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Detecting a Midlatitude Island Climate Signature in the Great Lakes Coastal Region of Ontario, Canada

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Abstract: A day-to-day temperature (DTD) variability metric was used to detect marine coastal climates in the province of Ontario, Canada. Eleven of fourteen climate stations on islands, most in the Great Lakes and two in other large water bodies, displayed marine characteristics using a day-to-day temperature metric threshold developed for ocean coastal locations in China and Canada with values below 2.35 for the daily minimum temperature variability. Detailed comparisons with neighbouring coastal stations were conducted for six focal areas in the Great Lakes and the marine effect on the local climate was unambiguously demonstrated in a statistically significant manner. Those displaying marine characteristics were all island climate stations, usually at an elevation close to the lake level, and the marine influence, as measured by day-to-day temperature variability, dropped off rapidly with distance and elevation from the local water body. The DTD metric was compared to a diurnal temperature range (DTR) metric. While DTR was able to distinguish in a statistically significant manner between islands and inland stations, an unambiguous threshold between the two was not possible, unlike DTD.

Keywords: island climate; day-to-day temperature variability; marine climate; continentality; Great Lakes

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1. Introduction

A novel new metric based on day-to-day (DTD) variability has been used to explore the identification of climate station temperature data as having a coastal, marine signature [1,2]. While the term "marine" is applied to climates that are influenced by oceans and seas, Ref. [2] showed that the Great Lakes have a detectable "marine" influence at at least two locations (Pelee Island and Toronto Island). There appears to be no obvious term as the equivalent for "marine" for large freshwater lakes. Even the term "coastal" used in [1,2] is typically applied in marine settings. We are settling on the term "shore climate" to refer to the influence of large freshwater bodies on the local climate record. We return to this nomenclature in the discussion.

The impact of water surfaces on the local climate has been evaluated with continentality metrics [3]. These metrics account for the mitigating effect of water surfaces on both temperature and precipitation. A frequently used metric is the difference between the mean monthly temperature of the coldest month and the warmest month of the year [4]. Accounting for latitude-dependent seasonality, other forms of this metric have been employed, such as normalizing the temperature difference by dividing by the sine of the latitude to account for seasonal variations in insolation [3–5]. Ref. [6] concluded that for urban–rural pairs of a coastal city (Tokyo), the distance from the ocean was a confounding consideration and needed to be accounted for. Stations removed from the ocean exhibited greater annual ranges in monthly temperatures, as expected, as found in [1] for Chinese coastal locations and locations inland. In this work, we turn to a different measure based on day-to-day temperature variability to assess the influence of a local water body.

As demonstrated in [1,2], coastal or shore climates form at the interface of land and water and are recognized as having a moderating effect on extremes of temperature due to the thermal inertia of the water bodies. Measurements taken over the water body or close to the land/water interface experience the full impact of the moderating effect of this hydro-inertia and it is found more generally in studies on continentality [3,4]. This effect diminishes with distance from the shore and with land elevation. While measurements taken at the shore or over the water body would reflect the direct radiative impact of the water body (surface partitioning of energy), locations inland depend on the advective nature of the atmosphere to propagate the impact of the water body, especially along low-relief landscapes. This was seen in [1] for the Changjiang River delta and in [2] along the Fraser River valley, along the Pacific coast of Canada. In [2], the two locations in the Great Lakes where the "marine" climate was detected were islands in Lake Ontario and Lake Erie, Toronto Island and Pelee Island, respectively. This is consistent with the advective effect of the water body developing an island circulation, much like an urban heat island [7–10], that is in this instance re-enforced by the presence of water in all directions. As introduced in [2], the winter months are excluded in the analysis due to the formation of lake ice which mitigates the impact of the hydro-inertia of local water bodies and mutes the shore climate effect.

The North American Great Lakes are the largest freshwater system in the world, accounting for 21% of the world's freshwater [11]. The Great Lakes have a discernible influence on the local climate, producing an extremes-mitigating lake breeze circulation, particularly during the summer and fall [8,10–13], and related lake effect precipitation, particularly detectable in the winter [14,15], as well as impacting the frequency and strength of extratropical storms [16]. The seasonal appearance of lake ice also impacts the regional climate [11,17–20].

A day-to-day temperature variability framework [DTD] developed by [21] has been found to be an increasingly useful metric to detect nuanced variations in temperature that are reflective of land use and local hydro-climatological conditions [10,21–29]. Ref. [21] introduced the difference in the monthly mean of the absolute difference between a day's mean temperature with the previous day's mean temperature (DTD) as a measure of thermal variability. An additional metric (ΔDTD) has also been introduced, that is, the difference between the DTD calculated from the maximum temperature (DTD_{Tmax}) and that calculated from the minimum temperature (DTD_{Tmin}) of the day. This new metric has been shown to be a good measure to detect urbanized landscapes [10,22,27]. For urban landscapes, insolation is partitioned predominantly into sensible heat, subsurface heat, and to a lesser extent, latent heat (evaporation of surface water). The response is mainly a substantial increase in temperature (sensible heat) for a given radiative input. Rural environments, as well as coastal environments, with the same radiative input, partition considerably more energy into latent heat, evaporating surface water and producing fog and clouds. This in turn dampens the day-to-day variability, as shown in [1] for coastal locations in East China. They examined annual day-to-day temperature variability along China's eastern coast, comparing coastal areas to those inland from the coast. The minimum temperature variability was found to be the clearest indicator of coastalization. In addition, this metric was found to be superior and more nuanced than traditional measures of continentality/coastalization. This measure has been used to detect the influence of the Adriatic Sea on local climate data by [28], for the South China coast of Guangdong [29], and for Canadian coasts [2].

Based on these considerations, the day-to-day temperature variability framework will continue to be used to detect the impact of coastalization on climate records [1,2,29] in the Great Lakes region of Ontario, Canada. The key metric was the day-to-day variability of the minimum temperature of the day (DTDTmin) which was modified in [2] to account for the radiatively distinct winter season. In addition, we will compare this method to the diurnal temperature range (DTR), a metric inspired by continentality measures [3–6]. This is the difference between the maximum temperature of the day and the minimum temperature of the day, a scaled version of continentality that is measured by the difference of the maximum monthly temperature and minimum monthly temperature developed by [3].

In this work, the research objective is to determine if there is a detectable "marine" climate employing temperature variability metrics for the Great Lakes region using the climate records of the Province of Ontario, Canada.

2. Materials and Methods

2.1. Data

Daily minimum and maximum temperature data from Ontario, Canada, climate stations are used, taken from the national climate data archive maintained by Environment and Climate Change Canada (https://climate.weather.gc.ca/; accessed on 20 May 2024). For the Province of Ontario, there are 21 stations that contain "Island" in the station name. Of these, seven of the stations do not have appropriate (hourly rather than daily) or sufficient data (missing or short records) to be used in this analysis. Although ten years of data were used in [2,24], this requirement was relaxed in this work in order to increase the number of climate records used. The remaining fourteen climate stations are listed in Table 1 and displayed in Figure 1. We note that the same time period is not used for all stations due to the uneven records in which a common time period was not possible. The use of asynchronous time periods is not ideal. However, the DTD metric (see Section 2.2) tends to be robust over time. As an example, we show the 10-year running mean for the Toronto station for the period 1961 to 1990 (Figure 2). The results lying between 3.1 °C and 3.2 °C are remarkably consistent over time.

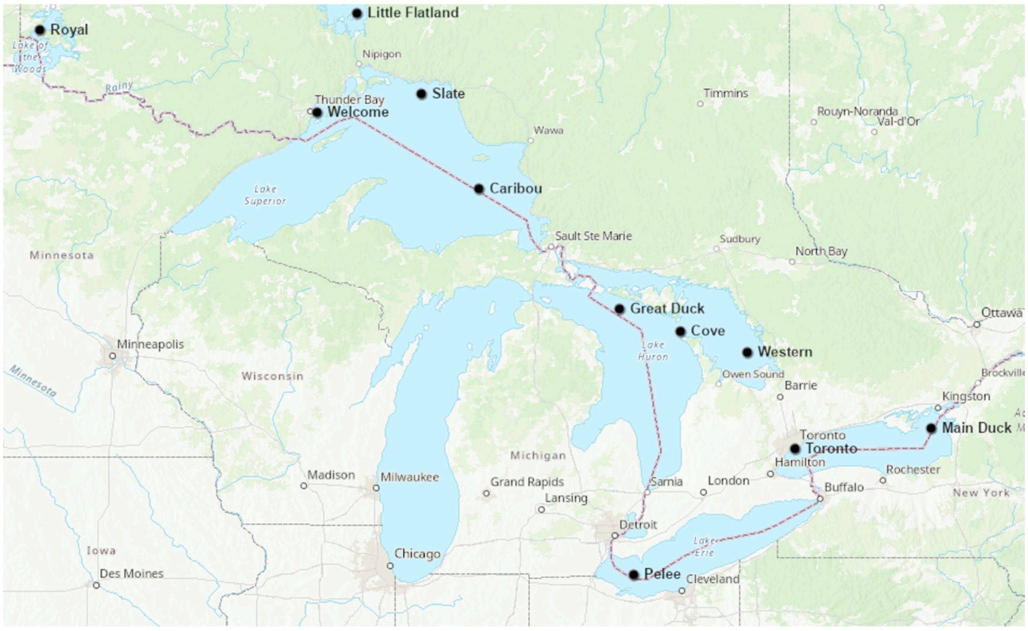

Figure 1. Island stations in Ontario, Canada, which met the $ADTD_{Tmin}$ threshold of 2.35 °C. Scale: 1:20,000,000.

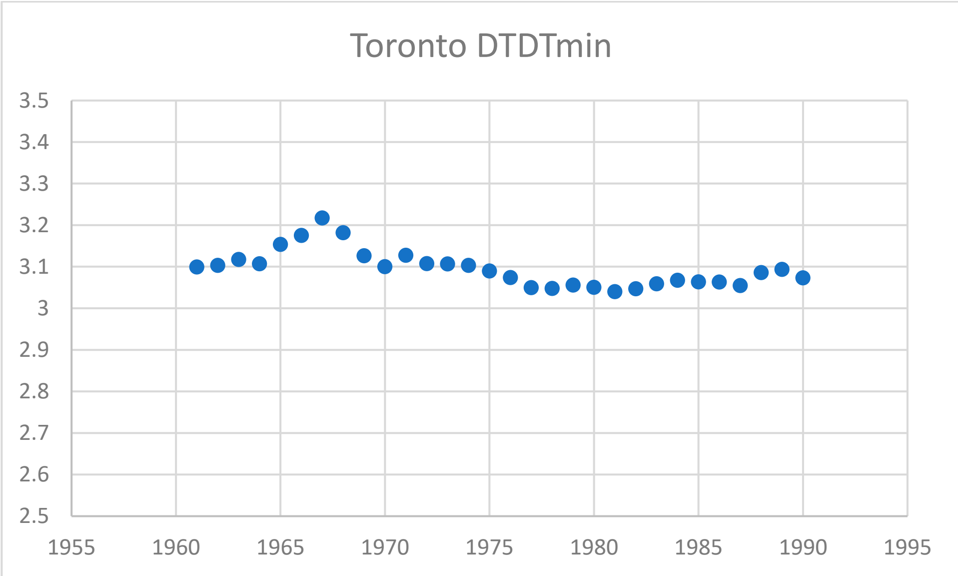

Figure 2. DTD_{Tmin} 10-year running mean for the period 1961 to 1990 for Toronto (°C).

Table 1. Island climate stations in Ontario, Canada, including latitude, longitude, elevation, and time period sampled.

Station	Latitude (N)	Longitude (W)	Elevation (m)	Years
Pelee Island	41.75	82.68	175.30	1961–1970
Toronto Island A	43.63	79.4	76.50	1991–2000
Main Duck Island	43.93	76.63	75.00	1971–1980
Wolfe Island	44.15	76.53	90.00	1987–1995
Grenadier Island	44.42	75.85	82.00	2001–2010
Western Island	45.03	80.37	191.10	1996–1998, 2000–2001
Cove Island	45.33	81.73	180.70	1970–1979
Great Duck Island	45.65	82.97	182.80	1970–1979
Cockburn Island	45.95	83.3	185.90	1900–1909
Caribou Island	47.33	85.83	187.00	1971–1980
Welcome Island	48.37	89.12	211.40	2009–2013
Slate Island	48.62	87	185.90	1971–1980
Royal Island	49.47	94.76	329.00	2016–2018, 2021
Little Flatland Island	49.69	88.31	261.00	2012–2018

2.2. Methods

As noted above, the DTD temperature variability framework developed by [21,22] was used. We use the metrics previously developed and presented below (Equation (1)). Also noted above, DTD_{Tmin} (the day-to-day variability of the minimum temperature of the day) was identified as the clearest indicator of coastal versus inland sites along China's east coast [1], and it was confirmed by [29] for China's south coast. Refs. [2,24] applied this metric to Canadian climate stations, using a modified metric that excluded the winter season (December, January, and February), $ADTD_{Tmin}$. The threshold fell between 2.24 °C and 2.39 °C in [2] and 2.30 °C was used in [24]. This metric is calculated for each station. For six focal areas, two in Lake Ontario, one in Lake Erie, two in Lake Huron, and one in Lake Superior, the island stations are compared to nearby shore climate stations.

In this work, the DTD temperature variability metrics are used, initiated by [21] and applied to coastal environments in [1,2,24] using Equation (1):

$$DTD = \sum_i | T_i - T_{i-1} | / (N - 1) \quad (1)$$

where i is a counter over the period of interest, N, with N − 1 pairs of values. For this analysis, only the minimum temperature of the day, Tmin, is used and the winter months (December, January, and February) are omitted, ADTDTmin, as conducted in [2,24].

In addition to DTD metrics, the diurnal temperature range (DTR) is also used to assess the climate stations in this study. As with DTD, the winter months are excluded in the calculation. DTR is defined by Equation (2):

$$DTR = \sum_i (Tmax_i - Tmin_i)/N \quad (2)$$

using the same nomenclature used for DTD.

3. Results

3.1. Island Station Analysis

Of the 14 locations, 10 locations are below the DTD_{Tmin} 2.30 °C threshold used in [24], and 1 other is at 2.34 °C (Great Duck Island) which is within the range established in [2], which extended to 2.39 °C. The remaining stations, Wolfe Island, Grenadier Island, and Cockburn Island, are well above the threshold and italicized in Table 2. Wolfe Island and Grenadier Island are located at the eastern end of Lake Ontario in the St. Lawrence Seaway. Cockburn Island is located as part of a series of sizable islands which divides Lake Huron from Georgian Bay (Figure 1). Of the ten below the threshold, eight were in the Great Lakes and two (Royal Island and Little Flatland Island) were in lakes that were substantive in size but smaller than the Great Lakes in Northern Ontario (Lake of the Woods, Lake Nipigon).

Table 2. DTD and DTR analysis for the 14 island stations. DTD_{Tmin}, $ADTD_{Tmin}$, and ADTR are multi-year averages in °C. $ADTD_{Tmin}$ and ADTR are calculated excluding the winter months, December, January, and February. Italicized entries do not meet the marine threshold established in [2] of 2.30.

Station	DTD_{Tmin}	$ADTD_{Tmin}$	ADTR	Lake
Pelee Island	2.06	1.89	7.52	Erie
Toronto Island A	2.28	1.94	7.30	Ontario
Main Duck Island	2.08	1.95	5.52	Ontario
Wolfe Island	*3.57*	*3.12*	*8.25*	*Ontario*
Grenadier Island	*2.91*	*2.48*	*9.84*	*Ontario*
Western Island	2.39	1.89	6.52	Huron
Cove Island	1.79	1.75	6.12	Huron
Great Duck Island	*2.4*	*2.34*	*6.86*	*Huron*
Cockburn Island	*3.23*	*2.9*	*11.13*	*Huron*
Caribou Island	1.32	1.31	4.93	Superior
Welcome Island	2.23	1.87	6.62	Superior
Slate Island	2.13	2.05	7.02	Superior
Royal Island	2.76	2.26	9.22	Lake of the Woods
Little Flatland Island	2.62	2.15	8.25	Lake Nipigon

Five island stations are not considered in the subsequent focal area analysis (Section 3.2). These are Western Island in Georgian Bay, Slate and Caribou Islands in Lake Superior and two stations not in the Great Lakes, Little Flatland Island in Lake Nipigon and Royal Island in Lake of the Woods (Figure 1). None of these five stations had close enough "shore" stations for comparison or stations with sufficient data quality and/or quantity. All five were below the 2.30 threshold used in [24] (Table 2). Caribou Island is located 65 km from the Canadian shore, the farthest from shore among all 14 stations examined, and had the lowest $ADTD_{Tmin}$ of 1.31 (Table 2).

The diurnal temperature range (ADTR) results were largely consistent with the $ADTD_{Tmin}$ results. This is illustrated in the scatterplot (Figure 3). Regression analysis found an R^2 of 0.60. The DTD analysis provided an unambiguous threshold to identify island climates of 2.35 °C. However, a specific threshold for DTR was not determined as there is a range of values of DTR that is ambiguous, not clearly island nor inland. Although 8.25 °C appears to be a threshold, two stations straddle this value, one identified as an island (Little Flatland Island) and the other not (Wolfe Island). However, Royal Island with an $ADTD_{Tmin}$ below the threshold has an ADTR that greatly exceeds 8.25 °C (9.22). This ambiguity was also found for the monthly continental analysis in [1].

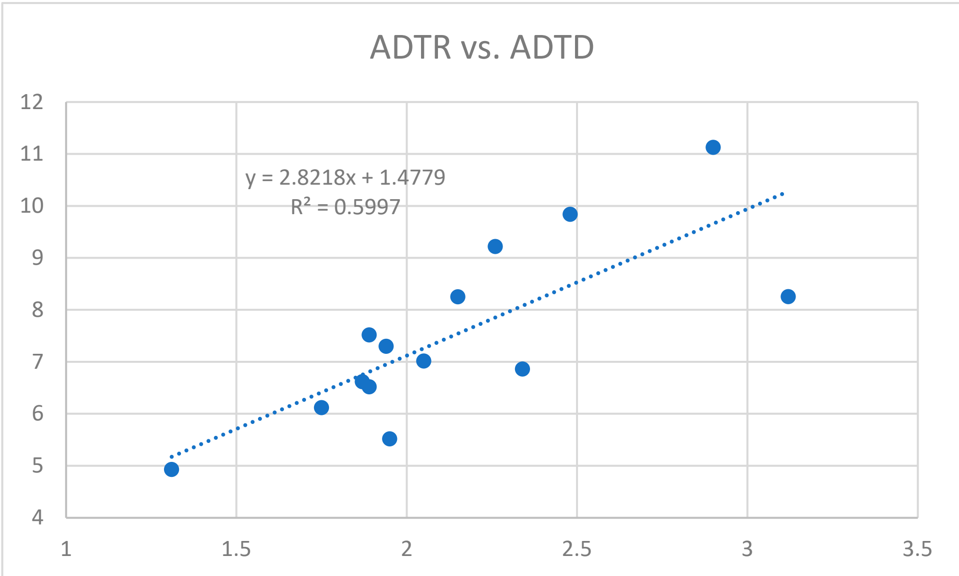

Figure 3. ADTR and $ADTD_{Tmin}$ scatterplot with ADTR on the abscissa and $ADTD_{Tmin}$ on the ordinate from stations listed in Table 1. Both in °C.

3.2. Local Comparisons for Six Focal Areas

Six focal areas are explored by examining local shore climate stations in the vicinity of an identified island location. This will provide context for the stations that did not meet the threshold as well provide insight into inland detectability of a shore climates. The six focal areas including additional climate stations analysed are listed in Table 3 and presented in Figures 4–9.

Table 3. Six focal areas in the Great Lakes. See also Figures 4–9. DTD_{Tmin}, $ADTD_{Tmin}$, and ADTR are multi-year averages in °C. $ADTD_{Tmin}$ and ADTR are calculated excluding the winter months, December, January, and February.

Stations	Latitude	Longitude	Elevation	Years	DTD_{Tmin}	$ADTD_{Tmin}$	ADTR
Kingston							
Kingston CS	44.22	76.6	93.00	2011–2020	3.31	2.98	9.50
Wolfe Island	44.15	76.53	90.00	1987–1995	3.57	3.12	8.25
Grenadier Island	44.42	75.85	82.00	2001–2010	2.91	2.48	9.84
Main Duck Island	43.93	76.63	75.00	1971–1980	2.08	1.95	5.52
Toronto							
Toronto	43.67	79.4	112.50	1991–2000	2.76	2.46	7.42
Toronto Pearson	43.68	79.68	173.40	1991–2000	2.76	2.47	10.27
Clarkson	43.52	79.62	93.00	1951–1960	2.81	2.51	9.85
Toronto Island A	43.63	79.4	76.50	1991–2000	2.28	1.94	7.30
Pelee							
Point Pelee CS	41.95	82.52	176.80	2003–2011	2.7	2.6	8.37
Leamington	42.05	82.63	213.40	1966–1975	2.93	2.81	7.76
Kingsville	42.04	82.67	200.00	1991–2000	2.87	2.81	8.51
Pelee Island	41.75	82.68	175.30	1961–1970	2.06	1.89	7.52
Tobermory							
Tobermory	45.25	81.67	182.90	1971–1980	2.9	2.59	7.89
Tobermory Cyprus Lake	45.23	81.53	190.00	1989–1993	3.97	3.69	10.45
Tobermory RCS	45.23	81.63	213.50	2011–2020	2.84	2.47	8.25
Cove Island	45.33	81.73	180.70	1970–1979	1.79	1.75	6.12
Gore Bay							
Gore Bay CS	45.88	82.57	188.60	2011–2020	3.17	2.69	9.26
Gore Bay	45.92	82.47	190.50	1971–1980	4	3.44	9.70
Cockburn Island	45.95	83.3	185.90	1900–1909	3.23	2.9	11.13
Great Duck Island	45.65	82.97	182.80	1970–1979	2.4	2.34	6.90
Thunder Bay							
Thunder Bay A	48.37	89.33	199.30	1991–2000	3.77	3.35	12.57
Port Arthur	48.43	89.22	195.10	1931–1940	3.89	3.3	10.19
Thunder Bay WPCP	48.4	89.23	184.40	1970–1979	3.84	3.31	10.09
Welcome Island	48.37	89.12	211.40	2009–2013	2.23	1.87	6.62

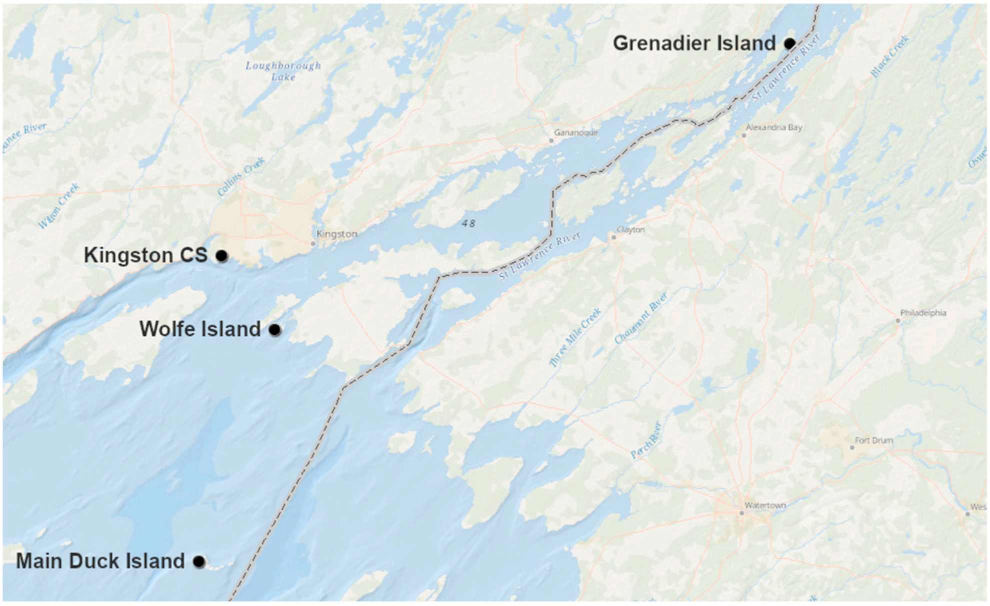

Figure 4. Main Duck Island and neighbouring climate stations (Kingston CS, Wolfe Island, and Grenadier Island), located at the eastern end of Lake Ontario. Scale: 1:600,000.

Figure 5. Toronto Island and nearby stations (Toronto, Clarkson, and Toronto Pearson), located at the western end of Lake Ontario (Figure 1). Scale: 1:250,000.

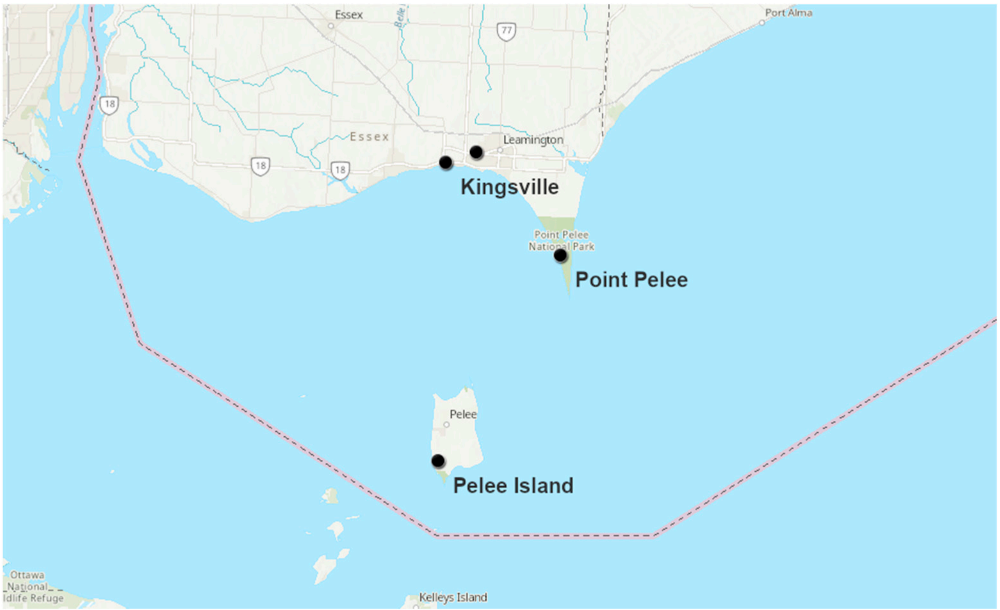

Figure 6. Pelee Island of western end of Lake Erie with shore stations of Point Pelee, Leamington, and Kingsville. Scale: 1:500,000.

Figure 7. Cove Island and nearby stations in Tobermory (Tobermory, Tobermory RCS, and Tobermory Cyprus Lake). Scale: 1:250,000.

Figure 8. Great Duck Island and neighbouring climate stations (Gore Bay, Gore Bay CS, and Cockburn Island). Scale: 1:400,000.

Figure 9. Welcome Island and Thunder Bay climate stations (Thunder Bay A, Thunder Bay WPCP, and Port Arthur) in northern Lake Superior. Scale: 1:100,000.

3.2.1. Kingston

Three of the island stations are binned in this eastern Lake Ontario cluster (Figure 4; see Main Duck Island in Figure 1). Main Duck Island is the only one of the four stations to meet the shore climate criteria ($ADTD_{Tmin} < 2.30$) (Table 3) with a value of 1.95. It is located in Lake Ontario near the US/Canada border and the station has an elevation of 75 m, 2 m above the elevation of Lake Ontario (73 m). The other two island climate stations (Wolfe Island and Grenadier Island) are located in the St. Lawrence Seaway with limited surface water fetch surrounding the islands and are 9 and 17 m above the lake level, respectively. Kingston CS is a climate station located at the Kingston airport near the shore of Lake Ontario, 20 m above the lake level. This suggests that the size of the island, elevation, and expanse of water around the island are key factors in determining the impact of the water environment on the climate record. The ADTR results have the same distinct low value for Main Duck Island (5.52) but a reversed order for the other three climate stations.

3.2.2. Toronto

Toronto Island Airport climate station, 3.5 m above the level of Lake Ontario, is binned with three stations located on land (Figure 5 and identified as Toronto in Figure 1). The Toronto station is located 4 km north on one of the campuses of the University of Toronto, almost 40 m above the lake level. The other two stations are located directly west, one near the shore (Clarkson), 20 m above the lake level, and the other further in-land at Pearson International Airport, 100 m above the lake level. Toronto Island climate station data are distinct from the other three stations with an $ADTD_{Tmin}$ of 1.95, whereas the other three exceed 2.4 (Table 3). The ADTR results indicate that Toronto Island Airport has the lowest value (7.30), but this value is less distinct from the other stations compared to the $ADTD_{Tmin}$ analysis. The Toronto station's ADTR is marginally larger at 7.42, in spite of the substantial increase in elevation (40 m).

3.2.3. Pelee

Pelee Island (2 m above the Lake Erie level) is located in the southwestern end of Lake Erie (Figure 6 and identified as Pelee in Figure 1) and is compared to Point Pelee, Kingsville, and Leamington (at 4 m, 27 m, and 40 m, respectively, above the lake level). As in the case of Toronto Island, Pelee Island is distinctively lower than the shoreline stations with an $ADTD_{Tmin}$ of 1.89 and the others exceed 2.6 (Table 3). An inland gradient, distance, and elevation appear evident with a median value at Point Pelee (2.6) and 2.81 at both Kingsville and Leamington. Point Pelee is located on a peninsula extending into Lake Erie and the other two are further inland (Figure 5). The ADTR analysis also identified Pelee Island as having the lowest value (7.52). However, as was the case with the Toronto cluster, the difference between Pelee Island and the other stations was less distinct (Leamington, for example, is marginally larger at 7.76) in spite of being inland and 40 m higher in elevation.

3.2.4. Tobermory

Tobermory is located on a peninsula extending into Georgian Bay, a part of Lake Huron (Figure 7 and identified as "Cove" in Figure 1). Cove Island is located in Georgian Bay, approximately ten kilometres north of Tobermory, and is 4 m above the Lake Huron water level. The $ADTD_{Tmin}$ value (1.75) is distinctly lower than the three Tobermory climate stations (Tobermory, Tobermory RCS, and Tobermory Cyprus Lake), at elevations above lake level of 7 m, 38 m, and 14 m, respectively, with values ranging from 2.84 to 3.97 (Table 3). The ADTR results are consistent with the $ADTD_{Tmin}$ results, with Cove Island having the lowest value (6.12) and Tobermory Cyprus Lake having the highest (10.45).

3.2.5. Gore Bay

Gore Bay is located further north in Georgian Bay on Manitoulin Island, part of an archipelago that separates Georgian Bay from the rest of Lake Huron (Figure 8 and identified as Great Duck in Figure 1). Great Duck Island, at an elevation of 7 m above the lake level, has the lowest value of $ADTD_{Tmin}$ of 2.34 which exceeds the threshold used in [24] but is within the range identified for coastal stations in [2], that is, 2.25 to 2.39. The other three stations (Gore Bay, Gore Bay CS, and Cockburn Island) at elevations of 15 m, 13 m, and 10 m, respectively, have values of this metric that exceed 2.6 (Table 3). Manitoulin Island and Cockburn Island are much larger islands than Great Duck Island which is surrounded by a lengthy fetch of water. This is the only cluster where the ADTR analysis provides a greater distinction between island climates and the other stations with Great Duck Island at 6.90 and the other three above 9.25.

3.2.6. Thunder Bay

Thunder Bay is located on the northwest shores of Lake Superior (Figure 9 and identified as Welcome Island in Figure 1). Welcome Island is located about 15 km south in Lake Superior and the $ADTD_{Tmin}$ of 2.23 is distinctively lower than the stations on the shore with values exceeding 3.75, the largest values for shore climate stations of all the comparison groups. In spite of the proximity of Thunder Bay to Lake Superior, the city has Lake Superior to the east and the prevailing weather is from the west, thus limiting the amount of lake-influenced air masses experienced by the city and surrounding area. Welcome Island is surrounded by water (Figure 9). The ADTR analysis is consistent with the $ADTD_{Tmin}$ analysis, with Welcome Island being distinctly different from the shore stations.

All six focal areas illustrated the impact of the localized environment factor of surrounding water for the island climate stations compared to neighbouring shore climate stations. This is illustrated in Figure 10 which shows for the six focal areas the $ADTD_{Tmin}$ for each area. The island locations (red) were unambiguously lower than all other stations (blue) and this was confirmed by a *t*-test ($p < 0.001$). Figure 11 is the same analysis for ADTR which was also statistically significant using a *t*-test ($p < 0.001$). The distinction between the red points and the blue points are less clear for this metric, particularly for Toronto and Pelee, consistent with the results in Section 3.1. To quantify the relative distinctness of the island station, we take the difference of the island station from the average of the nearby inland stations and normalized these by dividing by the average for $ADTD_{Tmin}$ and ADTR, respectively, for the six focal areas. Averaging these results across the six clusters produces a difference measure of 0.32 (0.09) for $ADTD_{Tmin}$ and 0.28 (0.12) for ADTR with the standard deviation in parentheses. $ADTD_{Tmin}$ values (higher) are more distinct with less variability (lower standard deviation) compared to ADTR. In contrast to all of the other clusters, Welcome Island does not have the lowest relative elevation within this cluster, as did all the other Islands. It is an island of high relief with a lighthouse perched over 30 m above the lake level and the climate station is located 28 m above the lake level. In contrast, the inland stations are located less than 17 m above the lake level.

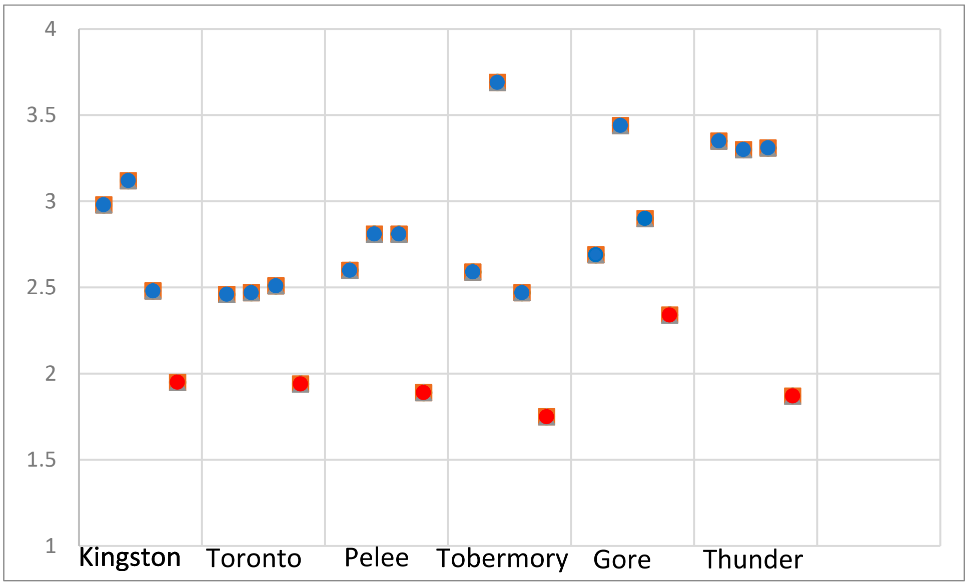

Figure 10. $ADTD_{Tmin}$ for the six focus areas listed in Table 3 and following the same order. Stations in red are the island climate stations that satisfy the coastal requirement developed elsewhere [1,2,24], ADTD = 2.35. The blue stations are the other stations in each cluster.

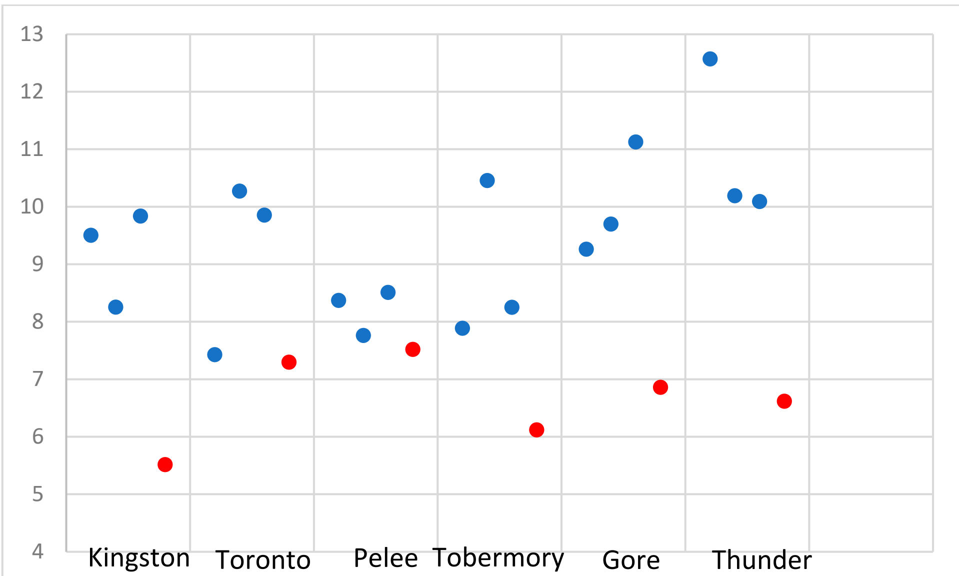

Figure 11. ADTR for the six focus areas listed in Table 3 and following the same order. Stations in red are the island climate stations (see Figure 10). The blue stations are the other stations in each cluster.

4. Discussion

The day-to-day temperature variability framework (DTD) was novelly successful in exploring the impact of large water bodies in Ontario, Canada, in particular, in the Great Lakes and surrounding lakes, on the climate record. Marine bodies had been shown to act to mitigate temperature variability for coastal environments in China, the Mediterranean, and Canada [1,2,24,26,29], particularly for the minimum temperature of the day. In [2], two climate stations in the Great Lakes demonstrated characteristics of a coastal climate. In this work, more climate stations in Ontario are examined. Nine additional climate stations with coastal characteristics were identified on islands in the Great Lakes and two other smaller lakes (Lake Nipigon and Lake of the Woods). For six of the island locations, nearby shoreline climate stations were examined and shown not to exhibit as clearly the same hydro-meteorological inertia (manifested as the mitigation of day-to-day variation in minimum temperature of the day) that islands surrounded by large bodies of water do. In fact, the inland penetration, in contrast to marine environments [1,2,24,26,29], appears quite limited and no climate station located on a shoreline met the criteria developed in [2,24], only those located on islands. In addition, for five of the six clusters, the elevation of the island station was the closest to the elevation of the lake, illustrating that both elevation and inland displacement are important as found in [1] for the Changjiang Delta. This is not to say that there are no other regional impacts of the Great Lakes and other large water bodies on the local climate as measured by other metrics such as temperature extremes, precipitation distribution, and frequency and distribution of midlatitude cyclones as demonstrated in other studies [12–17].

In addition to the DTD analysis, a diurnal temperature range (DTR) metric was also explored using the same climate stations and same data sets. In general, this metric was also able to identify the island stations in a statistically significant fashion, as was the case for DTD. However, unlike DTD metrics, an unambiguous threshold to distinguish between island and other climate stations was not realized with an overlap in DTR for the two groups. Related to this, a novel distinctiveness measure showed that DTR results were also less distinct and more variable compared to the more consistent and constrained DTD metric.

The key minimum temperature day-to-day temperature variability metric for island climates was consistent with that found for marine coastal regions [1,2,24,26,29] arising from the same underlying radiative and dynamic mechanisms. This study, though, provided a refinement of the island climate threshold to 2.35 within the range of 2.25 to 2.39 found in [2], superseding the value of 2.30 used in [24]. Coastal and island environments partition considerably more surface energy at night into latent heat, evaporating surface water and producing fog and clouds. This reduces the nighttime radiative loss which in turn dampens the day-to-day temperature variability as seen for the island climates in this work. The comparison with local coastal stations indicates that this effect is limited and mirrors marine coastal stations for relatively smaller islands that are surrounded by extensive fetches of water sources (relatively large water bodies) such as the Great Lakes and other large water bodies (Lake Nipigon and Lakes of the Woods).

Finally, in the Introduction, we pondered the nomenclature for the type of climate that is influenced by large bodies of fresh water, trying to avoid terminology that tends to be used exclusively for saltwater bodies such as "marine" and "coastal". While "shore climate" was put forward, the results of this work and ultimate application to only islands in the Great Lakes and two large neighbouring lakes suggests that the term "island climate" might be a better designation.

5. Conclusions

Using a day-to-day temperature variability (DTD) framework, clear signature "island climates" have been established in the Great Lakes and two other large water bodies in Ontario, Canada, a characteristic not shared by nearby shoreline climate stations. This work enabled us to refine the threshold for such to 2.35 °C up from 2.30 °C used in [24] based on [2]. The inland stations are influenced by the presence of large expanses of lake water but not in the well-defined way island climates were shown to be in this work. The island signature is consistent with that found for marine environments [1,26,29], reflective of radiative considerations that mitigated the variability of nighttime temperatures. A diurnal temperature range (DTR) metric was also effective in identifying island climates but with some ambiguity on a precise threshold not found in the day-to-day temperature variability metrics. The day-to-day temperature variability framework, which has been effectively used to identify urban, rural, peri-urban, marine, mountain, and airport climates, is also effective in providing an additional category, "island climate", and contributes to a "decision tree" proposed in [24] to identify landscape types solely using temperature variability.

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