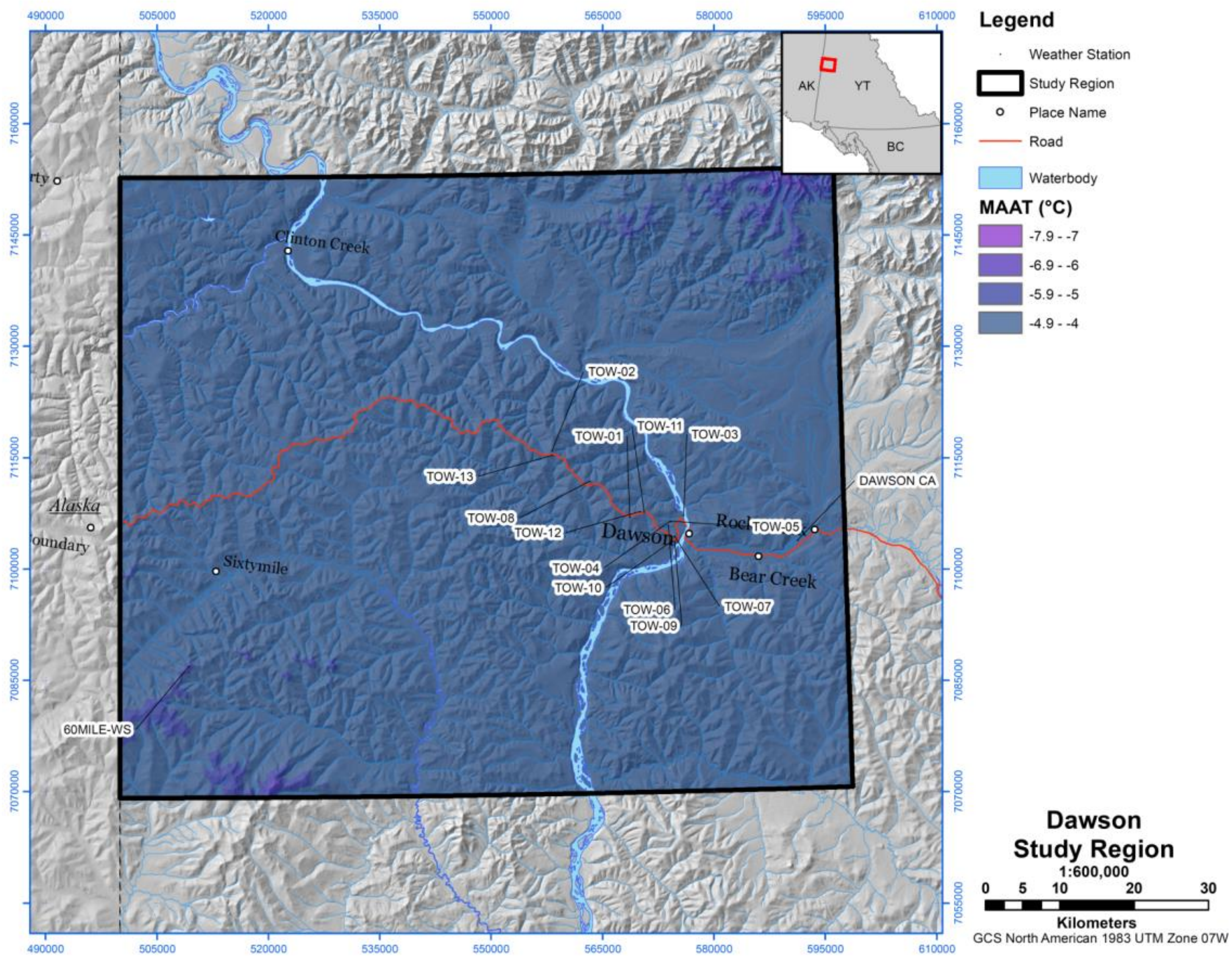

Figure 28: Predicted mean annual air temperature for the Dawson Study area using measured climate data.

4.3.1. TTOP predictions

Results from the TTOP-model for the three study regions are presented in this section using climate data from 2007-2014. Results from the TTOP-model (Figure 29; Figure 32; Figure 35) are compared to results from the TOFF-model (Figure 30; Figure 33; Figure 36) and the BTS-model (Bonnaventure et al., 2012) (Figure 31; Figure 34; Figure 37). Permafrost likelihoods are investigated by comparing the distribution of probabilities or likelihoods within elevation classes and by land cover class. In addition the modelled likelihoods are compared to measured TTOP temperatures.

TTOP predictions for five scenarios (very cold, cold, median, warm and very warm) were merged into a likelihood map for each area. The values of N_F, N_T and R_K were taken from Chapter 2 and are summarized below in Table 7. TOFF-model predictions were also merged into permafrost likelihood using five scenarios from the distribution of measured total offsets (see Figure 14). The total offset values from very cold to very warm are: 1.1, 2.4, 3.0, 3.8 and 5.6°C (Table 7). The model is a very simple calculation of MAAT + total offset. The BTS permafrost probability model that exists for southern Yukon and northern British Columbia (Bonnaventure et al., 2012) was reclassified into 6 classes: 0, 0.01-0.2, 0.21-0.4, 0.41-0.6, 0.61-0.8, and 0.81-1.

Table 7: Values of N_F, N_T and R_K used in the spatial modelling scearios of TTOP (taken from Table 5 in Chapter 2).

		Very cold	Cold	Median	Warm	Very warm
Coniferous or Mixed	N_F	0.55	0.35	0.25	0.15	0.06
	N_T	0.64	0.73	0.79	0.90	0.96
	R_K	0.61	0.75	0.91	1.04	1.28
Deciduous	N_F	0.48	0.47	0.37	0.26	0.12
	N_T	0.77	0.87	0.93	0.96	0.99
	R_K	0.83	0.90	0.96	1.09	1.20
Rock	N_F	0.97	0.89	0.82	0.80	0.78
	N_T	0.95	1.17	1.30	1.33	1.47
	R_K	0.64	0.91	1.03	1.63	1.88
Shrub	N_F	0.60	0.46	0.37	0.29	0.18
	N_T	0.66	0.77	0.85	0.99	1.12
	R_K	0.37	0.64	0.87	1.01	1.27
Tundra	N_F	0.58	0.50	0.45	0.39	0.37
	N_T	0.84	0.93	0.96	1.01	1.04
	R_K	0.52	0.66	0.93	0.96	1.07
Tundra (Maritime)	N_F	0.39	0.23	0.19	0.15	0.08
	N_T	1.00	1.08	1.12	1.18	1.30
	R_K	0.95	0.96	0.99	1.01	1.03
Total Offset		1.07	2.35	2.98	3.76	5.63

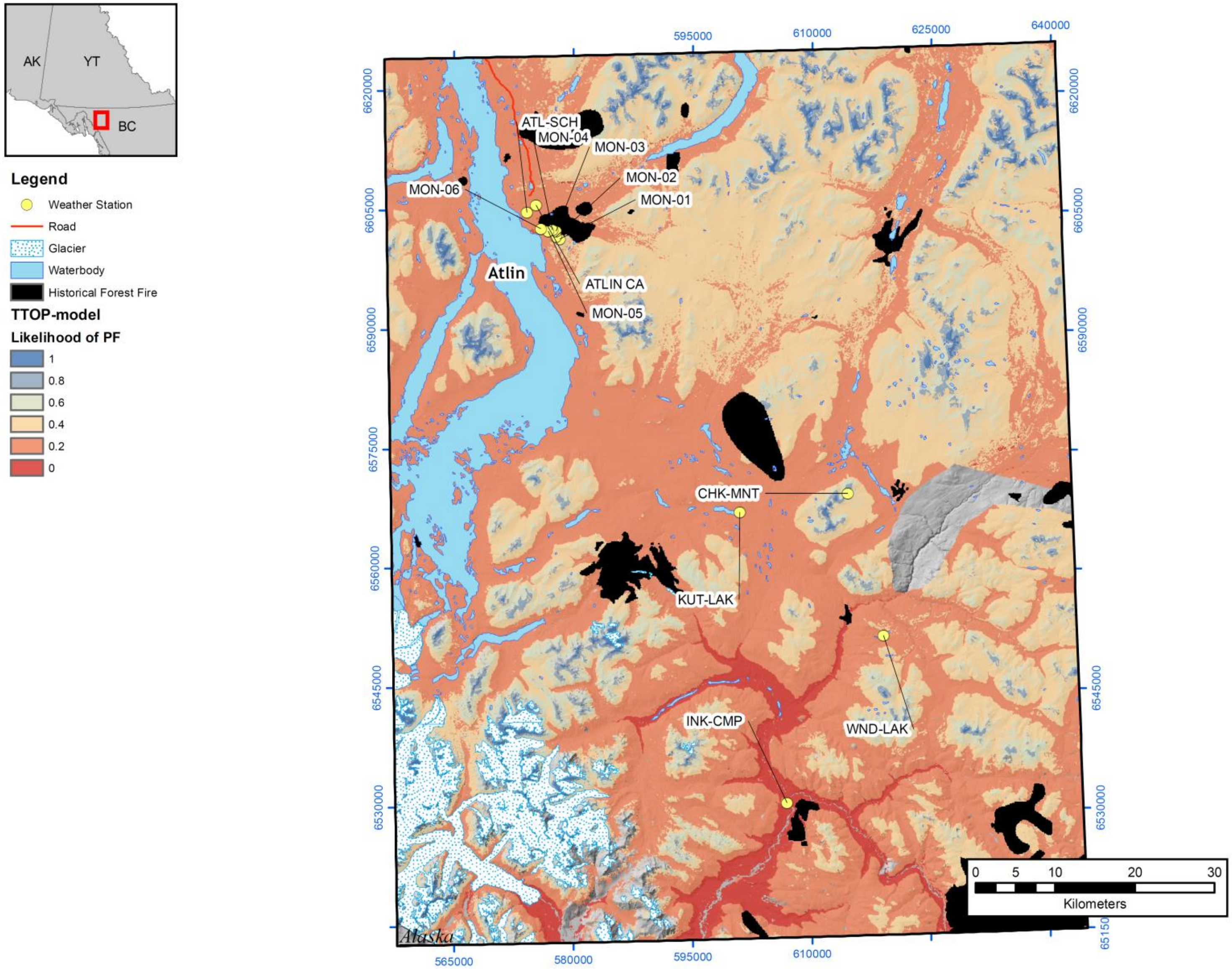

Figure 29: Likelihood of permafrost in the Atlin study area using the TTOP-model. Coordinate system: NAD83, UTM08.

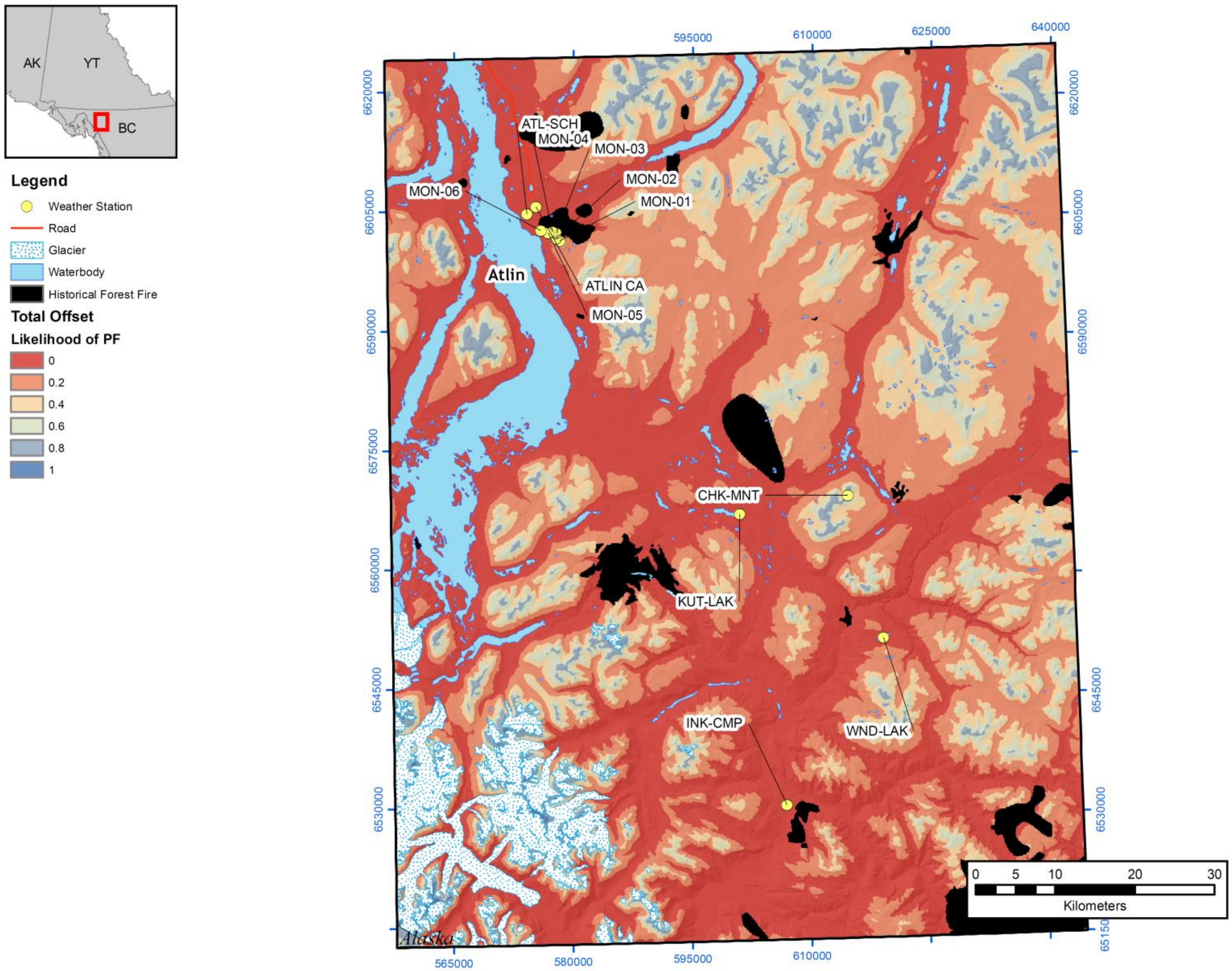

Figure 30: Likelihood of permafrost in the Atlin study area using the Total Offset model. Coordinate system: NAD83, UTM08.

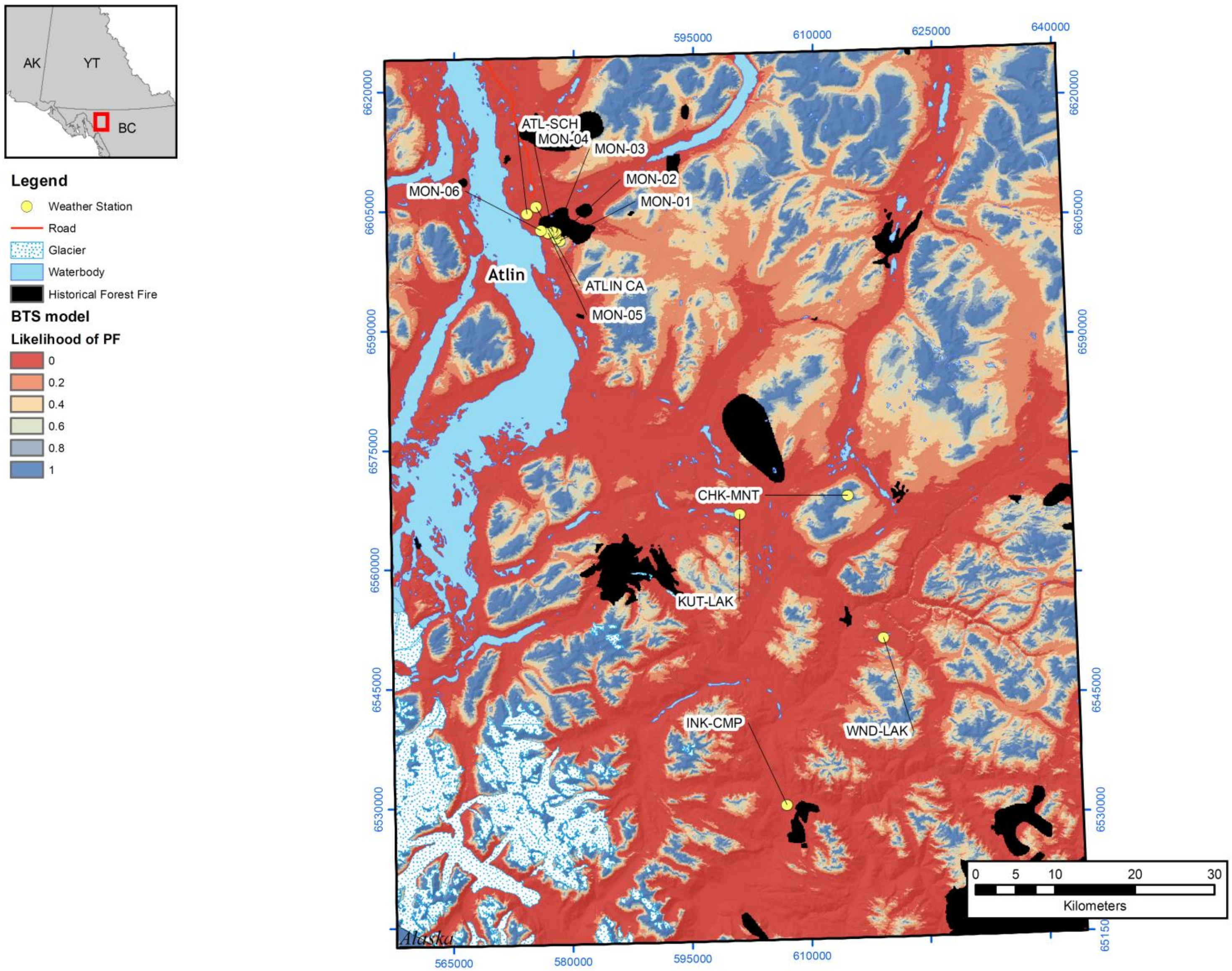

Figure 31: Likelihood of permafrost in the Atlin study area using the BTS model (reclassified from Bonnaventure et al., 2012). Coordinate system: NAD83, UTM08.

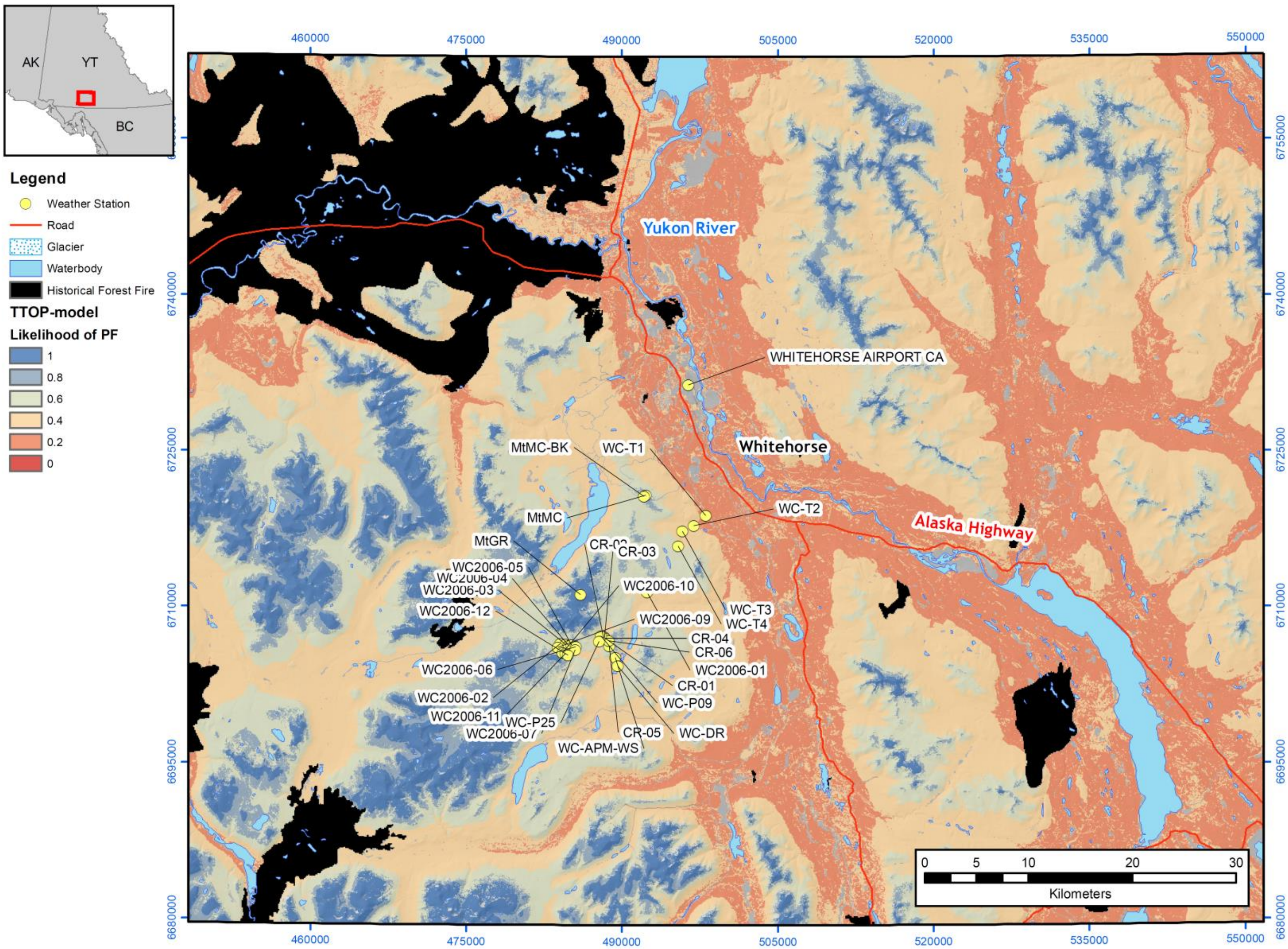

Figure 32: Likelihood of permafrost in the Whitehorse study area using the TTOP-model. Coordinate system: NAD83, UTM08.

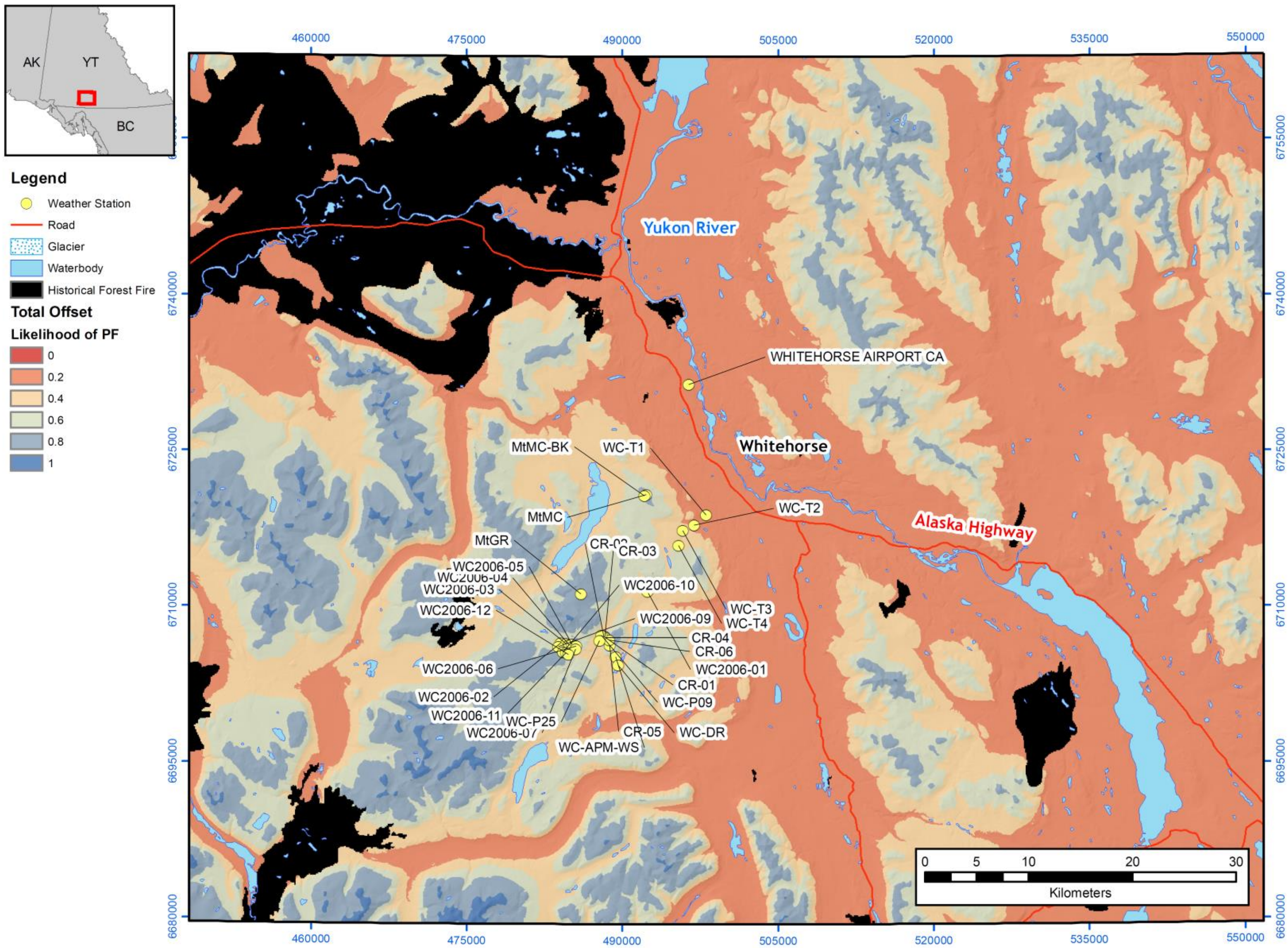

Figure 33: Likelihood of permafrost in the Whitehorse study area using the Total Offset model. Coordinate system: NAD83, UTM08.

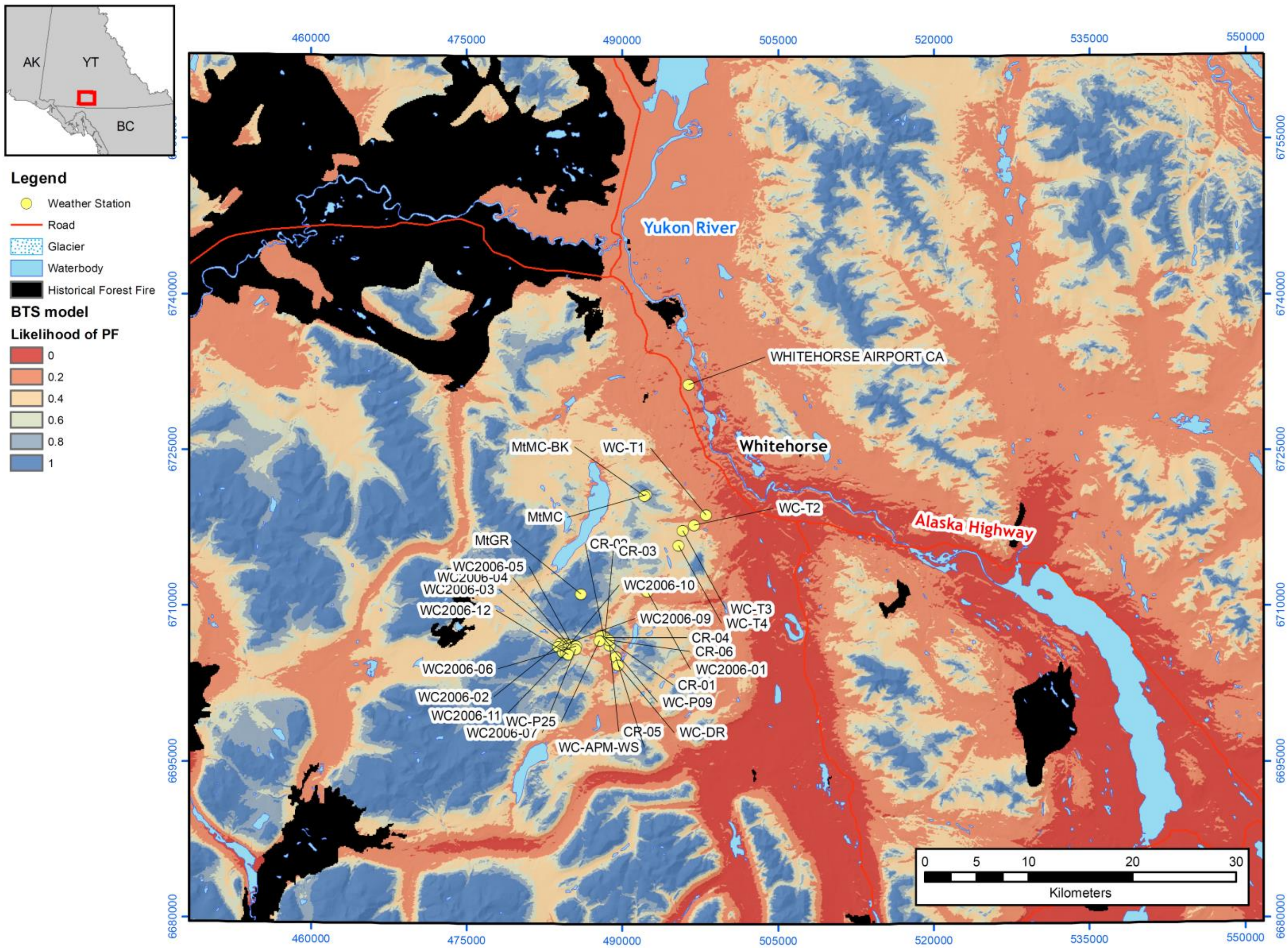

Figure 34: Likelihood of permafrost in the Whitehorse study area using the BTS-model (reclassified from Bonnaventure et al., 2012). Coordinate system: NAD83, UTM08.

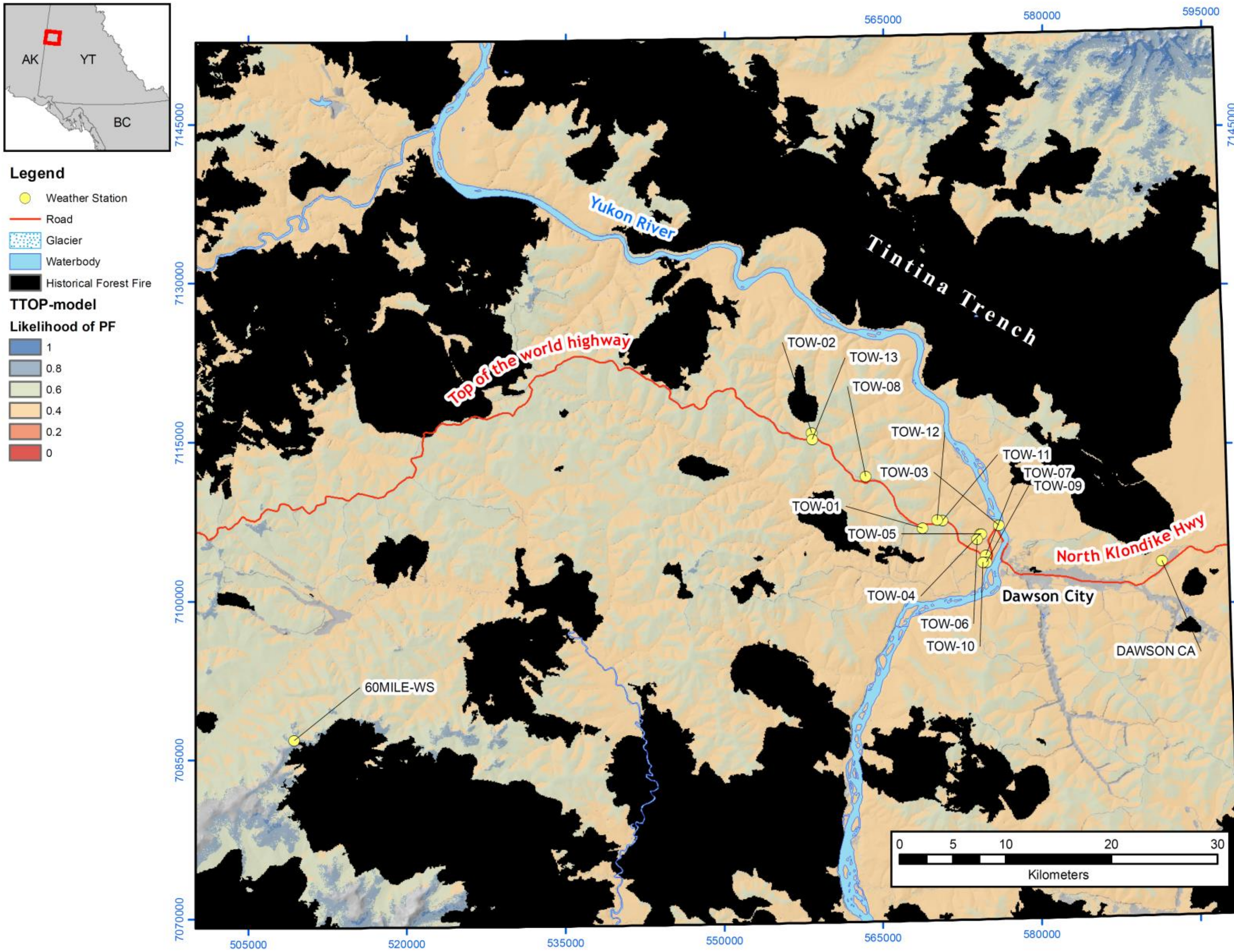

Figure 35: Likelihood of permafrost in the Dawson study area using the TTOP-model. Coordinate system: NAD83, UTM07.

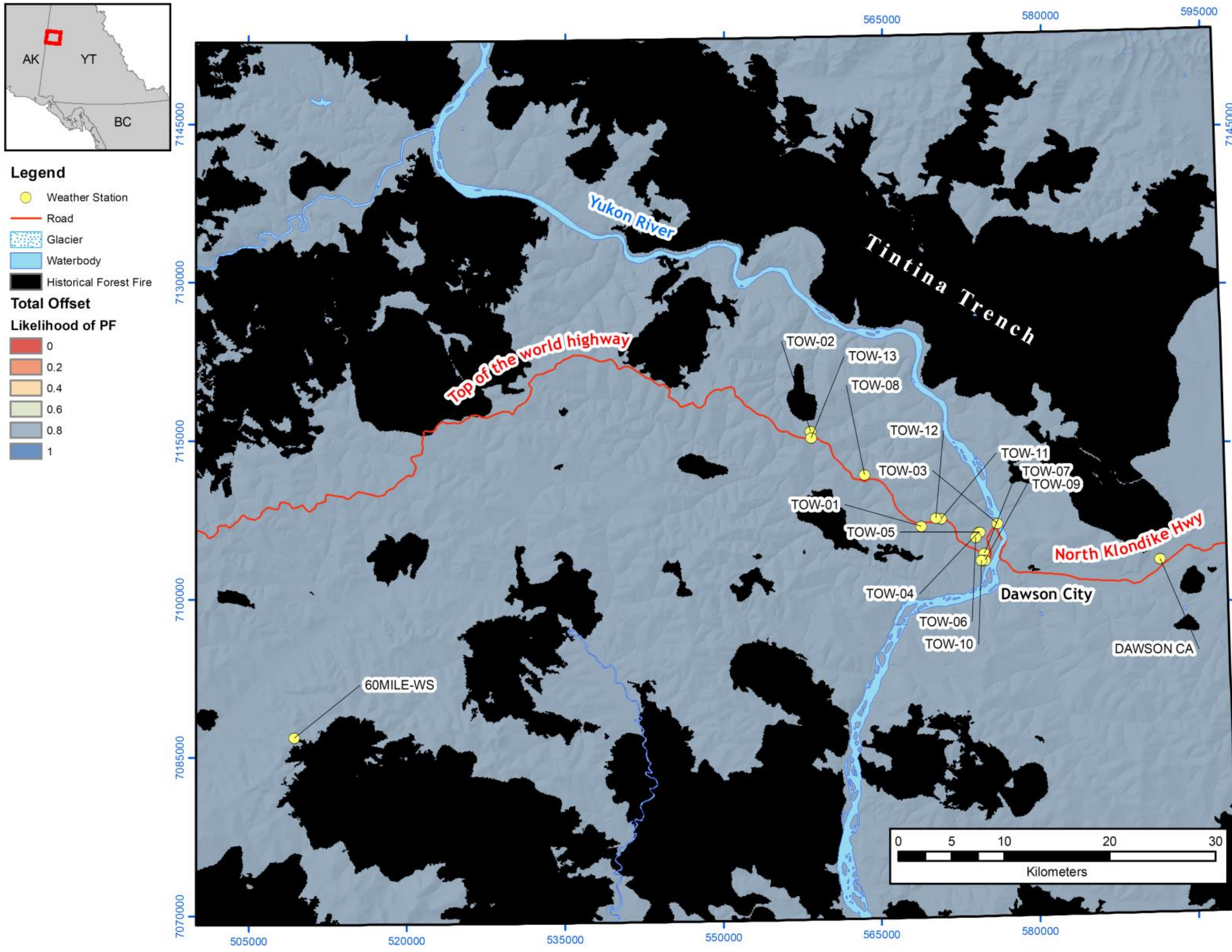

Figure 36: Likelihood of permafrost in the Dawson study area using the Total Offset model. Coordinate system: NAD83, UTM07.

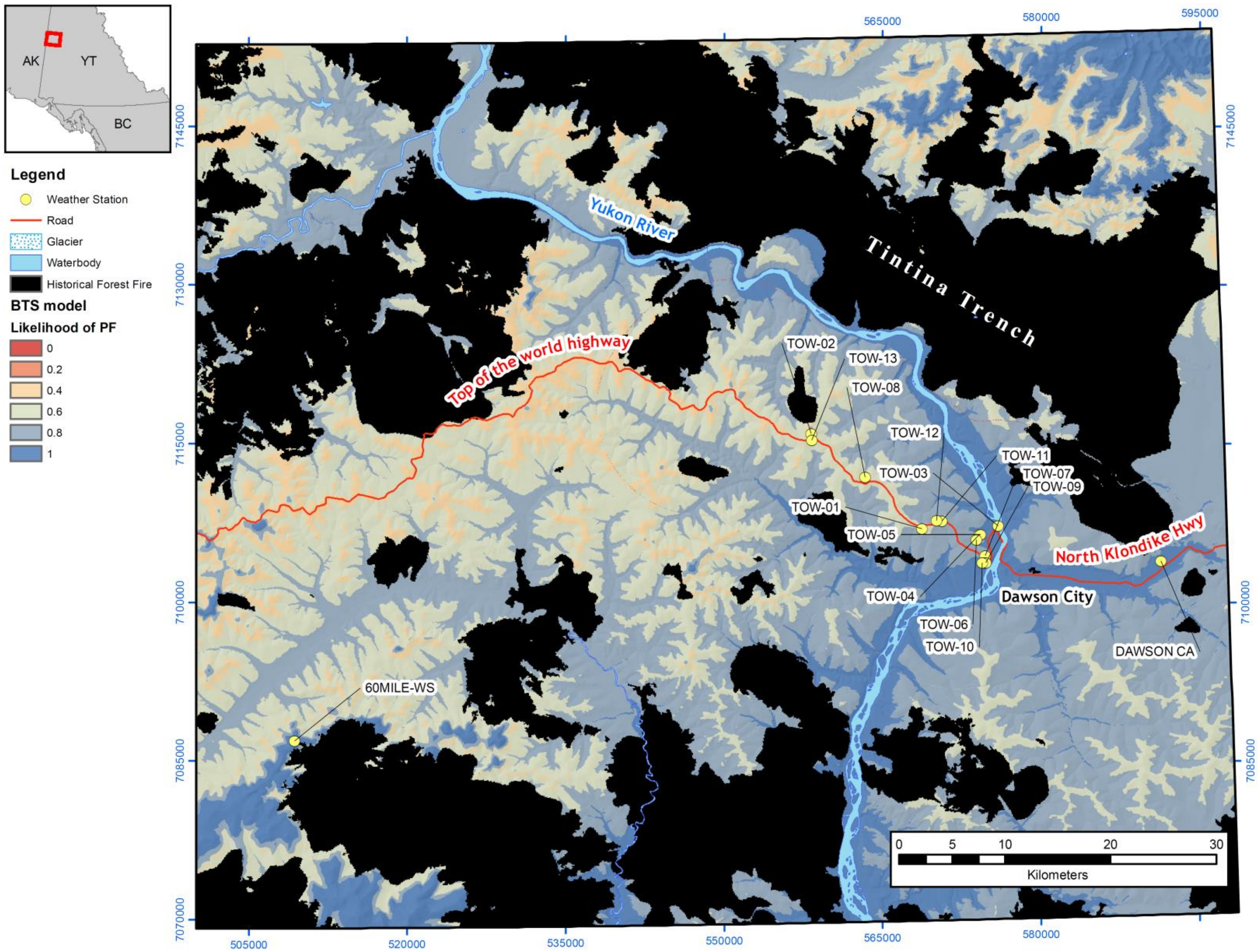

Figure 37: Likelihood of permafrost in the Dawson study area using the BTS model (reclassified from Bonnaventure et al., 2012). Coordinate system: NAD83, UTM07.

4.3.2. Model comparison

The TTOP-model predicts that 27%, 43% and 48% of the Atlin, Whitehorse and Dawson study areas are underlain by permafrost, respectively (Table 8). In contrast, the TOFF and BTS models predict likelihoods of 26 % and 30% of the Atlin area, 44% and 39% of the Whitehorse, and 80% and 43% of the Dawson study areas, respectively (Table 8). The models are generally in agreement for the Atlin study area, where permafrost is strongly related to elevation. The Whitehorse results are also in agreement with a range of predictions of 5%. Here, permafrost is also strongly related to elevation, with some permafrost possible below treeline. In Dawson, however, the models differ considerably. The TOFF model predicts a mean likelihood of 80% permafrost in the Dawson area, whereas the TTOP and BTS models have much more conservative predictions of 47% and 58%.

Table 8: Percent of the study areas with permafrost likelihoods that are above 0.5 for Atlin, Whitehorse and Dawson using the TTOP, TOFF and BTS models.

	TTOP	TOFF	BTS
Atlin	27%	26%	30%
Whitehorse	43%	44%	39%
Dawson	47%	80%	58%

Predicted likelihoods of permafrost for each of the three models in each of the three study regions were grouped for comparison into elevation classes (Figure 38). In Atlin, a rapid transition exists at elevations of about 1200 and 1600 m a.s.l. between unlikely and likely permafrost predictions in all three models. While the three models generally agree in terms of pattern, the BTS model has higher permafrost probabilities for nearly all elevation groups and the TTOP-model has lower permafrost probabilities at higher elevations. Permafrost is unlikely below 1000 m a.s.l. and very unlikely below 500 m a.s.l. In Whitehorse, a similar transition from lower to higher permafrost likelihoods occurs between about 1200 and 1500 m a.s.l.. The three models again generally agree on the trends in permafrost likelihood with elevation, but the BTS model has a greater range of probabilities at lower elevations. The models indicate that permafrost is possible at all elevations present in the region. In Dawson, there is considerable difference in the predictions from the three models. The BTS-model has a sharp transition between lower permafrost probabilities and higher permafrost probabilities between 1200 and 1400 m a.s.l. as median values increase from 0.5 to 0.8 over 200 m (Figure 38). Below 1200 m a.s.l. the BTS model shows decreasing probability as elevations increase. The thermal offset model relies heavily on air temperature and has a nearly uniform prediction of permafrost likelihood in the area due to a homogenous predicted MAAT of about -4°C (see Figure 28). The mean likelihood using this model is about 0.8. The TTOP-model predicts about 0.5 likelihood from 400 to 1200 m a.s.l. and then likelihoods increase with elevation above treeline. The range of values is smaller at lower elevations than at higher elevations.

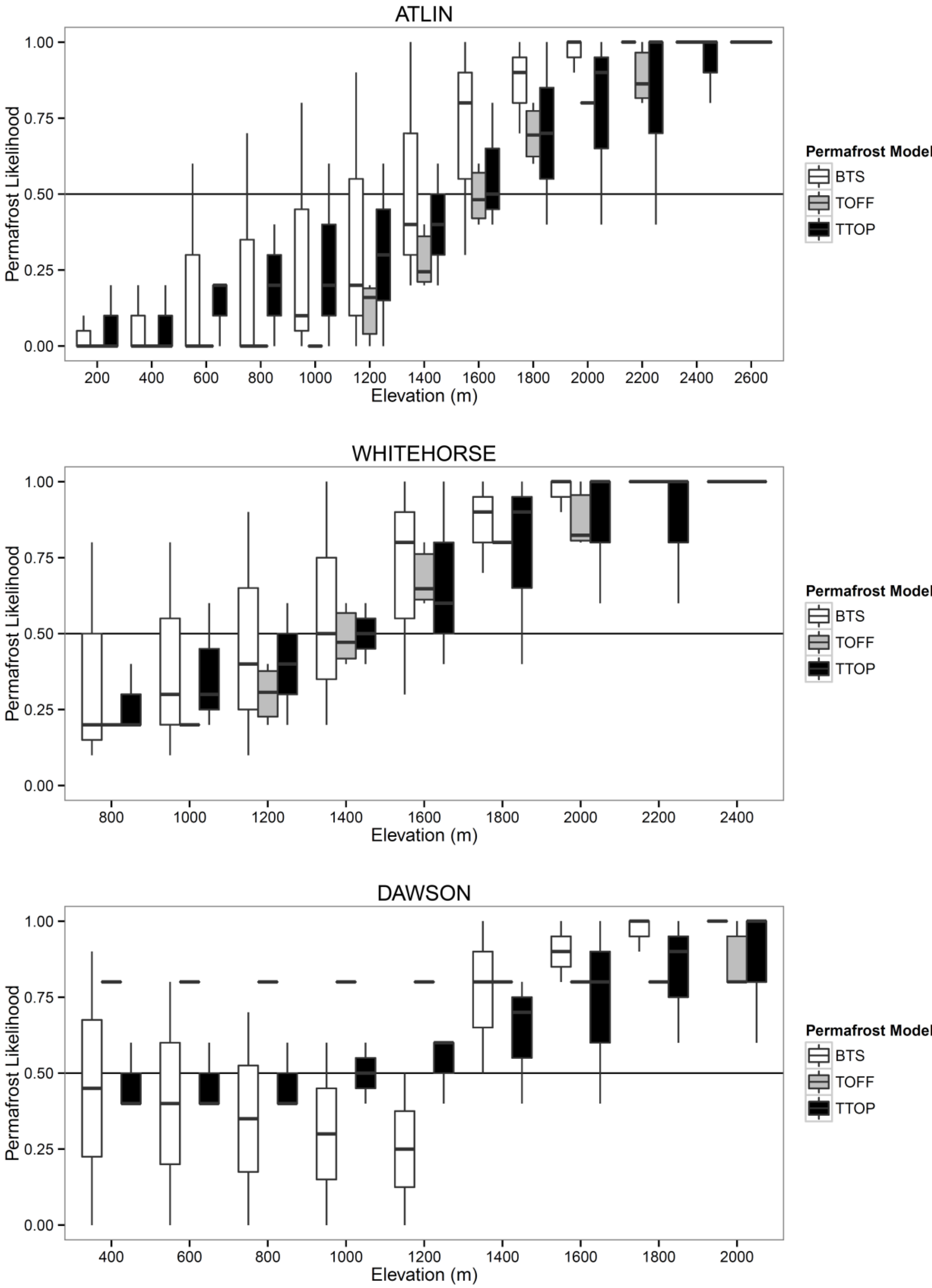

Figure 38: Extracted permafrost probabilities or likelihoods from three spatial models (BTS, TOFF and TTOP) for the three study areas compared against elevation. The flat boxes represent nearly uniform MAAT with single TOFF offset, resulting in very similar results.

Predicted probabilities of permafrost distribution were grouped into land cover classes for each of the three models in each of the three study regions. Differing spatial patterns of permafrost probabilities can be found (Figure 39). In Atlin, the three models generally agree that low probabilities of permafrost exist in deciduous and coniferous forests, and shrubs, and higher probabilities of permafrost exist in maritime tundra and rock land covers. BTS models the highest permafrost probabilities for each land cover class, TOFF models the lowest and TTOP is in between. In Whitehorse, the patterns are generally similar to Atlin, though higher probabilities exist throughout. Forest classes have the lowest probabilities, shrubs are nearly at 0.5 and both tundra and rock have high probabilities. In Dawson, permafrost likelihoods are variable between models. The BTS model yields very similar results for all land cover classes characterized by a wide range of values that have a median between 0.3 and 0.4. The TOFF model predicts high probabilities for all land cover classes with nearly no variability, once again owing to the uniform MAAT prediction in that area (see Figure 28). The TTOP model predicts high permafrost probabilities for rock and tundra, slightly lower for shrub and below 0.5 values for coniferous and deciduous.

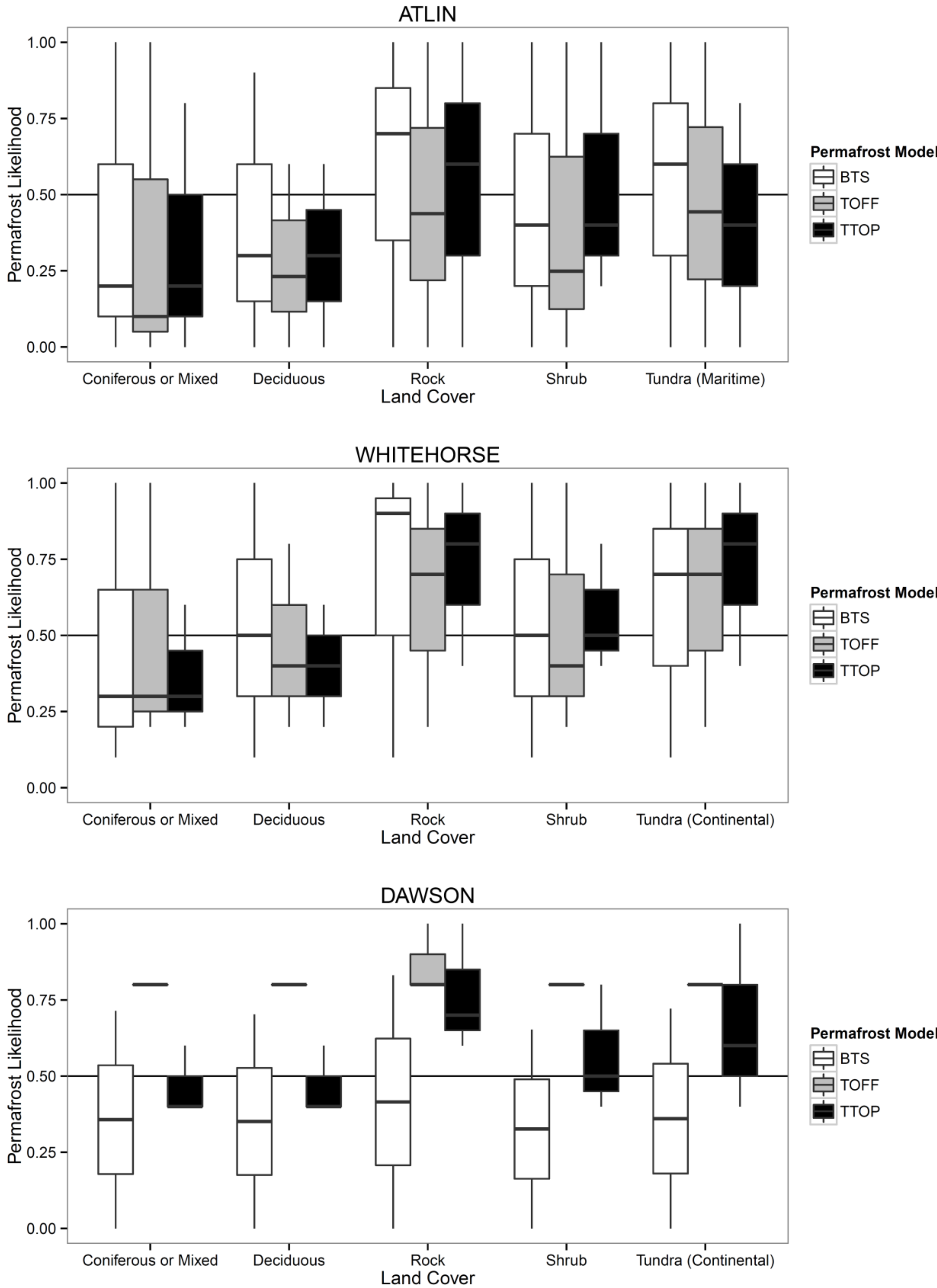

Figure 39: Extracted permafrost probabilities or likelihoods from three models (BTS, TOFF and TTOP) for the three study areas compared against land cover classes from the EOSD dataset.

Gridded spatial predictions for all of the stations were compared with measured TTOP values for individual station years. Scatter plots with linear models and boxplots were made for the TTOP (Figure 40[A,B]), TOFF (Figure 40[C,D]) and BTS (Figure 40[E,F]) models. Linear models return r^2 values of 0.2, 0.16 and 0.16 for the TTOP, TOFF and BTS predictions. The TTOP model has no predictions that are above a probability of 0.6 with measured TTOP values above zero, whereas both of the other models do. None of the models have predictions that are below a probability of 0.4 with measured TTOP values below zero. All models seem to predict the absence of permafrost equally (between 0-0.4), though the TTOP-model has more success at predicting permafrost.

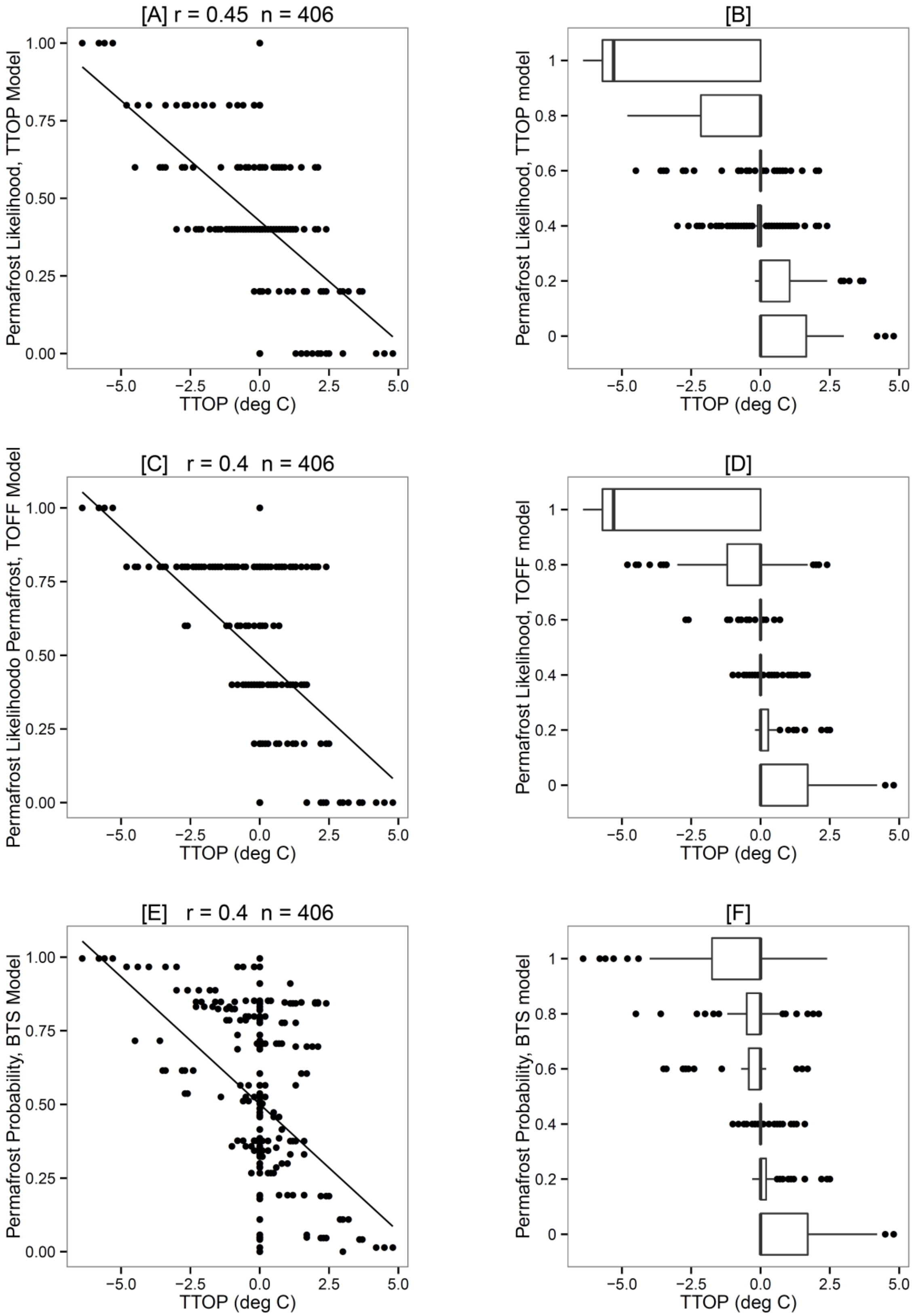

Figure 40: Scatterplots and boxplots of the probability of permafrost and measured TTOP values for individual station-years using the TTOP [A,B], TOFF [C,D] and BTS [E,F] models. Scatterplots have linear models overlain and model statistics above.

Gridded spatial predictions of permafrost likelihood from the three models are compared spatially by differencing the output maps. ESRI ArcMap 10.2 Raster Calculator was used for the calculation, though

The BTS- and TTOP-models and the TOFF- and TTOP-models are differenced in the Atlin (Figure 41; Figure 42), Whitehorse (Figure 43; Figure 44) and Dawson (Figure 45; Figure 46) study areas. The difference between the modelled likelihood of permafrost predicted by the BTS- and the TTOP-models range from -0.6 to 0.6 and the difference between the modelled likelihood of permafrost predicted by the TOFF- and the TTOP-models range from -0.6 to 0.4. Positive difference values indicate that the TTOP-model predicts lower permafrost likelihoods and negative difference values indicate that the TTOP-model predicts higher permafrost likelihoods.

In Atlin, both the BTS- and TTOP-models are similar in the high alpine but show important differences near treeline (Figure 41). The TTOP-model predicts lower likelihoods of permafrost in the subalpine than the BTS-model. In the valleys, both models are quite similar though TTOP predicts slightly higher likelihoods with difference values extending to -0.2. Strong contrasts exist in the valley – notably about 15 km to the SEE of the Atlin town centre – here the model construction is visible. The TTOP-model is highly influenced by land cover and the BTS-model is not. Similar large contrasts in the valley bottoms due to vegetation cover are present in the TOFF- and TTOP-model differencing (Figure 42). Near treeline, interesting banding is present, again due to the difference in model predictions based on the vegetation class that determines treeline.

In Whitehorse, both BTS- and TTOP-models are similar in the high alpine and in the valleys but show important differences on northern aspects (Figure 43). The TTOP-model predicts lower likelihoods of permafrost on northern aspects than the BTS-model. In the valleys, both models are quite similar though TTOP predicts slightly higher likelihoods with difference values extending to -0.3 in local vegetation controlled sites. The TOFF- and TTOP-models show less agreement. Moderate to high difference values are found throughout the study area with the most agreement at treeline (Figure 44). The TOFF-model predicts higher likelihoods than the TTOP-model.

In Dawson, both BTS- and TTOP-models are similar in the alpine and high elevation areas, though there are important differences in valley bottoms (Figure 45). The TTOP-model predicts lower likelihoods of permafrost in valley bottoms than the BTS-model. The BTS model predicts permafrost throughout valley bottoms and the TTOP-model put most valleys at a 0.5 likelihood of permafrost. The TOFF- and TTOP-models show less agreement. The TOFF-model predicts permafrost everywhere and the TTOP-model does not (Figure 46).

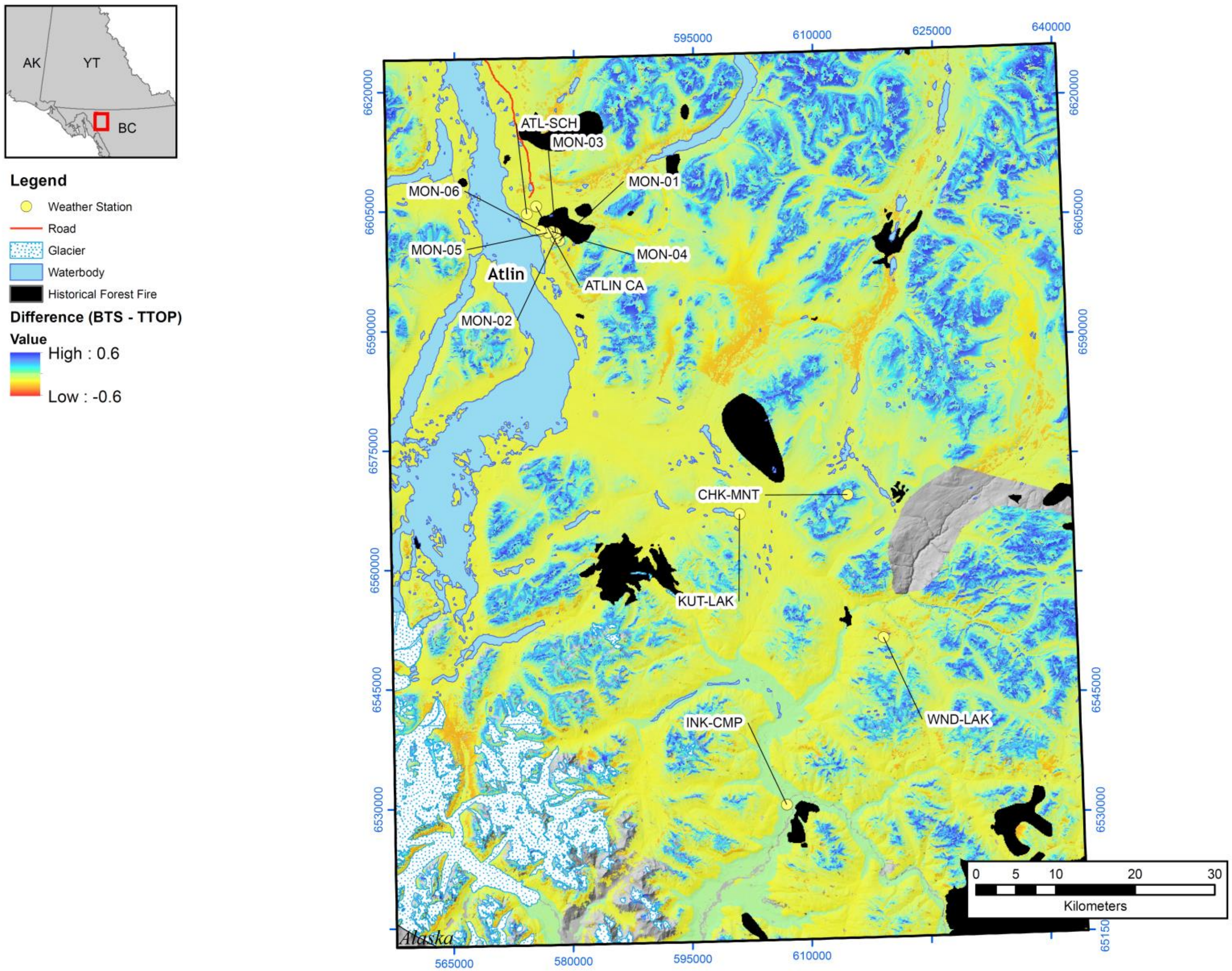

Figure 41: Difference surface between the spatial implementation of the BTS- and the TTOP-models in the Atlin study area.

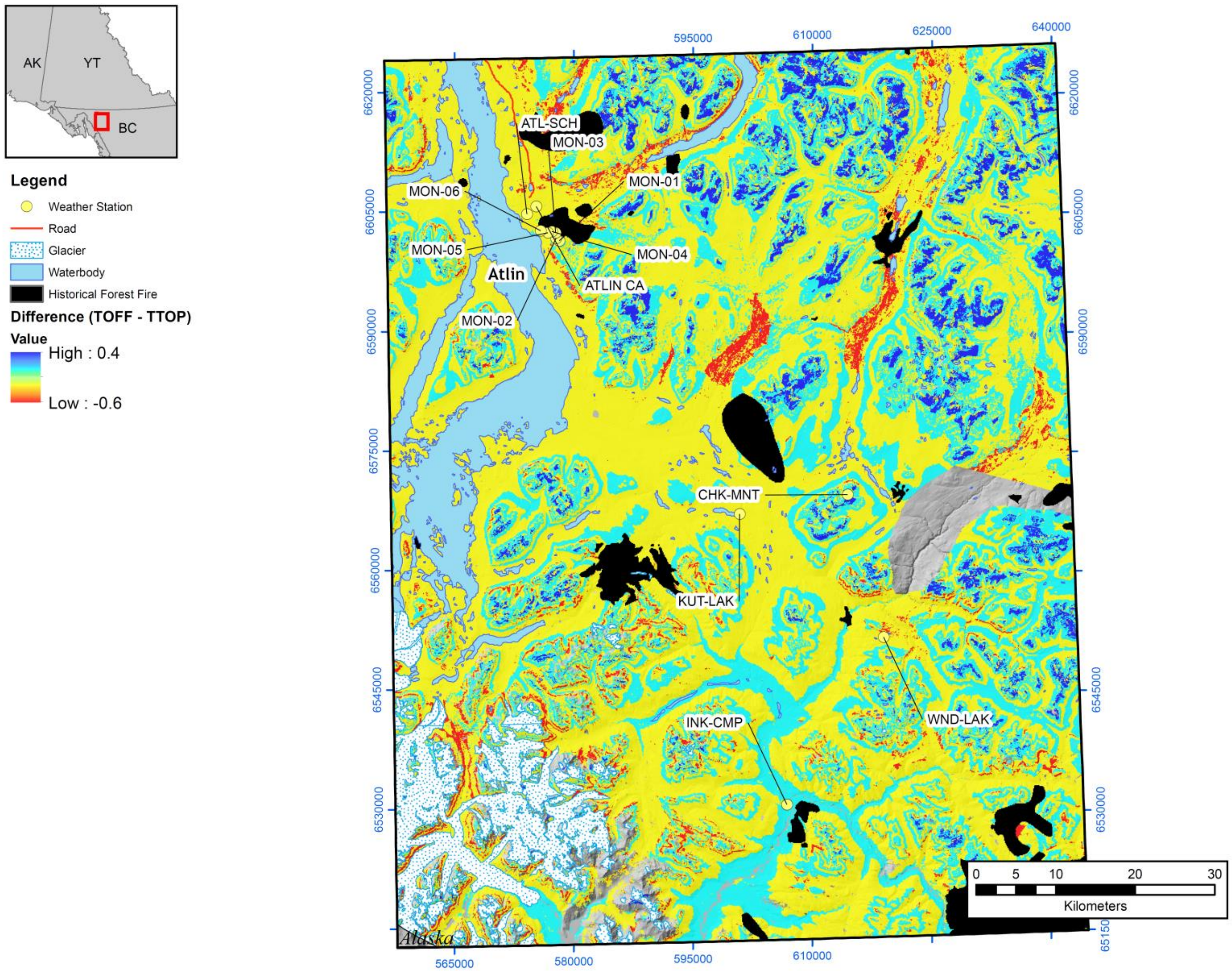

Figure 42: Difference surface between the spatial implementation of the TOFF- and the TTOP-models in the Atlin study area.

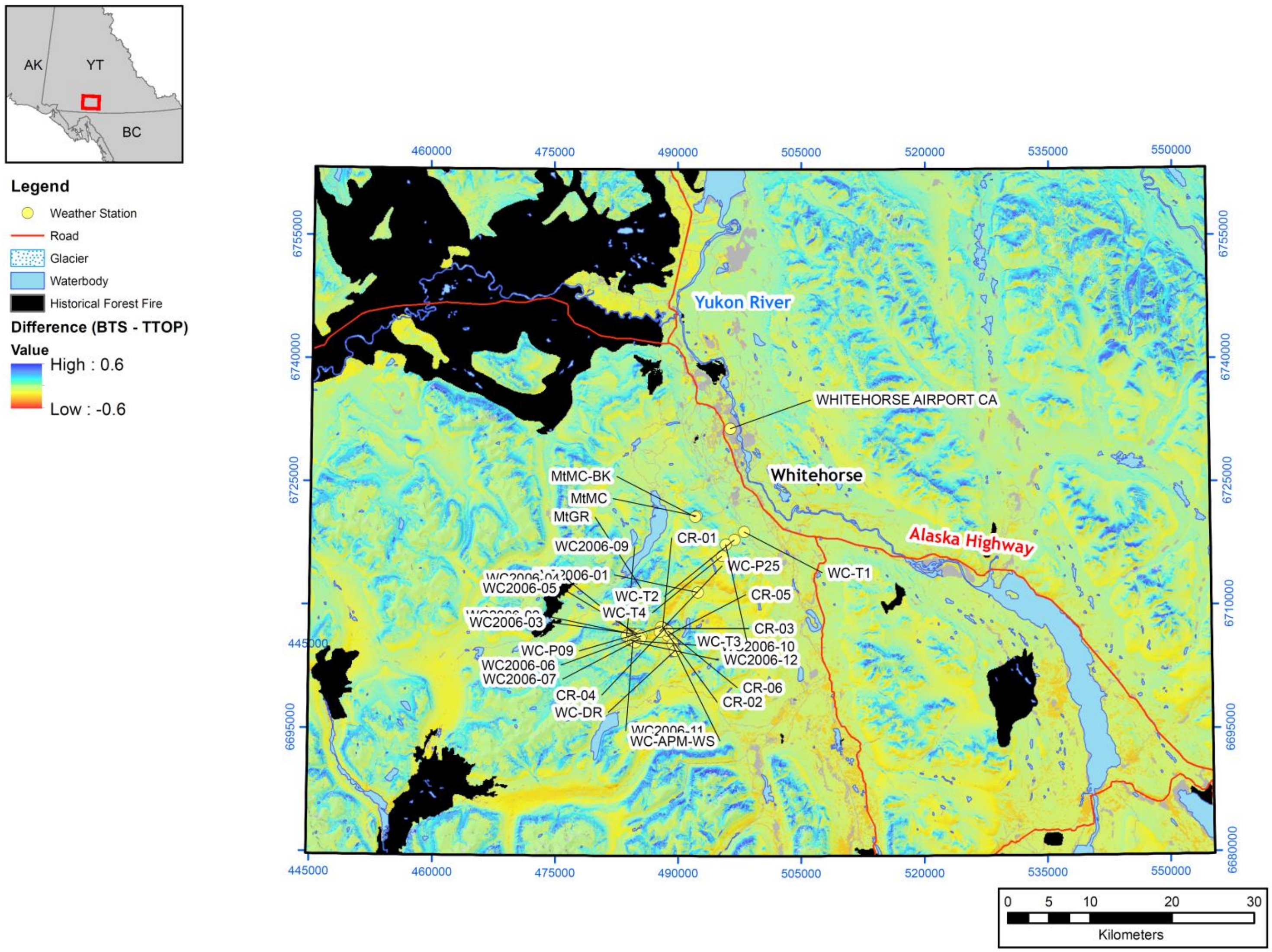

Figure 43: Difference surface between the spatial implementation of the BTS- and the TTOP-models in the Whitehorse study area.

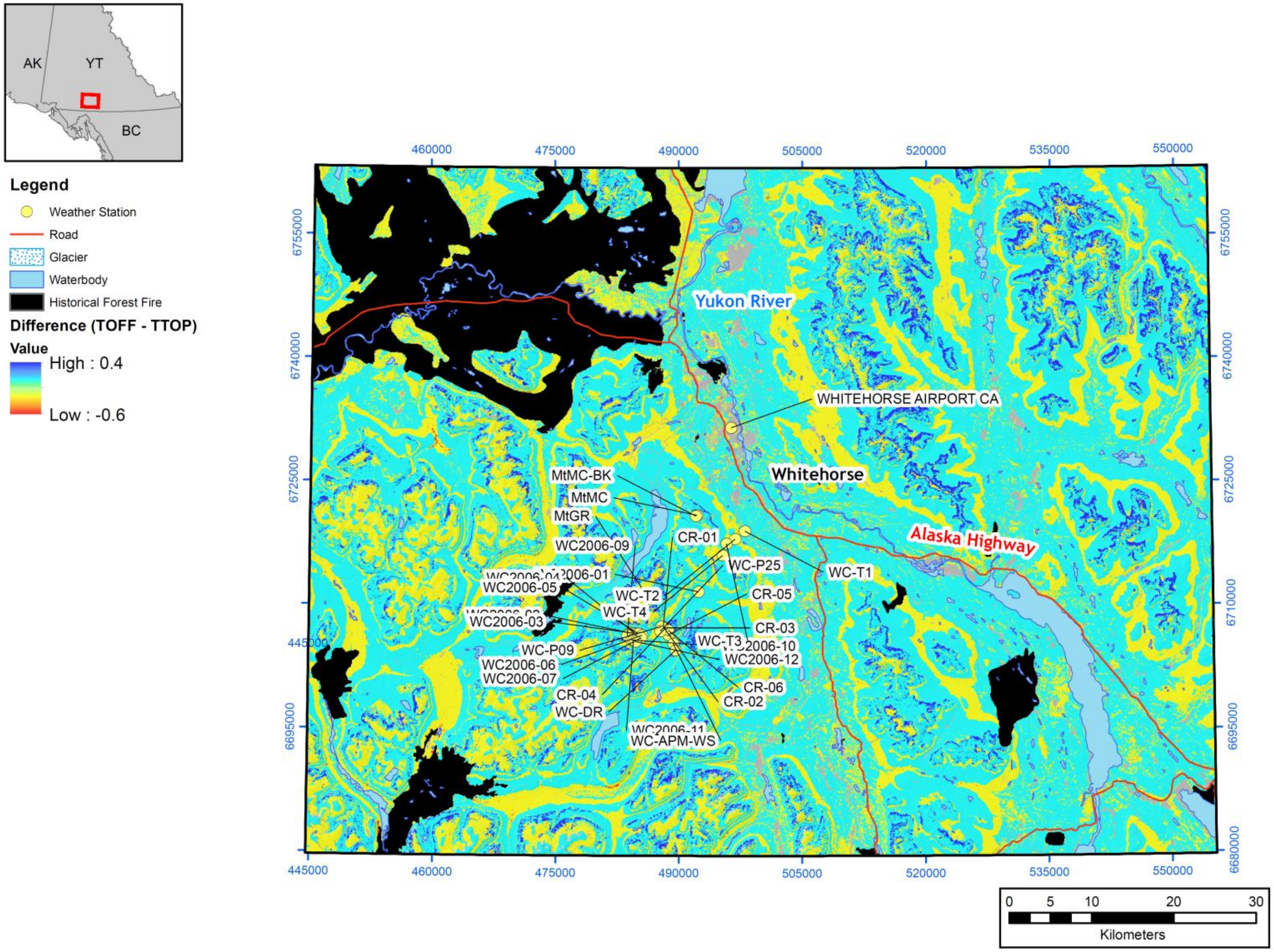

Figure 44: Difference surface between the spatial implementation of the TOFF- and the TTOP-models in the Whitehorse study area.

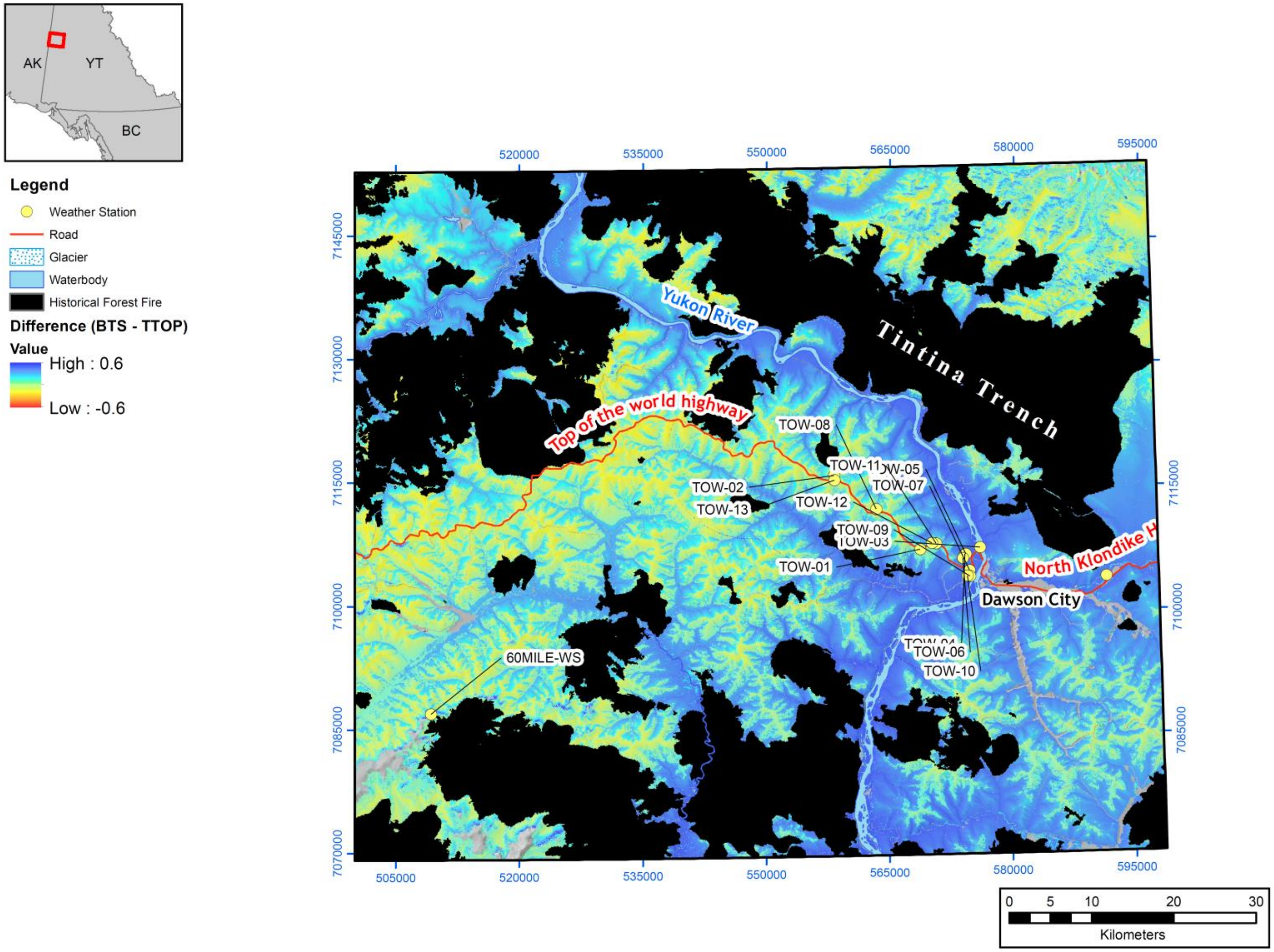

Figure 45: Difference surface between the spatial implementation of the BTS- and the TTOP-models in the Dawson study area.

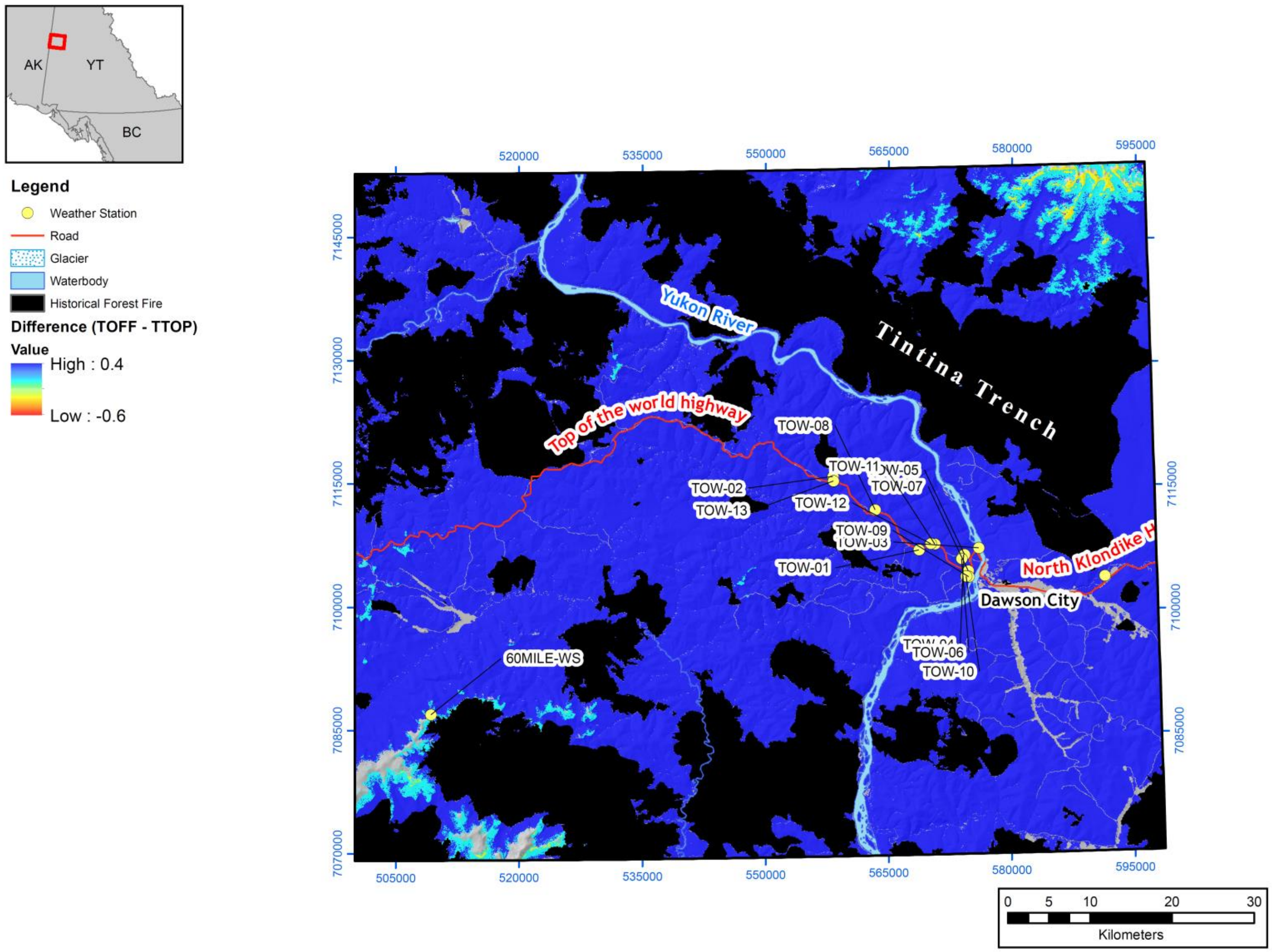

Figure 46: Difference surface between the spatial implementation of the TOFF- and the TTOP-models in the Dawson study area

4.4. Concluding remarks

Two questions were stated at the beginning of this chapter: (1) what are the predicted patterns of permafrost distribution in the three study areas, and (2) how does the TTOP-model compare to other predictions of permafrost distribution in these areas?

For the TTOP-model, 30 x 30 m resolution spatial predictions were made for F/TDD_A and MAAT, then ground surface temperatures were predicted and finally TTOP. TDD_A exhibits a linear relationship with elevation that is identical in all study areas (-1273°C-days/km; Figure 24), suggesting that elevation is the main control on TDD_A. FDD_A is best characterized by a polynomial relationship with elevation for each individual study area but with a high degree of variability along that regression. In Atlin, the FDD_A-LR is about 600°C-days/km whereas Whitehorse and Dawson have different lapse rates above and below treeline. Above treeline they are 700°C-days/km and -450°C-days/km, and below treeline they are -100°C-days/km and -1100°C-days/km, respectively (Figure 25). MAAT in the Atlin region decreases at -4.6°C/km both above and below treeline. The Whitehorse region has a SLR of -4.9°C/km above treeline and a SLR of -2.8°C/km below treeline. The Dawson region has a SLR of -2.7°C/km above treeline and a SLR of -0.1°C/km below treeline.

The land cover driven TTOP-model predicts that 27%, 43% and 48% of the Atlin, Whitehorse and Dawson study areas are underlain by permafrost, respectively (Table 8). Other models generally agree with these values, with the most variability between models being in Dawson. It is important to note that the TTOP and TOFF models share the same air temperature predictions as inputs while the BTS model has a different input air temperature field. The BTS model uses two linear surface lapse rates for above and below treeline (Bonnaventure et al., 2012) where the other models use a polynomial function. This is particularly evident in the

Dawson study area where two distinct lapse rates can be observed in the BTS model with a sharp step change at treeline that is not present in the other models. Once again, the most disagreement between when comparing permafrost likelihood with elevation is in the Dawson study area (Figure 38). When comparing predictions from the three models to land cover units, the values are most well constrained in the TTOP model, owing to those units being part of the input data. The other models have more variability in these plots because they are topo-climatic models that do not incorporate vegetation.

When comparing the predicted likelihood of permafrost to the measured temperatures at the top of permafrost, the TTOP-model outperformed the other models because it is the only one of the three that predicts above 0.8 likelihoods for permafrost sites and below 0.2 likelihoods for non-permafrost sites (Figure 40).

The TTOP-model is the best at discriminating permafrost and non-permafrost sites. All sites with permafrost likelihoods above 0.8 have TTOP values showing the presence of permafrost, and all sites with permafrost likelihoods below 0.4 have TTOP values showing that permafrost is absent. The other two models were not as consistent in making predictions with these high and low likelihood values.

CHAPTER 5: Discussion and conclusion

5.1. Introduction

The four previous chapters work together to introduce a large climate dataset based on 58 stations and explore climate-permafrost interactions using environmental variables. The land cover driven TTOP-model is then assessed and implemented spatially throughout the three study areas. This concluding chapter aims to condense the findings of this thesis and place them in the context of the scientific literature.

5.2. Climate-permafrost

The climate data presented in this thesis represents a dataset in space, time and magnitude. 58 weather stations that measure air, ground surface and top of permafrost temperatures were incorporated into this research in areas where existing data is sparse at best. The timeframe of the data begins in 2007 and ends in 2014. Stations vary in accessibility from easily accessible roadside locations to more distant hike-in or fly-in stations. The presented database is, in itself, a contribution to understanding climate-permafrost interactions in these regions.

Comparing the present data to previously published values of N_F, N_T and R_K, and values of the surface and thermal offsets, similarities and differences exist. Lewkowicz et al. (2012) report *n*-factors of similar magnitude and with similar means to these, also for Yukon and northern British Columbia. However, tundra and rock classes are grouped together in that study.

Thermal offset values above and below zero have been found in this thesis. Positive thermal offsets indicate MAGST < TTOP and negative thermal offsets indicate MAGST > TTOP. The positive values are less reported in the Arctic literature than the more common negative values. Burn and Smith (1988) report TO between -0.4 and -1.7 °C for permafrost locations and associate the variability to soil moisture. Both Hasler et al. (2014) and Rödder and Kneisel (2012) measured positive and negative TO values, the former between -1.8 and +1.0°C, and the latter between -2.0°C and +1.0°C. Hasler et al. (2014) suggest that a positive TO may be linked with the surface moss cover or with transient effects associated with the latent heat requirements of melting ice within the active layer. However, it is more likely that a positive TO should reflect a higher thermal conductivity in summer than winter.

Thermal offsets are linked to R_K through the TTOP equation. R_K were calculated from field measurements of ground surface and TTOP temperatures by isolating R_K from the TTOP equation. These calculated R_K values are both above and below 1. Smith and Riseborough (1996, 2002) expect values in the range 0.6–0.9 for mineral soil and as low as 0.3 for organic soils, depending on the amount of soil moisture. However, in dry conditions, R_K values > 1 can be expected (Jorgenson and Kreig, 1988; Riseborough and Smith, 1998). In fact, R_K values of up to 1.4 were reported by Jorgenson and Kreig (1988).

In conclusion, the data presented confirms the expected values of N_F and N_T, although the calculated, not measured, values of R_K were unexpected. The literature supports that these unexpected values are correct, however further analysis of active layer moisture and organic mat thickness and composition is required.

5.3. Environmental variables

Similar locations could be expected to have similar climate-permafrost transfer functions. But local heterogeneity, linked to snow distribution, shading distribution and active layer hydrology, play a critical role. Using a coarse DEM and land cover classification (30 x 30 m) only broad spatial patterns of this variability can be observed. A more refined understanding would require much higher resolution spatial datasets that are not feasible for this scale of modelling. Elevation was found to have a significant influence on N_F, N_T and R_K and land cover was found to be the most suitable classification for the differentiation of non-topographic parameters. Many studies have investigated the relationships between N_F, N_T and R_K with air temperature, measured snow depth, and land cover (e.g., Lewkowicz et al., 2012; Riseborough and Smith, 1998; Smith and Riseborough, 2002), this is the first investigation of their relation to topographic attributes that include elevation, slope, aspect and TPI.

5.4. TTOP-model

The TTOP model relies heavily on the proper parameterisation of air temperature. Spatially variable seasonal surface lapse rates present challenges to these predictions. Previous annual air temperature models have used linear surface lapse rates to represent air temperature inversions below treeline and different linear models above treeline. This project uses polynomial models to better reflect a gradual transition from densely forested regions, to regions of sparse trees, and later shrubs and alpine tundra. Below treeline annual SLR of -2.2°C/km and of +0.7°C/km were obtained in the Wolf Creek region (similar to the Whitehorse study area) and the Dawson region, using a synthetic year (Lewkowicz and Bonnaventure, 2011). These are very comparable to the values of -2.8°C/km and -0.1°C/km found over the same regions by modelling seasonal freezing and thawing degree-days individually and then calculating MAAT.

Overall the TTOP-model has some success at predicting TTOP values, though the model offers only a slight improvement to the extremely simple TOFF-model. This shows that the TOFF-model serves as a very good first approximation of TTOP values. In future research, TOFF success may be improved by establishing TOFF values for each land cover class and each study area.

Many published studies that use the TTOP-model use few measured input values (e.g., Gisnås et al., 2013; Janke et al., 2012; Juliussen and Humlum, 2007) while others use only textbook values (e.g., Henry and Smith, 2001; Stevens et al., 2010; Wright et al., 2003). This study demonstrates that about 50 station-years is the critical number of stations required for acceptable success rates. Fewer input data decreases success rapidly, and more station-years may not be justified by the modest increase in success.

A sensitivity analysis, one of the first of its kind, confirms that the limits of discontinuous permafrost are strongly related, not only to R_K, but also to N_F (e.g., Zhang et al., 1998). Our sensitivity analysis also suggests that summer air temperatures have greater impact on permafrost temperatures than winter air temperatures. There are many implications of these results, especially when considering the effects of projected changes in climate on TTOP values. The IPCC (2013) project increases in winter air temperatures that are greater than those of summer air temperatures. In a way, since the model is less sensitive to changes in winter temperatures and more to changes in summer temperatures, the overall effect of the change on TTOP may be attenuated by this seasonal difference.

5.5. Spatial patterns

Spatial predictions of permafrost likelihood were calculated using the TTOP and TOFF models and were reclassified from Bonnaventure et al. (2012). These models are useful for investigating expected patterns of distribution, but they should be supplemented with field data and expert advice if used for a specific location. The quality of the spatial datasets was not assessed in this thesis, as these input datasets are regarded as high quality final products. The purpose of this thesis is not to validate these datasets; rather, it is to use available datasets to explore the TTOP-model.

Permafrost in the Atlin study area is controlled by elevation. Likelihood of permafrost increases with elevation. This is mainly attributed to the absence of air temperature inversions in winter. The result of this is that all year, air temperature decreases with elevation. The Whitehorse study area presents a slightly more complicated story. High likelihoods are also associated with high elevations, but lower elevations may be suitable for permafrost given appropriate land cover. Permafrost likelihood results in the Dawson study area are very complex. This is most likely due to complications that relate to aspect, the organic mat, land cover classification errors, and active layer moisture. Air temperature modelling suggests that permafrost can potentially be anywhere in Dawson, thus site specific factors are critical. Each model incorporates these factors differently, and the resulting likelihoods are very different. An improved understanding, and mapping, of site specific variables would greatly improve modelling attempts in Dawson.

5.6. Future work

Future research on climate-permafrost interactions should investigate more closely the impact of the thickness as well as the moisture of the organic mat. Methods of mapping the organic mat spatially should also be investigated. Similarly, the active layer moisture content and active layer materials should be better documented on the site-specific level in order to better group R_K values. Finer resolution mapping of land cover, surficial geology and of topography would be required.

The TOFF model had better results than expected. Future research could explore the possibilities of improving the simple TOFF model by characterizing TOFF for different land cover classes, etc. The TOFF model may prove to be a useful tool to quickly characterize the likelihood of permafrost in the field based on mean annual air temperature.

The TTOP-model is a physically based equilibrium model and is a useful tool in understanding the behaviour and distribution of permafrost. Future research on the TTOP-model in this area should aim to expand the modelling area to the entire Yukon and northern British Columbia. This could be done with additional air, ground surface and TTOP measurements. Future research should use the TTOP-model to investigate past and future permafrost conditions in these regions. Little Ice Age or projected warming scenarios could be modelled. The TTOP-model could also be used to assess changes in climate by using ecological succession as the driver for change.

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ANNEX 1: Annual Means

ATL-SCH	2008	2009	2010	2011	2012	2013	2014	Mean	S.Dev.
MAAT				-0.2	1.3			*0.5*	*1.0*
MAGST				1.9	3.3	0.5		*1.9*	*1.4*
TTOP				2.2	2.3		2.4	*2.3*	*0.1*
TDDA				1589	1566			*1578*	*16*
TDDS				1518	1569			*1543*	*36*
NT				1.0	1.0			*1.0*	*0.0*
FDDA				1698	1143	1738	1628	*1552*	*276*
FDDS				829	425	839	759	*713*	*195*
NF				0.5	0.4	0.5	0.5	*0.5*	*0.1*
RK				1.1	0.8			*0.9*	*0.2*
SO				2.2	2.0			*2.1*	*0.2*
TO				0.3	-1.0			*-0.4*	*0.9*

INK-CMP	2008	2009	2010	2011	2012	2013	2014	Mean	S.Dev.
MAAT									
MAGST						6.4		*6.4*	
TTOP				4.2	4.8		4.5	*4.5*	*0.3*
TDDA									
TDDS						2295		*2295*	
NT									
FDDA							1063	*1063*	
FDDS				13		23	17	*18*	*5*
NF							0.0	*0.0*	
RK									
SO									
TO									

KUT-LAK	2008	2009	2010	2011	2012	2013	2014	Mean	S.Dev.
MAAT				-1.9	-0.7			*-1.3*	*0.9*
MAGST				3.5	3.7	3.3		*3.5*	*0.2*
TTOP					3.6	3.6	3.7	*3.6*	*0.1*
TDDA				1334	1369			*1351*	*25*

CHK-MNT	2008	2009	2010	2011	2012	2013	2014	Mean	S.Dev.
MAAT				-5.1	-4.1			*-4.6*	*0.7*
MAGST				1.5	1.1	-1.1		*0.5*	*1.4*
TTOP				1.1				*1.1*	
TDDA				581	647			*614*	*47*
TDDS				573	716			*644*	*101*
NT				1.0	1.1			*1.0*	*0.1*
FDDA				2169	2149		1849	*2055*	*179*
FDDS				121	314		808	*414*	*354*
NF				0.1	0.1		0.4	*0.2*	*0.2*
RK				0.9				*0.9*	
SO				5.6	5.2			*5.4*	*0.3*
TO				-0.3				*-0.3*	

KSAL-CMP	2008	2009	2010	2011	2012	2013	2014	Mean	S.Dev.
MAAT									
MAGST				2.4				*2.4*	
TTOP							3.0	*3.0*	
TDDA				1581				*1581*	
TDDS				1249				*1249*	
NT				0.8				*0.8*	
FDDA					1192			*1192*	
FDDS				420	97		16	*178*	*213*
NF					0.1			*0.1*	
RK									
SO									
TO									

MON-01	2008	2009	2010	2011	2012	2013	2014	Mean	S.Dev.
MAAT				-3.8	-2.7			*-3.2*	*0.8*
MAGST				1.4	1.7			*1.6*	*0.2*
TTOP				1.5	1.5	1.7		*1.6*	*0.1*
TDDA				777	774			*776*	*3*

TDDS				1393	1272			*1333*	*86*
NT				1.0	0.9			*1.0*	*0.1*
FDDA				1927	1000			*1463*	*656*
FDDS				124	11	150	86	*93*	*60*
NF				0.1	0.0			*0.0*	*0.0*
RK					1.0			*1.0*	
SO				5.1	2.4			*3.8*	*1.9*
TO					-0.1	0.3		*0.1*	*0.3*

MON-02	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT				-2.9	-1.8			*-2.4*	*0.8*
MAGST				1.2	0.1			*0.6*	*0.8*
TTOP				1.3	0.2			*0.8*	*0.8*
TDDA				895	913			*904*	*12*
TDDS				896	866			*881*	*21*
NT				1.0	0.9			*1.0*	*0.0*
FDDA				1910	1527			*1718*	*271*
FDDS				483	848			*666*	*257*
NF				0.3	0.6		0.0	*0.3*	*0.3*
RK				1.1	1.1			*1.1*	*0.0*
SO				3.9	1.7			*2.8*	*1.5*
TO				0.1	0.2			*0.1*	*0.0*

MON-04	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT									
MAGST				2.2	2.7	1.1		*2.0*	*0.8*
TTOP				2.4	2.5		2.2	*2.4*	*0.1*
TDDA									
TDDS				961	977			*969*	*11*
NT									
FDDA				1676			1524	*1600*	*108*
FDDS				154	40		238	*144*	*99*
NF				0.1			0.2	*0.1*	*0.0*
RK				1.1	1.0			*1.0*	*0.1*
SO									
TO				0.2	-0.2			*0.0*	*0.3*

TDDS				1032	875			*954*	*111*
NT				1.3	1.1			*1.2*	*0.1*
FDDA				2129	1707	2167		*2001*	*256*
FDDS				502	274	487		*421*	*127*
NF				0.2	0.2	0.2		*0.2*	*0.0*
RK				1.0	0.9			*1.0*	*0.1*
SO				5.2	4.2			*4.7*	*0.7*
TO				0.1	-0.2			*-0.1*	*0.2*

MON-03	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT				-2.3	-1.1			*-1.7*	*0.9*
MAGST				0.2	0.6	-0.1		*0.2*	*0.3*
TTOP				0.1	0.3		-0.2	*0.1*	*0.3*
TDDA				1003	970			*987*	*24*
TDDS				769	705			*737*	*45*
NT				0.8	0.7			*0.7*	*0.0*
FDDA				1826	1399		1503	*1576*	*222*
FDDS				710	497		752	*653*	*137*
NF				0.4	0.4		0.5	*0.4*	*0.1*
RK				1.0	0.9			*0.9*	*0.1*
SO				2.4	1.7			*2.1*	*0.5*
TO				0.0	-0.3			*-0.2*	*0.2*

MON-05	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT				-0.3	1.1			*0.4*	*1.0*
MAGST				3.0	3.4	3.1		*3.2*	*0.2*
TTOP					3.0	2.9	3.2	*3.0*	*0.1*
TDDA				1485	1471			*1478*	*9*
TDDS				1394	1269	1515		*1393*	*123*
NT				0.9	0.9			*0.9*	*0.1*
FDDA				1636	1109		1435	*1393*	*266*
FDDS				279	87	341	218	*231*	*109*
NF				0.2	0.1		0.2	*0.1*	*0.0*
RK					0.9	0.9		*0.9*	*0.0*
SO				3.5	2.2			*2.9*	*0.9*
TO					-0.4	-0.2		*-0.3*	*0.2*

MON-06	2008	2009	2010	2011	2012	2013	2014	Mean	S.Dev.
MAAT					0.9			*0.9*	
MAGST					2.6			*2.6*	
TTOP					1.7			*1.7*	
TDDA					1476			*1476*	
TDDS					1070			*1070*	
NT					0.7			*0.7*	
FDDA					1198	1774		*1486*	*408*
FDDS					144	516		*330*	*262*
NF					0.1	0.3		*0.2*	*0.1*
RK					0.7			*0.7*	
SO					1.8			*1.8*	
TO					-1.0			*-1.0*	

60MILE-WS	2008	2009	2010	2011	2012	2013	2014	Mean	S.Dev.
MAAT	-6.0					-6.4		*-6.2*	*0.3*
MAGST	-4.1					-4.6		*-4.4*	*0.3*
TTOP		-4.8	-3.0	-4.0	-4.4	-4.8	-3.4	*-4.1*	*0.7*
TDDA	692					1091		*892*	*282*
TDDS	832					994		*913*	*114*
NT	1.2					0.9		*1.1*	*0.2*
FDDA	2883	3200				3391	2515	*2997*	*384*
FDDS	2349	2550				2625	2020	*2386*	*271*
NF	0.8	0.8				0.8	0.8	*0.8*	*0.0*
RK						0.9		*0.9*	
SO	1.8					1.8		*1.8*	*0.0*
TO						-0.2		*-0.2*	

TOW-01	2008	2009	2010	2011	2012	2013	2014	Mean	S.Dev.
MAAT	-5.8	-5.8	-3.8	-5.8	-5.5	-6.5		*-5.5*	*0.9*
MAGST	-3.3	-3.2	-2.0	-2.8	-2.8	-3.4		*-2.9*	*0.5*
TTOP	-2.8	-3.5	-2.7	-2.4	-2.8	-3.4	-2.4	*-2.9*	*0.4*
TDDA	706	1006	1009	889	897	1063		*928*	*128*
TDDS	485	679	709	661	518	611		*611*	*91*
NT	0.7	0.7	0.7	0.7	0.6	0.6		*0.7*	*0.1*
FDDA	2868	3195	2407	3061	2898	3407	2553	*2913*	*350*

WND-LAK	2008	2009	2010	2011	2012	2013	2014	Mean	S.Dev.
MAAT				-2.2	-1.1			*-1.6*	*0.8*
MAGST				1.5	2.1	0.7		*1.4*	*0.7*
TTOP							1.7	*1.7*	
TDDA				1145	1156			*1150*	*8*
TDDS				733	938			*836*	*145*
NT				0.6	0.8			*0.7*	*0.1*
FDDA				1905	1538		1643	*1695*	*189*
FDDS				224	168		68	*153*	*79*
NF				0.1	0.1		0.0	*0.1*	*0.0*
RK									
SO				3.5	3.2			*3.3*	*0.2*
TO									

60MILE-BK	2008	2009	2010	2011	2012	2013	2014	Mean	S.Dev.
MAAT	-4.3	-3.1	-3.1		-3.2	-2.2		*-3.2*	*0.8*
MAGST	0.2	-0.6	0.0	1.3	0.5	0.9		*0.4*	*0.7*
TTOP	-0.8	-0.6	-0.2	-0.2	-0.2			*-0.4*	*0.3*
TDDA	954	1077			1008	1025		*1016*	*51*
TDDS	998	868	1018	1027	967	1041		*986*	*63*
NT	1.0	0.8			1.0	1.0		*1.0*	*0.1*
FDDA	2498	2209	2245		2168	1792		*2182*	*253*
FDDS	929	1101	1012	534	790	691		*843*	*212*
NF	0.4	0.5	0.5		0.4	0.4		*0.4*	*0.1*
RK	0.7	1.0	0.9	0.4	0.7			*0.8*	*0.2*
SO	4.4	2.5			3.7	3.1		*3.4*	*0.8*
TO	-1.0	0.0	-0.2	-1.6	-0.7			*-0.7*	*0.6*

TOW-02	2008	2009	2010	2011	2012	2013	2014	Mean	S.Dev.
MAAT	-4.6							*-4.6*	
MAGST	-3.3							*-3.3*	
TTOP	-3.6	-4.5						*-4.0*	*0.6*
TDDA	997							*997*	
TDDS	970							*970*	
NT	1.0							*1.0*	
FDDA	2718	3211						*2965*	*349*

FDDS	1690	1852	1424	1683	1546	1828	1243	*1609*	*220*
NF	0.6	0.6	0.6	0.5	0.5	0.5	0.5	*0.6*	*0.0*
RK	1.4	0.8	0.6	1.2	1.0	1.0		*1.0*	*0.3*
SO	2.6	2.8	1.9	3.1	2.7	3.1		*2.7*	*0.5*
TO	0.4	-0.3	-0.8	0.3	0.0	0.0		*-0.1*	*0.4*

TOW-03	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT	-4.3	-5.6	-2.7	-4.6	-3.7	-6.4		*-4.6*	*1.3*
MAGST	-0.9	0.1	0.6	-0.4	0.6	-0.5		*-0.1*	*0.6*
TTOP	-3.0	-2.6	-2.2	-2.6	-1.8	-2.6	-1.6	*-2.3*	*0.5*
TDDA	1641	1744	1780	1721	1775	1740		*1734*	*51*
TDDS	1598	1410	1499	1410	1401	1331		*1441*	*93*
NT	1.0	0.8	0.8	0.8	0.8	0.8		*0.8*	*0.1*
FDDA	3217	3797	2803	3496	3187	4122	3407	*3432*	*431*
FDDS	1910	1371	1296	1544	1191	1503	990	*1401*	*293*
NF	0.6	0.4	0.5	0.4	0.4	0.4	0.3	*0.4*	*0.1*
RK	0.5	0.3	0.3	0.4	0.4	0.4		*0.4*	*0.1*
SO	3.5	5.7	3.4	4.5	4.4	6.1		*4.6*	*1.1*
TO	-2.1	-2.7	-2.8	-2.3	-2.4	-2.1		*-2.4*	*0.3*

TOW-05	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT	-3.5			-3.4	-2.7			*-3.2*	*0.5*
MAGST	-0.9			0.2	0.3			*-0.1*	*0.7*
TTOP	-0.2	-0.5		0.3	0.4	0.0		*0.0*	*0.4*
TDDA	1660			1749	1810			*1740*	*75*
TDDS	1277			1364	1264			*1302*	*54*
NT	0.8			0.8	0.7			*0.7*	*0.0*
FDDA	2980	3486		3124	2886	3692		*3234*	*343*
FDDS	1620	1141		1287	1150	1202		*1280*	*199*
NF	0.5	0.3		0.4	0.4	0.3		*0.4*	*0.1*
RK	1.2			1.0	1.0			*1.1*	*0.1*
SO	2.7			4.0	3.3			*3.3*	*0.7*
TO	0.7			0.1	0.1			*0.3*	*0.4*

TOW-07	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT	-3.6		-1.5	-3.7				*-2.9*	*1.2*
MAGST	0.6	0.8	1.7	1.7	1.7			*1.3*	*0.5*

FDDS	2204	2580						*2392*	*266*
NF	0.8	0.8						*0.8*	*0.0*
RK	0.9							*0.9*	
SO	1.3							*1.3*	
TO	-0.2							*-0.2*	

TOW-04	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT		-5.4	-2.7	-4.5	-3.7			*-4.1*	*1.2*
MAGST	-0.4	-0.5	0.5	0.6	1.1			*0.3*	*0.7*
TTOP	-2.1	-2.3	-1.6	-1.4	-0.9	-1.4		*-1.6*	*0.5*
TDDA		1684	1715	1636	1683			*1679*	*33*
TDDS	1329	1174	1317	1208	1241			*1254*	*67*
NT		0.7	0.8	0.7	0.7			*0.7*	*0.0*
FDDA	4323	3749	2714	3387	3101	3965		*3540*	*589*
FDDS	1464	1348	1150	981	848	1206		*1166*	*228*
NF	0.3	0.4	0.4	0.3	0.3	0.3		*0.3*	*0.1*
RK	0.5	0.4	0.4	0.4	0.4			*0.4*	*0.0*
SO		5.2	3.2	5.4	5.0			*4.7*	*1.0*
TO	-1.8	-1.8	-2.0	-2.0	-1.9			*-1.9*	*0.1*

TOW-06	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT	-4.1	-5.2	-2.3		-3.5			*-3.8*	*1.2*
MAGST	-2.2	-1.2	-0.1	-1.8	-1.1			*-1.3*	*0.8*
TTOP	-1.2	-1.5	-0.9	-1.0	-0.9	-1.2		*-1.1*	*0.2*
TDDA	1531	1666	1724		1657			*1644*	*81*
TDDS	1196	1073	1237	1247	1234			*1198*	*72*
NT	0.8	0.6	0.7		0.7			*0.7*	*0.1*
FDDA	3098	3633	2587	3295	3014	3823		*3242*	*446*
FDDS	2022	1510	1271	1929	1635	1923		*1715*	*293*
NF	0.7	0.4	0.5	0.6	0.5	0.5		*0.5*	*0.1*
RK	1.3	0.9	0.8	1.2	1.1			*1.1*	*0.2*
SO	2.0	4.2	2.3		2.6			*2.8*	*1.0*
TO	1.0	-0.3	-0.8	0.8	0.2			*0.2*	*0.8*

TOW-08	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT	-3.9	-4.4	-2.2	-3.8				*-3.6*	*1.0*
MAGST	-1.0	-1.9	0.5	0.2	3.2			*0.2*	*1.9*

TTOP			0.9		1.3	0.8		*1.0*	*0.3*
TDDA	1547		1796	1662				*1668*	*125*
TDDS	1205	1072	1267	1215	1221			*1196*	*73*
NT	0.8		0.7	0.7				*0.7*	*0.0*
FDDA	2899	3376	2365	3023	2834			*2899*	*365*
FDDS	965	809	617	607	610	995		*767*	*182*
NF	0.3	0.2	0.3	0.2	0.2			*0.2*	*0.1*
RK			0.7		0.9			*0.8*	*0.1*
SO	4.4		3.3	5.4				*4.4*	*1.0*
TO			-0.8		-0.4			*-0.6*	*0.3*

TOW-09	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT	-4.9							*-4.9*	
MAGST	1.2	2.1	2.5	1.7	2.6			*2.0*	*0.6*
TTOP	0.9	1.5	2.1	2.0	2.1	1.5		*1.7*	*0.5*
TDDA									
TDDS	1192	1416	1641	1599	1603			*1490*	*188*
NT									
FDDA	3030	3520		3167		3722		*3360*	*318*
FDDS	785	674	744	963	676	1146		*831*	*187*
NF	0.3	0.2		0.3		0.3		*0.3*	*0.1*
RK	0.9	0.9	0.9	1.1	0.9			*0.9*	*0.1*
SO									
TO	-0.2	-0.5	-0.4	0.3	-0.5			*-0.3*	*0.3*

TOW-11	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT	-3.6	-4.4	-1.6	-3.7	-2.9			*-3.2*	*1.1*
MAGST	1.0	1.7	2.7	2.8	2.6			*2.2*	*0.8*
TTOP	1.7	1.3	1.9	2.1				*1.7*	*0.4*
TDDA	1394	1604	1650	1492	1544			*1537*	*100*
TDDS	1196	1253	1303	1293	1306			*1270*	*47*
NT	0.9	0.8	0.8	0.9	0.8			*0.8*	*0.0*
FDDA	2718	3247	2205	2864	2644	3363		*2840*	*423*
FDDS	823	622	310	258	350	729		*515*	*240*
NF	0.3	0.2	0.1	0.1	0.1	0.2		*0.2*	*0.1*
RK	1.2	0.9	0.8	0.8				*0.9*	*0.2*

TTOP	-0.5	-1.4	0.2	-0.2				*-0.5*	*0.7*
TDDA	1109	1362	1349	1240				*1265*	*118*
TDDS	870	694	959	867				*847*	*111*
NT	0.8	0.5	0.7	0.7				*0.7*	*0.1*
FDDA	2629	3050	2198	2744				*2655*	*353*
FDDS	1252	1393	788	780				*1053*	*316*
NF	0.5	0.5	0.4	0.3				*0.4*	*0.1*
RK	1.2	1.3	0.9	0.8				*1.1*	*0.2*
SO	3.1	2.7	2.8	4.4				*3.2*	*0.8*
TO	0.5	0.5	-0.3	-0.4				*0.1*	*0.5*

TOW-10	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT		-4.3	-1.5	-3.3				*-3.0*	*1.5*
MAGST	0.4	1.9	2.1	1.4	1.5			*1.5*	*0.6*
TTOP	1.1	1.3	2.0	2.4	2.1		1.2	*1.7*	*0.6*
TDDA		1903	1939	1846				*1896*	*47*
TDDS	1297	1421	1692	1716	1618			*1549*	*182*
NT		0.7	0.9	0.9				*0.8*	*0.1*
FDDA		3473	2486	3098			2986	*3011*	*407*
FDDS	1151	737	933	1193	1098		1397	*1085*	*227*
NF		0.2	0.4	0.4			0.5	*0.4*	*0.1*
RK	1.2	0.9	1.0	1.2	1.2			*1.1*	*0.2*
SO		6.2	3.6	4.9				*4.9*	*1.3*
TO	0.6	-0.6	-0.1	1.0	0.7			*0.3*	*0.6*

TOW-12	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT	-3.5	-4.3	-1.6	-3.5	-2.8			*-3.1*	*1.0*
MAGST	0.2	0.7	1.4	1.6	1.6			*1.1*	*0.6*
TTOP	0.1	-0.1	0.2	0.7	0.8	0.6		*0.4*	*0.4*
TDDA	1389	1629	1603	1491	1514			*1525*	*96*
TDDS	949	913	1235	1043	922			*1012*	*135*
NT	0.7	0.6	0.8	0.7	0.6			*0.7*	*0.1*
FDDA	2739	3252	2251	2904	2657	3393		*2866*	*416*
FDDS	860	664	731	448	339	881		*654*	*220*
NF	0.3	0.2	0.3	0.2	0.1	0.3		*0.2*	*0.1*
RK	1.0	0.7	0.7	0.7	0.7			*0.7*	*0.1*

SO	4.6	6.2	4.2	6.6	5.6			*5.5*	*1.0*
TO	0.6	-0.4	-0.8	-0.7				*-0.3*	*0.7*

TOW-13	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT	-3.8	-4.5			-3.2			*-3.8*	*0.7*
MAGST	1.3	0.4	2.2	1.5	1.9			*1.5*	*0.7*
TTOP									
TDDA	1125	1323			1329			*1259*	*116*
TDDS	1016	869	1454	1299	1069			*1141*	*234*
NT	0.9	0.7			0.8			*0.8*	*0.1*
FDDA	2568	3020			2498	3137		*2806*	*320*
FDDS	523	734	679	726	374	503		*590*	*146*
NF	0.2	0.2			0.1	0.2		*0.2*	*0.0*
RK									
SO	5.3	5.0			5.1			*5.1*	*0.1*
TO									

CR-02	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT	-4.3	-3.1	-3.1		-3.2	-2.2		*-3.2*	*0.8*
MAGST	0.2	-0.6	0.0	1.3	0.5	0.9		*0.4*	*0.7*
TTOP	-0.8	-0.6	-0.2	-0.2	-0.2			*-0.4*	*0.3*
TDDA	954	1077			1008	1025		*1016*	*51*
TDDS	998	868	1018	1027	967	1041		*986*	*63*
NT	1.0	0.8			1.0	1.0		*1.0*	*0.1*
FDDA	2498	2209	2245		2168	1792		*2182*	*253*
FDDS	929	1101	1012	534	790	691		*843*	*212*
NF	0.4	0.5	0.5		0.4	0.4		*0.4*	*0.1*
RK	0.7	1.0	0.9	0.4	0.7			*0.8*	*0.2*
SO	4.4	2.5			3.7	3.1		*3.4*	*0.8*
TO	-1.0	0.0	-0.2	-1.6	-0.7			*-0.7*	*0.6*

CR-04	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT	-3.8	-3.2	-2.9		-3.4			*-3.3*	*0.4*
MAGST	-1.0	-1.3	-0.4	0.2	-0.4	-0.5		*-0.6*	*0.5*
TTOP	-1.2	-1.1	-0.5	-0.7				*-0.9*	*0.3*
TDDA	866	786			886			*846*	*53*
TDDS	869	716	918	889	835	751		*830*	*80*

SO	3.9	5.1	3.2	5.5	4.7			*4.5*	*0.9*
TO	-0.1	-0.8	-1.2	-0.8	-0.7			*-0.7*	*0.4*

CR-01	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT		-3.5	-1.7	-3.8	-2.5			*-2.9*	*1.0*
MAGST	-0.1	0.8	1.1	1.0	1.0			*0.8*	*0.5*
TTOP	-0.1	0.1		0.3	0.0			*0.1*	*0.2*
TDDA		1102	1063	900	930			*999*	*99*
TDDS	868	1015	899	882	857			*904*	*64*
NT		0.9	0.8	1.0	0.9			*0.9*	*0.1*
FDDA		2424	1739	2352	1943	2440		*2180*	*319*
FDDS	888	734	505	523	480	818		*658*	*178*
NF		0.3	0.3	0.2	0.2	0.3		*0.3*	*0.0*
RK	1.0	0.8		0.7	0.6			*0.8*	*0.2*
SO		4.4	2.9	5.0	3.8			*4.0*	*0.9*
TO	0.0	-0.7		-0.8	-0.9			*-0.6*	*0.4*

CR-03	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT	-3.6	-3.2	-2.8	-1.3				*-2.7*	*1.0*
MAGST	-0.8	-1.3	-0.2	-0.2	-0.3	-0.1		*-0.5*	*0.5*
TTOP			-0.4	-0.6	-0.6			*-0.5*	*0.1*
TDDA	1025	843	1195	1080				*1036*	*147*
TDDS	1128	832	1153	886	972	960		*989*	*128*
NT	1.1	1.0	1.0	0.8				*1.0*	*0.1*
FDDA	2341	1989	2225	1566				*2030*	*342*
FDDS	1431	1290	1222	956	1066	996		*1160*	*185*
NF	0.6	0.6	0.5	0.6				*0.6*	*0.0*
RK			0.9	0.8	0.9			*0.9*	*0.0*
SO	2.8	1.9	2.6	1.1				*2.1*	*0.8*
TO			-0.2	-0.4	-0.3			*-0.3*	*0.1*

CR-05	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT				-1.7		-3.1		*-2.4*	*1.0*
MAGST	-4.8			-1.0	-3.0	-2.5		*-2.8*	*1.6*
TTOP				-2.6	-2.7			*-2.6*	*0.1*
TDDA				967		811		*889*	*110*
TDDS				1128	888	878		*965*	*141*

NT	1.0	0.9			0.9			*1.0*	*0.0*
FDDA	2291	1957	2138		2162			*2137*	*138*
FDDS	1246	1183	1056	832	968	939		*1037*	*156*
NF	0.5	0.6	0.5		0.4			*0.5*	*0.1*
RK	0.9	1.1	1.0	0.7				*0.9*	*0.2*
SO	2.9	1.9			3.1			*2.6*	*0.6*
TO	-0.1	0.2	-0.1	-0.8				*-0.2*	*0.4*

CR-06	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT	-5.1	-4.6	-3.5	-2.2				*-3.9*	*1.3*
MAGST	0.1	-0.5	0.1	1.1	-0.1	0.9		*0.3*	*0.6*
TTOP	-0.5	-0.4	0.2	-0.2				*-0.2*	*0.3*
TDDA	797	611	1035	914				*839*	*181*
TDDS	762	578	756	721	551			*673*	*101*
NT	1.0	0.9	0.7	0.8				*0.9*	*0.1*
FDDA	2647	2309	2362	1762				*2270*	*370*
FDDS	744	745	703	329	604			*625*	*175*
NF	0.3	0.3	0.3	0.2				*0.3*	*0.1*
RK	0.7	1.0	1.0	0.3				*0.8*	*0.3*
SO	5.1	4.2	3.8	3.4				*4.1*	*0.7*
TO	-0.5	0.0	0.1	-1.3				*-0.4*	*0.7*

MtMC-BK	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT		-5.1	-4.0	-4.5				*-4.5*	*0.5*
MAGST		-1.4	-2.2	-0.8				*-1.5*	*0.7*
TTOP									
TDDA	872	722	737	1031				*840*	*144*
TDDS	689	606	590	868				*688*	*127*
NT	0.8	0.8	0.8	0.8				*0.8*	*0.0*
FDDA		2579	2236	2610	2143			*2392*	*237*
FDDS		1109	1419	1158	1488			*1293*	*188*
NF		0.4	0.6	0.4	0.7			*0.6*	*0.1*
RK									
SO		3.7	1.8	3.5				*3.0*	*1.0*
TO									

WC2006-02	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**

NT				1.2		1.1		*1.1*	*0.1*
FDDA				1566		1974		*1770*	*288*
FDDS				1511	1933	1819		*1754*	*218*
NF				1.0		0.9		*0.9*	*0.0*
RK				0.5	1.1			*0.8*	*0.4*
SO				0.6		0.6		*0.6*	*0.0*
TO				-1.5	0.2			*-0.7*	*1.3*

MtMC	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT	-2.5	-4.9	-3.9	-4.3				*-3.9*	*1.0*
MAGST	-0.8	-3.4	-3.0	-1.7				*-2.2*	*1.2*
TTOP			-1.1	-1.7	-2.3	-2.0		*-1.8*	*0.5*
TDDA	884	742	744	1058				*857*	*149*
TDDS	1181	968	967	1409				*1131*	*211*
NT	1.3	1.3	1.3	1.3				*1.3*	*0.0*
FDDA	1753	2506	2191	2557	2017			*2205*	*337*
FDDS	1462	2201	2092	2004	1973			*1946*	*285*
NF	0.8	0.9	1.0	0.8	1.0			*0.9*	*0.1*
RK			1.7	1.0				*1.4*	*0.5*
SO	1.6	1.5	0.9	2.5				*1.6*	*0.7*
TO			1.9	0.0				*0.9*	*1.3*

WC2006-01	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT	-3.0				-2.9	-1.8		*-2.6*	*0.7*
MAGST	1.3	0.9	2.0	2.9	2.3	2.2		*1.9*	*0.7*
TTOP	1.1	1.6						*1.4*	*0.3*
TDDA	1167				1073	1071		*1104*	*55*
TDDS	1315	1133	1443	1500	1224	1173		*1298*	*149*
NT	1.1				1.1	1.1		*1.1*	*0.0*
FDDA	2266	1888			2105	1738		*1999*	*233*
FDDS	849	814	735	414	407	322		*590*	*234*
NF	0.4	0.4			0.2	0.2		*0.3*	*0.1*
RK	1.0	1.2						*1.1*	*0.2*
SO	4.3				5.1	4.2		*4.5*	*0.5*
TO	-0.2	0.7						*0.3*	*0.6*

WC2006-03	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**

MAAT		-3.4						*-3.4*	
MAGST	0.5	-0.2						*0.2*	*0.4*
TTOP	0.6							*0.6*	
TDDA		854						*854*	
TDDS	1061	801						*931*	*184*
NT		0.9						*0.9*	
FDDA	2389	2071	2318					*2260*	*167*
FDDS	889	856	758					*834*	*68*
NF	0.4	0.4	0.3					*0.4*	*0.0*
RK	1.0							*1.0*	
SO		3.2						*3.2*	
TO	0.1							*0.1*	

WC2006-04	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT									
MAGST	1.4	2.0						*1.7*	*0.5*
TTOP									
TDDA									
TDDS	1301							*1301*	
NT									
FDDA			2161					*2161*	
FDDS	811		677					*744*	*95*
NF			0.3					*0.3*	
RK									
SO									
TO									

WC2006-06	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT	-3.6	-2.9						*-3.2*	*0.4*
MAGST	1.3	0.2						*0.8*	*0.8*
TTOP		0.5						*0.5*	
TDDA	1054	858						*956*	*139*
TDDS	1341	886						*1113*	*322*
NT	1.3	1.0						*1.2*	*0.2*
FDDA	2272	1918	2154					*2114*	*180*
FDDS	868	802	709					*793*	*80*

MAAT		-3.0						*-3.0*	
MAGST	0.6	-0.4						*0.1*	*0.7*
TTOP	0.5	0.7						*0.6*	*0.1*
TDDA		866						*866*	
TDDS	1110	977						*1044*	*94*
NT		1.1						*1.1*	
FDDA		1960	2267					*2113*	*217*
FDDS	889	1123	894					*969*	*134*
NF		0.6	0.4					*0.5*	*0.1*
RK	1.0	1.4						*1.2*	*0.3*
SO		2.6						*2.6*	
TO	-0.1	1.1						*0.5*	*0.9*

WC2006-05	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT	-3.6							*-3.6*	
MAGST	0.8	0.2						*0.5*	*0.4*
TTOP		0.7						*0.7*	
TDDA	1018							*1018*	
TDDS	1009	908						*959*	*71*
NT	1.0							*1.0*	
FDDA	2318		2162					*2240*	*110*
FDDS	726	847	581					*718*	*133*
NF	0.3		0.3					*0.3*	*0.0*
RK		1.2						*1.2*	
SO	4.3							*4.3*	
TO		0.5						*0.5*	

WC2006-07	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT	-3.8	-3.3						*-3.5*	*0.3*
MAGST	1.2	0.2						*0.7*	*0.7*
TTOP	0.8	1.0						*0.9*	*0.2*
TDDA	1080	1004						*1042*	*54*
TDDS	1054	908						*981*	*103*
NT	1.0	0.9						*0.9*	*0.1*
FDDA	2417	2194	2377					*2329*	*119*
FDDS	642	842	553					*679*	*148*

NF	0.4	0.4	0.3					*0.4*	*0.0*
RK		1.1						*1.1*	
SO	4.6	3.1						*3.9*	*1.1*
TO		0.3						*0.3*	

WC2006-08-MtGR	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT		-8.0	-6.3	-5.8				*-6.7*	*1.1*
MAGST		-6.6	-4.9	-4.1		-6.3		*-5.5*	*1.2*
TTOP	-5.8	-5.6			-6.4	-5.3		*-5.8*	*0.4*
TDDA	432	205	499	374				*377*	*126*
TDDS	615	314	646	496		399		*494*	*141*
NT	1.4	1.5	1.3	1.3				*1.4*	*0.1*
FDDA		2931	2919	2380				*2743*	*315*
FDDS		2554	2519	1896		2731		*2425*	*364*
NF		0.9	0.9	0.8				*0.8*	*0.0*
RK		1.6				2.0		*1.8*	*0.3*
SO		1.3	1.5	1.7				*1.5*	*0.2*
TO		1.0				1.0		*1.0*	*0.0*

WC2006-10	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT									
MAGST	-0.4	-0.9						*-0.6*	*0.3*
TTOP		-0.8						*-0.8*	
TDDA									
TDDS	860	695						*777*	*117*
NT									
FDDA									
FDDS	1024	1022	919					*988*	*60*
NF									
RK		1.1						*1.1*	
SO									
TO		0.1						*0.1*	

WC2006-12	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT	-3.4	-3.0						*-3.2*	*0.3*
MAGST	0.3	-0.3						*0.0*	*0.4*
TTOP	-0.7	-0.4						*-0.6*	*0.2*

NF	0.3	0.4	0.2					*0.3*	*0.1*
RK	0.9	1.3						*1.1*	*0.3*
SO	4.8	3.4						*4.1*	*1.0*
TO	-0.4	0.9						*0.2*	*0.9*

WC2006-09	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT	-3.6	-3.0						*-3.3*	*0.5*
MAGST	0.6	0.0						*0.3*	*0.4*
TTOP	0.1	0.0						*0.0*	*0.1*
TDDA	1041	860						*950*	*128*
TDDS	1140	911						*1026*	*162*
NT	1.1	1.1						*1.1*	*0.0*
FDDA	2303	1949	2155					*2136*	*177*
FDDS	914	900	1033					*949*	*73*
NF	0.4	0.5	0.5					*0.4*	*0.0*
RK	0.8	1.0						*0.9*	*0.1*
SO	4.1	3.0						*3.5*	*0.8*
TO	-0.6	0.0						*-0.3*	*0.4*

WC2006-11	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT		-3.0						*-3.0*	
MAGST	-0.8	-1.0						*-0.9*	*0.1*
TTOP	-0.8	-0.8						*-0.8*	*0.0*
TDDA		868						*868*	
TDDS	746	727						*736*	*14*
NT		0.8						*0.8*	
FDDA		1967	2165					*2066*	*140*
FDDS	1046	1095	965					*1036*	*66*
NF		0.6	0.4					*0.5*	*0.1*
RK	1.0	1.1						*1.1*	*0.1*
SO		2.0						*2.0*	
TO	0.0	0.2						*0.1*	*0.2*

WC-APM-WS	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT				-4.2				*-4.2*	
MAGST				0.9	1.9	1.5		*1.5*	*0.5*
TTOP	-0.3	0.5	0.3	0.4				*0.2*	*0.4*

TDDA	1072	874						*973*	*140*
TDDS	971	730						*850*	*170*
NT	0.9	0.8						*0.9*	*0.1*
FDDA	2325	1982	2178					*2162*	*172*
FDDS	883	856	737					*825*	*78*
NF	0.4	0.4	0.3					*0.4*	*0.0*
RK	0.6	1.0						*0.8*	*0.2*
SO	3.7	2.7						*3.2*	*0.7*
TO	-1.0	-0.1						*-0.5*	*0.6*

WC-DR	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT		-3.9	-4.3					*-4.1*	*0.3*
MAGST	1.0	1.2	2.6					*1.6*	*0.9*
TTOP									
TDDA		946						*946*	
TDDS	1344	1030	1257					*1210*	*162*
NT		1.1						*1.1*	
FDDA		2374	2638					*2506*	*187*
FDDS	999	578	287	73				*484*	*401*
NF		0.2	0.1					*0.2*	*0.1*
RK									
SO		5.2						*5.2*	
TO									

WC-P25	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT									
MAGST						0.8		*0.8*	
TTOP					0.1			*0.1*	
TDDA									
TDDS						301		*301*	
NT									
FDDA									
FDDS						15		*15*	
NF									
RK									
SO									

TDDA									
TDDS				901	889	829		*873*	*39*
NT									
FDDA				2212				*2212*	
FDDS				569	179	286		*345*	*201*
NF				0.3				*0.3*	
RK				0.8				*0.8*	
SO									
TO				-0.5				*-0.5*	

WC-P09	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT						-3.0		*-3.0*	
MAGST	-0.3	-0.7			0.0	0.4		*-0.1*	*0.5*
TTOP	-1.0	-1.0		-0.5	-0.3			*-0.7*	*0.3*
TDDA						944		*944*	
TDDS	947	795			874	875		*873*	*62*
NT						0.9		*0.9*	
FDDA						2066		*2066*	
FDDS	1045	1033	977		873	707		*927*	*141*
NF						0.3		*0.3*	
RK	0.7	0.9			0.9			*0.8*	*0.1*
SO						3.5		*3.5*	
TO	-0.7	-0.3			-0.3			*-0.4*	*0.2*

WC-T1	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT			-2.3	-0.3	-2.2	-1.0		*-1.5*	*1.0*
MAGST			0.3	1.6	1.2	1.8		*1.2*	*0.7*
TTOP		0.7	1.6	1.2	1.6	1.0		*1.2*	*0.4*
TDDA			1536	1517	1364	1395		*1453*	*86*
TDDS			1331	1366	1188	1201		*1272*	*90*
NT			0.9	0.9	0.9	0.9		*0.9*	*0.0*
FDDA	2416		2473	1660	2210	1787		*2109*	*368*
FDDS	1368		1228	783	746	552		*935*	*346*
NF	0.6		0.5	0.5	0.3	0.3		*0.4*	*0.1*
RK			1.4	0.9	1.1	0.8		*1.0*	*0.3*
SO			2.9	2.0	3.5	2.9		*2.8*	*0.6*

TO									

WC-T2	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT	-3.1		-2.3	-0.4	-2.5	-1.1		*-1.9*	*1.1*
MAGST	2.0	-0.7	1.7	2.1	1.7	2.0		*1.5*	*1.1*
TTOP						0.6		*0.6*	
TDDA	1359		1433	1390	1238	1257		*1335*	*85*
TDDS	1380	465	1283	1315	1135	1124		*1117*	*335*
NT	1.0		0.9	0.9	0.9	0.9		*0.9*	*0.1*
FDDA	2328	1800	2366	1566	2178	1715		*1992*	*341*
FDDS	578	638	654	564	541	377		*558*	*99*
NF	0.2	0.4	0.3	0.4	0.2	0.2		*0.3*	*0.1*
RK						0.5		*0.5*	
SO	4.9		4.3	2.5	4.2	3.3		*3.8*	*0.9*
TO						-1.3		*-1.3*	

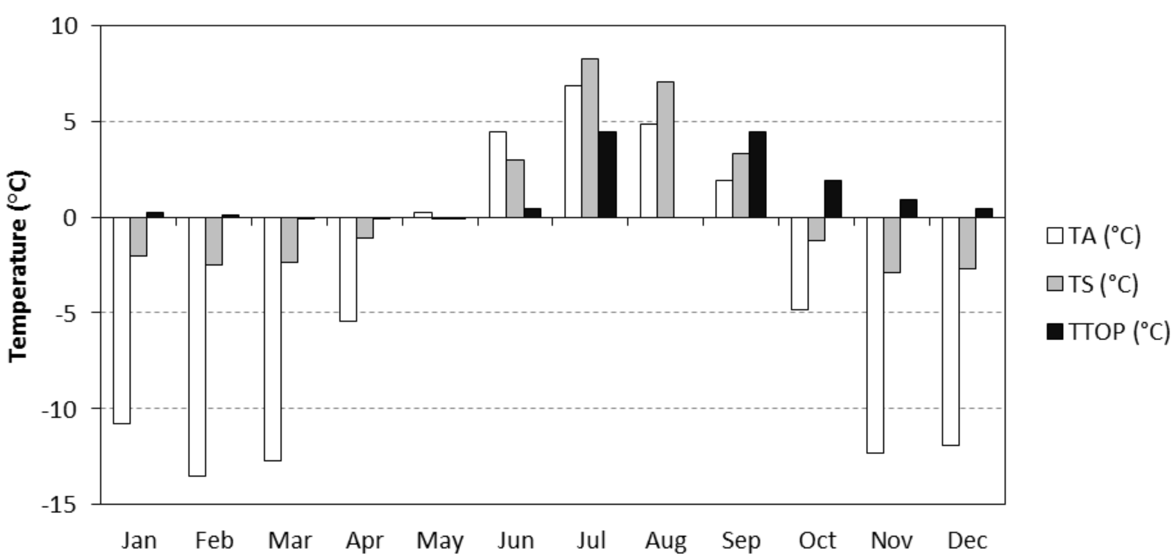
WC-T4	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT			-3.1		-3.6	-2.3		*-3.0*	*0.6*
MAGST	0.7		1.7	2.2	1.8	1.7		*1.6*	*0.5*
TTOP						0.8		*0.8*	
TDDA			1111		944	936		*997*	*99*
TDDS	982		1135	1106	1002	980		*1041*	*74*
NT			1.0		1.1	1.0		*1.0*	*0.0*
FDDA	2436		2314		2315	1879		*2236*	*245*
FDDS	757		522	330	353	341		*461*	*183*
NF	0.3		0.2		0.2	0.2		*0.2*	*0.1*
RK						0.7		*0.7*	
SO			5.0		5.5	4.3		*4.9*	*0.6*
TO						-0.9		*-0.9*	

TO			1.3	-0.3	0.4	-0.8		*0.1*	*0.9*

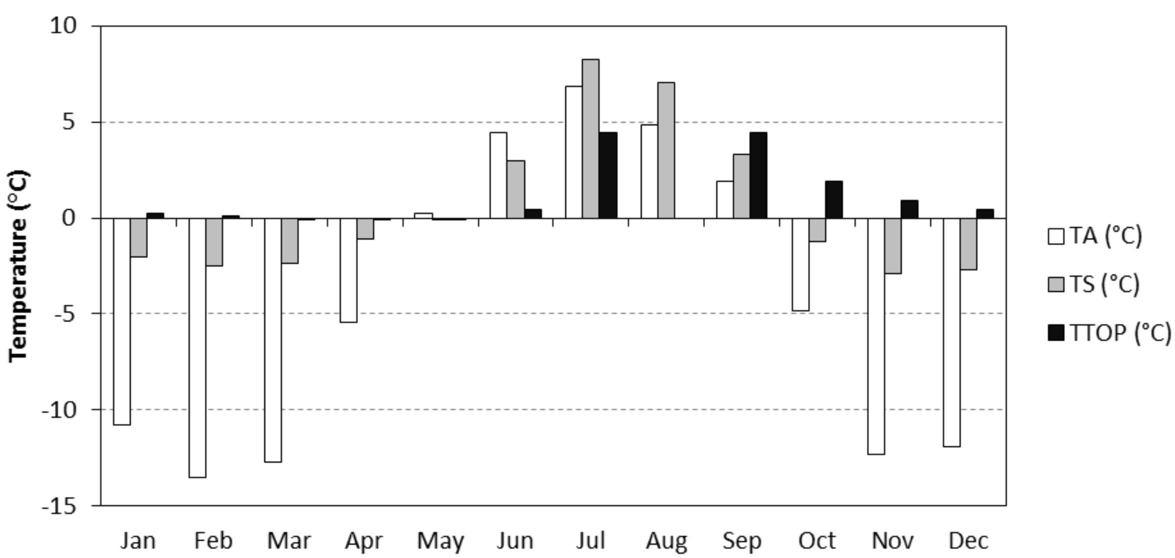
WC-T3	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Mean**	**S.Dev.**
MAAT				-0.3	-3.3	-1.9		*-1.8*	*1.5*
MAGST			1.9	3.6	1.7	2.6		*2.5*	*0.9*
TTOP		1.2		1.3	1.6	1.1		*1.3*	*0.2*
TDDA				1300	1115			*1207*	*131*
TDDS			1214	1245	1038			*1166*	*112*
NT				1.0	0.9			*0.9*	*0.0*
FDDA	2437			1370	2306			*2038*	*582*
FDDS	576		440	80	424	985		*501*	*327*
NF	0.2			0.1	0.2			*0.2*	*0.1*
RK				0.4	1.0			*0.7*	*0.4*
SO				3.4	4.9			*4.2*	*1.1*
TO				-2.3	-0.1	-1.5		*-1.3*	*1.1*

ANNEX 2: Station Metadata

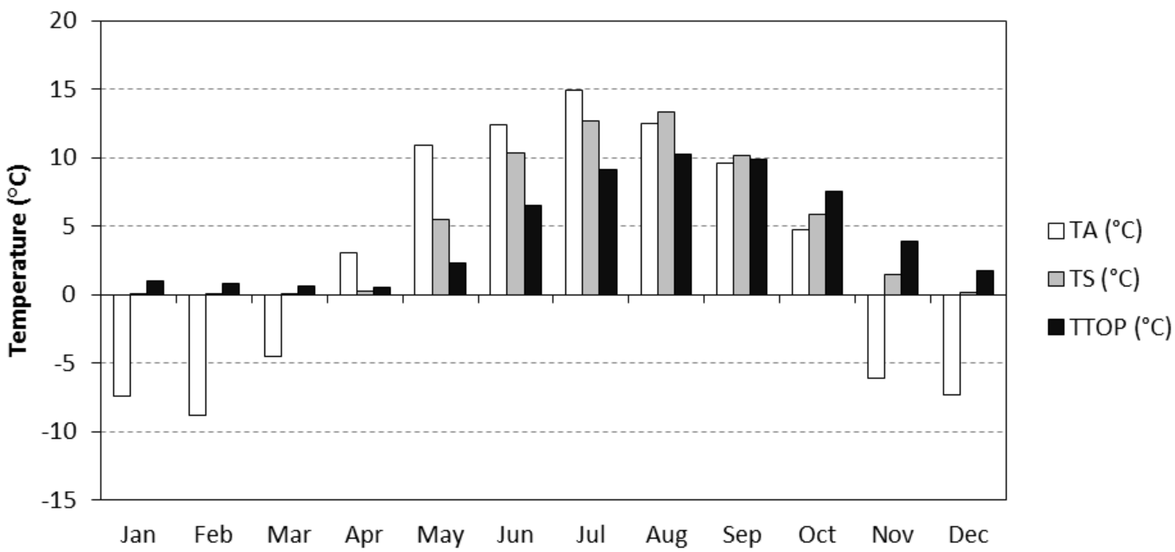
ATLIN	**ATL-SCH**	**Mean**	***°C***	**n**	**σ**	**Blended**	***TA (°C)***	***TS (°C)***	***TTOP (°C)***
Start	*2010*	**MAAT**	*0.5*	*2*	*1.0*	**Jan**	*-10.4*	*-3.9*	*-0.1*
End	*2014*	**MAGST**	*1.9*	*3*	*1.4*	**Feb**	*-9.7*	*-4.7*	*-0.6*
Latitude (°N)	*59.5747*	**TTOP**	*2.3*	*3*	*0.1*	**Mar**	*-8.6*	*-5.2*	*-1.4*
Longitude (°W)	*133.6874*		***°C-days***	**n**	**σ**	**Apr**	*0.5*	*-0.3*	*-0.3*
Elevation (m a.s.l.)	*705*	**TDD_A**	*1578*	*2*	*16*	**May**	*7.2*	*7.1*	*0.7*
Slope (°)	*5*	**FDD_A**	*1552*	*4*	*276*	**Jun**	*10.4*	*11.0*	*3.7*
Aspect (°)	*275*	**TDD_S**	*1543*	*2*	*36*	**Jul**	*12.5*	*12.6*	*5.9*
TPI50 (m)	*-0.1*	**FDD_S**	*713*	*4*	*195*	**Aug**	*10.9*	*10.7*	*6.6*
TPI200 (m)	*-1.4*		**Values**	**n**	**σ**	**Sep**	*7.7*	*6.9*	*6.4*
TPI700 (m)	*3.4*	**N_T**	*1.0*	*2*	*0.0*	**Oct**	*1.7*	*1.0*	*4.2*
PISR (WH/m^2)	*5160*	**N_F**	*0.5*	*4*	*0.1*	**Nov**	*-7.6*	*-3.6*	*1.6*
Land Cover	*Deciduous*	**R_K**	*0.9*	*2*	*0.2*	**Dec**	*-12.3*	*-4.5*	*0.3*
Texture	*NA*	**S_O**	*2.1*	*2*	*0.2*	**Jan-Jul**	*23.0*	*16.5*	*6.1*
Materials	*NA*	**T_O**	*-0.4*	*2*	*0.9*				
TST_{MIN}	*23-Apr*								
TST_{MAX}	*02-May*								
FST_{MIN}	*06-Nov*								
FST_{MAX}	*02-Nov*								



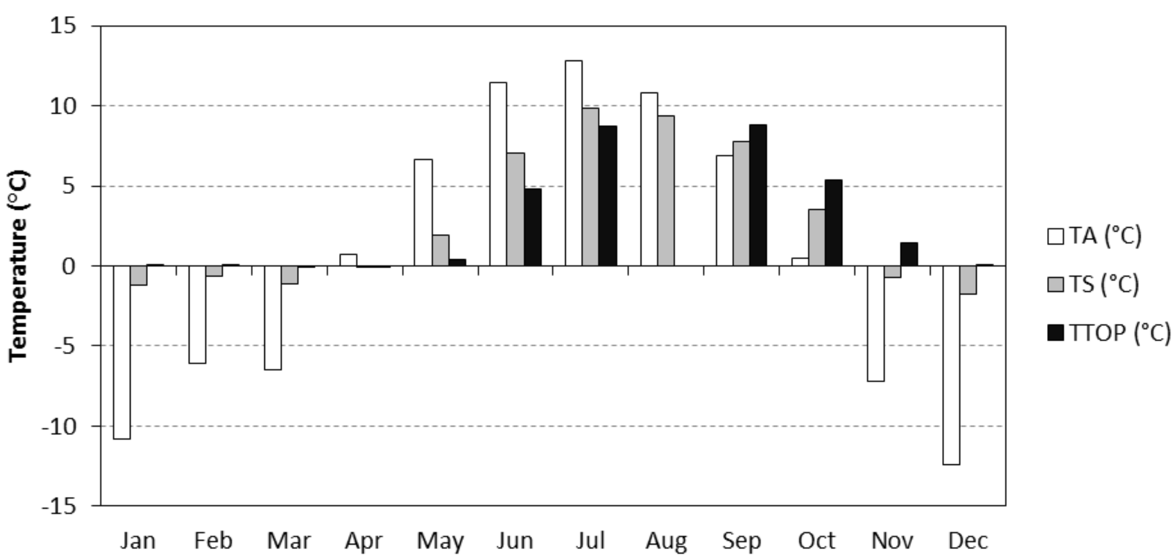
ATLIN	**CHK-MNT**	**Mean**	***°C***	**n**	**σ**	**Blended**	***TA (°C)***	***TS (°C)***	***TTOP (°C)***
Start	*2010*	**MAAT**	*-4.6*	*2*	*0.7*	**Jan**	*-10.8*	*-2.0*	*0.2*
End	*2014*	**MAGST**	*0.5*	*3*	*1.4*	**Feb**	*-13.5*	*-2.5*	*0.1*
Latitude (°N)	*59.2494*	**TTOP**	*1.1*	*1*		**Mar**	*-12.7*	*-2.4*	*-0.0*
Longitude (°W)	*132.9937*		***°C-days***	**n**	**σ**	**Apr**	*-5.4*	*-1.1*	*-0.1*
Elevation (m a.s.l.)	*1650*	**TDD_A**	*614*	*2*	*47*	**May**	*0.3*	*-0.1*	*-0.1*
Slope (°)	*15*	**FDD_A**	*2055*	*3*	*179*	**Jun**	*4.5*	*3.0*	*0.4*
Aspect (°)	*117*	**TDD_S**	*644*	*2*	*101*	**Jul**	*6.8*	*8.2*	*4.5*
TPI50 (m)	*-1.4*	**FDD_S**	*414*	*3*	*354*	**Aug**	*4.8*	*7.1*	
TPI200 (m)	*-2.0*		**Values**	**n**	**σ**	**Sep**	*1.9*	*3.3*	*4.5*
TPI700 (m)	*55.2*	**N_T**	*1.0*	*2*	*0.1*	**Oct**	*-4.9*	*-1.2*	*1.9*
PISR (WH/m^2)	*5854*	**N_F**	*0.2*	*3*	*0.2*	**Nov**	*-12.3*	*-2.9*	*0.9*
Land Cover	*Tundra (Maritime)*	**R_K**	*0.9*	*1*		**Dec**	*-11.9*	*-2.7*	*0.4*
Texture	*NA*	**S_O**	*5.4*	*2*	*0.3*	**Jan-Jul**	*17.6*	*10.2*	*4.7*
Materials	*NA*	**T_O**	*-0.3*	*1*					
TST_{MIN}	*16-May*								
TST_{MAX}	*21-May*								
FST_{MIN}	*16-Nov*								
FST_{MAX}	*22-Oct*								



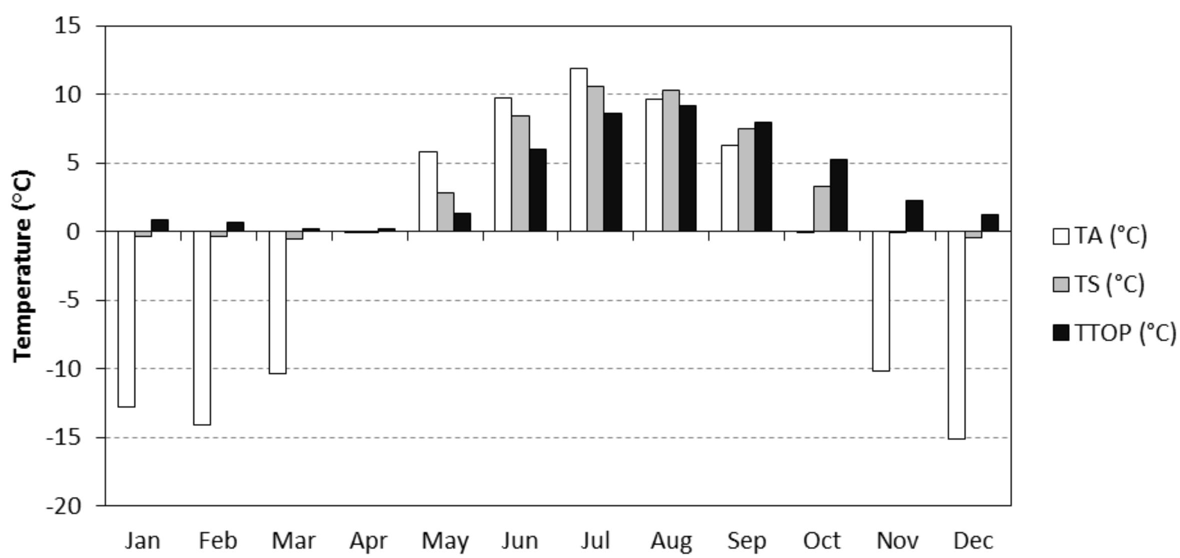
ATLIN	INK-CMP	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	2010	MAAT		0		Jan	-7.4	0.1	1.0
End	2014	MAGST	6.4	1		Feb	-8.8	0.1	0.8
Latitude (°N)	58.9022	TTOP	4.5	3	0.3	Mar	-4.5	0.0	0.6
Longitude (°W)	133.1463		°C-days	n	σ	Apr	3.1	0.3	0.5
Elevation (m a.s.l.)	85	TDD_A		0		May	10.9	5.5	2.3
Slope (°)	17	FDD_A	1063	1		Jun	12.4	10.3	6.5
Aspect (°)	94	TDD_S	2295	1		Jul	15.0	12.7	9.1
TPI50 (m)	2.5	FDD_S	18	3	5	Aug	12.5	13.3	10.2
TPI200 (m)	0.8		Values	n	σ	Sep	9.6	10.1	9.9
TPI700 (m)	-45.3	N_T		0		Oct	4.8	5.9	7.5
PISR (WH/m^2)	4372	N_F	0.0	1		Nov	-6.1	1.5	3.9
Land Cover	Deciduous	R_K		0		Dec	-7.3	0.1	1.8
Texture	NA	S_O		0		Jan-Jul	22.4	12.7	10.1
Materials	NA	T_O		0					
TST_{MIN}	18-May								
TST_{MAX}	27-Mar								
FST_{MIN}	23-Dec								
FST_{MAX}	18-Nov								



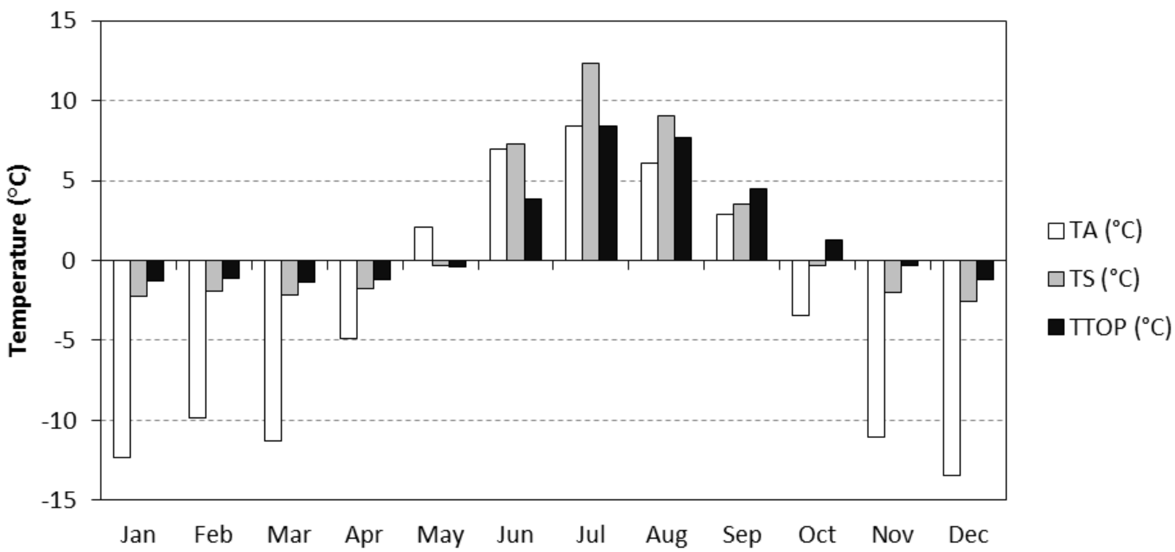
ATLIN	**KSAL-CMP**	**Mean**	***°C***	**n**	**σ**	**Blended**	***TA (°C)***	***TS (°C)***	***TTOP (°C)***
Start	*2010*	**MAAT**		*0*		**Jan**	*-10.8*	*-1.2*	*0.1*
End	*2014*	**MAGST**	*2.4*	*1*		**Feb**	*-6.1*	*-0.6*	*0.1*
Latitude (°N)	*58.7167*	**TTOP**	*3.0*	*1*		**Mar**	*-6.5*	*-1.1*	*-0.0*
Longitude (°W)	*132.9441*		***°C-days***	**n**	**σ**	**Apr**	*0.7*	*-0.0*	*-0.0*
Elevation (m a.s.l.)	*537*	**TDD_A**	*1581*	*1*		**May**	*6.6*	*1.9*	*0.4*
Slope (°)	*0*	**FDD_A**	*1192*	*1*		**Jun**	*11.4*	*7.0*	*4.8*
Aspect (°)	*-1*	**TDD_S**	*1249*	*1*		**Jul**	*12.8*	*9.8*	*8.7*
TPI50 (m)	*0.0*	**FDD_S**	*178*	*3*	*213*	**Aug**	*10.8*	*9.3*	
TPI200 (m)	*0.0*		**Values**	**n**	**σ**	**Sep**	*6.9*	*7.8*	*8.8*
TPI700 (m)	*0.0*	**N_T**	*0.8*	*1*		**Oct**	*0.4*	*3.5*	*5.3*
PISR (WH/m^2)	*0*	**N_F**	*0.1*	*1*		**Nov**	*-7.2*	*-0.7*	*1.4*
Land Cover	*Coniferous or Mixed*	**R_K**		*0*		**Dec**	*-12.4*	*-1.7*	*0.1*
Texture	*NA*	**S_O**		*0*		**Jan-Jul**	*23.6*	*11.0*	*8.8*
Materials	*NA*	**T_O**		*0*					
TST_{MIN}	*09-Apr*								
TST_{MAX}	*13-Apr*								
FST_{MIN}	*16-Nov*								
FST_{MAX}	*19-Nov*								



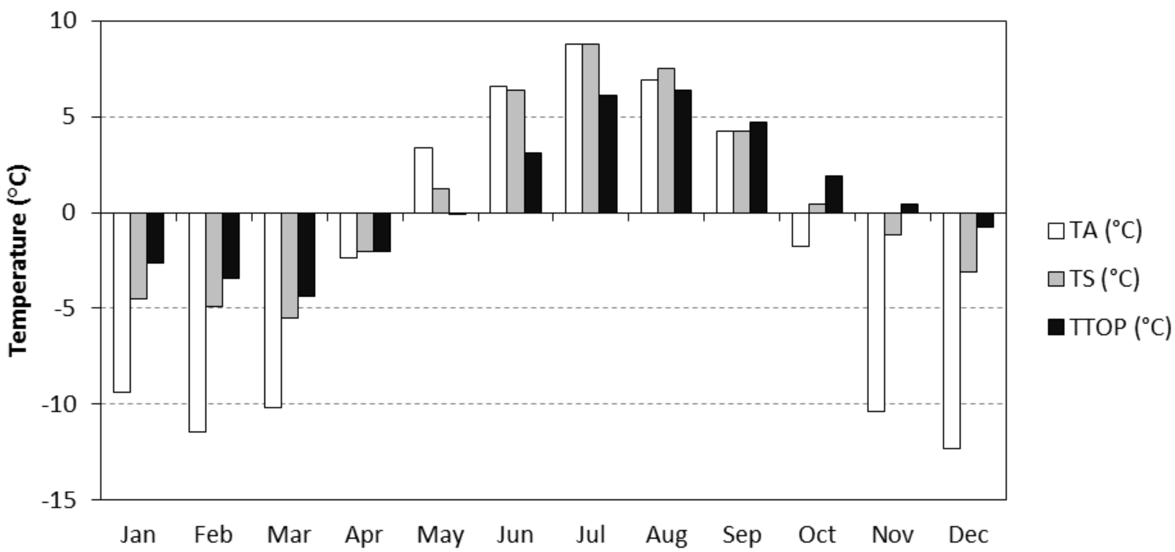
ATLIN	KUT-LAK	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2010*	**MAAT**	*-1.3*	*2*	*0.9*	**Jan**	*-12.8*	*-0.3*	*0.9*
End	*2014*	**MAGST**	*3.5*	*3*	*0.2*	**Feb**	*-14.1*	*-0.3*	*0.6*
Latitude (°N)	*59.2311*	**TTOP**	*3.6*	*3*	*0.1*	**Mar**	*-10.4*	*-0.6*	*0.2*
Longitude (°W)	*133.2326*		***°C-days***	**n**	**σ**	**Apr**	*-0.1*	*-0.1*	*0.2*
Elevation (m a.s.l.)	*742*	**TDD_A**	*1351*	*2*	*25*	**May**	*5.8*	*2.8*	*1.4*
Slope (°)	*2*	**FDD_A**	*1463*	*2*	*656*	**Jun**	*9.7*	*8.4*	*6.0*
Aspect (°)	*262*	**TDD_S**	*1333*	*2*	*86*	**Jul**	*11.9*	*10.6*	*8.6*
TPI50 (m)	*-0.6*	**FDD_S**	*93*	*4*	*60*	**Aug**	*9.6*	*10.3*	*9.2*
TPI200 (m)	*-1.9*		**Values**	**n**	**σ**	**Sep**	*6.3*	*7.5*	*8.0*
TPI700 (m)	*-16.5*	**N_T**	*1.0*	*2*	*0.1*	**Oct**	*-0.1*	*3.3*	*5.2*
PISR (WH/m^2)	*5137*	**N_F**	*0.0*	*2*	*0.0*	**Nov**	*-10.2*	*-0.0*	*2.3*
Land Cover	*Coniferous or Mixed*	**R_K**	*1.0*	*1*		**Dec**	*-15.1*	*-0.4*	*1.2*
Texture	*NA*	**S_O**	*3.8*	*2*	*1.9*	**Jan-Jul**	*24.7*	*10.9*	*9.5*
Materials	*NA*	**T_O**	*0.1*	*2*	*0.3*				
TST_{MIN}	*06-May*								
TST_{MAX}	*01-Jun*								
FST_{MIN}	*18-Nov*								
FST_{MAX}	*16-Nov*								



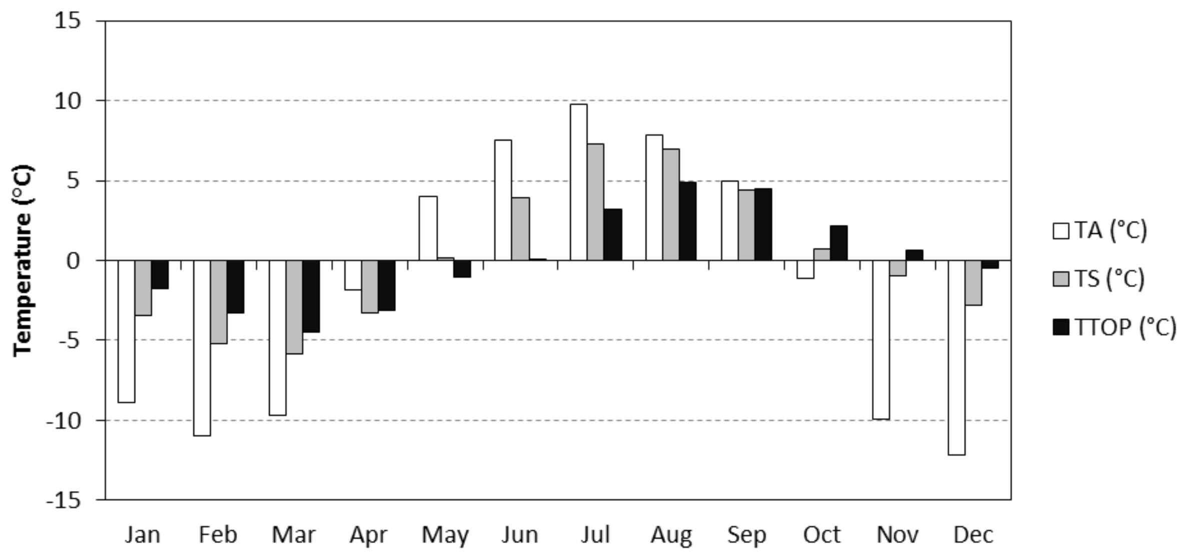
ATLIN	MON-01	Mean	°C	n	σ	Blended	*TA (°C)*	*TS (°C)*	*TTOP (°C)*
Start	*2010*	**MAAT**	*-3.2*	*2*	*0.8*	**Jan**	*-12.3*	*-2.3*	*-1.3*
End	*2014*	**MAGST**	*1.6*	*2*	*0.2*	**Feb**	*-9.8*	*-1.9*	*-1.1*
Latitude (°N)	*59.5440*	**TTOP**	*1.6*	*3*	*0.1*	**Mar**	*-11.3*	*-2.2*	*-1.4*
Longitude (°W)	*133.6167*		***°C-days***	**n**	**σ**	**Apr**	*-4.9*	*-1.8*	*-1.2*
Elevation (m a.s.l.)	*1410*	**TDD_A**	*776*	*2*	*3*	**May**	*2.1*	*-0.3*	*-0.4*
Slope (°)	*11*	**FDD_A**	*2001*	*3*	*256*	**Jun**	*6.9*	*7.3*	*3.9*
Aspect (°)	*353*	**TDD_S**	*954*	*2*	*111*	**Jul**	*8.4*	*12.3*	*8.4*
TPI50 (m)	*1.5*	**FDD_S**	*421*	*3*	*127*	**Aug**	*6.1*	*9.1*	*7.7*
TPI200 (m)	*5.7*		**Values**	**n**	**σ**	**Sep**	*2.9*	*3.5*	*4.5*
TPI700 (m)	*48.2*	**N_T**	*1.2*	*2*	*0.1*	**Oct**	*-3.5*	*-0.3*	*1.3*
PISR (WH/m^2)	*5312*	**N_F**	*0.2*	*3*	*0.0*	**Nov**	*-11.0*	*-2.0*	*-0.3*
Land Cover	*Tundra (Maritime)*	**R_K**	*1.0*	*2*	*0.1*	**Dec**	*-13.4*	*-2.6*	*-1.2*
Texture	*NA*	**S_O**	*4.7*	*2*	*0.7*	**Jan-Jul**	*20.7*	*14.6*	*9.7*
Materials	*NA*	**T_O**	*-0.1*	*2*	*0.2*				
TST_{MIN}	*18-May*								
TST_{MAX}	*12-May*								
FST_{MIN}	*26-Oct*								
FST_{MAX}	*11-Oct*								



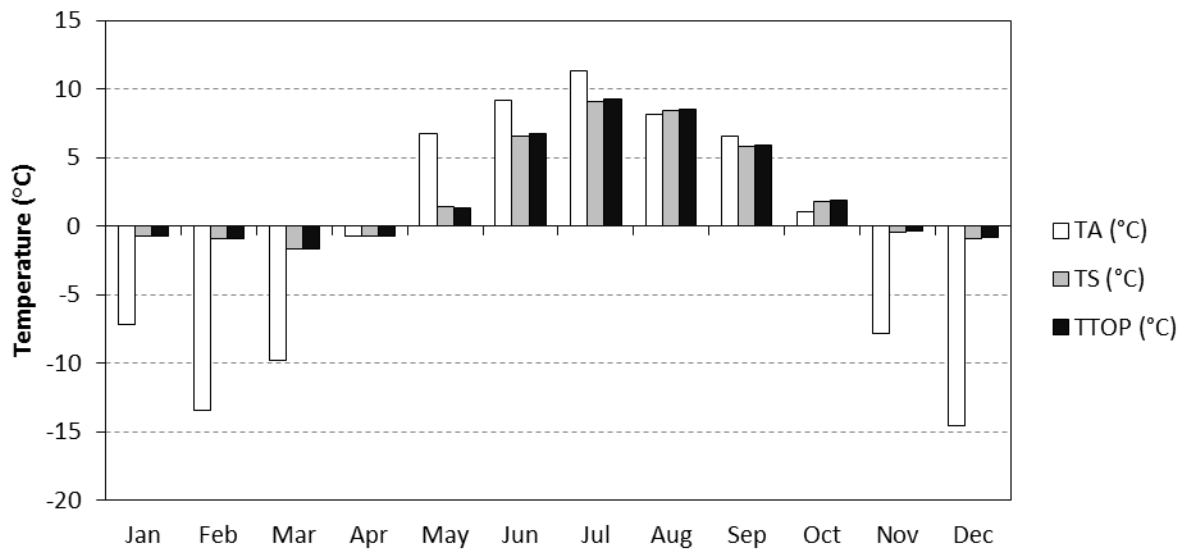
ATLIN	MON-02	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	2010	MAAT	-2.4	2	0.8	Jan	-9.4	-4.5	-2.7
End	2014	MAGST	0.6	2	0.8	Feb	-11.4	-4.9	-3.4
Latitude (°N)	59.5464	TTOP	0.8	2	0.8	Mar	-10.2	-5.5	-4.4
Longitude (°W)	133.6242		°C-days	n	σ	Apr	-2.4	-2.0	-2.1
Elevation (m a.s.l.)	1347	TDD_A	904	2	12	May	3.4	1.3	-0.0
Slope (°)	14	FDD_A	1718	2	271	Jun	6.5	6.4	3.1
Aspect (°)	304	TDD_S	881	2	21	Jul	8.8	8.8	6.1
TPI50 (m)	2.0	FDD_S	666	2	257	Aug	6.9	7.5	6.4
TPI200 (m)	11.0		Values	n	σ	Sep	4.2	4.3	4.7
TPI700 (m)	68.8	N_T	1.0	2	0.0	Oct	-1.8	0.4	1.9
PISR (WH/m^2)	5213	N_F	0.4	2	0.2	Nov	-10.4	-1.2	0.4
Land Cover	Shrub	R_K	1.1	2	0.0	Dec	-12.3	-3.1	-0.8
Texture	NA	S_O	2.8	2	1.5	Jan-Jul	18.2	13.3	8.7
Materials	NA	T_O	0.1	2	0.0				
TST_{MIN}	17-May								
TST_{MAX}	18-May								
FST_{MIN}	09-Nov								
FST_{MAX}	19-Oct								



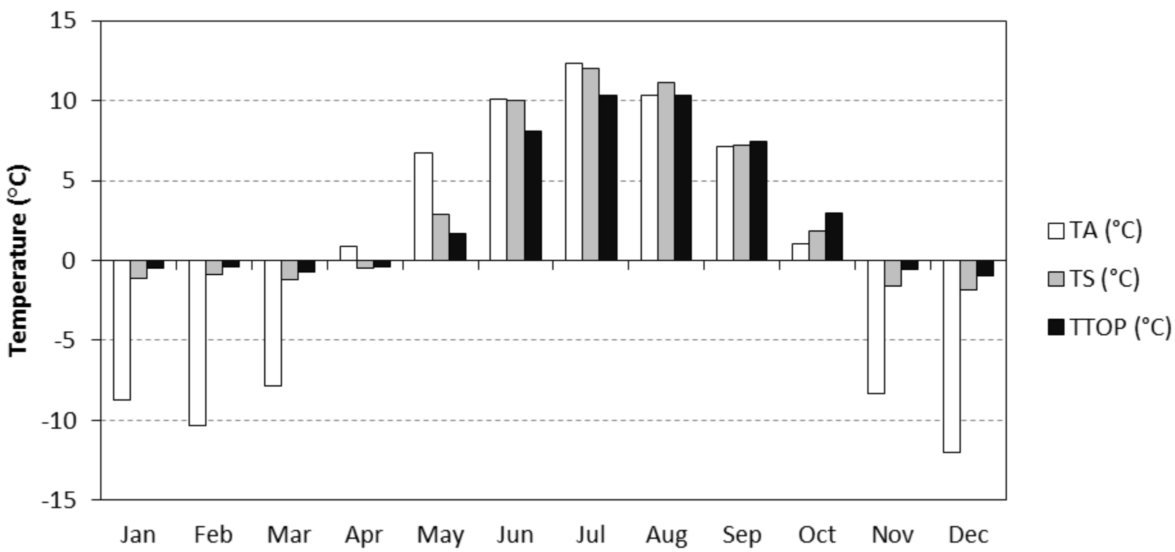
ATLIN	MON-03	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2010*	**MAAT**	*-1.7*	*2*	*0.9*	**Jan**	*-8.9*	*-3.4*	*-1.8*
End	*2014*	**MAGST**	*0.2*	*3*	*0.3*	**Feb**	*-11.0*	*-5.2*	*-3.3*
Latitude (°N)	*59.5528*	**TTOP**	*0.1*	*3*	*0.3*	**Mar**	*-9.7*	*-5.8*	*-4.5*
Longitude (°W)	*133.6245*		***°C-days***	**n**	**σ**	**Apr**	*-1.8*	*-3.3*	*-3.2*
Elevation (m a.s.l.)	*1238*	**TDD_A**	*987*	*2*	*24*	**May**	*4.0*	*0.2*	*-1.1*
Slope (°)	*23*	**FDD_A**	*1576*	*3*	*222*	**Jun**	*7.5*	*3.9*	*0.1*
Aspect (°)	*319*	**TDD_S**	*737*	*2*	*45*	**Jul**	*9.8*	*7.3*	*3.2*
TPI50 (m)	*-2.8*	**FDD_S**	*653*	*3*	*137*	**Aug**	*7.8*	*7.0*	*4.9*
TPI200 (m)	*-6.1*		**Values**	**n**	**σ**	**Sep**	*4.9*	*4.4*	*4.5*
TPI700 (m)	*33.6*	**N_T**	*0.7*	*2*	*0.0*	**Oct**	*-1.1*	*0.7*	*2.2*
PISR (WH/m^2)	*4668*	**N_F**	*0.4*	*3*	*0.1*	**Nov**	*-9.9*	*-0.9*	*0.7*
Land Cover	*Shrub*	**R_K**	*0.9*	*2*	*0.1*	**Dec**	*-12.2*	*-2.8*	*-0.5*
Texture	*NA*	**S_O**	*2.1*	*2*	*0.5*	**Jan-Jul**	*18.6*	*10.7*	*5.0*
Materials	*NA*	**T_O**	*-0.2*	*2*	*0.2*				
TST_{MIN}	*19-May*								
TST_{MAX}	*02-Jun*								
FST_{MIN}	*08-Nov*								
FST_{MAX}	*03-Nov*								



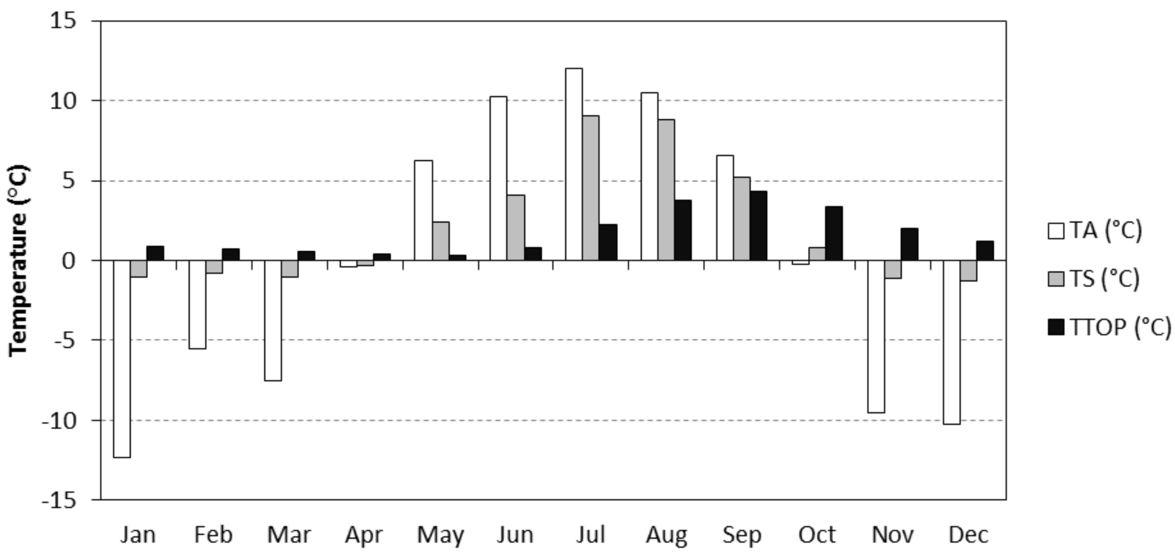
ATLIN	MON-04	Mean	°C	n	σ	Blended	*TA (°C)*	*TS (°C)*	*TTOP (°C)*
Start	*2010*	**MAAT**		*0*		**Jan**	*-7.2*	*-0.8*	*-0.7*
End	*2014*	**MAGST**	*2.0*	*3*	*0.8*	**Feb**	*-13.4*	*-1.0*	*-0.9*
Latitude (°N)	*59.5543*	**TTOP**	*2.4*	*3*	*0.1*	**Mar**	*-9.8*	*-1.6*	*-1.6*
Longitude (°W)	*133.6325*		***°C-days***	**n**	**σ**	**Apr**	*-0.7*	*-0.8*	*-0.7*
Elevation (m a.s.l.)	*1103*	**TDD_A**		*0*		**May**	*6.8*	*1.4*	*1.3*
Slope (°)	*24*	**FDD_A**	*1600*	*2*	*108*	**Jun**	*9.2*	*6.6*	*6.7*
Aspect (°)	*266*	**TDD_S**	*969*	*2*	*11*	**Jul**	*11.4*	*9.1*	*9.2*
TPI50 (m)	*2.7*	**FDD_S**	*144*	*3*	*99*	**Aug**	*8.1*	*8.4*	*8.5*
TPI200 (m)	*12.0*		**Values**	**n**	**σ**	**Sep**	*6.5*	*5.8*	*5.9*
TPI700 (m)	*45.9*	**N_T**		*0*		**Oct**	*1.1*	*1.8*	*1.9*
PISR (WH/m^2)	*5043*	**N_F**	*0.1*	*2*	*0.0*	**Nov**	*-7.8*	*-0.4*	*-0.3*
Land Cover	*Coniferous or Mixed*	**R_K**	*1.0*	*2*	*0.1*	**Dec**	*-14.6*	*-0.9*	*-0.8*
Texture	*NA*	**S_O**		*0*		**Jan-Jul**	*18.5*	*9.9*	*10.0*
Materials	*NA*	**T_O**	*-0.0*	*2*	*0.3*				
TST_{MIN}	*30-Apr*								
TST_{MAX}	*16-Apr*								
FST_{MIN}	*18-Nov*								
FST_{MAX}	*04-Nov*								



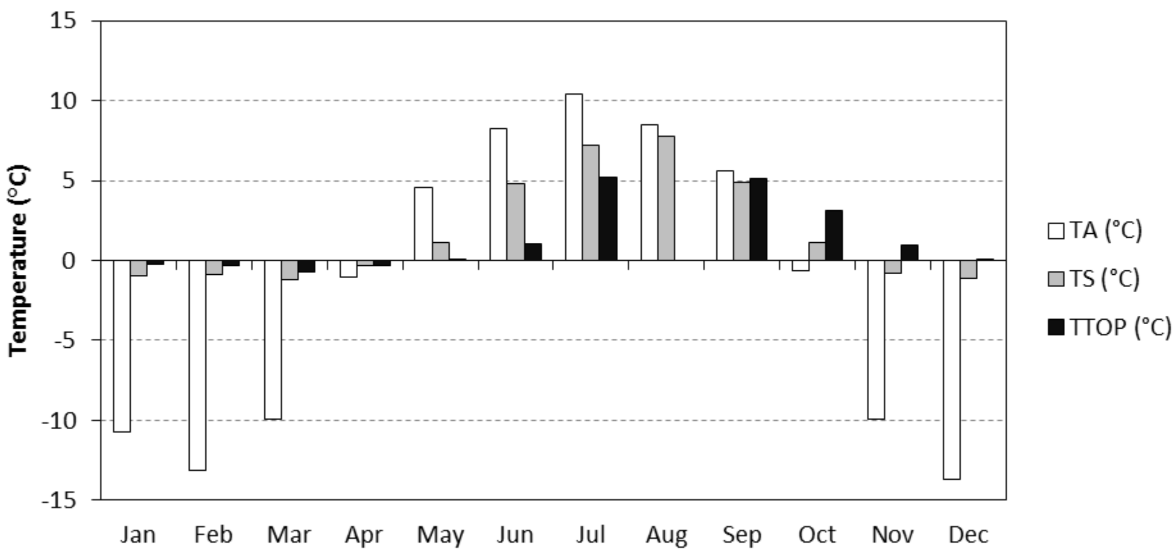
ATLIN	MON-05	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	2010	MAAT	0.4	2	1.0	Jan	-8.7	-1.1	-0.5
End	2014	MAGST	3.2	3	0.2	Feb	-10.4	-0.9	-0.4
Latitude (°N)	59.5533	TTOP	3.0	3	0.1	Mar	-7.9	-1.2	-0.7
Longitude (°W)	133.6415		°C-days	n	σ	Apr	0.9	-0.5	-0.4
Elevation (m a.s.l.)	954	TDD_A	1478	2	9	May	6.7	2.8	1.7
Slope (°)	14	FDD_A	1393	3	266	Jun	10.1	10.0	8.1
Aspect (°)	279	TDD_S	1393	3	123	Jul	12.3	12.0	10.3
TPI50 (m)	0.2	FDD_S	231	4	109	Aug	10.4	11.1	10.3
TPI200 (m)	10.9		Values	n	σ	Sep	7.1	7.2	7.4
TPI700 (m)	43.2	N_T	0.9	2	0.1	Oct	1.0	1.9	3.0
PISR (WH/m^2)	5179	N_F	0.1	3	0.0	Nov	-8.3	-1.6	-0.6
Land Cover	Coniferous or Mixed	R_K	0.9	2	0.0	Dec	-12.1	-1.8	-0.9
Texture	NA	S_O	2.9	2	0.9	Jan-Jul	21.1	13.2	10.8
Materials	NA	T_O	-0.3	2	0.2				
TST_{MIN}	26-Apr								
TST_{MAX}	04-May								
FST_{MIN}	27-Oct								
FST_{MAX}	03-Nov								



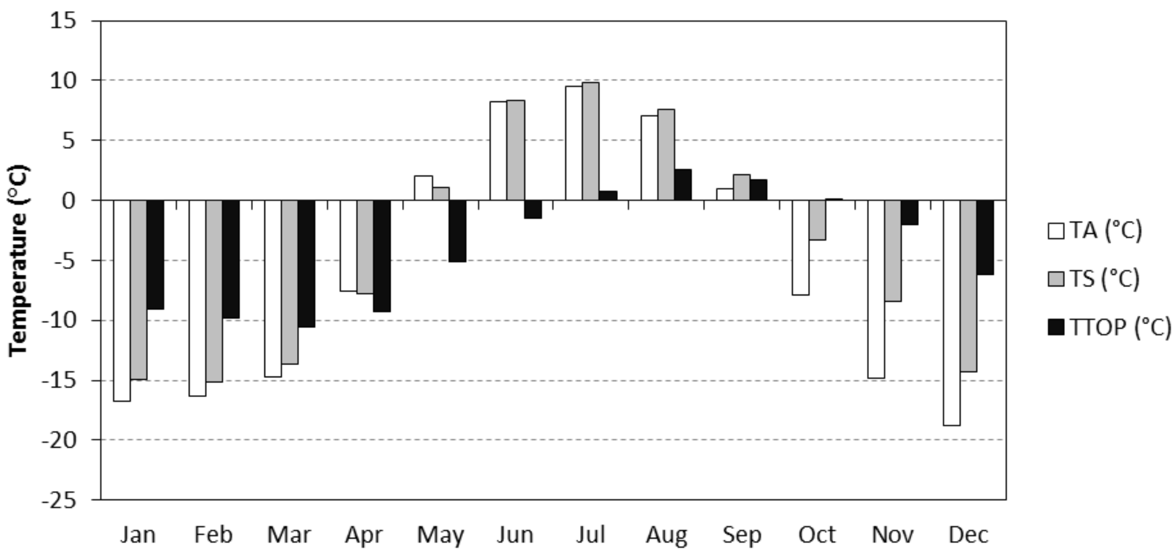
ATLIN	MON-06	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2010*	**MAAT**	*0.9*	*1*		**Jan**	*-12.3*	*-1.1*	*0.9*
End	*2014*	**MAGST**	*2.6*	*1*		**Feb**	*-5.5*	*-0.8*	*0.7*
Latitude (°N)	*59.5557*	**TTOP**	*1.7*	*1*		**Mar**	*-7.5*	*-1.1*	*0.5*
Longitude (°W)	*133.6577*		***°C-days***	**n**	**σ**	**Apr**	*-0.4*	*-0.3*	*0.4*
Elevation (m a.s.l.)	*731*	**TDD_A**	*1476*	*1*		**May**	*6.2*	*2.4*	*0.3*
Slope (°)	*7*	**FDD_A**	*1486*	*2*	*408*	**Jun**	*10.2*	*4.1*	*0.8*
Aspect (°)	*268*	**TDD_S**	*1070*	*1*		**Jul**	*12.0*	*9.1*	*2.2*
TPI50 (m)	*1.5*	**FDD_S**	*330*	*2*	*262*	**Aug**	*10.5*	*8.8*	*3.8*
TPI200 (m)	*1.2*		**Values**	**n**	**σ**	**Sep**	*6.6*	*5.2*	*4.3*
TPI700 (m)	*-7.7*	**N_T**	*0.7*	*1*		**Oct**	*-0.3*	*0.8*	*3.4*
PISR (WH/m²)	*5181*	**N_F**	*0.2*	*2*	*0.1*	**Nov**	*-9.6*	*-1.1*	*2.0*
Land Cover	*Coniferous or Mixed*	**R_K**	*0.7*	*1*		**Dec**	*-10.3*	*-1.3*	*1.2*
Texture	*NA*	**S_O**	*1.8*	*1*		**Jan-Jul**	*24.4*	*10.1*	*3.1*
Materials	*NA*	**T_O**	*-1.0*	*1*					
TST_{MIN}	*23-Apr*								
TST_{MAX}	*12-May*								
FST_{MIN}	*02-Nov*								
FST_{MAX}	*17-Oct*								



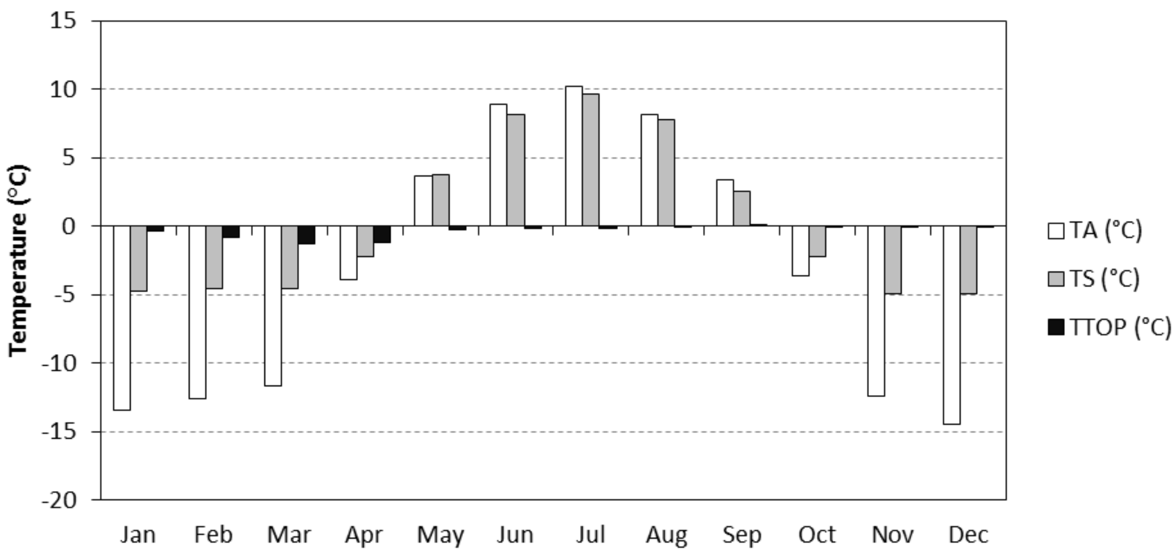
ATLIN	WND-LAK	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	2010	MAAT	-1.6	2	0.8	Jan	-10.7	-0.9	-0.2
End	2014	MAGST	1.4	3	0.7	Feb	-13.1	-0.9	-0.3
Latitude (°N)	59.0877	TTOP	1.7	1		Mar	-9.9	-1.2	-0.8
Longitude (°W)	132.9246		°C-days	n	σ	Apr	-1.1	-0.4	-0.3
Elevation (m a.s.l.)	895	TDD_A	1150	2	8	May	4.6	1.1	0.0
Slope (°)	0	FDD_A	1695	3	189	Jun	8.2	4.8	1.1
Aspect (°)	-1	TDD_S	836	2	145	Jul	10.4	7.2	5.2
TPI50 (m)	-0.1	FDD_S	153	3	79	Aug	8.5	7.7	
TPI200 (m)	-0.6		Values	n	σ	Sep	5.6	4.9	5.1
TPI700 (m)	-13.2	N_T	0.7	2	0.1	Oct	-0.6	1.1	3.1
PISR (WH/m^2)	5211	N_F	0.1	3	0.0	Nov	-9.9	-0.8	1.0
Land Cover	Coniferous or Mixed	R_K		0		Dec	-13.7	-1.1	0.0
Texture	NA	S_O	3.3	2	0.2	Jan-Jul	21.2	8.1	5.4
Materials	NA	T_O		0					
TST_{MIN}	06-May								
TST_{MAX}	12-Apr								
FST_{MIN}	09-Nov								
FST_{MAX}	16-Nov								



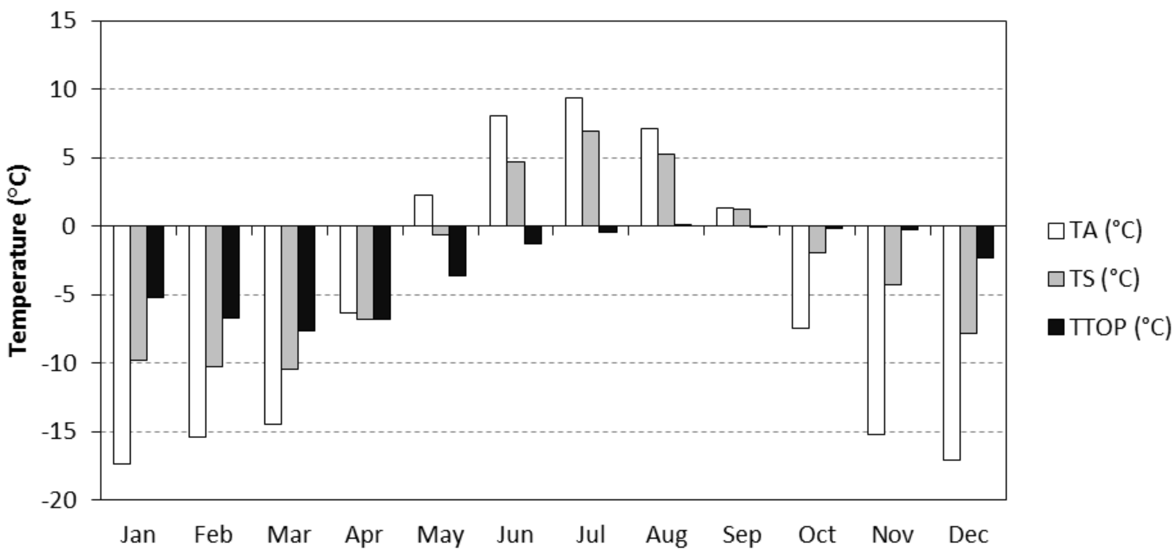
DAWSON	60MILE-WS	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2007*	**MAAT**	*-6.2*	*2*	*0.3*	**Jan**	*-16.7*	*-15.0*	*-9.1*
End	*2012*	**MAGST**	*-4.4*	*2*	*0.3*	**Feb**	*-16.3*	*-15.1*	*-9.8*
Latitude (°N)	*63.9095*	**TTOP**	*-4.1*	*6*	*0.7*	**Mar**	*-14.7*	*-13.6*	*-10.6*
Longitude (°W)	*140.8104*		**°C-days**	**n**	**σ**	**Apr**	*-7.6*	*-7.8*	*-9.3*
Elevation (m a.s.l.)	*1447*	**TDD_A**	*892*	*2*	*282*	**May**	*2.1*	*1.1*	*-5.1*
Slope (°)	*12*	**FDD_A**	*2997*	*4*	*384*	**Jun**	*8.2*	*8.4*	*-1.5*
Aspect (°)	*356*	**TDD_S**	*913*	*2*	*114*	**Jul**	*9.5*	*9.8*	*0.8*
TPI50 (m)	*1.7*	**FDD_S**	*2386*	*4*	*271*	**Aug**	*7.0*	*7.6*	*2.6*
TPI200 (m)	*16.0*		**Values**	**n**	**σ**	**Sep**	*1.0*	*2.2*	*1.7*
TPI700 (m)	*70.0*	**N_T**	*1.1*	*2*	*0.2*	**Oct**	*-7.9*	*-3.3*	*0.0*
PISR (WH/m^2)	*5045*	**N_F**	*0.8*	*4*	*0.0*	**Nov**	*-14.8*	*-8.4*	*-2.0*
Land Cover	*Rock*	**R_K**	*0.9*	*1*		**Dec**	*-18.8*	*-14.2*	*-6.2*
Texture	*NA*	**S_O**	*1.8*	*2*	*0.0*	**Jan-Jul**	*26.2*	*24.8*	*9.9*
Materials	*b*	**T_O**	*-0.2*	*1*					
TST_{MIN}	*28-Apr*								
TST_{MAX}	*25-May*								
FST_{MIN}	*22-Sep*								
FST_{MAX}	*20-Sep*								



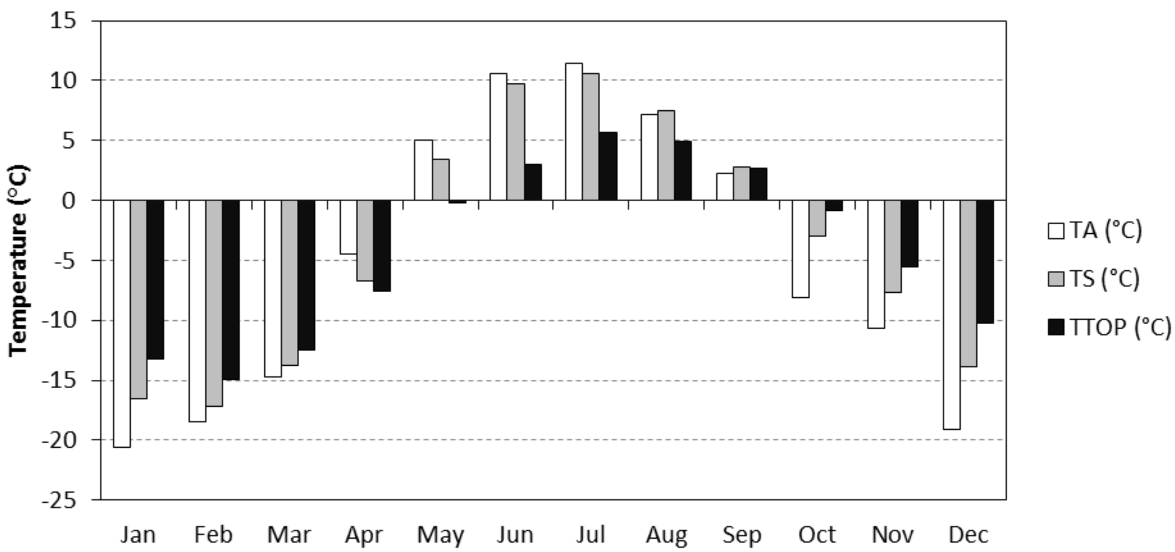
DAWSON	60MILE-BK	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	2007	MAAT	-3.2	5	0.8	Jan	-13.4	-4.7	-0.3
End	2014	MAGST	0.4	6	0.7	Feb	-12.6	-4.6	-0.9
Latitude (°N)	0.0000	TTOP	-0.4	5	0.3	Mar	-11.6	-4.6	-1.3
Longitude (°W)	0.0000		°C-days	n	σ	Apr	-3.9	-2.2	-1.2
Elevation (m a.s.l.)	1440	TDD_A	1016	4	51	May	3.6	3.7	-0.3
Slope (°)	0	FDD_A	2182	5	253	Jun	8.9	8.2	-0.2
Aspect (°)	0	TDD_S	986	6	63	Jul	10.2	9.6	-0.2
TPI50 (m)	0.0	FDD_S	843	6	212	Aug	8.2	7.8	-0.0
TPI200 (m)	0.0		Values	n	σ	Sep	3.3	2.5	0.0
TPI700 (m)	0.0	N_T	1.0	4	0.1	Oct	-3.6	-2.2	-0.1
PISR (WH/m^2)	5045	N_F	0.4	5	0.1	Nov	-12.4	-4.9	-0.1
Land Cover	Tundra	R_K	0.8	5	0.2	Dec	-14.5	-5.0	-0.1
Texture	NA	S_O	3.4	4	0.8	Jan-Jul	23.6	14.3	0.5
Materials	b	T_O	-0.7	5	0.6				
TST_{MIN}	30-Apr								
TST_{MAX}	14-Apr								
FST_{MIN}	05-Oct								
FST_{MAX}	10-Oct								



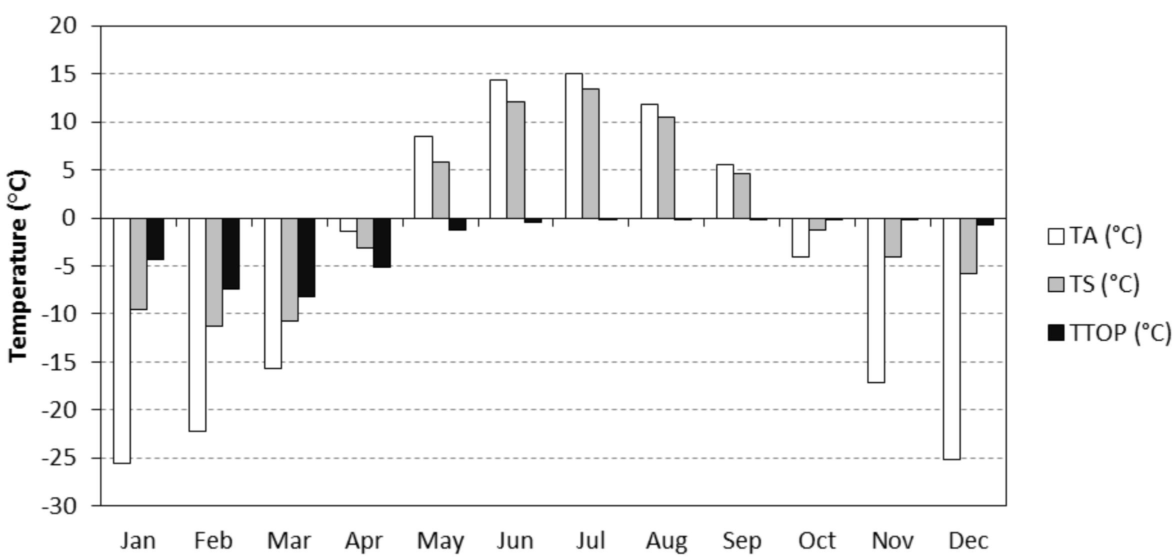
DAWSON	TOW-01	Mean	*°C*	n	σ	Blended	*TA (°C)*	*TS (°C)*	*TTOP (°C)*
Start	*2007*	**MAAT**	*-5.5*	*6*	*0.9*	**Jan**	*-17.3*	*-9.8*	*-5.2*
End	*2014*	**MAGST**	*-2.9*	*6*	*0.5*	**Feb**	*-15.4*	*-10.3*	*-6.7*
Latitude (°N)	*64.0827*	**TTOP**	*-2.9*	*7*	*0.4*	**Mar**	*-14.5*	*-10.4*	*-7.6*
Longitude (°W)	*139.5917*		***°C-days***	**n**	**σ**	**Apr**	*-6.4*	*-6.8*	*-6.8*
Elevation (m a.s.l.)	*1010*	**TDD_A**	*928*	*6*	*128*	**May**	*2.3*	*-0.6*	*-3.7*
Slope (°)	*3*	**FDD_A**	*2913*	*7*	*350*	**Jun**	*8.1*	*4.7*	*-1.3*
Aspect (°)	*9*	**TDD_S**	*611*	*6*	*91*	**Jul**	*9.4*	*7.0*	*-0.5*
TPI50 (m)	*0.9*	**FDD_S**	*1609*	*7*	*220*	**Aug**	*7.1*	*5.3*	*0.1*
TPI200 (m)	*10.8*		**Values**	**n**	**σ**	**Sep**	*1.3*	*1.3*	*-0.0*
TPI700 (m)	*62.8*	**N_T**	*0.7*	*6*	*0.1*	**Oct**	*-7.4*	*-1.9*	*-0.1*
PISR (WH/m²)	*5155*	**N_F**	*0.6*	*7*	*0.0*	**Nov**	*-15.2*	*-4.3*	*-0.3*
Land Cover	*Shrub*	**R_K**	*1.0*	*6*	*0.3*	**Dec**	*-17.1*	*-7.8*	*-2.3*
Texture	*mf*	**S_O**	*2.7*	*6*	*0.5*	**Jan-Jul**	*26.7*	*16.7*	*5.7*
Materials	*c*	**T_O**	*-0.1*	*6*	*0.4*				
TST_{MIN}	*19-May*								
TST_{MAX}	*26-May*								
FST_{MIN}	*17-Sep*								
FST_{MAX}	*20-Sep*								



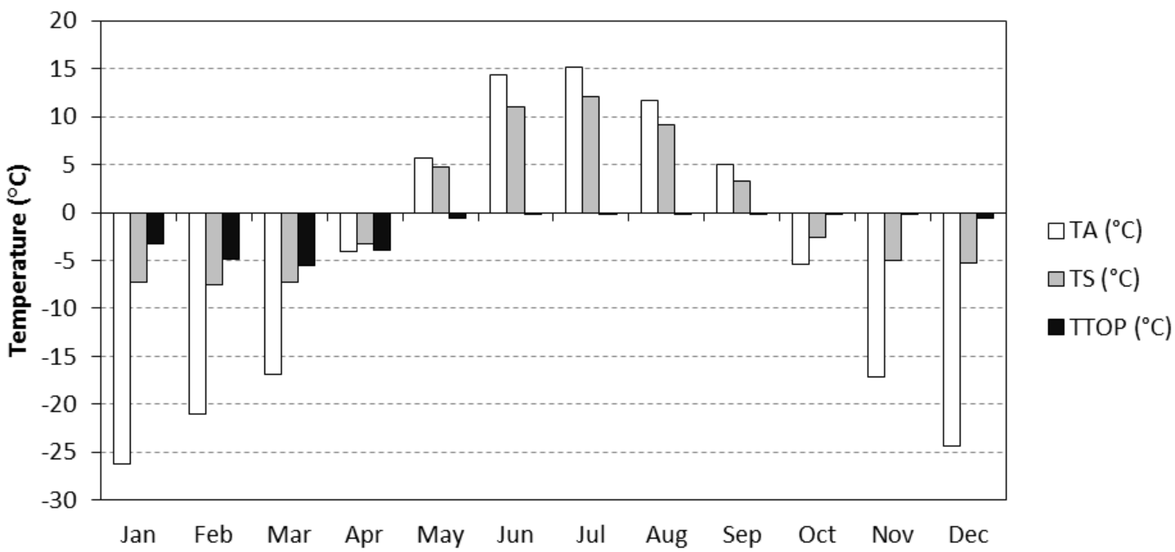
DAWSON	TOW-02	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	2007	MAAT	-4.6	1		Jan	-20.6	-16.6	-13.2
End	2009	MAGST	-3.3	1		Feb	-18.4	-17.1	-14.9
Latitude (°N)	64.1651	TTOP	-4.0	2	0.6	Mar	-14.8	-13.7	-12.5
Longitude (°W)	139.8029		°C-days	n	σ	Apr	-4.4	-6.7	-7.6
Elevation (m a.s.l.)	1223	TDD_A	997	1		May	5.0	3.4	-0.2
Slope (°)	1	FDD_A	2965	2	349	Jun	10.6	9.7	3.0
Aspect (°)	270	TDD_S	970	1		Jul	11.5	10.6	5.6
TPI50 (m)	0.5	FDD_S	2392	2	266	Aug	7.2	7.5	5.0
TPI200 (m)	5.8		Values	n	σ	Sep	2.3	2.8	2.7
TPI700 (m)	57.1	N_T	1.0	1		Oct	-8.1	-3.0	-0.8
PISR (WH/m^2)	5428	N_F	0.8	2	0.0	Nov	-10.7	-7.7	-5.5
Land Cover	Rock	R_K	0.9	1		Dec	-19.1	-13.9	-10.3
Texture	mf	S_O	1.3	1		Jan-Jul	32.1	27.2	18.8
Materials	c	T_O	-0.2	1					
TST_{MIN}	28-Apr								
TST_{MAX}	03-May								
FST_{MIN}	22-Sep								
FST_{MAX}	25-Sep								



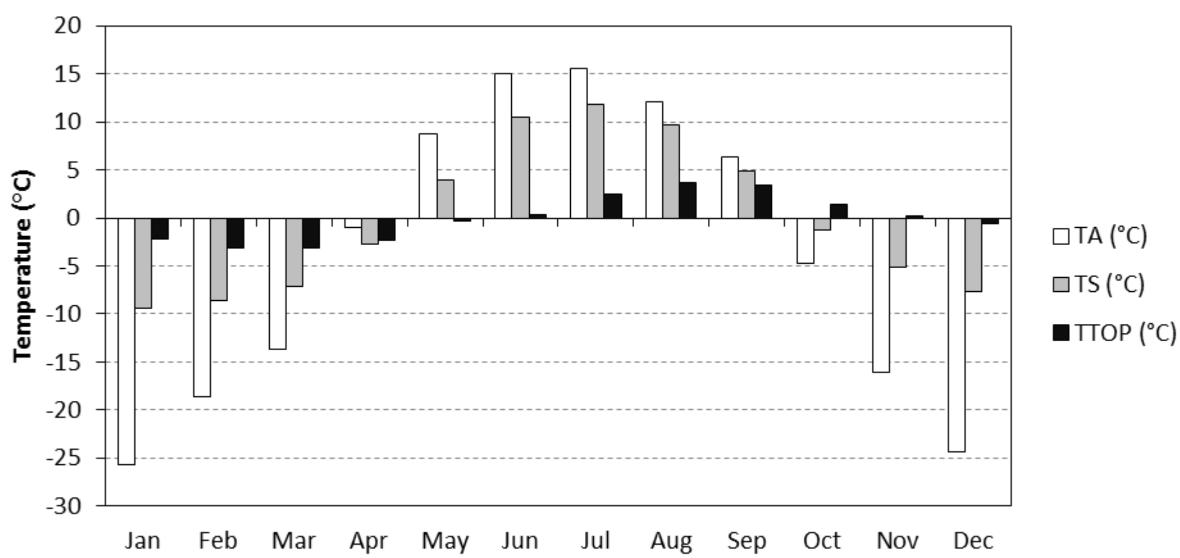
DAWSON	TOW-03	Mean	°C	n	σ	Blended	*TA (°C)*	*TS (°C)*	*TTOP (°C)*
Start	*2007*	**MAAT**	*-4.6*	*6*	*1.3*	**Jan**	*-25.5*	*-9.6*	*-4.4*
End	*2014*	**MAGST**	*-0.1*	*6*	*0.6*	**Feb**	*-22.2*	*-11.2*	*-7.3*
Latitude (°N)	*64.0836*	**TTOP**	*-2.3*	*7*	*0.5*	**Mar**	*-15.7*	*-10.7*	*-8.3*
Longitude (°W)	*139.4431*		***°C-days***	**n**	**σ**	**Apr**	*-1.4*	*-3.1*	*-5.2*
Elevation (m a.s.l.)	*331*	TDD_A	*1734*	*6*	*51*	**May**	*8.5*	*5.9*	*-1.3*
Slope (°)	*1*	FDD_A	*3432*	*7*	*431*	**Jun**	*14.4*	*12.1*	*-0.5*
Aspect (°)	*31*	TDD_S	*1441*	*6*	*93*	**Jul**	*15.1*	*13.5*	*-0.3*
TPI50 (m)	*-0.2*	FDD_S	*1401*	*7*	*293*	**Aug**	*11.8*	*10.5*	*-0.1*
TPI200 (m)	*-0.8*		**Values**	**n**	**σ**	**Sep**	*5.5*	*4.6*	*-0.1*
TPI700 (m)	*-22.1*	N_T	*0.8*	*6*	*0.1*	**Oct**	*-4.0*	*-1.3*	*-0.1*
PISR (WH/m^2)	*4712*	N_F	*0.4*	*7*	*0.1*	**Nov**	*-17.1*	*-4.1*	*-0.1*
Land Cover	*Shrub*	R_K	*0.4*	*6*	*0.1*	**Dec**	*-25.1*	*-5.8*	*-0.8*
Texture	*s*	S_O	*4.6*	*6*	*1.1*	**Jan-Jul**	*40.6*	*23.0*	*4.6*
Materials	*f*	T_O	*-2.4*	*6*	*0.3*				
TST_{MIN}	*25-Apr*								
TST_{MAX}	*12-May*								
FST_{MIN}	*04-Oct*								
FST_{MAX}	*11-Oct*								



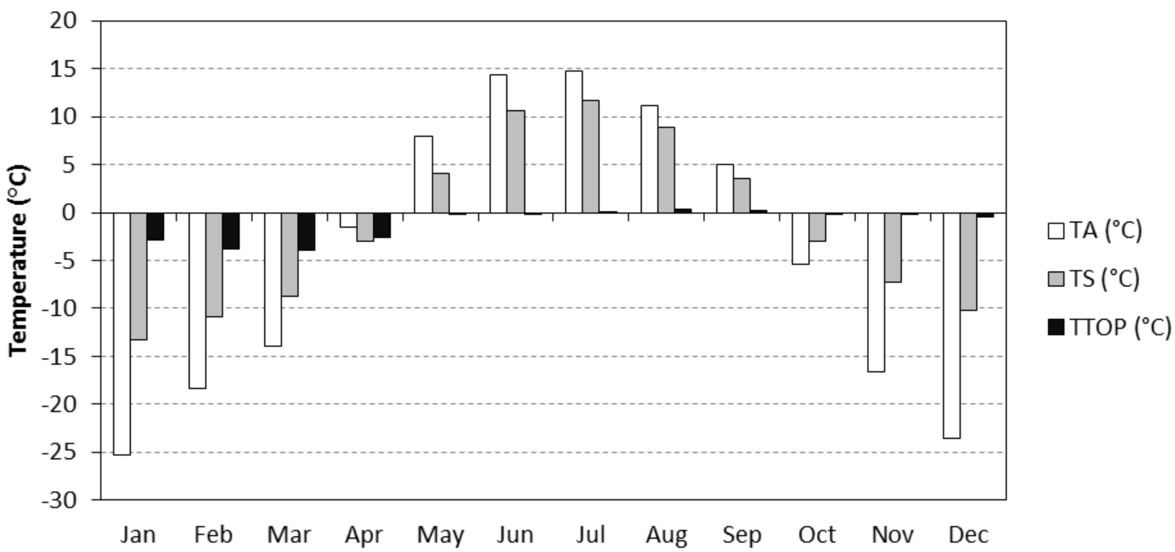
DAWSON	TOW-04	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2007*	**MAAT**	*-4.1*	*4*	*1.2*	**Jan**	*-26.2*	*-7.2*	*-3.3*
End	*2014*	**MAGST**	*0.3*	*5*	*0.7*	**Feb**	*-21.0*	*-7.6*	*-4.9*
Latitude (°N)	*64.0766*	**TTOP**	*-1.6*	*6*	*0.5*	**Mar**	*-16.8*	*-7.3*	*-5.5*
Longitude (°W)	*139.4808*		***°C-days***	**n**	**σ**	**Apr**	*-4.1*	*-3.2*	*-4.0*
Elevation (m a.s.l.)	*484*	**TDD_A**	*1679*	*4*	*33*	**May**	*5.7*	*4.7*	*-0.6*
Slope (°)	*9*	**FDD_A**	*3540*	*6*	*589*	**Jun**	*14.3*	*11.0*	*-0.2*
Aspect (°)	*66*	**TDD_S**	*1254*	*5*	*67*	**Jul**	*15.1*	*12.0*	*-0.1*
TPI50 (m)	*-1.1*	**FDD_S**	*1166*	*6*	*228*	**Aug**	*11.6*	*9.1*	*-0.0*
TPI200 (m)	*-8.1*		**Values**	**n**	**σ**	**Sep**	*5.0*	*3.3*	*-0.0*
TPI700 (m)	*-27.3*	**N_T**	*0.7*	*4*	*0.0*	**Oct**	*-5.4*	*-2.6*	*-0.0*
PISR (WH/m^2)	*4649*	**N_F**	*0.3*	*6*	*0.1*	**Nov**	*-17.1*	*-5.0*	*-0.0*
Land Cover	*Shrub*	**R_K**	*0.4*	*5*	*0.0*	**Dec**	*-24.3*	*-5.3*	*-0.6*
Texture	*mf*	**S_O**	*4.7*	*4*	*1.0*	**Jan-Jul**	*41.3*	*19.3*	*3.4*
Materials	*c*	**T_O**	*-1.9*	*5*	*0.1*				
TST_{MIN}	*28-Apr*								
TST_{MAX}	*16-May*								
FST_{MIN}	*22-Sep*								
FST_{MAX}	*10-Oct*								



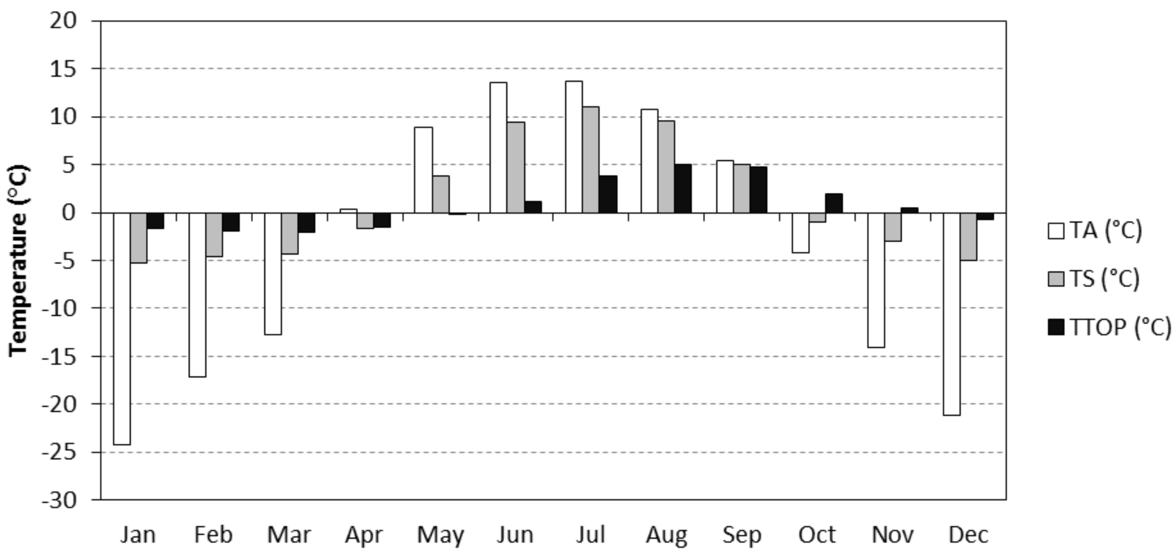
DAWSON	TOW-05	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2007*	**MAAT**	*-3.2*	*3*	*0.5*	**Jan**	*-25.7*	*-9.4*	*-2.2*
End	*2014*	**MAGST**	*-0.1*	*3*	*0.7*	**Feb**	*-18.6*	*-8.5*	*-3.1*
Latitude (°N)	*64.0768*	**TTOP**	*-0.0*	*5*	*0.4*	**Mar**	*-13.7*	*-7.1*	*-3.2*
Longitude (°W)	*139.4784*		**°C-days**	**n**	**σ**	**Apr**	*-1.0*	*-2.7*	*-2.3*
Elevation (m a.s.l.)	*503*	**TDD_A**	*1740*	*3*	*75*	**May**	*8.8*	*4.0*	*-0.3*
Slope (°)	*8*	**FDD_A**	*3234*	*5*	*343*	**Jun**	*15.1*	*10.5*	*0.4*
Aspect (°)	*27*	**TDD_S**	*1302*	*3*	*54*	**Jul**	*15.5*	*11.8*	*2.5*
TPI50 (m)	*-2.8*	**FDD_S**	*1280*	*5*	*199*	**Aug**	*12.1*	*9.7*	*3.7*
TPI200 (m)	*-14.9*		**Values**	**n**	**σ**	**Sep**	*6.3*	*4.9*	*3.4*
TPI700 (m)	*-33.1*	**N_T**	*0.7*	*3*	*0.0*	**Oct**	*-4.8*	*-1.3*	*1.4*
PISR (WH/m^2)	*4511*	**N_F**	*0.4*	*5*	*0.1*	**Nov**	*-16.1*	*-5.2*	*0.2*
Land Cover	*Coniferous or Mixed*	**R_K**	*1.1*	*3*	*0.1*	**Dec**	*-24.4*	*-7.7*	*-0.6*
Texture	*mf*	**S_O**	*3.3*	*3*	*0.7*	**Jan-Jul**	*41.2*	*21.2*	*4.6*
Materials	*c*	**T_O**	*0.3*	*3*	*0.4*				
TST_{MIN}	*27-Apr*								
TST_{MAX}	*17-May*								
FST_{MIN}	*04-Oct*								
FST_{MAX}	*10-Oct*								



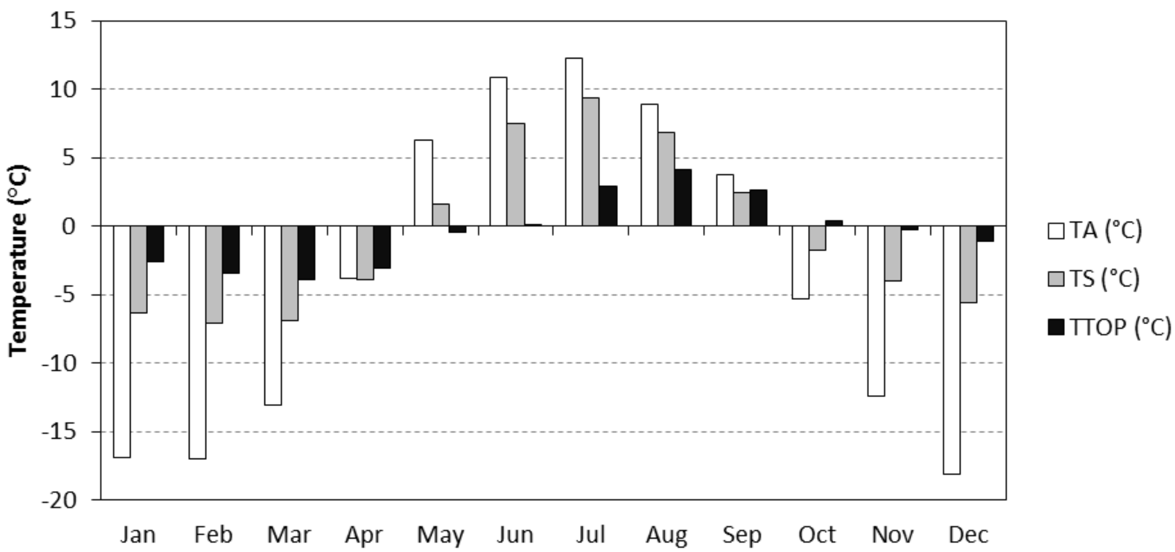
DAWSON	TOW-06	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	2007	MAAT	-3.8	4	1.2	Jan	-25.3	-13.2	-2.8
End	2014	MAGST	-1.3	5	0.8	Feb	-18.4	-10.9	-3.9
Latitude (°N)	64.0721	TTOP	-1.1	6	0.2	Mar	-13.9	-8.7	-3.9
Longitude (°W)	139.4864		°C-days	n	σ	Apr	-1.5	-2.9	-2.6
Elevation (m a.s.l.)	570	TDD_A	1644	4	81	May	7.9	4.0	-0.2
Slope (°)	7	FDD_A	3242	6	446	Jun	14.4	10.6	-0.1
Aspect (°)	59	TDD_S	1198	5	72	Jul	14.7	11.6	0.1
TPI50 (m)	0.2	FDD_S	1715	6	293	Aug	11.2	8.8	0.4
TPI200 (m)	0.0		Values	n	σ	Sep	5.0	3.5	0.2
TPI700 (m)	-2.0	N_T	0.7	4	0.1	Oct	-5.4	-3.0	-0.0
PISR (WH/m^2)	4800	N_F	0.5	6	0.1	Nov	-16.7	-7.3	-0.1
Land Cover	Coniferous or Mixed	R_K	1.1	5	0.2	Dec	-23.6	-10.2	-0.5
Texture	mf	S_O	2.8	4	1.0	Jan-Jul	40.0	24.9	3.0
Materials	c	T_O	0.2	5	0.8				
TST_{MIN}	27-Apr								
TST_{MAX}	22-May								
FST_{MIN}	22-Sep								
FST_{MAX}	10-Oct								



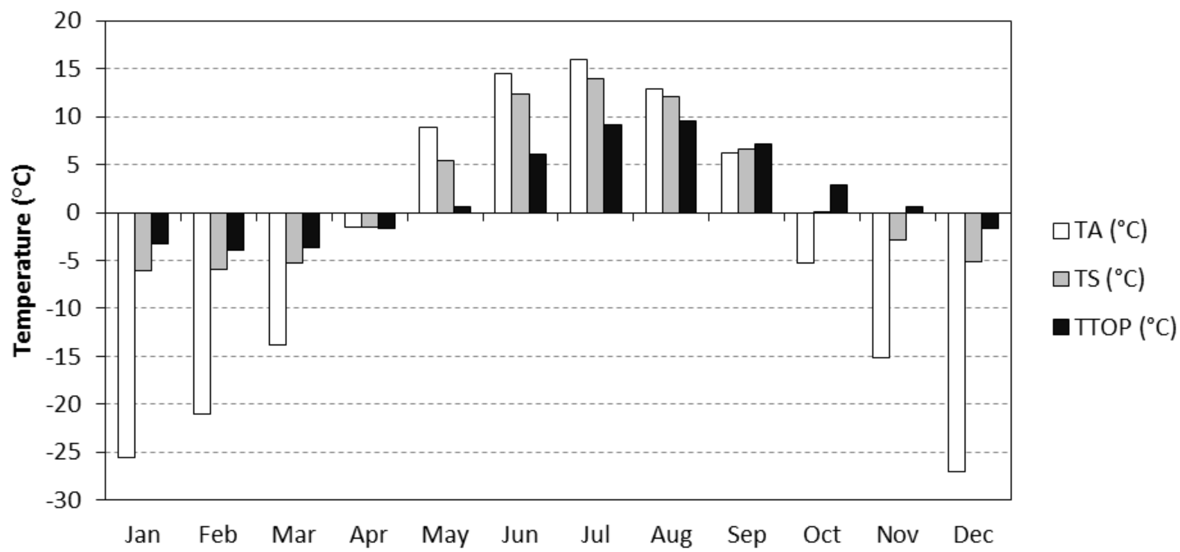
DAWSON	TOW-07	Mean	*°C*	n	σ	Blended	*TA (°C)*	*TS (°C)*	*TTOP (°C)*
Start	*2007*	**MAAT**	*-2.9*	*3*	*1.2*	**Jan**	*-24.3*	*-5.3*	*-1.6*
End	*2014*	**MAGST**	*1.3*	*5*	*0.5*	**Feb**	*-17.2*	*-4.6*	*-1.9*
Latitude (°N)	*64.0588*	**TTOP**	*1.0*	*3*	*0.3*	**Mar**	*-12.7*	*-4.3*	*-2.0*
Longitude (°W)	*139.4696*		***°C-days***	**n**	**σ**	**Apr**	*0.3*	*-1.7*	*-1.5*
Elevation (m a.s.l.)	*701*	**TDD_A**	*1668*	*3*	*125*	**May**	*8.9*	*3.8*	*-0.2*
Slope (°)	*4*	**FDD_A**	*2899*	*5*	*365*	**Jun**	*13.5*	*9.5*	*1.1*
Aspect (°)	*155*	**TDD_S**	*1196*	*5*	*73*	**Jul**	*13.7*	*11.0*	*3.8*
TPI50 (m)	*1.5*	**FDD_S**	*767*	*6*	*182*	**Aug**	*10.8*	*9.5*	*5.0*
TPI200 (m)	*15.3*		**Values**	**n**	**σ**	**Sep**	*5.5*	*5.0*	*4.7*
TPI700 (m)	*97.7*	**N_T**	*0.7*	*3*	*0.0*	**Oct**	*-4.2*	*-1.0*	*2.0*
PISR (WH/m^2)	*5154*	**N_F**	*0.2*	*5*	*0.1*	**Nov**	*-14.1*	*-3.0*	*0.4*
Land Cover	*Coniferous or Mixed*	**R_K**	*0.8*	*2*	*0.1*	**Dec**	*-21.2*	*-5.0*	*-0.7*
Texture	*mf*	**S_O**	*4.4*	*3*	*1.0*	**Jan-Jul**	*38.0*	*16.3*	*5.4*
Materials	*c*	**T_O**	*-0.6*	*2*	*0.3*				
TST_{MIN}	*26-Apr*								
TST_{MAX}	*04-May*								
FST_{MIN}	*04-Oct*								
FST_{MAX}	*10-Oct*								



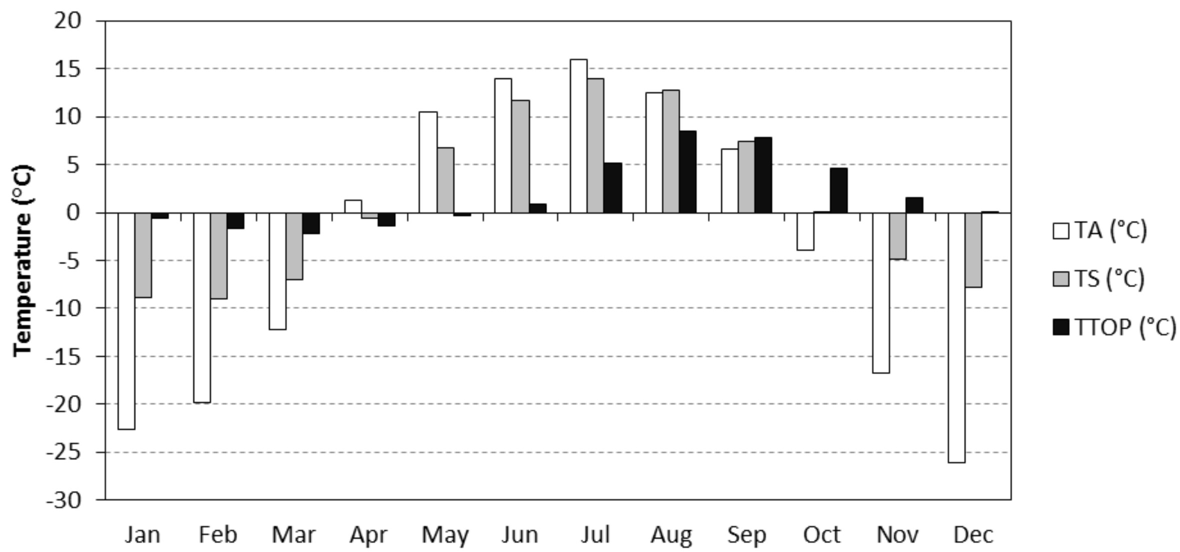
DAWSON	**TOW-08**	**Mean**	***°C***	**n**	**σ**	**Blended**	***TA (°C)***	***TS (°C)***	***TTOP (°C)***
Start	*2007*	**MAAT**	*-3.6*	*4*	*1.0*	**Jan**	*-16.9*	*-6.3*	*-2.6*
End	*2014*	**MAGST**	*0.2*	*5*	*1.9*	**Feb**	*-17.0*	*-7.1*	*-3.4*
Latitude (°N)	*64.1274*	**TTOP**	*-0.5*	*4*	*0.7*	**Mar**	*-13.1*	*-6.9*	*-3.9*
Longitude (°W)	*139.6993*		***°C-days***	**n**	**σ**	**Apr**	*-3.8*	*-3.9*	*-3.0*
Elevation (m a.s.l.)	*1119*	**TDD_A**	*1265*	*4*	*118*	**May**	*6.3*	*1.6*	*-0.4*
Slope (°)	*22*	**FDD_A**	*2655*	*4*	*353*	**Jun**	*10.9*	*7.5*	*0.2*
Aspect (°)	*23*	**TDD_S**	*847*	*4*	*111*	**Jul**	*12.3*	*9.3*	*2.9*
TPI50 (m)	*1.6*	**FDD_S**	*1053*	*4*	*316*	**Aug**	*8.8*	*6.9*	*4.1*
TPI200 (m)	*9.2*		**Values**	**n**	**σ**	**Sep**	*3.7*	*2.5*	*2.7*
TPI700 (m)	*36.1*	**N_T**	*0.7*	*4*	*0.1*	**Oct**	*-5.3*	*-1.8*	*0.4*
PISR (WH/m^2)	*4207*	**N_F**	*0.4*	*4*	*0.1*	**Nov**	*-12.4*	*-4.0*	*-0.2*
Land Cover	*Shrub*	**R_K**	*1.1*	*4*	*0.2*	**Dec**	*-18.1*	*-5.6*	*-1.1*
Texture	*mf*	**S_O**	*3.2*	*4*	*0.8*	**Jan-Jul**	*29.1*	*15.7*	*5.5*
Materials	*c*	**T_O**	*0.1*	*4*	*0.5*				
TST_{MIN}	*10-May*								
TST_{MAX}	*20-May*								
FST_{MIN}	*21-Sep*								
FST_{MAX}	*11-Oct*								



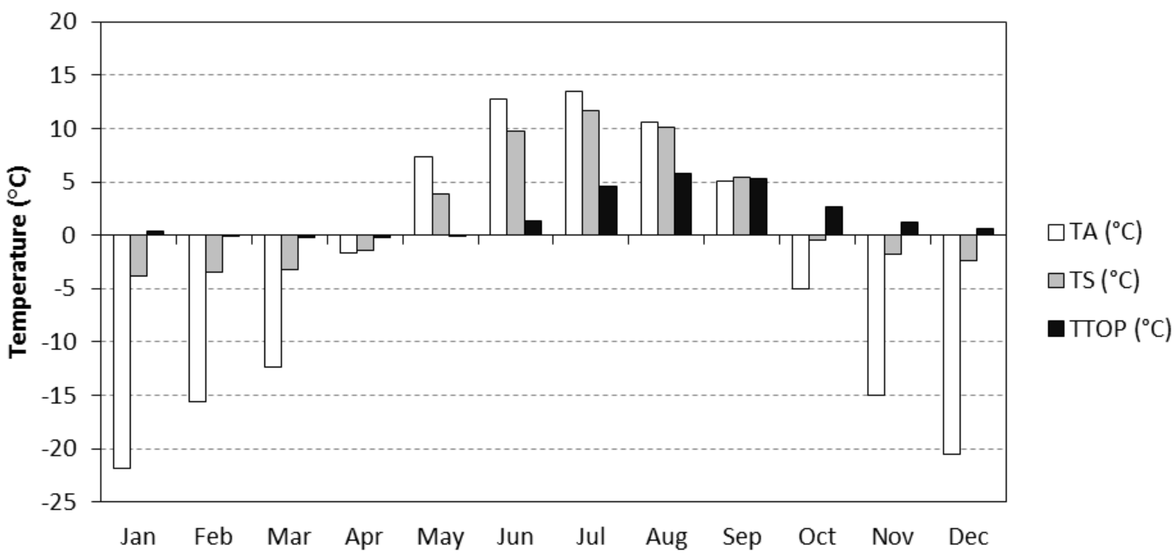
DAWSON	TOW-09	Mean	°C	n	σ	Blended	*TA (°C)*	*TS (°C)*	*TTOP (°C)*
Start	*2007*	**MAAT**	*-4.9*	*1*		**Jan**	*-25.5*	*-6.1*	*-3.3*
End	*2014*	**MAGST**	*2.0*	*5*	*0.6*	**Feb**	*-21.0*	*-5.9*	*-3.9*
Latitude (°N)	*64.0525*	**TTOP**	*1.7*	*6*	*0.5*	**Mar**	*-13.8*	*-5.2*	*-3.7*
Longitude (°W)	*139.4690*		***°C-days***	**n**	**σ**	**Apr**	*-1.5*	*-1.5*	*-1.7*
Elevation (m a.s.l.)	*477*	**TDD_A**		*0*		**May**	*8.8*	*5.4*	*0.7*
Slope (°)	*15*	**FDD_A**	*3360*	*4*	*318*	**Jun**	*14.5*	*12.4*	*6.1*
Aspect (°)	*187*	**TDD_S**	*1490*	*5*	*188*	**Jul**	*15.9*	*13.9*	*9.2*
TPI50 (m)	*-1.2*	**FDD_S**	*831*	*6*	*187*	**Aug**	*12.9*	*12.1*	*9.6*
TPI200 (m)	*-10.6*		**Values**	**n**	**σ**	**Sep**	*6.2*	*6.6*	*7.1*
TPI700 (m)	*-2.3*	**N_T**		*0*		**Oct**	*-5.3*	*0.1*	*2.9*
PISR (WH/m^2)	*5158*	**N_F**	*0.3*	*4*	*0.1*	**Nov**	*-15.2*	*-2.8*	*0.5*
Land Cover	*Deciduous*	**R_K**	*0.9*	*5*	*0.1*	**Dec**	*-27.1*	*-5.2*	*-1.6*
Texture	*mf*	**S_O**		*0*		**Jan-Jul**	*41.5*	*19.9*	*12.5*
Materials	*c*	**T_O**	*-0.3*	*5*	*0.3*				
TST_{MIN}	*25-Apr*								
TST_{MAX}	*11-May*								
FST_{MIN}	*04-Oct*								
FST_{MAX}	*11-Oct*								



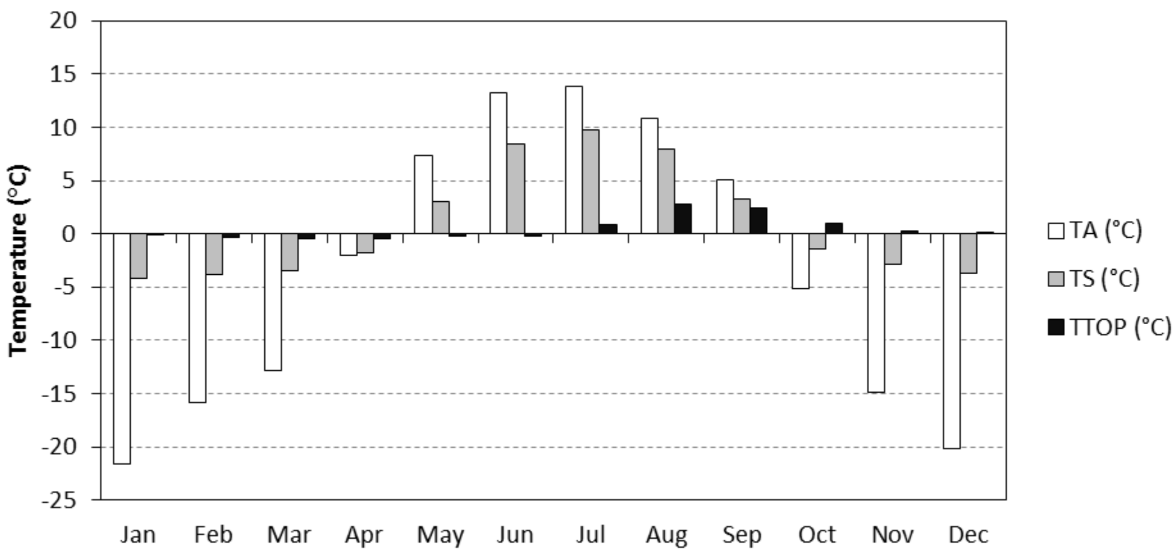
DAWSON	TOW-10	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2007*	**MAAT**	*-3.0*	*3*	*1.5*	**Jan**	*-22.6*	*-8.9*	*-0.7*
End	*2014*	**MAGST**	*-0.3*	*6*	*4.4*	**Feb**	*-19.8*	*-9.0*	*-1.6*
Latitude (°N)	*64.0528*	**TTOP**	*1.7*	*6*	*0.6*	**Mar**	*-12.2*	*-7.0*	*-2.2*
Longitude (°W)	*139.4758*		***°C-days***	**n**	**σ**	**Apr**	*1.3*	*-0.5*	*-1.4*
Elevation (m a.s.l.)	*490*	**TDD_A**	*1896*	*3*	*47*	**May**	*10.5*	*6.7*	*-0.3*
Slope (°)	*15*	**FDD_A**	*3011*	*4*	*407*	**Jun**	*14.0*	*11.7*	*0.9*
Aspect (°)	*213*	**TDD_S**	*1549*	*5*	*182*	**Jul**	*15.9*	*14.0*	*5.2*
TPI50 (m)	*-0.3*	**FDD_S**	*1085*	*6*	*227*	**Aug**	*12.5*	*12.7*	*8.5*
TPI200 (m)	*-0.3*		**Values**	**n**	**σ**	**Sep**	*6.7*	*7.4*	*7.9*
TPI700 (m)	*2.2*	**N_T**	*0.8*	*3*	*0.1*	**Oct**	*-3.9*	*0.0*	*4.5*
PISR (WH/m^2)	*5233*	**N_F**	*0.4*	*4*	*0.1*	**Nov**	*-16.8*	*-4.8*	*1.6*
Land Cover	*Deciduous*	**R_K**	*1.1*	*5*	*0.2*	**Dec**	*-26.1*	*-7.9*	*0.1*
Texture	*mf*	**S_O**	*4.9*	*3*	*1.3*	**Jan-Jul**	*38.5*	*22.9*	*5.9*
Materials	*c*	**T_O**	*0.3*	*5*	*0.6*				
TST_{MIN}	*24-Apr*								
TST_{MAX}	*18-Apr*								
FST_{MIN}	*04-Oct*								
FST_{MAX}	*20-Oct*								



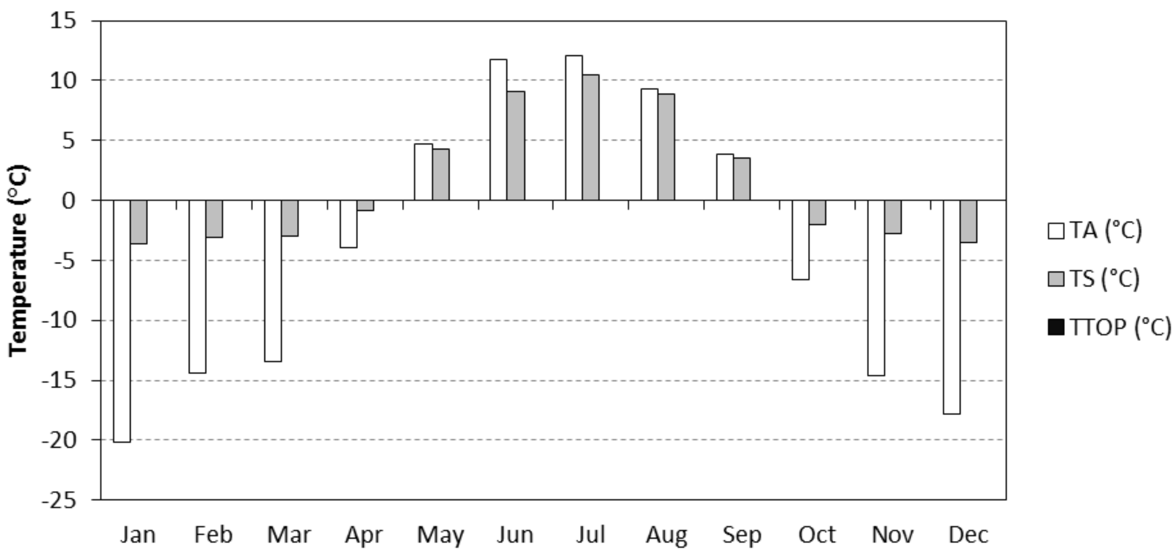
DAWSON	TOW-11	Mean	*°C*	n	σ	Blended	*TA (°C)*	*TS (°C)*	*TTOP (°C)*
Start	*2007*	**MAAT**	*-3.2*	*5*	*1.1*	**Jan**	*-21.8*	*-3.9*	*0.3*
End	*2014*	**MAGST**	*2.2*	*5*	*0.8*	**Feb**	*-15.6*	*-3.5*	*-0.0*
Latitude (°N)	*64.0888*	**TTOP**	*1.7*	*4*	*0.4*	**Mar**	*-12.3*	*-3.2*	*-0.3*
Longitude (°W)	*139.5522*		***°C-days***	**n**	**σ**	**Apr**	*-1.6*	*-1.4*	*-0.2*
Elevation (m a.s.l.)	*842*	**TDD_A**	*1537*	*5*	*100*	**May**	*7.3*	*3.8*	*-0.1*
Slope (°)	*3*	**FDD_A**	*2840*	*6*	*423*	**Jun**	*12.8*	*9.8*	*1.3*
Aspect (°)	*167*	**TDD_S**	*1270*	*5*	*47*	**Jul**	*13.4*	*11.6*	*4.6*
TPI50 (m)	*0.3*	**FDD_S**	*515*	*6*	*240*	**Aug**	*10.6*	*10.2*	*5.8*
TPI200 (m)	*1.1*		**Values**	**n**	**σ**	**Sep**	*5.1*	*5.4*	*5.4*
TPI700 (m)	*15.4*	**N_T**	*0.8*	*5*	*0.0*	**Oct**	*-5.0*	*-0.5*	*2.7*
PISR (WH/m^2)	*5237*	**N_F**	*0.2*	*6*	*0.1*	**Nov**	*-15.0*	*-1.8*	*1.2*
Land Cover	*Coniferous or Mixed*	**R_K**	*0.9*	*4*	*0.2*	**Dec**	*-20.5*	*-2.4*	*0.7*
Texture	*mf*	**S_O**	*5.5*	*5*	*1.0*	**Jan-Jul**	*35.2*	*15.5*	*4.9*
Materials	*c*	**T_O**	*-0.3*	*4*	*0.7*				
TST_{MIN}	*26-Apr*								
TST_{MAX}	*22-May*								
FST_{MIN}	*04-Oct*								
FST_{MAX}	*10-Oct*								



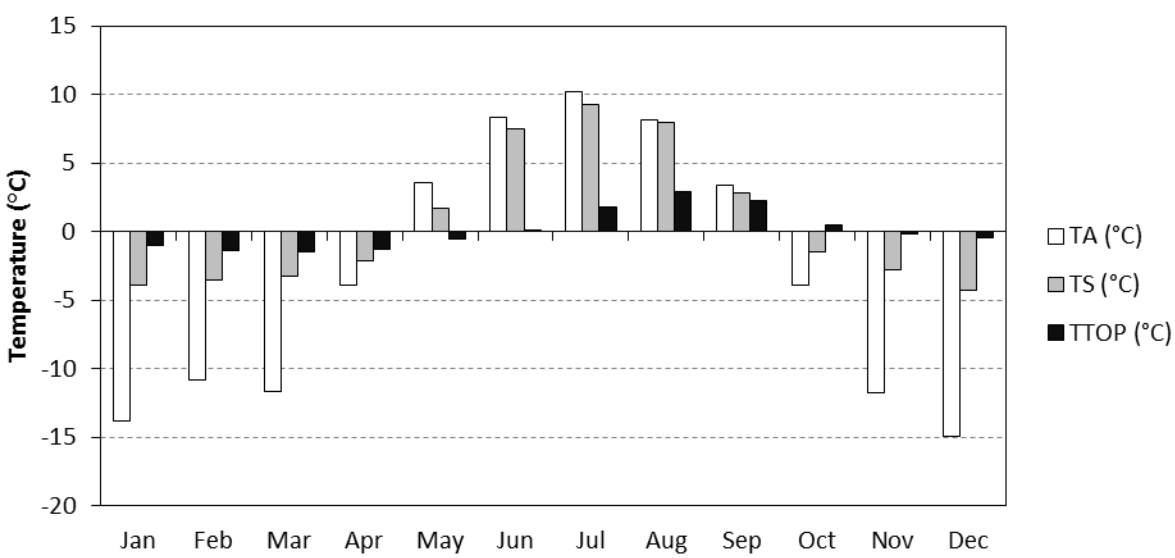
DAWSON	TOW-12	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2007*	**MAAT**	*-3.1*	*5*	*1.0*	**Jan**	*-21.6*	*-4.2*	*-0.1*
End	*2014*	**MAGST**	*1.1*	*5*	*0.6*	**Feb**	*-15.8*	*-3.9*	*-0.3*
Latitude (°N)	*64.0894*	**TTOP**	*0.4*	*6*	*0.4*	**Mar**	*-12.8*	*-3.4*	*-0.5*
Longitude (°W)	*139.5622*		***°C-days***	**n**	**σ**	**Apr**	*-2.0*	*-1.8*	*-0.5*
Elevation (m a.s.l.)	*858*	**TDD_A**	*1525*	*5*	*96*	**May**	*7.3*	*3.0*	*-0.3*
Slope (°)	*7*	**FDD_A**	*2866*	*6*	*416*	**Jun**	*13.2*	*8.4*	*-0.2*
Aspect (°)	*334*	**TDD_S**	*1012*	*5*	*135*	**Jul**	*13.9*	*9.8*	*0.8*
TPI50 (m)	*-0.3*	**FDD_S**	*654*	*6*	*220*	**Aug**	*10.9*	*8.0*	*2.8*
TPI200 (m)	*0.0*		**Values**	**n**	**σ**	**Sep**	*5.0*	*3.3*	*2.4*
TPI700 (m)	*15.6*	**N_T**	*0.7*	*5*	*0.1*	**Oct**	*-5.2*	*-1.4*	*1.0*
PISR (WH/m^2)	*4906*	**N_F**	*0.2*	*6*	*0.1*	**Nov**	*-14.9*	*-2.8*	*0.2*
Land Cover	*Coniferous or Mixed*	**R_K**	*0.7*	*5*	*0.1*	**Dec**	*-20.1*	*-3.7*	*0.0*
Texture	*mf*	**S_O**	*4.5*	*5*	*0.9*	**Jan-Jul**	*35.5*	*14.0*	*0.9*
Materials	*c*	**T_O**	*-0.7*	*5*	*0.4*				
TST_{MIN}	*02-May*								
TST_{MAX}	*25-May*								
FST_{MIN}	*22-Sep*								
FST_{MAX}	*10-Oct*								



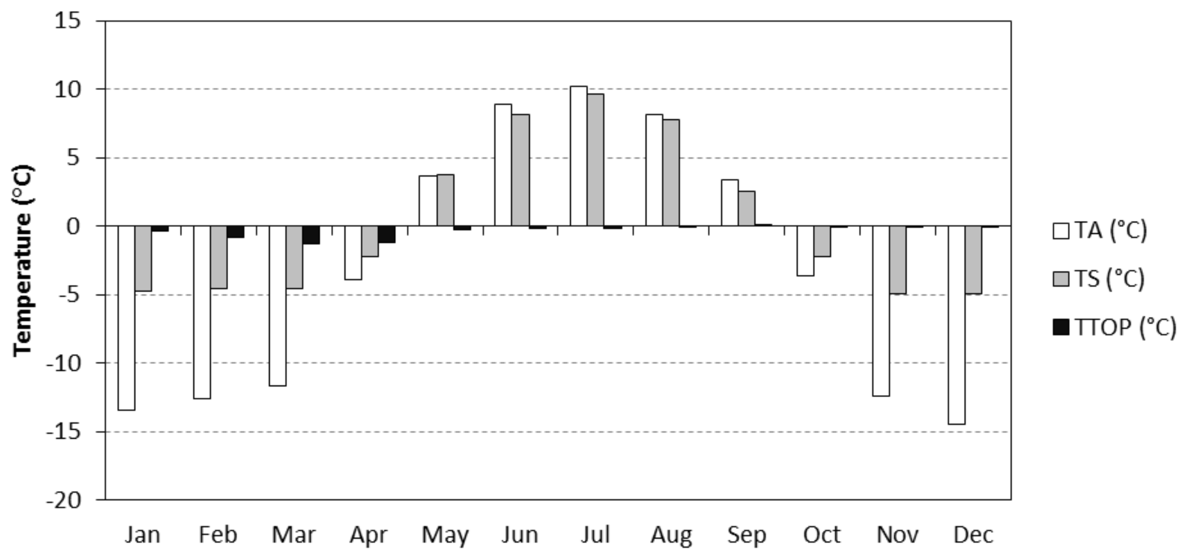
DAWSON	TOW-13	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2007*	**MAAT**	*-3.8*	*3*	*0.7*	**Jan**	*-20.1*	*-3.6*	
End	*2014*	**MAGST**	*1.5*	*5*	*0.7*	**Feb**	*-14.4*	*-3.1*	
Latitude (°N)	*64.1597*	**TTOP**		*0*		**Mar**	*-13.4*	*-2.9*	
Longitude (°W)	*139.8019*		**°C-days**	**n**	**σ**	**Apr**	*-4.0*	*-0.8*	
Elevation (m a.s.l.)	*1116*	**TDD_A**	*1259*	*3*	*116*	**May**	*4.7*	*4.3*	
Slope (°)	*17*	**FDD_A**	*2806*	*4*	*320*	**Jun**	*11.8*	*9.1*	
Aspect (°)	*180*	**TDD_S**	*1141*	*5*	*234*	**Jul**	*12.1*	*10.5*	
TPI50 (m)	*0.2*	**FDD_S**	*590*	*6*	*146*	**Aug**	*9.3*	*8.9*	
TPI200 (m)	*4.5*		**Values**	**n**	**σ**	**Sep**	*3.8*	*3.6*	
TPI700 (m)	*26.0*	**N_T**	*0.8*	*3*	*0.1*	**Oct**	*-6.6*	*-2.0*	
PISR (WH/m^2)	*5723*	**N_F**	*0.2*	*4*	*0.0*	**Nov**	*-14.6*	*-2.7*	
Land Cover	*Shrub*	**R_K**		*0*		**Dec**	*-17.8*	*-3.6*	
Texture	*mf*	**S_O**	*5.1*	*3*	*0.1*	**Jan-Jul**	*32.2*	*14.1*	
Materials	*c*	**T_O**		*0*					
TST_{MIN}	*29-Apr*								
TST_{MAX}	*23-May*								
FST_{MIN}	*22-Sep*								
FST_{MAX}	*09-Oct*								



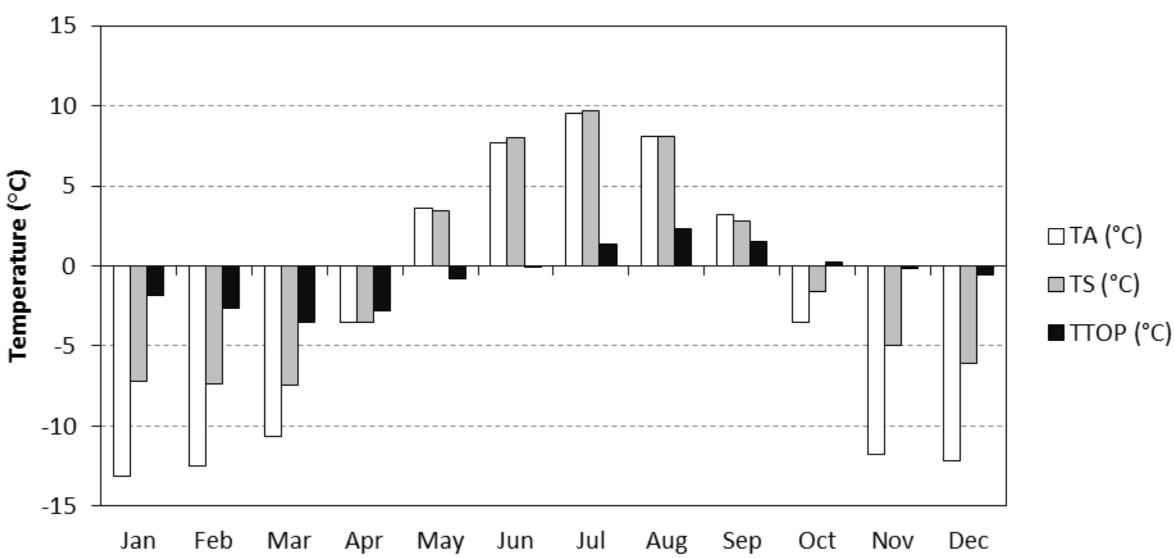
WHITEHORSE	CR-01	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	2006	MAAT	-2.9	4	1.0	Jan	-13.8	-3.9	-1.1
End	2014	MAGST	0.8	5	0.5	Feb	-10.8	-3.5	-1.4
Latitude (°N)	60.4996	TTOP	0.1	4	0.2	Mar	-11.7	-3.3	-1.5
Longitude (°W)	135.2162		°C-days	n	σ	Apr	-3.9	-2.1	-1.3
Elevation (m a.s.l.)	1260	TDD_A	999	4	99	May	3.5	1.7	-0.5
Slope (°)	4	FDD_A	2180	5	319	Jun	8.3	7.5	0.0
Aspect (°)	238	TDD_S	904	5	64	Jul	10.2	9.3	1.8
TPI50 (m)	-0.8	FDD_S	658	6	178	Aug	8.2	7.9	3.0
TPI200 (m)	-5.2		Values	n	σ	Sep	3.3	2.9	2.3
TPI700 (m)	-64.1	N_T	0.9	4	0.1	Oct	-3.9	-1.5	0.5
PISR (WH/m^2)	5153	N_F	0.3	5	0.0	Nov	-11.8	-2.8	-0.1
Land Cover	Shrub	R_K	0.8	4	0.2	Dec	-15.0	-4.3	-0.4
Texture	mf	S_O	4.0	4	0.9	Jan-Jul	24.1	13.1	2.9
Materials	c	T_O	-0.6	4	0.4				
TST_{MIN}	09-May								
TST_{MAX}	16-May								
FST_{MIN}	03-Oct								
FST_{MAX}	10-Oct								



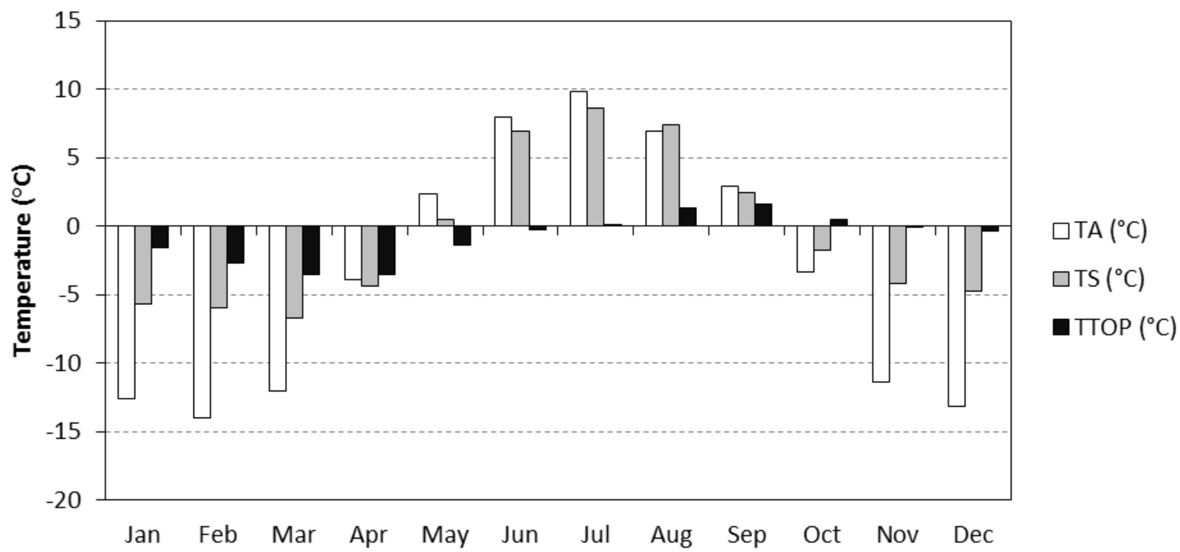
WHITEHORSE	CR-02	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2006*	**MAAT**	*-3.2*	*5*	*0.8*	**Jan**	*-13.4*	*-4.7*	*-0.3*
End	*2014*	**MAGST**	*0.4*	*6*	*0.7*	**Feb**	*-12.6*	*-4.6*	*-0.9*
Latitude (°N)	*60.4994*	**TTOP**	*-0.4*	*5*	*0.3*	**Mar**	*-11.6*	*-4.6*	*-1.3*
Longitude (°W)	*135.2153*		***°C-days***	**n**	**σ**	**Apr**	*-3.9*	*-2.2*	*-1.2*
Elevation (m a.s.l.)	*1271*	**TDD_A**	*1016*	*4*	*51*	**May**	*3.6*	*3.7*	*-0.3*
Slope (°)	*5*	**FDD_A**	*2182*	*5*	*253*	**Jun**	*8.9*	*8.2*	*-0.2*
Aspect (°)	*225*	**TDD_S**	*986*	*6*	*63*	**Jul**	*10.2*	*9.6*	*-0.2*
TPI50 (m)	*-0.5*	**FDD_S**	*843*	*6*	*212*	**Aug**	*8.2*	*7.8*	*-0.0*
TPI200 (m)	*-9.6*		**Values**	**n**	**σ**	**Sep**	*3.3*	*2.5*	*0.0*
TPI700 (m)	*-70.9*	**N_T**	*1.0*	*4*	*0.1*	**Oct**	*-3.6*	*-2.2*	*-0.1*
PISR (WH/m^2)	*5156*	**N_F**	*0.4*	*5*	*0.1*	**Nov**	*-12.4*	*-4.9*	*-0.1*
Land Cover	*Shrub*	**R_K**	*0.8*	*5*	*0.2*	**Dec**	*-14.5*	*-5.0*	*-0.1*
Texture	*mf*	**S_O**	*3.4*	*4*	*0.8*	**Jan-Jul**	*23.6*	*14.3*	*0.5*
Materials	*b*	**T_O**	*-0.7*	*5*	*0.6*				
TST_{MIN}	*30-Apr*								
TST_{MAX}	*14-Apr*								
FST_{MIN}	*05-Oct*								
FST_{MAX}	*10-Oct*								



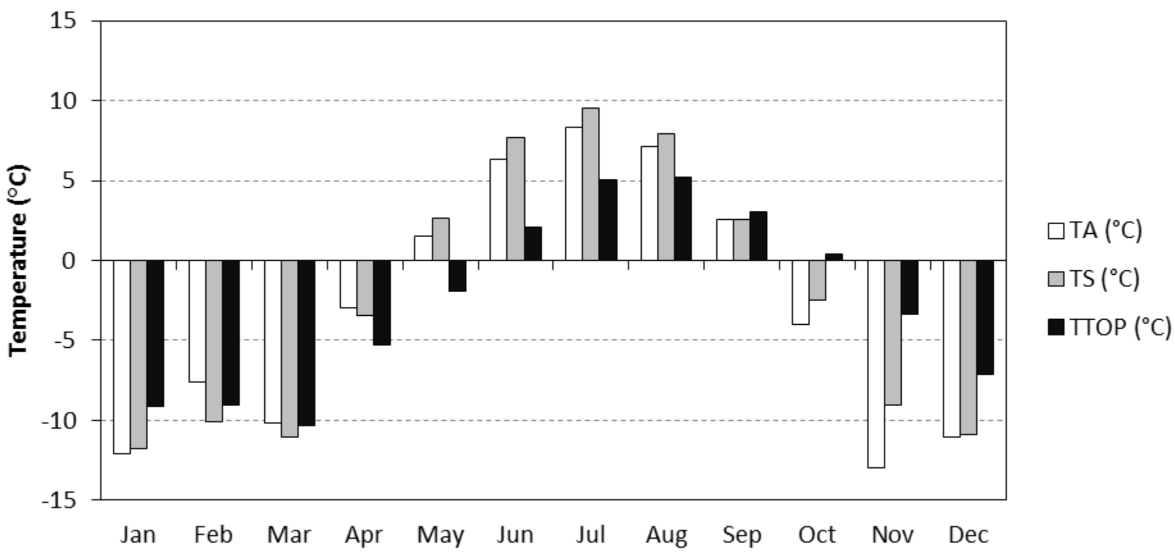
WHITEHORSE	CR-03	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	2006	MAAT	-2.7	4	1.0	Jan	-13.2	-7.2	-1.8
End	2014	MAGST	-0.5	6	0.5	Feb	-12.5	-7.4	-2.6
Latitude (°N)	60.4988	TTOP	-0.5	3	0.1	Mar	-10.7	-7.5	-3.5
Longitude (°W)	135.2134		°C-days	n	σ	Apr	-3.5	-3.5	-2.8
Elevation (m a.s.l.)	1363	TDD_A	1036	4	147	May	3.6	3.4	-0.8
Slope (°)	26	FDD_A	2030	4	342	Jun	7.7	8.0	-0.0
Aspect (°)	313	TDD_S	989	6	128	Jul	9.5	9.7	1.4
TPI50 (m)	-3.2	FDD_S	1160	6	185	Aug	8.1	8.1	2.3
TPI200 (m)	-23.3		Values	n	σ	Sep	3.2	2.8	1.5
TPI700 (m)	-76.4	N_T	1.0	4	0.1	Oct	-3.5	-1.6	0.2
PISR (WH/m^2)	4290	N_F	0.6	4	0.0	Nov	-11.8	-4.9	-0.2
Land Cover	Shrub	R_K	0.9	3	0.0	Dec	-12.2	-6.1	-0.5
Texture	mf	S_O	2.1	4	0.8	Jan-Jul	22.7	16.9	3.2
Materials	b	T_O	-0.3	3	0.1				
TST_{MIN}	02-May								
TST_{MAX}	19-May								
FST_{MIN}	05-Oct								
FST_{MAX}	10-Oct								



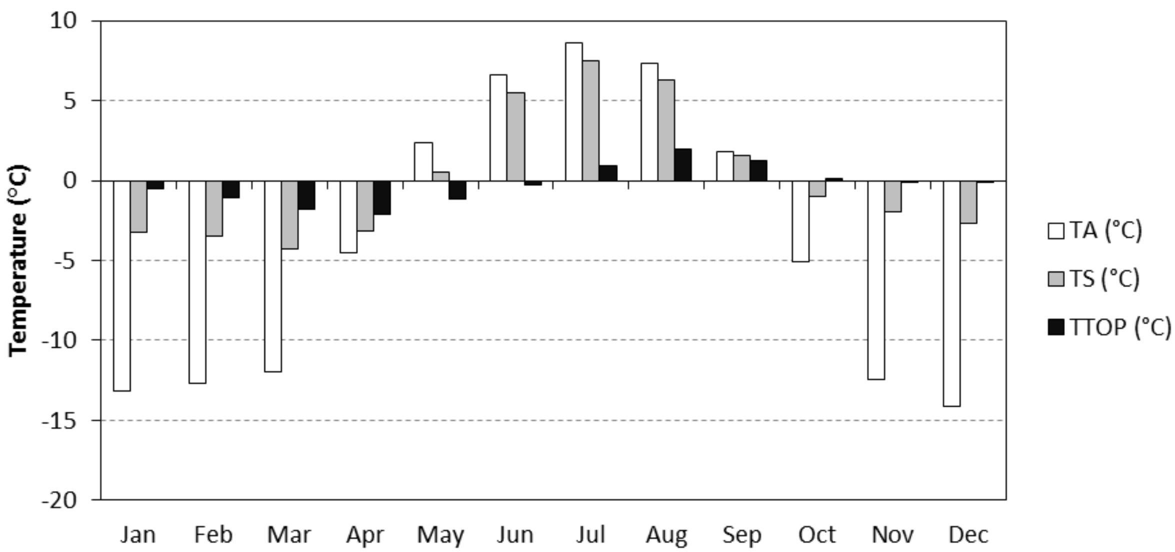
WHITEHORSE	CR-04	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	2006	MAAT	-3.3	4	0.4	Jan	-12.6	-5.7	-1.6
End	2014	MAGST	-0.6	6	0.5	Feb	-14.0	-5.9	-2.7
Latitude (°N)	60.4979	TTOP	-0.9	4	0.3	Mar	-12.1	-6.7	-3.5
Longitude (°W)	135.2121		°C-days	n	σ	Apr	-3.9	-4.4	-3.5
Elevation (m a.s.l.)	1457	TDD_A	846	3	53	May	2.4	0.5	-1.4
Slope (°)	36	FDD_A	2137	4	138	Jun	7.9	7.0	-0.2
Aspect (°)	307	TDD_S	830	6	80	Jul	9.9	8.6	0.1
TPI50 (m)	1.3	FDD_S	1037	6	156	Aug	7.0	7.4	1.4
TPI200 (m)	3.2		Values	n	σ	Sep	2.9	2.4	1.6
TPI700 (m)	-23.3	N_T	1.0	3	0.0	Oct	-3.4	-1.8	0.5
PISR (WH/m^2)	3851	N_F	0.5	4	0.1	Nov	-11.3	-4.2	-0.0
Land Cover	Tundra	R_K	0.9	4	0.2	Dec	-13.1	-4.7	-0.4
Texture	mf	S_O	2.6	3	0.6	Jan-Jul	22.4	14.3	1.7
Materials	b	T_O	-0.2	4	0.4				
TST_{MIN}	23-May								
TST_{MAX}	02-Jun								
FST_{MIN}	01-Oct								
FST_{MAX}	10-Oct								



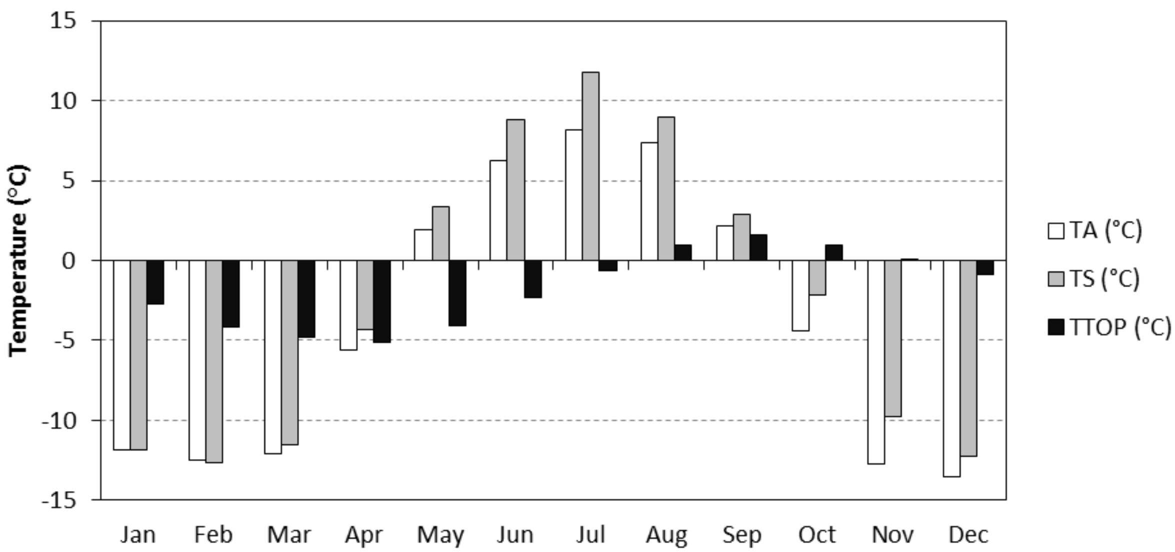
WHITEHORSE	CR-05	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2006*	**MAAT**	*-2.4*	*2*	*1.0*	**Jan**	*-12.1*	*-11.8*	*-9.2*
End	*2014*	**MAGST**	*-2.8*	*4*	*1.6*	**Feb**	*-7.6*	*-10.1*	*-9.0*
Latitude (°N)	*60.4910*	**TTOP**	*-2.6*	*2*	*0.1*	**Mar**	*-10.2*	*-11.0*	*-10.3*
Longitude (°W)	*135.2047*		***°C-days***	**n**	**σ**	**Apr**	*-2.9*	*-3.5*	*-5.3*
Elevation (m a.s.l.)	*1495*	**TDD_A**	*889*	*2*	*110*	**May**	*1.6*	*2.7*	*-1.9*
Slope (°)	*20*	**FDD_A**	*1770*	*2*	*288*	**Jun**	*6.3*	*7.6*	*2.1*
Aspect (°)	*164*	**TDD_S**	*965*	*3*	*141*	**Jul**	*8.3*	*9.5*	*5.0*
TPI50 (m)	*-0.8*	**FDD_S**	*1754*	*3*	*218*	**Aug**	*7.1*	*7.9*	*5.2*
TPI200 (m)	*-2.8*		**Values**	**n**	**σ**	**Sep**	*2.6*	*2.6*	*3.0*
TPI700 (m)	*17.1*	**N_T**	*1.1*	*2*	*0.1*	**Oct**	*-4.0*	*-2.5*	*0.4*
PISR (WH/m^2)	*5708*	**N_F**	*0.9*	*2*	*0.0*	**Nov**	*-13.0*	*-9.1*	*-3.4*
Land Cover	*Rock*	**R_K**	*0.8*	*2*	*0.4*	**Dec**	*-11.0*	*-10.9*	*-7.1*
Texture	*mf*	**S_O**	*0.6*	*2*	*0.0*	**Jan-Jul**	*20.4*	*21.3*	*14.2*
Materials	*m*	**T_O**	*-0.7*	*2*	*1.3*				
TST_{MIN}	*23-Apr*								
TST_{MAX}	*20-May*								
FST_{MIN}	*12-Oct*								
FST_{MAX}	*10-Oct*								



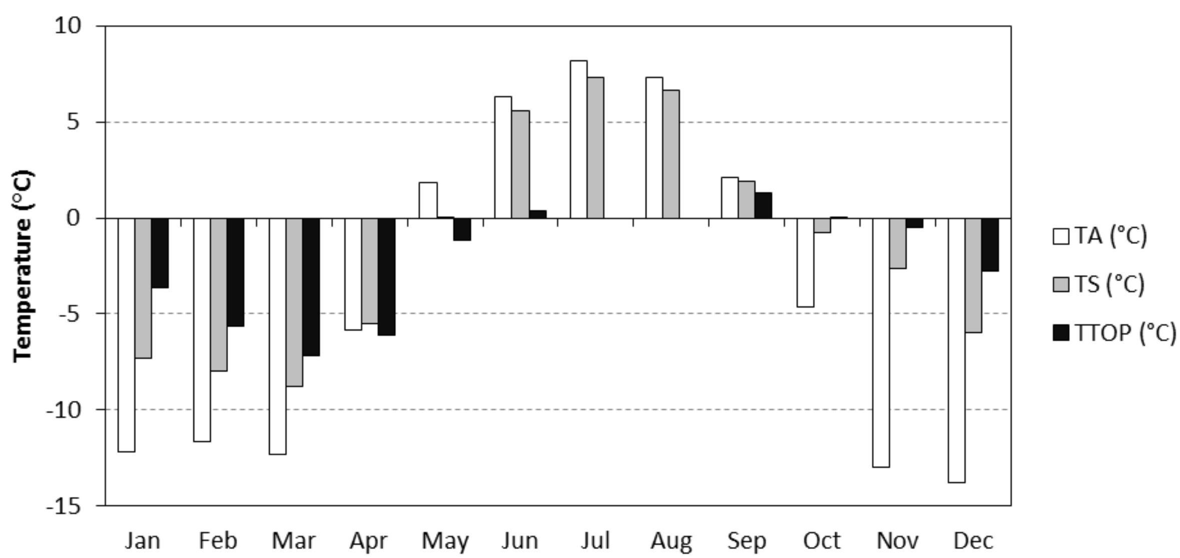
WHITEHORSE	CR-06	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2006*	**MAAT**	*-3.9*	*4*	*1.3*	**Jan**	*-13.2*	*-3.2*	*-0.5*
End	*2014*	**MAGST**	*0.3*	*6*	*0.6*	**Feb**	*-12.7*	*-3.5*	*-1.1*
Latitude (°N)	*60.4959*	**TTOP**	*-0.2*	*4*	*0.3*	**Mar**	*-11.9*	*-4.3*	*-1.8*
Longitude (°W)	*135.2052*		***°C-days***	**n**	**σ**	**Apr**	*-4.5*	*-3.2*	*-2.1*
Elevation (m a.s.l.)	*1555*	**TDD_A**	*839*	*4*	*181*	**May**	*2.4*	*0.5*	*-1.1*
Slope (°)	*7*	**FDD_A**	*2270*	*4*	*370*	**Jun**	*6.6*	*5.5*	*-0.3*
Aspect (°)	*270*	**TDD_S**	*673*	*5*	*101*	**Jul**	*8.6*	*7.5*	*0.9*
TPI50 (m)	*0.6*	**FDD_S**	*625*	*5*	*175*	**Aug**	*7.3*	*6.3*	*2.0*
TPI200 (m)	*2.6*		**Values**	**n**	**σ**	**Sep**	*1.8*	*1.6*	*1.2*
TPI700 (m)	*39.2*	**N_T**	*0.9*	*4*	*0.1*	**Oct**	*-5.1*	*-1.0*	*0.1*
PISR (WH/m^2)	*5551*	**N_F**	*0.3*	*4*	*0.1*	**Nov**	*-12.5*	*-2.0*	*-0.0*
Land Cover	*Shrub*	**R_K**	*0.8*	*4*	*0.3*	**Dec**	*-14.1*	*-2.6*	*-0.1*
Texture	*mf*	**S_O**	*4.1*	*4*	*0.7*	**Jan-Jul**	*21.8*	*10.7*	*1.4*
Materials	*m*	**T_O**	*-0.4*	*4*	*0.7*				
TST_{MIN}	*22-May*								
TST_{MAX}	*30-May*								
FST_{MIN}	*30-Sep*								
FST_{MAX}	*10-Oct*								



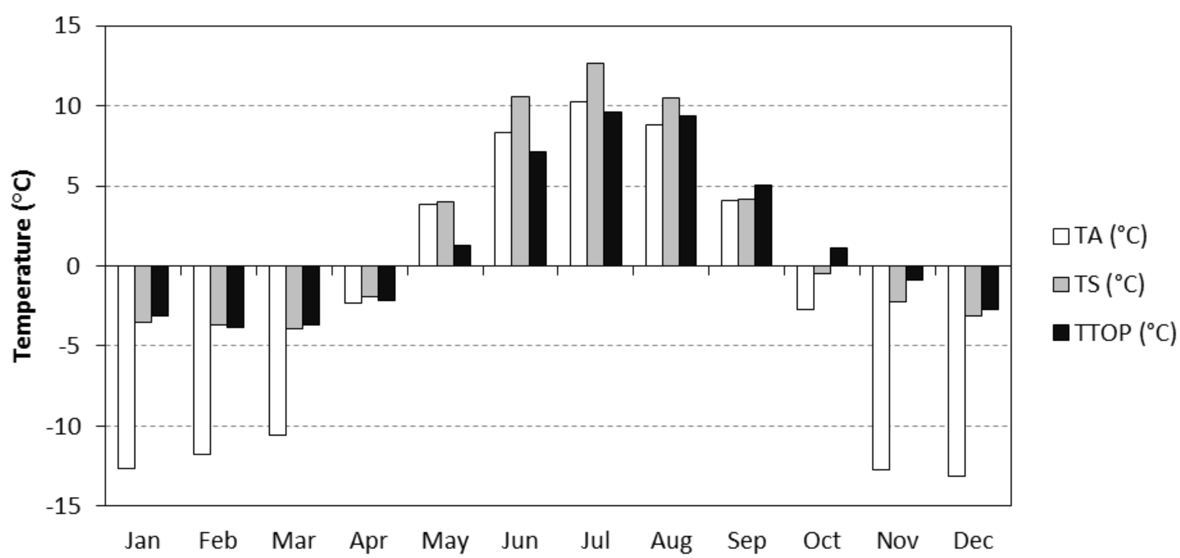
WHITEHORSE	MtMC	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2009*	**MAAT**	*-3.9*	*4*	*1.0*	**Jan**	*-11.9*	*-11.9*	*-2.7*
End	*2014*	**MAGST**	*-2.2*	*4*	*1.2*	**Feb**	*-12.5*	*-12.6*	*-4.2*
Latitude (°N)	*60.6217*	**TTOP**	*-1.8*	*4*	*0.5*	**Mar**	*-12.1*	*-11.5*	*-4.8*
Longitude (°W)	*135.1414*		**°C-days**	**n**	**σ**	**Apr**	*-5.6*	*-4.3*	*-5.1*
Elevation (m a.s.l.)	*1567*	**TDD_A**	*857*	*4*	*149*	**May**	*1.9*	*3.4*	*-4.1*
Slope (°)	*6*	**FDD_A**	*2205*	*5*	*337*	**Jun**	*6.3*	*8.8*	*-2.4*
Aspect (°)	*13*	**TDD_S**	*1131*	*4*	*211*	**Jul**	*8.2*	*11.7*	*-0.7*
TPI50 (m)	*-0.2*	**FDD_S**	*1946*	*5*	*285*	**Aug**	*7.3*	*9.0*	*1.0*
TPI200 (m)	*1.9*		**Values**	**n**	**σ**	**Sep**	*2.2*	*2.9*	*1.6*
TPI700 (m)	*25.6*	**N_T**	*1.3*	*4*	*0.0*	**Oct**	*-4.4*	*-2.2*	*1.0*
PISR (WH/m^2)	*5611*	**N_F**	*0.9*	*5*	*0.1*	**Nov**	*-12.7*	*-9.7*	*0.1*
Land Cover	*Rock*	**R_K**	*1.4*	*2*	*0.5*	**Dec**	*-13.5*	*-12.3*	*-0.9*
Texture	*mf*	**S_O**	*1.6*	*4*	*0.7*	**Jan-Jul**	*20.1*	*23.6*	*3.4*
Materials	*m*	**T_O**	*0.9*	*2*	*1.3*				
TST_{MIN}	*24-Apr*								
TST_{MAX}	*01-May*								
FST_{MIN}	*27-Sep*								
FST_{MAX}	*27-Sep*								



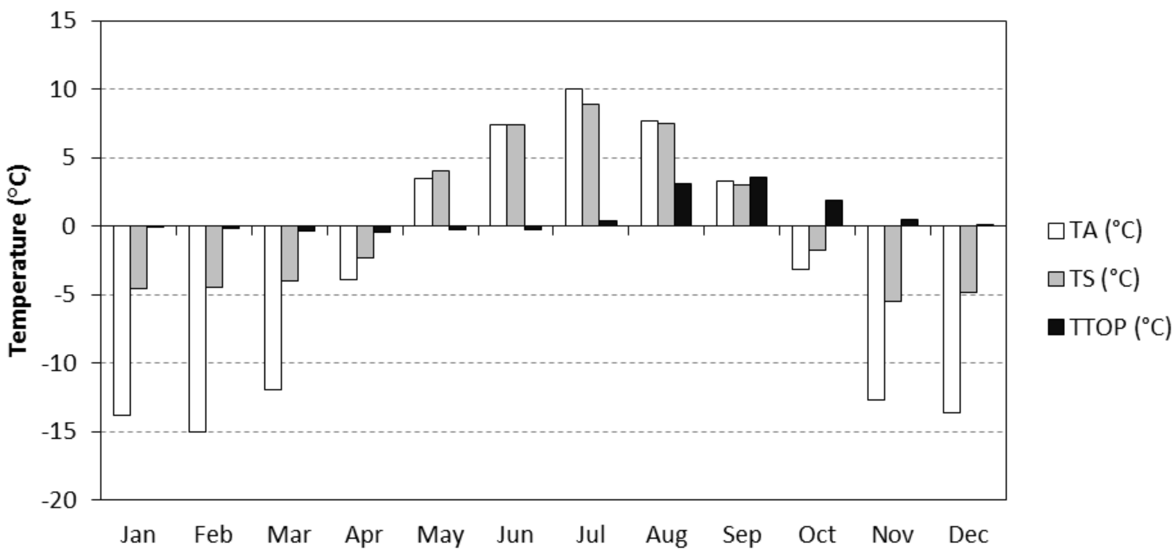
WHITEHORSE	MtMC-BK	Mean	°C	n	σ	Blended	*TA (°C)*	*TS (°C)*	*TTOP (°C)*
Start	*2009*	**MAAT**	*-4.5*	*3*	*0.5*	**Jan**	*-12.2*	*-7.3*	*-3.6*
End	*2014*	**MAGST**	*-1.5*	*3*	*0.7*	**Feb**	*-11.7*	*-8.0*	*-5.7*
Latitude (°N)	*60.6204*	**TTOP**		*0*		**Mar**	*-12.3*	*-8.8*	*-7.2*
Longitude (°W)	*135.1445*		***°C-days***	**n**	**σ**	**Apr**	*-5.8*	*-5.5*	*-6.1*
Elevation (m a.s.l.)	*1565*	**TDD_A**	*840*	*4*	*144*	**May**	*1.8*	*0.0*	*-1.2*
Slope (°)	*7*	**FDD_A**	*2392*	*4*	*237*	**Jun**	*6.3*	*5.6*	*0.3*
Aspect (°)	*280*	**TDD_S**	*688*	*4*	*127*	**Jul**	*8.2*	*7.3*	
TPI50 (m)	*0.4*	**FDD_S**	*1293*	*4*	*188*	**Aug**	*7.3*	*6.6*	
TPI200 (m)	*2.2*		**Values**	**n**	**σ**	**Sep**	*2.1*	*1.9*	*1.3*
TPI700 (m)	*26.7*	**N_T**	*0.8*	*4*	*0.0*	**Oct**	*-4.6*	*-0.7*	*0.1*
PISR (WH/m^2)	*5741*	**N_F**	*0.6*	*4*	*0.1*	**Nov**	*-12.9*	*-2.6*	*-0.5*
Land Cover	*Shrub*	**R_K**		*0*		**Dec**	*-13.8*	*-6.0*	*-2.7*
Texture	*mf*	**S_O**	*3.0*	*3*	*1.0*	**Jan-Jul**	*20.3*	*14.6*	
Materials	*m*	**T_O**		*0*					
TST_{MIN}	*17-May*								
TST_{MAX}	*07-May*								
FST_{MIN}	*23-Sep*								
FST_{MAX}	*27-Sep*								



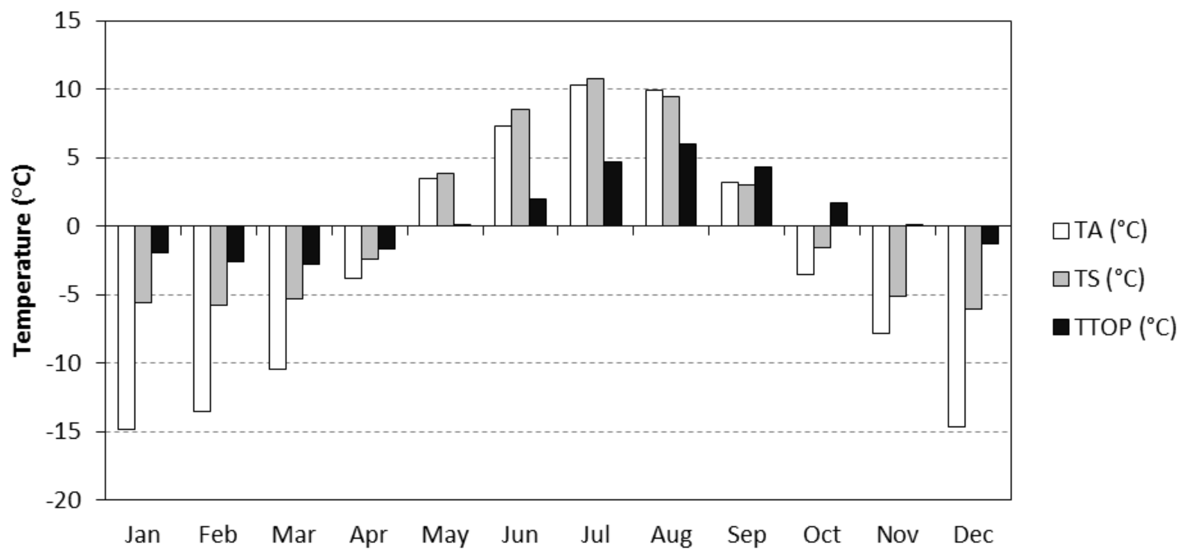
WHITEHORSE	WC2006-01	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	2006	MAAT	-2.6	3	0.7	Jan	-12.7	-3.5	-3.1
End	2010	MAGST	1.9	6	0.7	Feb	-11.8	-3.7	-3.8
Latitude (°N)	60.5380	TTOP	1.4	2	0.3	Mar	-10.5	-3.9	-3.7
Longitude (°W)	135.1384		°C-days	n	σ	Apr	-2.3	-1.9	-2.2
Elevation (m a.s.l.)	1266	TDD_A	1104	3	55	May	3.8	4.0	1.3
Slope (°)	3	FDD_A	1999	4	233	Jun	8.3	10.5	7.1
Aspect (°)	56	TDD_S	1298	6	149	Jul	10.2	12.7	9.6
TPI50 (m)	0.3	FDD_S	590	6	234	Aug	8.8	10.5	9.4
TPI200 (m)	0.5		Values	n	σ	Sep	4.1	4.2	5.0
TPI700 (m)	18.3	N_T	1.1	3	0.0	Oct	-2.7	-0.5	1.1
PISR (WH/m^2)	5388	N_F	0.3	4	0.1	Nov	-12.7	-2.2	-0.9
Land Cover	Shrub	R_K	1.1	2	0.2	Dec	-13.1	-3.1	-2.7
Texture	mf	S_O	4.5	3	0.5	Jan-Jul	22.9	16.2	12.7
Materials	m	T_O	0.3	2	0.6				
TST_{MIN}	07-May								
TST_{MAX}	20-May								
FST_{MIN}	12-Oct								
FST_{MAX}	18-Oct								



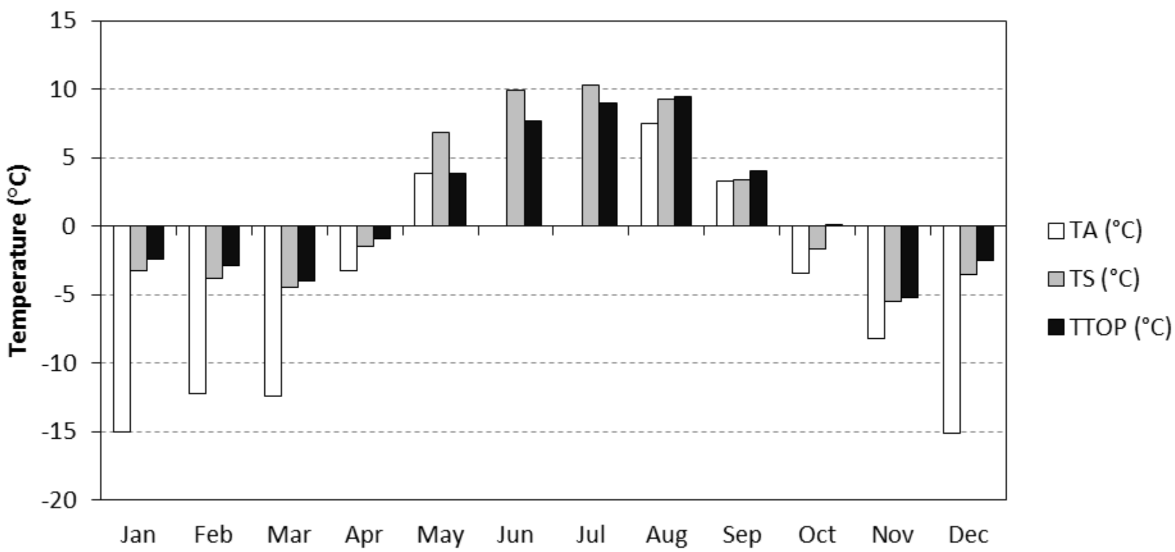
WHITEHORSE	WC2006-02	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	2006	MAAT	-3.4	1		Jan	-13.8	-4.6	-0.1
End	2010	MAGST	0.2	2	0.4	Feb	-15.0	-4.5	-0.2
Latitude (°N)	60.4932	TTOP	0.6	1		Mar	-11.9	-4.0	-0.3
Longitude (°W)	135.2902		°C-days	n	σ	Apr	-3.9	-2.3	-0.5
Elevation (m a.s.l.)	1349	TDD_A	854	1		May	3.5	4.0	-0.3
Slope (°)	6	FDD_A	2260	3	167	Jun	7.4	7.4	-0.2
Aspect (°)	204	TDD_S	931	2	184	Jul	10.0	8.9	0.4
TPI50 (m)	-0.8	FDD_S	834	3	68	Aug	7.7	7.5	3.1
TPI200 (m)	-2.4		Values	n	σ	Sep	3.3	3.0	3.5
TPI700 (m)	-39.5	N_T	0.9	1		Oct	-3.1	-1.7	1.9
PISR (WH/m^2)	5699	N_F	0.4	3	0.0	Nov	-12.7	-5.5	0.5
Land Cover	Shrub	R_K	1.0	1		Dec	-13.6	-4.8	0.1
Texture	g	S_O	3.2	1		Jan-Jul	23.8	13.4	0.5
Materials	f	T_O	0.1	1					
TST_{MIN}	30-Apr								
TST_{MAX}	01-May								
FST_{MIN}	12-Oct								
FST_{MAX}	04-Oct								



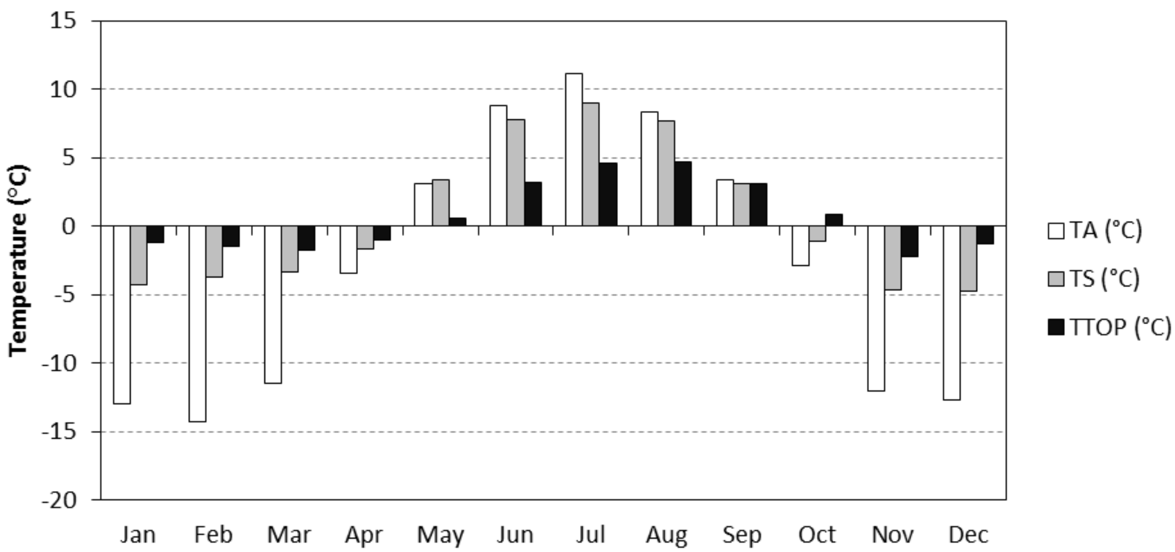
WHITEHORSE	WC2006-03	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2006*	**MAAT**	*-3.0*	*1*		**Jan**	*-14.9*	*-5.6*	*-2.0*
End	*2010*	**MAGST**	*0.1*	*2*	*0.7*	**Feb**	*-13.5*	*-5.8*	*-2.6*
Latitude (°N)	*60.4927*	**TTOP**	*0.6*	*2*	*0.1*	**Mar**	*-10.5*	*-5.3*	*-2.8*
Longitude (°W)	*135.2808*		***°C-days***	**n**	**σ**	**Apr**	*-3.8*	*-2.4*	*-1.7*
Elevation (m a.s.l.)	*1387*	**TDD_A**	*866*	*1*		**May**	*3.5*	*3.9*	*0.0*
Slope (°)	*17*	**FDD_A**	*2113*	*2*	*217*	**Jun**	*7.3*	*8.5*	*2.0*
Aspect (°)	*216*	**TDD_S**	*1044*	*2*	*94*	**Jul**	*10.3*	*10.7*	*4.7*
TPI50 (m)	*0.2*	**FDD_S**	*969*	*3*	*134*	**Aug**	*10.0*	*9.5*	*6.0*
TPI200 (m)	*9.0*		**Values**	**n**	**σ**	**Sep**	*3.2*	*3.0*	*4.3*
TPI700 (m)	*12.3*	**N_T**	*1.1*	*1*		**Oct**	*-3.6*	*-1.6*	*1.7*
PISR (WH/m^2)	*5814*	**N_F**	*0.5*	*2*	*0.1*	**Nov**	*-7.8*	*-5.1*	*0.1*
Land Cover	*Shrub*	**R_K**	*1.2*	*2*	*0.3*	**Dec**	*-14.7*	*-6.1*	*-1.3*
Texture	*mf*	**S_O**	*2.6*	*1*		**Jan-Jul**	*25.2*	*16.3*	*6.7*
Materials	*m*	**T_O**	*0.5*	*2*	*0.9*				
TST_{MIN}	*01-May*								
TST_{MAX}	*30-Apr*								
FST_{MIN}	*12-Oct*								
FST_{MAX}	*04-Oct*								



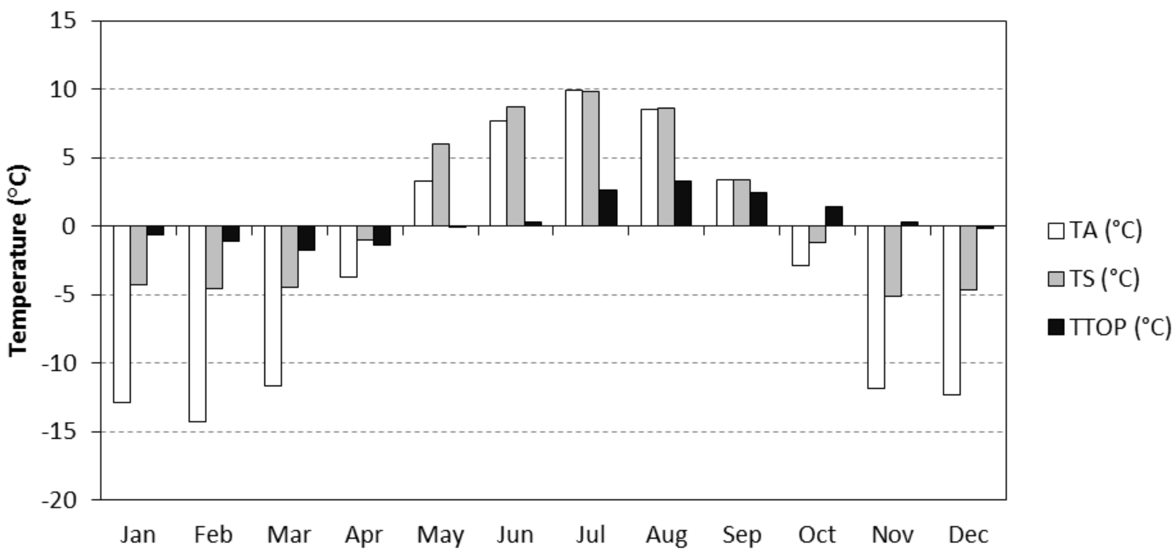
WHITEHORSE	WC2006-04	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	2006	MAAT		0		Jan	-15.0	-3.2	-2.4
End	2010	MAGST	1.7	2	0.5	Feb	-12.2	-3.8	-2.9
Latitude (°N)	60.4918	TTOP		0		Mar	-12.4	-4.5	-4.0
Longitude (°W)	135.2756		°C-days	n	σ	Apr	-3.3	-1.5	-1.0
Elevation (m a.s.l.)	1386	TDD_A		0		May	3.8	6.8	3.9
Slope (°)	13	FDD_A	2161	1		Jun		9.9	7.7
Aspect (°)	198	TDD_S	1301	1		Jul		10.3	9.0
TPI50 (m)	1.5	FDD_S	744	2	95	Aug	7.5	9.3	9.4
TPI200 (m)	10.3		Values	n	σ	Sep	3.3	3.4	4.1
TPI700 (m)	13.4	N_T		0		Oct	-3.5	-1.6	0.2
PISR (WH/m^2)	5773	N_F	0.3	1		Nov	-8.2	-5.4	-5.2
Land Cover	Shrub	R_K		0		Dec	-15.1	-3.6	-2.5
Texture	mf	S_O		0		Jan-Jul		13.5	11.4
Materials	m	T_O		0					
TST_{MIN}	21-Apr								
TST_{MAX}	01-May								
FST_{MIN}	12-Oct								
FST_{MAX}	04-Oct								



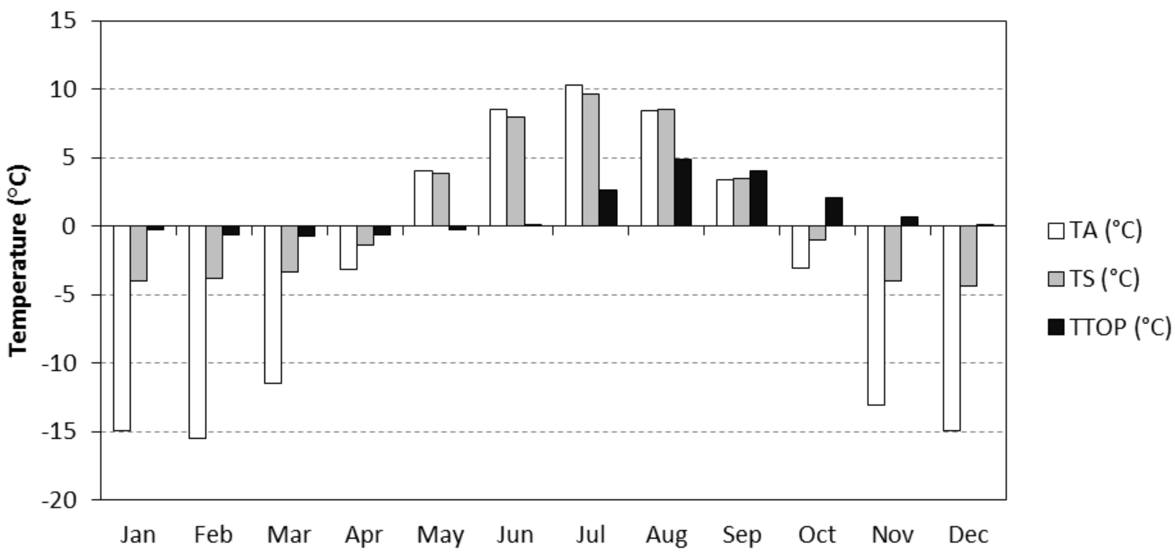
WHITEHORSE	WC2006-05	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	2006	MAAT	-3.6	1		Jan	-13.0	-4.3	-1.2
End	2010	MAGST	0.5	2	0.4	Feb	-14.3	-3.7	-1.5
Latitude (°N)	60.4922	TTOP	0.7	1		Mar	-11.4	-3.3	-1.7
Longitude (°W)	135.2705		°C-days	n	σ	Apr	-3.4	-1.7	-1.0
Elevation (m a.s.l.)	1390	TDD_A	1018	1		May	3.1	3.4	0.6
Slope (°)	18	FDD_A	2240	2	110	Jun	8.8	7.7	3.2
Aspect (°)	206	TDD_S	959	2	71	Jul	11.1	9.0	4.6
TPI50 (m)	-3.1	FDD_S	718	3	133	Aug	8.3	7.7	4.7
TPI200 (m)	-16.0		Values	n	σ	Sep	3.4	3.1	3.1
TPI700 (m)	-17.2	N_T	1.0	1		Oct	-2.9	-1.1	0.8
PISR (WH/m^2)	5668	N_F	0.3	2	0.0	Nov	-12.0	-4.6	-2.2
Land Cover	Shrub	R_K	1.2	1		Dec	-12.7	-4.7	-1.3
Texture	mf	S_O	4.3	1		Jan-Jul	24.1	13.3	5.8
Materials	m	T_O	0.5	1					
TST_{MIN}	16-May								
TST_{MAX}	03-May								
FST_{MIN}	12-Oct								
FST_{MAX}	04-Oct								



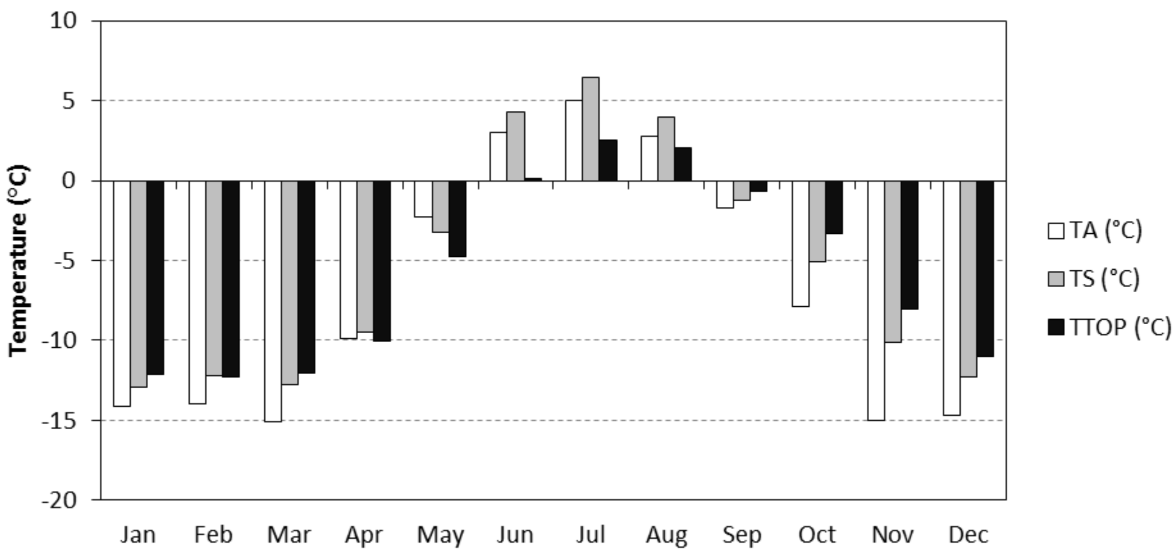
WHITEHORSE	WC2006-06	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	2006	MAAT	-3.2	2	0.4	Jan	-12.8	-4.3	-0.7
End	2010	MAGST	0.8	2	0.8	Feb	-14.2	-4.6	-1.1
Latitude (°N)	60.4903	TTOP	0.5	1		Mar	-11.7	-4.4	-1.8
Longitude (°W)	135.2628		°C-days	n	σ	Apr	-3.7	-1.1	-1.4
Elevation (m a.s.l.)	1426	TDD_A	956	2	139	May	3.3	6.0	-0.0
Slope (°)	22	FDD_A	2114	3	180	Jun	7.7	8.7	0.3
Aspect (°)	210	TDD_S	1113	2	322	Jul	9.9	9.8	2.7
TPI50 (m)	2.0	FDD_S	793	3	80	Aug	8.5	8.6	3.3
TPI200 (m)	13.1		Values	n	σ	Sep	3.4	3.4	2.5
TPI700 (m)	37.3	N_T	1.2	2	0.2	Oct	-2.9	-1.2	1.4
PISR (WH/m^2)	5800	N_F	0.4	3	0.0	Nov	-11.8	-5.1	0.3
Land Cover	Shrub	R_K	1.1	1		Dec	-12.3	-4.7	-0.2
Texture	mf	S_O	3.9	2	1.1	Jan-Jul	22.8	14.1	3.3
Materials	m	T_O	0.3	1					
TST_{MIN}	16-Apr								
TST_{MAX}	29-Apr								
FST_{MIN}	13-Oct								
FST_{MAX}	04-Oct								



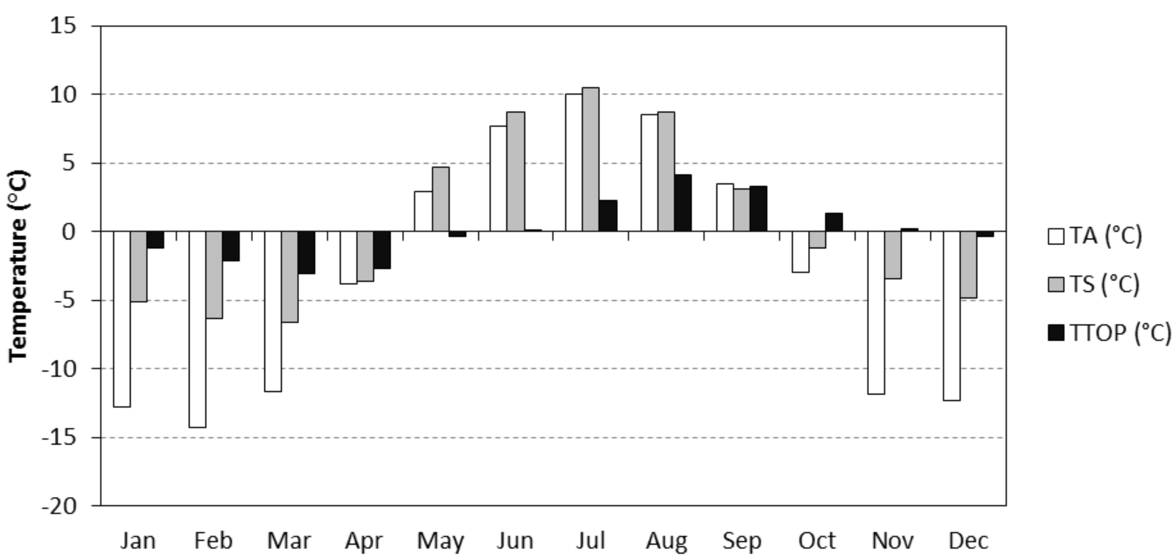
WHITEHORSE	WC2006-07	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2006*	**MAAT**	*-3.5*	*2*	*0.3*	**Jan**	*-14.9*	*-4.0*	*-0.2*
End	*2010*	**MAGST**	*0.7*	*2*	*0.7*	**Feb**	*-15.4*	*-3.8*	*-0.6*
Latitude (°N)	*60.4879*	**TTOP**	*0.9*	*2*	*0.2*	**Mar**	*-11.4*	*-3.4*	*-0.7*
Longitude (°W)	*135.2645*		**°C-days**	**n**	**σ**	**Apr**	*-3.2*	*-1.4*	*-0.6*
Elevation (m a.s.l.)	*1288*	**TDD_A**	*1042*	*2*	*54*	**May**	*4.0*	*3.9*	*-0.3*
Slope (°)	*5*	**FDD_A**	*2329*	*3*	*119*	**Jun**	*8.5*	*8.0*	*0.1*
Aspect (°)	*203*	**TDD_S**	*981*	*2*	*103*	**Jul**	*10.3*	*9.6*	*2.6*
TPI50 (m)	*-2.2*	**FDD_S**	*679*	*3*	*148*	**Aug**	*8.4*	*8.5*	*4.8*
TPI200 (m)	*-19.0*		**Values**	**n**	**σ**	**Sep**	*3.4*	*3.4*	*4.0*
TPI700 (m)	*-57.2*	**N_T**	*0.9*	*2*	*0.1*	**Oct**	*-3.1*	*-1.0*	*2.1*
PISR (WH/m^2)	*5575*	**N_F**	*0.3*	*3*	*0.1*	**Nov**	*-13.1*	*-4.0*	*0.7*
Land Cover	*Shrub*	**R_K**	*1.1*	*2*	*0.3*	**Dec**	*-14.9*	*-4.4*	*0.1*
Texture	*s*	**S_O**	*4.1*	*2*	*1.0*	**Jan-Jul**	*25.3*	*13.7*	*2.9*
Materials	*l*	**T_O**	*0.2*	*2*	*0.9*				
TST_{MIN}	*30-Apr*								
TST_{MAX}	*01-May*								
FST_{MIN}	*12-Oct*								
FST_{MAX}	*04-Oct*								



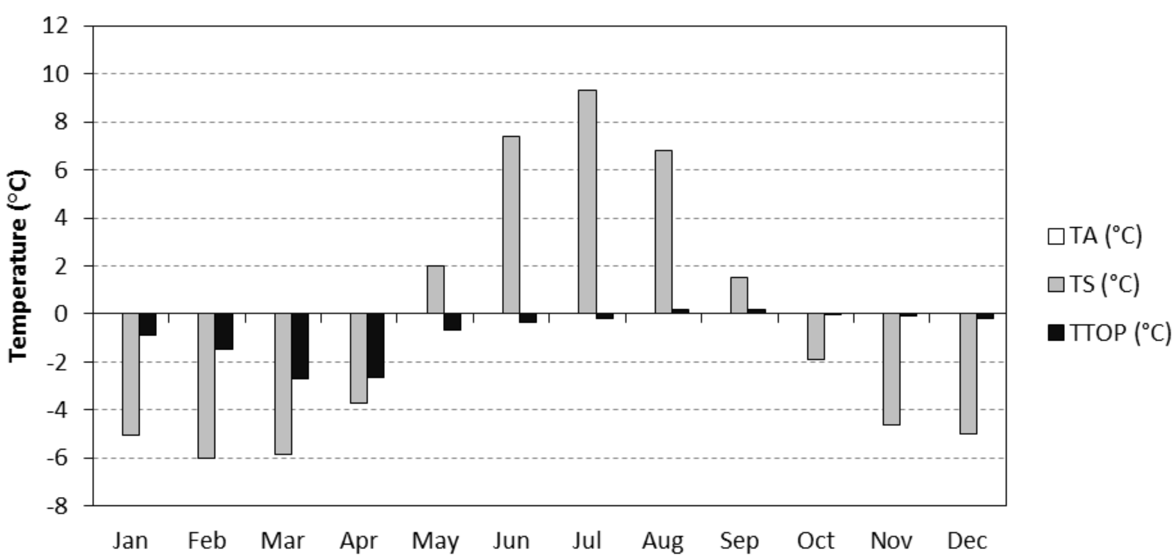
WHITEHORSE	WC2006-08-MtGR	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	2008	MAAT	-6.7	3	1.1	Jan	-14.1	-12.9	-12.1
End	2014	MAGST	-5.5	4	1.2	Feb	-14.0	-12.2	-12.3
Latitude (°N)	60.5354	TTOP	-5.8	4	0.4	Mar	-15.1	-12.8	-12.1
Longitude (°W)	135.2554		°C-days	n	σ	Apr	-9.9	-9.5	-10.1
Elevation (m a.s.l.)	2066	TDD_A	377	4	126	May	-2.2	-3.2	-4.7
Slope (°)	3	FDD_A	2743	3	315	Jun	3.0	4.3	0.2
Aspect (°)	63	TDD_S	494	5	141	Jul	5.0	6.4	2.5
TPI50 (m)	2.5	FDD_S	2425	4	364	Aug	2.8	4.0	2.0
TPI200 (m)	28.9		Values	n	σ	Sep	-1.7	-1.3	-0.7
TPI700 (m)	147.9	N_T	1.4	4	0.1	Oct	-7.9	-5.1	-3.3
PISR (WH/m^2)	6190	N_F	0.8	3	0.0	Nov	-15.0	-10.1	-8.0
Land Cover	Rock	R_K	1.8	2	0.3	Dec	-14.7	-12.3	-11.0
Texture	NA	S_O	1.5	3	0.2	Jan-Jul	19.1	19.4	14.6
Materials	b	T_O	1.0	2	0.0				
TST_{MIN}	24-May								
TST_{MAX}	09-Jun								
FST_{MIN}	16-Sep								
FST_{MAX}	06-Sep								



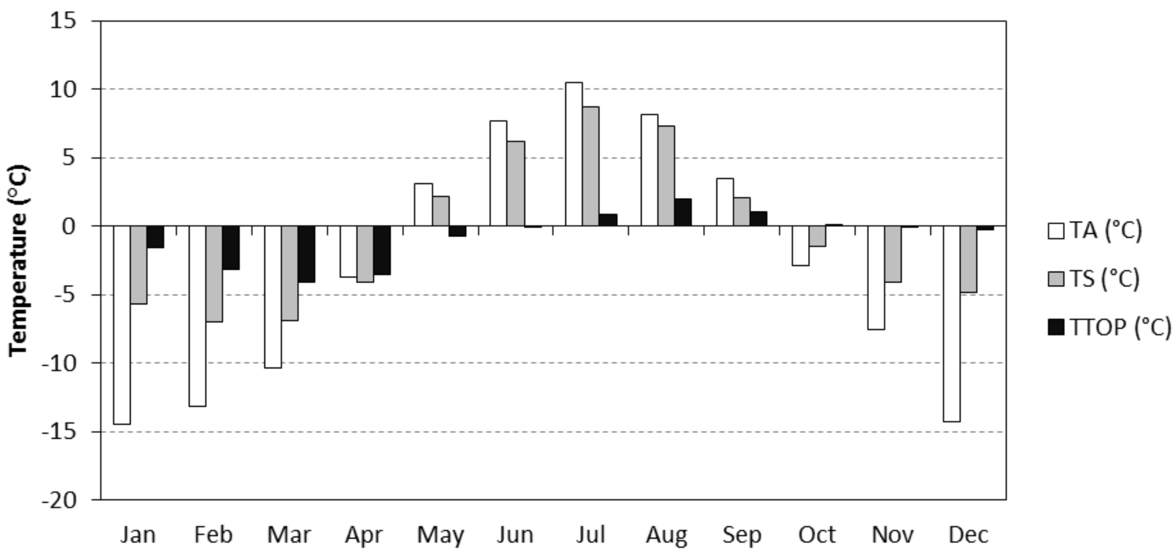
WHITEHORSE	WC2006-09	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2006*	**MAAT**	*-3.3*	*2*	*0.5*	**Jan**	*-12.8*	*-5.2*	*-1.2*
End	*2010*	**MAGST**	*0.3*	*2*	*0.4*	**Feb**	*-14.2*	*-6.3*	*-2.1*
Latitude (°N)	*60.4902*	**TTOP**	*0.0*	*2*	*0.1*	**Mar**	*-11.7*	*-6.6*	*-3.0*
Longitude (°W)	*135.2951*		**°C-days**	**n**	**σ**	**Apr**	*-3.8*	*-3.7*	*-2.7*
Elevation (m a.s.l.)	*1378*	**TDD_A**	*950*	*2*	*128*	**May**	*2.9*	*4.7*	*-0.4*
Slope (°)	*20*	**FDD_A**	*2136*	*3*	*177*	**Jun**	*7.7*	*8.7*	*0.1*
Aspect (°)	*64*	**TDD_S**	*1026*	*2*	*162*	**Jul**	*10.0*	*10.5*	*2.2*
TPI50 (m)	*-0.2*	**FDD_S**	*949*	*3*	*73*	**Aug**	*8.5*	*8.7*	*4.1*
TPI200 (m)	*-0.6*		**Values**	**n**	**σ**	**Sep**	*3.4*	*3.1*	*3.2*
TPI700 (m)	*-30.2*	**N_T**	*1.1*	*2*	*0.0*	**Oct**	*-2.9*	*-1.2*	*1.3*
PISR (WH/m^2)	*4940*	**N_F**	*0.4*	*3*	*0.0*	**Nov**	*-11.9*	*-3.5*	*0.2*
Land Cover	*Shrub*	**R_K**	*0.9*	*2*	*0.1*	**Dec**	*-12.3*	*-4.8*	*-0.4*
Texture	*mf*	**S_O**	*3.5*	*2*	*0.8*	**Jan-Jul**	*22.8*	*15.7*	*3.4*
Materials	*m*	**T_O**	*-0.3*	*2*	*0.4*				
TST_{MIN}	*30-Apr*								
TST_{MAX}	*30-Apr*								
FST_{MIN}	*12-Oct*								
FST_{MAX}	*04-Oct*								



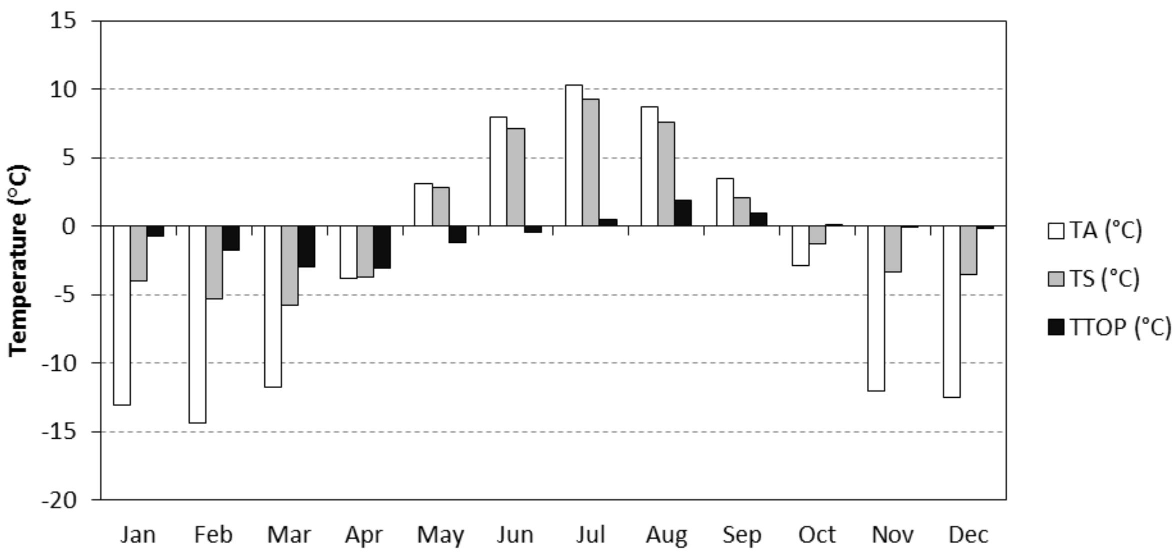
WHITEHORSE	**WC2006-10**	**Mean**	***°C***	**n**	**σ**	**Blended**	***TA (°C)***	***TS (°C)***	***TTOP (°C)***
Start	*2006*	**MAAT**		*0*		**Jan**		*-5.1*	*-0.9*
End	*2010*	**MAGST**	*-0.6*	*2*	*0.3*	**Feb**		*-6.0*	*-1.5*
Latitude (°N)	*60.4854*	**TTOP**	*-0.8*	*1*		**Mar**		*-5.8*	*-2.7*
Longitude (°W)	*135.2865*		***°C-days***	**n**	**σ**	**Apr**		*-3.7*	*-2.7*
Elevation (m a.s.l.)	*1373*	**TDD_A**		*0*		**May**		*2.0*	*-0.7*
Slope (°)	*22*	**FDD_A**		*0*		**Jun**		*7.4*	*-0.3*
Aspect (°)	*56*	**TDD_S**	*777*	*2*	*117*	**Jul**		*9.3*	*-0.2*
TPI50 (m)	*-5.2*	**FDD_S**	*988*	*3*	*60*	**Aug**		*6.8*	*0.2*
TPI200 (m)	*-19.5*		**Values**	**n**	**σ**	**Sep**		*1.5*	*0.2*
TPI700 (m)	*-40.7*	**N_T**		*0*		**Oct**		*-1.9*	*-0.1*
PISR (WH/m^2)	*4552*	**N_F**		*0*		**Nov**		*-4.6*	*-0.1*
Land Cover	*Shrub*	**R_K**	*1.1*	*1*		**Dec**		*-5.0*	*-0.2*
Texture	*mf*	**S_O**		*0*		**Jan-Jul**		*14.4*	*1.1*
Materials	*m*	**T_O**	*0.1*	*1*					
TST_{MIN}	*13-May*								
TST_{MAX}	*02-May*								
FST_{MIN}	*14-Sep*								
FST_{MAX}	*04-Oct*								



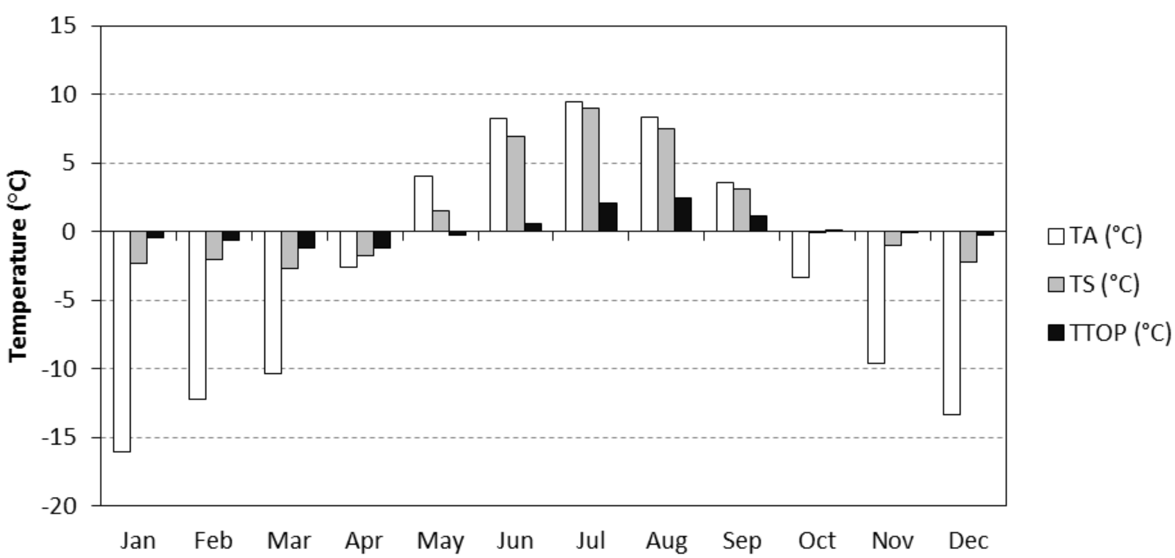
WHITEHORSE	WC2006-11	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2006*	**MAAT**	*-3.0*	*1*		**Jan**	*-14.5*	*-5.7*	*-1.5*
End	*2010*	**MAGST**	*-0.9*	*2*	*0.1*	**Feb**	*-13.2*	*-7.0*	*-3.1*
Latitude (°N)	*60.4850*	**TTOP**	*-0.8*	*2*	*0.0*	**Mar**	*-10.4*	*-6.9*	*-4.1*
Longitude (°W)	*135.2813*		**°C-days**	**n**	**σ**	**Apr**	*-3.8*	*-4.1*	*-3.5*
Elevation (m a.s.l.)	*1376*	**TDD_A**	*868*	*1*		**May**	*3.1*	*2.2*	*-0.8*
Slope (°)	*17*	**FDD_A**	*2066*	*2*	*140*	**Jun**	*7.7*	*6.2*	*-0.1*
Aspect (°)	*46*	**TDD_S**	*736*	*2*	*14*	**Jul**	*10.5*	*8.7*	*0.9*
TPI50 (m)	*1.5*	**FDD_S**	*1036*	*3*	*66*	**Aug**	*8.1*	*7.3*	*2.0*
TPI200 (m)	*10.9*		**Values**	**n**	**σ**	**Sep**	*3.5*	*2.1*	*1.1*
TPI700 (m)	*-2.7*	**N_T**	*0.8*	*1*		**Oct**	*-2.9*	*-1.5*	*0.1*
PISR (WH/m^2)	*4900*	**N_F**	*0.5*	*2*	*0.1*	**Nov**	*-7.5*	*-4.1*	*-0.1*
Land Cover	*Shrub*	**R_K**	*1.1*	*2*	*0.1*	**Dec**	*-14.3*	*-4.8*	*-0.2*
Texture	*mf*	**S_O**	*2.0*	*1*		**Jan-Jul**	*24.9*	*14.4*	*2.4*
Materials	*m*	**T_O**	*0.1*	*2*	*0.2*				
TST_{MIN}	*14-May*								
TST_{MAX}	*30-Apr*								
FST_{MIN}	*30-Sep*								
FST_{MAX}	*04-Oct*								



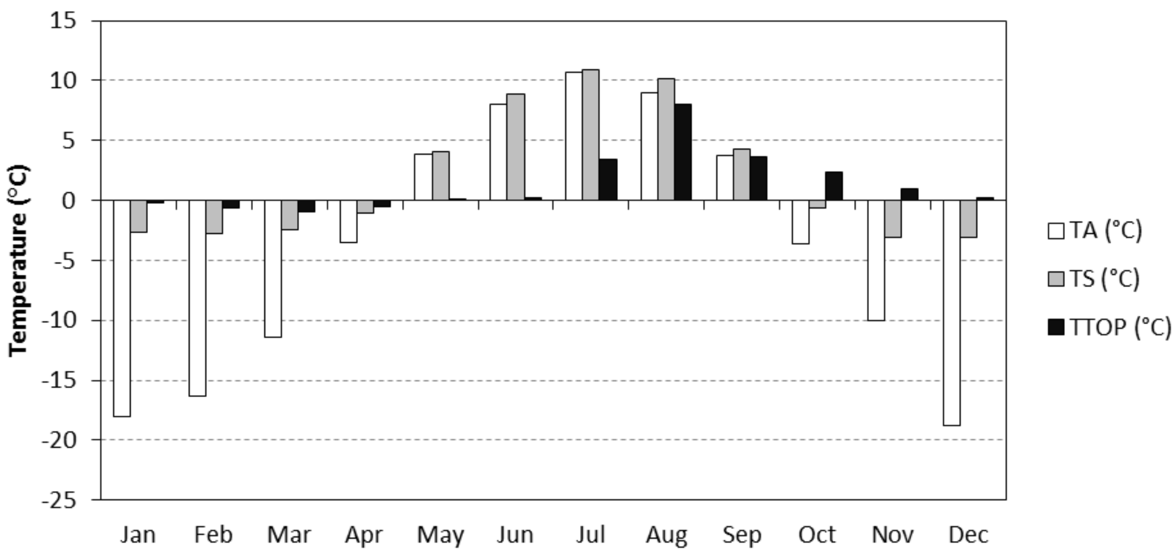
WHITEHORSE	WC2006-12	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2006*	**MAAT**	*-3.2*	*2*	*0.3*	**Jan**	*-13.0*	*-4.0*	*-0.7*
End	*2010*	**MAGST**	*-0.0*	*2*	*0.4*	**Feb**	*-14.3*	*-5.3*	*-1.8*
Latitude (°N)	*60.4835*	**TTOP**	*-0.6*	*2*	*0.2*	**Mar**	*-11.8*	*-5.8*	*-3.0*
Longitude (°W)	*135.2765*		**°C-days**	**n**	**σ**	**Apr**	*-3.8*	*-3.7*	*-3.0*
Elevation (m a.s.l.)	*1373*	**TDD_A**	*973*	*2*	*140*	**May**	*3.1*	*2.8*	*-1.2*
Slope (°)	*12*	**FDD_A**	*2162*	*3*	*172*	**Jun**	*7.9*	*7.1*	*-0.4*
Aspect (°)	*24*	**TDD_S**	*850*	*2*	*170*	**Jul**	*10.3*	*9.2*	*0.5*
TPI50 (m)	*-0.4*	**FDD_S**	*825*	*3*	*78*	**Aug**	*8.7*	*7.6*	*1.9*
TPI200 (m)	*-4.3*		**Values**	**n**	**σ**	**Sep**	*3.5*	*2.1*	*1.0*
TPI700 (m)	*-9.5*	**N_T**	*0.9*	*2*	*0.1*	**Oct**	*-2.9*	*-1.3*	*0.0*
PISR (WH/m^2)	*5079*	**N_F**	*0.4*	*3*	*0.0*	**Nov**	*-12.0*	*-3.4*	*-0.1*
Land Cover	*Shrub*	**R_K**	*0.8*	*2*	*0.2*	**Dec**	*-12.5*	*-3.6*	*-0.2*
Texture	*mf*	**S_O**	*3.2*	*2*	*0.7*	**Jan-Jul**	*23.3*	*13.2*	*1.2*
Materials	*m*	**T_O**	*-0.5*	*2*	*0.6*				
TST_{MIN}	*04-May*								
TST_{MAX}	*30-Apr*								
FST_{MIN}	*01-Oct*								
FST_{MAX}	*04-Oct*								



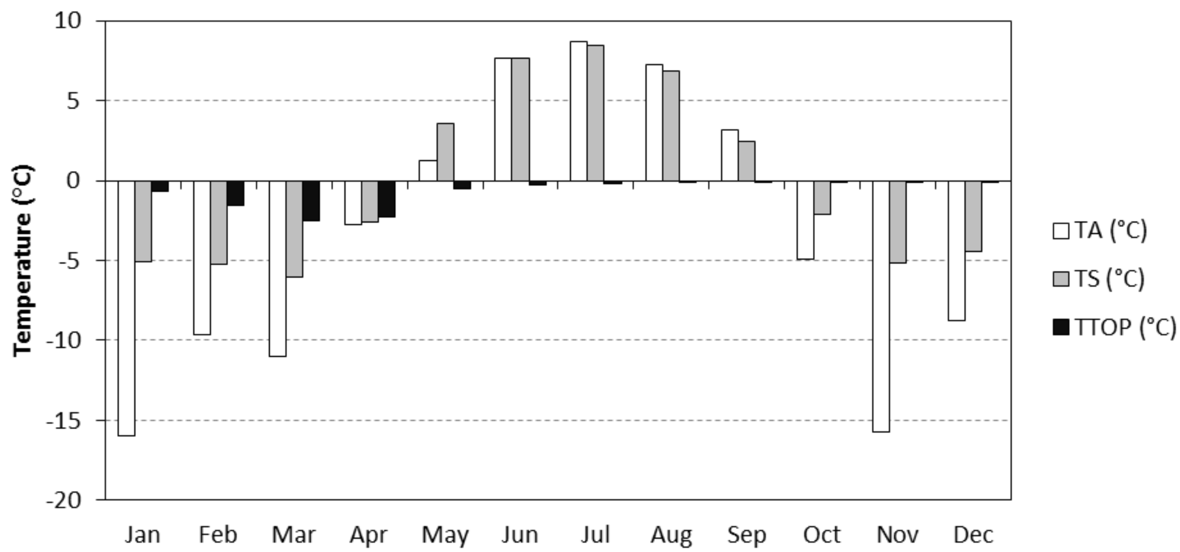
WHITEHORSE	**WC-APM-WS**	**Mean**	***°C***	**n**	**σ**	**Blended**	***TA (°C)***	***TS (°C)***	***TTOP (°C)***
Start	*2004*	**MAAT**	*-4.2*	*1*		**Jan**	*-16.0*	*-2.4*	*-0.5*
End	*2013*	**MAGST**	*1.5*	*3*	*0.5*	**Feb**	*-12.2*	*-2.1*	*-0.7*
Latitude (°N)	*60.4814*	**TTOP**	*0.2*	*4*	*0.4*	**Mar**	*-10.4*	*-2.7*	*-1.2*
Longitude (°W)	*135.1935*		***°C-days***	**n**	**σ**	**Apr**	*-2.6*	*-1.8*	*-1.2*
Elevation (m a.s.l.)	*1202*	**TDD_A**		*0*		**May**	*4.0*	*1.5*	*-0.3*
Slope (°)	*2*	**FDD_A**	*2212*	*1*		**Jun**	*8.3*	*6.9*	*0.6*
Aspect (°)	*198*	**TDD_S**	*873*	*3*	*39*	**Jul**	*9.5*	*9.0*	*2.1*
TPI50 (m)	*0.1*	**FDD_S**	*345*	*3*	*201*	**Aug**	*8.4*	*7.5*	*2.5*
TPI200 (m)	*-4.1*		**Values**	**n**	**σ**	**Sep**	*3.6*	*3.1*	*1.2*
TPI700 (m)	*-42.2*	**N_T**		*0*		**Oct**	*-3.3*	*-0.1*	*0.0*
PISR (WH/m^2)	*5280*	**N_F**	*0.3*	*1*		**Nov**	*-9.6*	*-1.0*	*-0.1*
Land Cover	*Shrub*	**R_K**	*0.8*	*1*		**Dec**	*-13.3*	*-2.2*	*-0.2*
Texture	*mf*	**S_O**		*0*		**Jan-Jul**	*25.5*	*11.3*	*2.5*
Materials	*m*	**T_O**	*-0.5*	*1*					
TST_{MIN}	*10-May*								
TST_{MAX}	*15-May*								
FST_{MIN}	*07-Oct*								
FST_{MAX}	*29-Sep*								



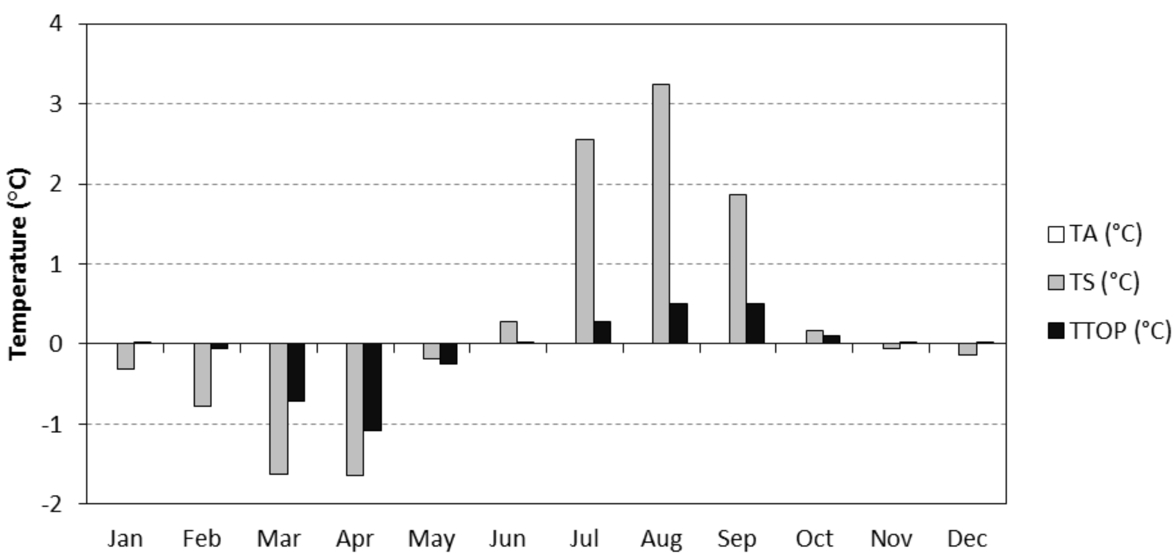
WHITEHORSE	WC-DR	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	2006	**MAAT**	-4.1	2	0.3	**Jan**	-18.0	-2.7	-0.2
End	2013	**MAGST**	1.6	3	0.9	**Feb**	-16.4	-2.8	-0.6
Latitude (°N)	60.4740	**TTOP**		0		**Mar**	-11.4	-2.4	-1.0
Longitude (°W)	135.1894		°C-days	n	σ	**Apr**	-3.5	-1.0	-0.5
Elevation (m a.s.l.)	1225	**TDD_A**	946	1		**May**	3.8	4.0	0.1
Slope (°)	2	**FDD_A**	2506	2	187	**Jun**	8.0	8.8	0.2
Aspect (°)	236	**TDD_S**	1210	3	162	**Jul**	10.7	11.0	3.5
TPI50 (m)	-0.1	**FDD_S**	484	4	401	**Aug**	8.9	10.2	8.1
TPI200 (m)	0.7		Values	n	σ	**Sep**	3.7	4.2	3.7
TPI700 (m)	-10.6	**N_T**	1.1	1		**Oct**	-3.6	-0.6	2.4
PISR (WH/m^2)	5453	**N_F**	0.2	2	0.1	**Nov**	-10.0	-3.1	1.0
Land Cover	Shrub	**R_K**		0		**Dec**	-18.8	-3.1	0.2
Texture	s	**S_O**	5.2	1		**Jan-Jul**	28.7	13.6	3.6
Materials	l	**T_O**		0					
TST_{MIN}	03-May								
TST_{MAX}	16-Apr								
FST_{MIN}	05-Oct								
FST_{MAX}	13-Oct								



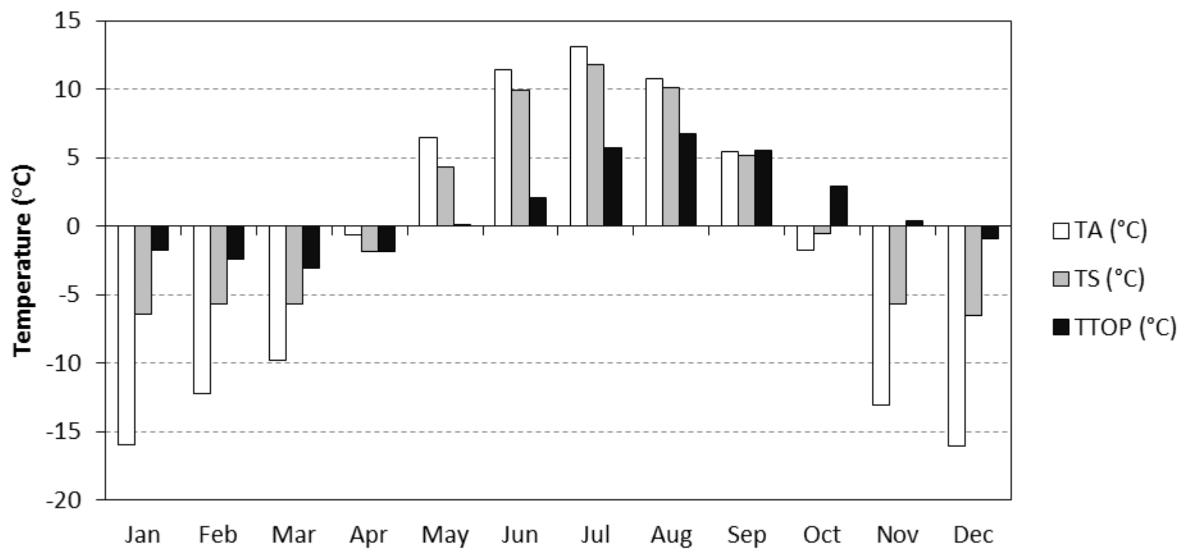
WHITEHORSE	WC-P09	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2006*	**MAAT**	*-3.0*	*1*		**Jan**	*-15.9*	*-5.1*	*-0.6*
End	*2013*	**MAGST**	*-0.1*	*4*	*0.5*	**Feb**	*-9.7*	*-5.2*	*-1.5*
Latitude (°N)	*60.5000*	**TTOP**	*-0.7*	*4*	*0.3*	**Mar**	*-11.0*	*-6.0*	*-2.5*
Longitude (°W)	*135.2192*		***°C-days***	**n**	**σ**	**Apr**	*-2.7*	*-2.6*	*-2.3*
Elevation (m a.s.l.)	*1241*	**TDD_A**	*944*	*1*		**May**	*1.2*	*3.5*	*-0.5*
Slope (°)	*0*	**FDD_A**	*2066*	*1*		**Jun**	*7.6*	*7.7*	*-0.2*
Aspect (°)	*-1*	**TDD_S**	*873*	*4*	*62*	**Jul**	*8.7*	*8.4*	*-0.2*
TPI50 (m)	*-0.3*	**FDD_S**	*927*	*5*	*141*	**Aug**	*7.2*	*6.8*	*-0.1*
TPI200 (m)	*-1.8*		**Values**	**n**	**σ**	**Sep**	*3.1*	*2.5*	*-0.1*
TPI700 (m)	*-41.4*	**N_T**	*0.9*	*1*		**Oct**	*-4.9*	*-2.1*	*-0.0*
PISR (WH/m^2)	*5263*	**N_F**	*0.3*	*1*		**Nov**	*-15.7*	*-5.2*	*-0.0*
Land Cover	*Shrub*	**R_K**	*0.8*	*3*	*0.1*	**Dec**	*-8.8*	*-4.5*	*-0.1*
Texture	*g*	**S_O**	*3.5*	*1*		**Jan-Jul**	*24.6*	*13.5*	*0.8*
Materials	*f*	**T_O**	*-0.4*	*3*	*0.2*				
TST_{MIN}	*21-Apr*								
TST_{MAX}	*06-May*								
FST_{MIN}	*05-Oct*								
FST_{MAX}	*10-Oct*								



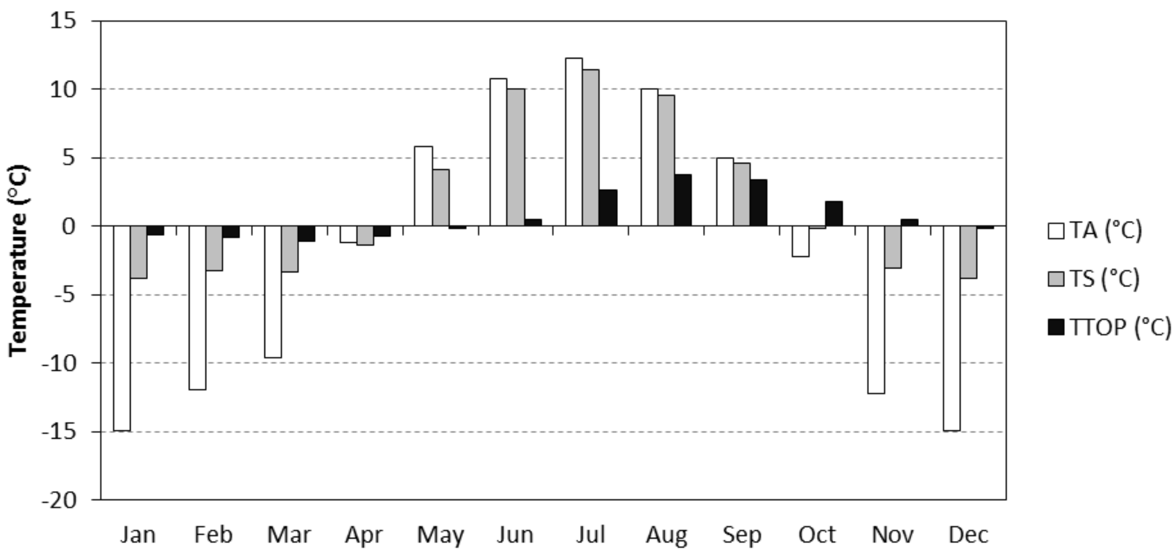
WHITEHORSE	WC-P25	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2006*	**MAAT**		*0*		**Jan**		*-0.3*	*0.0*
End	*2013*	**MAGST**	*0.8*	*1*		**Feb**		*-0.8*	*-0.1*
Latitude (°N)	*60.4952*	**TTOP**	*0.1*	*1*		**Mar**		*-1.6*	*-0.7*
Longitude (°W)	*135.2228*		***°C-days***	**n**	**σ**	**Apr**		*-1.6*	*-1.1*
Elevation (m a.s.l.)	*1235*	**TDD_A**		*0*		**May**		*-0.2*	*-0.2*
Slope (°)	*4*	**FDD_A**		*0*		**Jun**		*0.3*	*0.0*
Aspect (°)	*126*	**TDD_S**	*301*	*1*		**Jul**		*2.5*	*0.3*
TPI50 (m)	*0.0*	**FDD_S**	*15*	*1*		**Aug**		*3.2*	*0.5*
TPI200 (m)	*-2.4*		**Values**	**n**	**σ**	**Sep**		*1.9*	*0.5*
TPI700 (m)	*-39.5*	**N_T**		*0*		**Oct**		*0.2*	*0.1*
PISR (WH/m^2)	*5313*	**N_F**		*0*		**Nov**		*-0.1*	*0.0*
Land Cover	*Shrub*	**R_K**		*0*		**Dec**		*-0.1*	*0.0*
Texture	*g*	**S_O**		*0*		**Jan-Jul**		*2.9*	*0.3*
Materials	*f*	**T_O**		*0*					
TST_{MIN}	*16-May*								
TST_{MAX}	*16-May*								
FST_{MIN}	*18-Nov*								
FST_{MAX}	*22-Oct*								



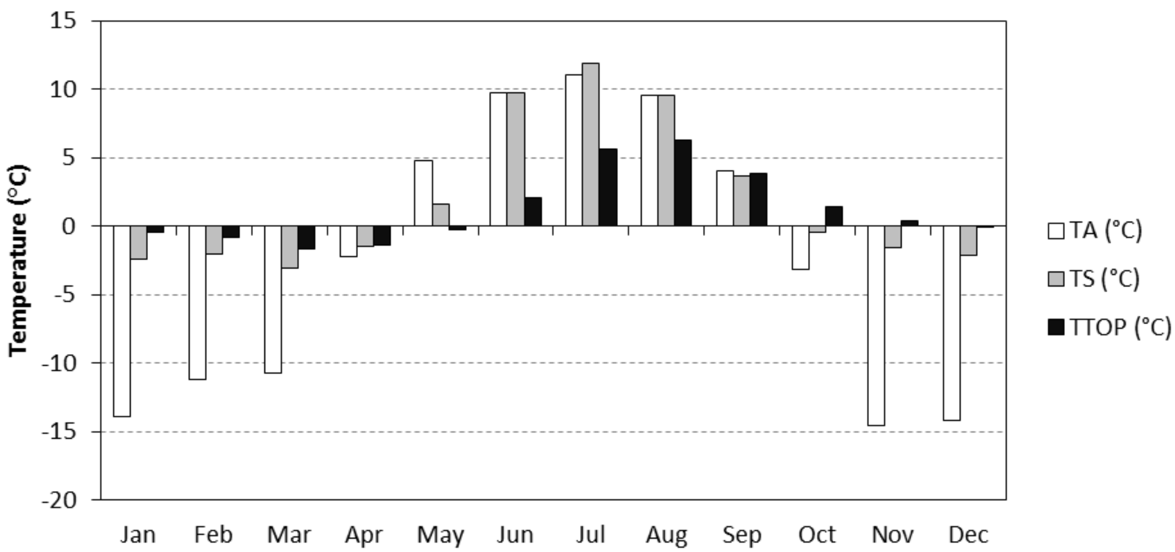
WHITEHORSE	WC-T1	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2006*	**MAAT**	*-1.5*	*4*	*1.0*	**Jan**	*-15.9*	*-6.4*	*-1.8*
End	*2014*	**MAGST**	*1.2*	*4*	*0.7*	**Feb**	*-12.2*	*-5.7*	*-2.4*
Latitude (°N)	*60.6044*	**TTOP**	*1.2*	*5*	*0.4*	**Mar**	*-9.8*	*-5.6*	*-3.1*
Longitude (°W)	*135.0354*		**°C-days**	**n**	**σ**	**Apr**	*-0.6*	*-1.8*	*-1.8*
Elevation (m a.s.l.)	*868*	**TDD_A**	*1453*	*4*	*86*	**May**	*6.4*	*4.3*	*0.0*
Slope (°)	*6*	**FDD_A**	*2109*	*5*	*368*	**Jun**	*11.4*	*9.9*	*2.1*
Aspect (°)	*12*	**TDD_S**	*1272*	*4*	*90*	**Jul**	*13.1*	*11.8*	*5.7*
TPI50 (m)	*0.1*	**FDD_S**	*935*	*5*	*346*	**Aug**	*10.8*	*10.1*	*6.8*
TPI200 (m)	*1.4*		**Values**	**n**	**σ**	**Sep**	*5.4*	*5.2*	*5.5*
TPI700 (m)	*-1.6*	**N_T**	*0.9*	*4*	*0.0*	**Oct**	*-1.7*	*-0.6*	*2.9*
PISR (WH/m^2)	*5107*	**N_F**	*0.4*	*5*	*0.1*	**Nov**	*-13.1*	*-5.7*	*0.4*
Land Cover	*Coniferous or Mixed*	**R_K**	*1.0*	*4*	*0.3*	**Dec**	*-16.0*	*-6.5*	*-0.9*
Texture	*mf*	**S_O**	*2.8*	*4*	*0.6*	**Jan-Jul**	*29.0*	*18.2*	*7.5*
Materials	*m*	**T_O**	*0.1*	*4*	*0.9*				
TST_{MIN}	*29-Apr*								
TST_{MAX}	*27-Apr*								
FST_{MIN}	*23-Oct*								
FST_{MAX}	*11-Oct*								



WHITEHORSE	WC-T2	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2006*	**MAAT**	*-1.9*	*5*	*1.1*	**Jan**	*-15.0*	*-3.8*	*-0.6*
End	*2014*	**MAGST**	*1.5*	*6*	*1.1*	**Feb**	*-12.0*	*-3.2*	*-0.8*
Latitude (°N)	*60.5955*	**TTOP**	*0.6*	*1*		**Mar**	*-9.6*	*-3.3*	*-1.1*
Longitude (°W)	*135.0569*		**°C-days**	**n**	**σ**	**Apr**	*-1.2*	*-1.4*	*-0.8*
Elevation (m a.s.l.)	*1011*	**TDD_A**	*1335*	*5*	*85*	**May**	*5.8*	*4.2*	*-0.1*
Slope (°)	*15*	**FDD_A**	*1992*	*6*	*341*	**Jun**	*10.7*	*10.0*	*0.5*
Aspect (°)	*84*	**TDD_S**	*1117*	*6*	*335*	**Jul**	*12.2*	*11.5*	*2.6*
TPI50 (m)	*0.8*	**FDD_S**	*558*	*6*	*99*	**Aug**	*10.1*	*9.6*	*3.8*
TPI200 (m)	*5.3*		**Values**	**n**	**σ**	**Sep**	*4.9*	*4.6*	*3.4*
TPI700 (m)	*2.6*	**N_T**	*0.9*	*5*	*0.1*	**Oct**	*-2.2*	*-0.1*	*1.8*
PISR (WH/m^2)	*5072*	**N_F**	*0.3*	*6*	*0.1*	**Nov**	*-12.3*	*-3.1*	*0.5*
Land Cover	*Coniferous or Mixed*	**R_K**	*0.5*	*1*		**Dec**	*-15.0*	*-3.8*	*-0.2*
Texture	*mf*	**S_O**	*3.8*	*5*	*0.9*	**Jan-Jul**	*27.2*	*15.3*	*3.2*
Materials	*m*	**T_O**	*-1.3*	*1*					
TST_{MIN}	*08-Apr*								
TST_{MAX}	*11-May*								
FST_{MIN}	*26-Oct*								
FST_{MAX}	*11-Oct*								



WHITEHORSE	WC-T3	Mean	°C	n	σ	Blended	*TA (°C)*	*TS (°C)*	*TTOP (°C)*
Start	*2006*	**MAAT**	*-1.8*	*3*	*1.5*	**Jan**	*-13.9*	*-2.4*	*-0.4*
End	*2014*	**MAGST**	*2.5*	*4*	*0.9*	**Feb**	*-11.2*	*-2.1*	*-0.8*
Latitude (°N)	*60.5904*	**TTOP**	*1.3*	*4*	*0.2*	**Mar**	*-10.7*	*-3.1*	*-1.6*
Longitude (°W)	*135.0769*		***°C-days***	**n**	**σ**	**Apr**	*-2.2*	*-1.5*	*-1.3*
Elevation (m a.s.l.)	*1145*	**TDD_A**	*1207*	*2*	*131*	**May**	*4.7*	*1.6*	*-0.3*
Slope (°)	*6*	**FDD_A**	*2038*	*3*	*582*	**Jun**	*9.7*	*9.8*	*2.1*
Aspect (°)	*48*	**TDD_S**	*1166*	*3*	*112*	**Jul**	*11.1*	*11.9*	*5.7*
TPI50 (m)	*0.0*	**FDD_S**	*501*	*5*	*327*	**Aug**	*9.6*	*9.6*	*6.2*
TPI200 (m)	*-0.5*		**Values**	**n**	**σ**	**Sep**	*4.1*	*3.6*	*3.9*
TPI700 (m)	*1.8*	**N_T**	*0.9*	*2*	*0.0*	**Oct**	*-3.1*	*-0.5*	*1.4*
PISR (WH/m^2)	*5297*	**N_F**	*0.2*	*3*	*0.1*	**Nov**	*-14.5*	*-1.6*	*0.4*
Land Cover	*Coniferous or Mixed*	**R_K**	*0.7*	*2*	*0.4*	**Dec**	*-14.2*	*-2.1*	*-0.0*
Texture	*mf*	**S_O**	*4.2*	*2*	*1.1*	**Jan-Jul**	*25.0*	*14.3*	*6.1*
Materials	*m*	**T_O**	*-1.3*	*3*	*1.1*				
TST_{MIN}	*22-May*								
TST_{MAX}	*01-Jul*								
FST_{MIN}	*05-Oct*								
FST_{MAX}	*10-Oct*								



WHITEHORSE	WC-T4	Mean	°C	n	σ	Blended	TA (°C)	TS (°C)	TTOP (°C)
Start	*2006*	**MAAT**	*-3.0*	*3*	*0.6*	**Jan**	*-13.2*	*-2.6*	*-0.9*
End	*2014*	**MAGST**	*2.6*	*6*	*2.5*	**Feb**	*-12.3*	*-2.4*	*-0.9*
Latitude (°N)	*60.5778*	**TTOP**	*0.8*	*1*		**Mar**	*-12.7*	*-2.7*	*-1.2*
Longitude (°W)	*135.0844*		***°C-days***	**n**	**σ**	**Apr**	*-4.4*	*-1.6*	*-0.9*
Elevation (m a.s.l.)	*1290*	**TDD_A**	*997*	*3*	*99*	**May**	*3.2*	*0.8*	*-0.2*
Slope (°)	*1*	**FDD_A**	*2236*	*4*	*245*	**Jun**	*9.0*	*9.3*	*2.6*
Aspect (°)	*207*	**TDD_S**	*1041*	*5*	*74*	**Jul**	*10.7*	*11.9*	*5.0*
TPI50 (m)	*1.2*	**FDD_S**	*461*	*5*	*183*	**Aug**	*7.9*	*9.1*	*4.3*
TPI200 (m)	*9.2*		**Values**	**n**	**σ**	**Sep**	*3.6*	*2.6*	*2.6*
TPI700 (m)	*18.2*	**N_T**	*1.0*	*3*	*0.0*	**Oct**	*-3.4*	*-1.1*	*1.0*
PISR (WH/m^2)	*5559*	**N_F**	*0.2*	*4*	*0.1*	**Nov**	*-13.7*	*-2.1*	*0.0*
Land Cover	*Shrub*	**R_K**	*0.7*	*1*		**Dec**	*-13.9*	*-2.4*	*-0.8*
Texture	*mf*	**S_O**	*4.9*	*3*	*0.6*	**Jan-Jul**	*24.0*	*14.5*	*5.9*
Materials	*c*	**T_O**	*-0.9*	*1*					
TST_{MIN}	*27-May*								
TST_{MAX}	*01-Jun*								
FST_{MIN}	*01-Oct*								
FST_{MAX}	*10-Oct*