Assessing Spatial Variability of Key Weather Elements at a Micrometeorological Scale

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ABSTRACT

In 2018, four meteorological stations were installed at Okanese First Nation (OFN). The objective of this paper is to document weather variability within OFN for 2019 and then evaluate the spatial variability using *in-situ* weather data during 2019. Temperature, wind speed/direction, pressure, and relative humidity was analyzed using heat maps. Rainfall was visualized as bar graphs. Correlation and ANOVA analyses were used to determine similarities between variables and stations, respectively. This analysis seeks to determine whether four stations are valuable for weather monitoring at Okanese First Nation.

1. Introduction

Micro-scale meteorology is based on both the spatial and temporal scales (Oke, 1987). Despite the relatively small scale, variability of weather elements can be substantial. For example, Sremac et al. (2021) showed temperature variations of 0.1 – 0.4 °C across 100 m of vertical range within an orchard biome and horizontal variability of up to 2.5 °C between the local meteorological station and study site (< 10 km). Across a glacial surface, Mott et al. (2020) observed variability of temperature, windspeed, and humidity at distances less than 300 m. In the agroforestry industry, temperature and relative humidity were observed to vary 2.3-3.2 °C and 6.6-9.3%, respectively, between open pasture and beneath a forest canopy within a 1.5 ha area (Karvatte et al., 2020). In an urban environment, DiGiovanni-White et al. (2018) report significant spatial differences in air temperature, relative humidity, and wind speed. Similarly, Onishi et al. (2019) investigate the potential for monitoring weather elements at super-resolution (< 5 m – 2 km) to observe urban heat island variability. In southern Saskatchewan, within the Prairie Pothole Region, annual air temperature has been observed to vary spatially by 9 °C and precipitation ranges between 300 – 900 mm per year (Millett et al., 2009).

This study examines micrometeorological variability within a portion of the Prairie Pothole Region, an agriculture-rich area of southern Saskatchewan, Canada. In this context, the micrometeorological scale is defined by DiGiovanni-White et al. (2018). In agriculture, micrometeorological variability can impact the surface energy balance and evapotranspiration (Burba and Verma, 2005), as well as the water availability for crops (Domingo et al., 1998). The objective of this paper is to document micrometeorology at Okanese First Nation (OFN) in 2019. Weather elements include, but are not limited to, air temperature, rainfall, barometric pressure, relative humidity, and wind speed/direction (Ahrens and Henson, 2018). To conduct this study, data from all four stations were compiled and analyzed to visualize variability at a micrometeorological scale. The purpose of this paper will be to understand causes and impacts of spatial variation of these elements and evaluate whether this variability warrants multiple stations.

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2. Methods & Data

The four meteorological stations established in OFN were installed in late 2018 and are located within a 220 km² area (Fig. 1.). Stations are located at the edge of farm fields, at least 12 m (4 x station height) from any obstructions (buildings, trees, etc.). OFN is in the Aspen Parkland ecoregion of Palliser's Triangle in central Canada, with a warm-summer humid continental (Dfb) Köppen climate type. All four stations use the RX3000 data logger from *Onset* (Bourne, MA) and include the same set of meteorological sensors installed at the same relative positions and heights. Each station is battery operated and charged via a 5W solar panel and contains a cellular modem for near-real time data access. On-board data storage is transmitted to a remote computer every three weeks for permanent archiving. Sensors on each station measure air temperature, relative humidity, wind speed/direction, barometric pressure, and rainfall. Each sensor is provided with a quoted measurement resolution. The temperature sensor has a resolution of 0.02 °C which allows for spatial variability to be detected at the hundredth of a degree Celsius. The resolution for the other sensors includes relative humidity at 0.01%, wind speed at 0.5 m/s, wind direction at 1.4 degrees, barometric pressure at 0.1 millibars, and for rainfall it is 0.2 mm. Sensor specification and further information regarding the meteorological station setup is available through the *Onset* website (Onset Computer Corporation, 2022). Station elevations range from 587 to 670 m asl. All stations were situated in locations more than 50 m from nearby obstructions.

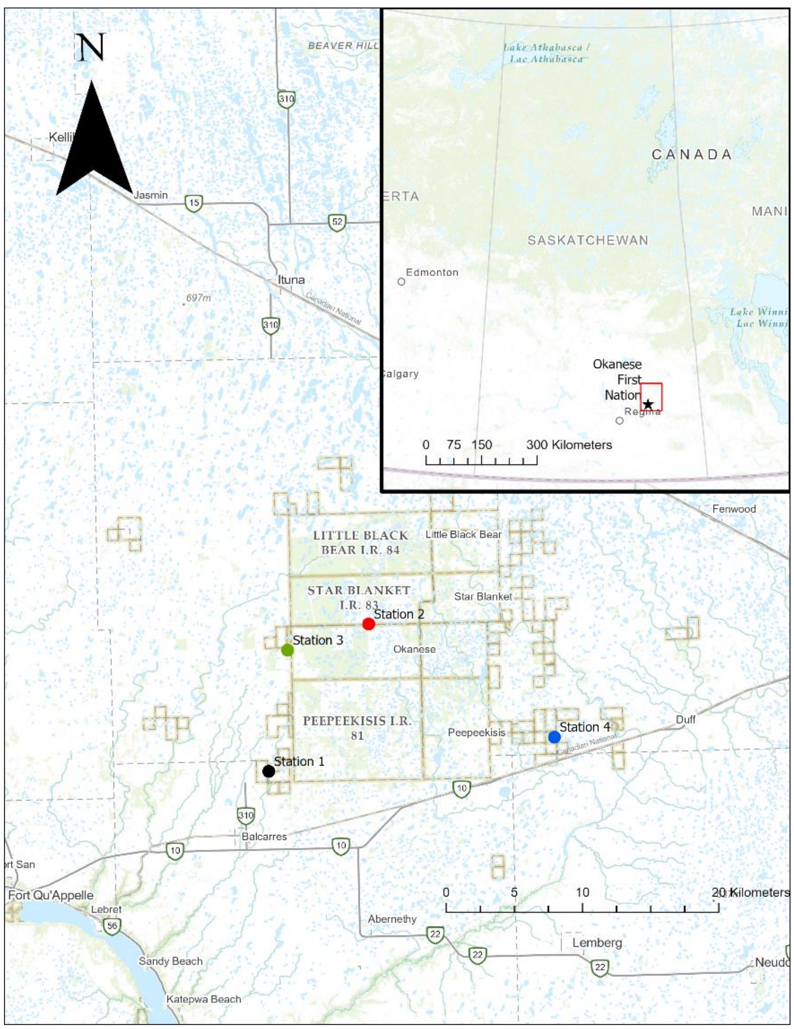

Figure 1. A map of the 4 meteorological stations in OFN located in southern Saskatchewan.

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3. Results and Discussion:

3.1 Rainfall variability

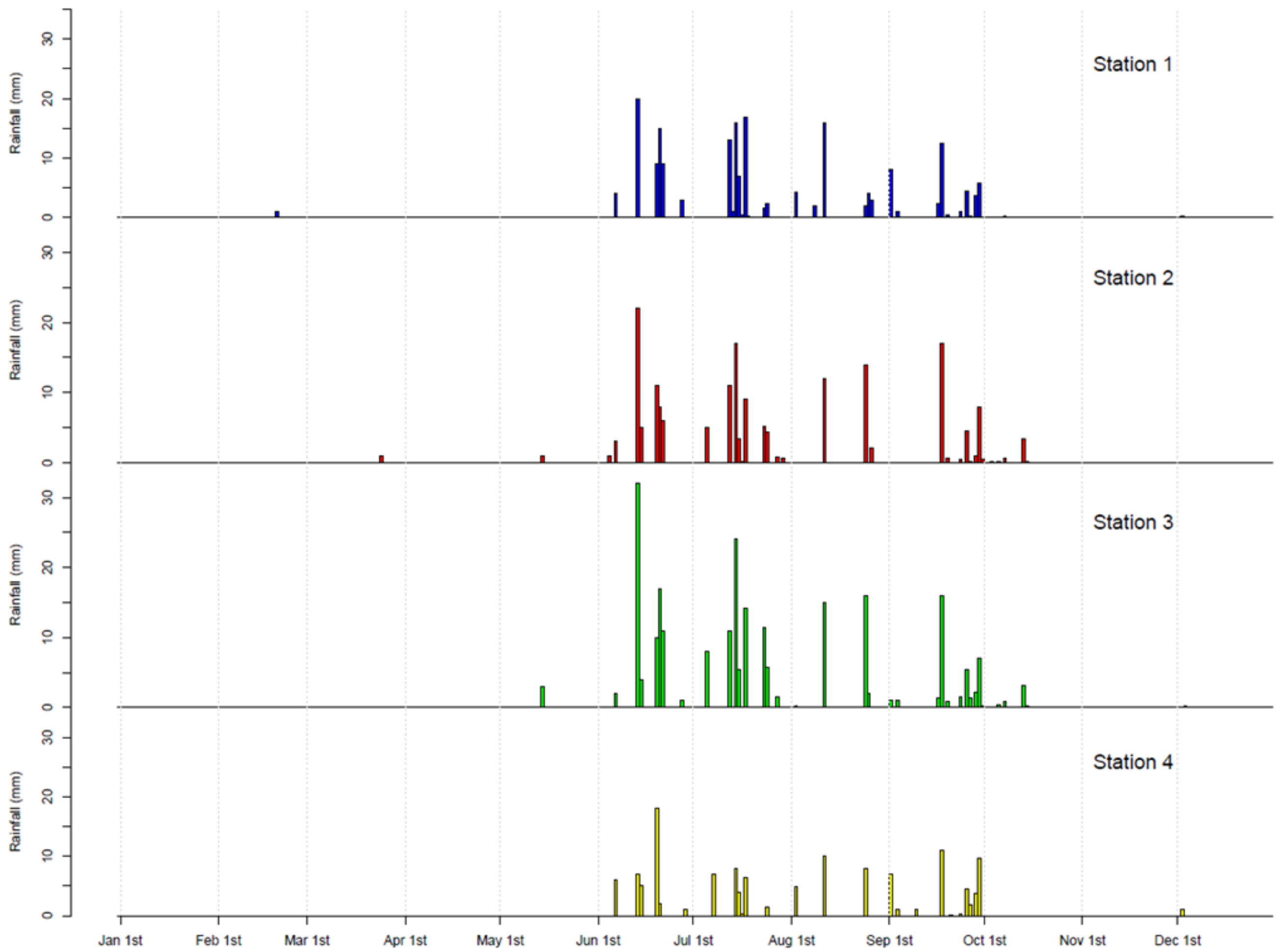

Figure 2. The daily sum of rainfall across four meteorological stations established at OFN in 2019.

Rainfall totals are seen to vary across the four meteorological stations (Fig. 2). Most rainfall events are observed concurrently at each station, though the magnitude varies. Also, some rainfall events are not recorded at all of the stations. For example, a small rainfall event in mid-October was observed at stations 2 and 3 (ie, most northern stations) but not at 1 and 4. Overall, station 4 received the least amount of rainfall over the year (130.4 mm) while station 3 received the most (237.4 mm), though these stations are still moderately related to each other ($r = 0.539$, $p < 0.001$). Stations 2 and 3 are the most similar ($r = 0.955$, $p < 0.001$). Station 4 also received the fewest number of days with rainfall (26) compared to 34, 35, and 36 days with recorded rain at stations 1, 2, and 3, respectively.

Despite the small study region, there is a relatively high amount of spatial variability. This is likely due to the highly variable nature of convective storm systems which dominate the Prairie region in summer. These meteorological events are often restricted to a small horizontal extent, are short-lived, and tend to occur as isolated storms (Oke, 1987). It is therefore possible for a particular convective storm to influence one station while leaving another with minimal or no rain recorded. On the other hand, frontal storm systems tend to influence a broader surface area, resulting in a connection between more distant stations (Oke, 1987). Station 4, the most easterly and the most distant of the four stations, records the least amount of rainfall over the study period, illustrating this spatial heterogeneity in rainfall totals. The question of why station 4 receives less rainfall overall remains unanswered.

3.2 Air temperature & barometric pressure variability

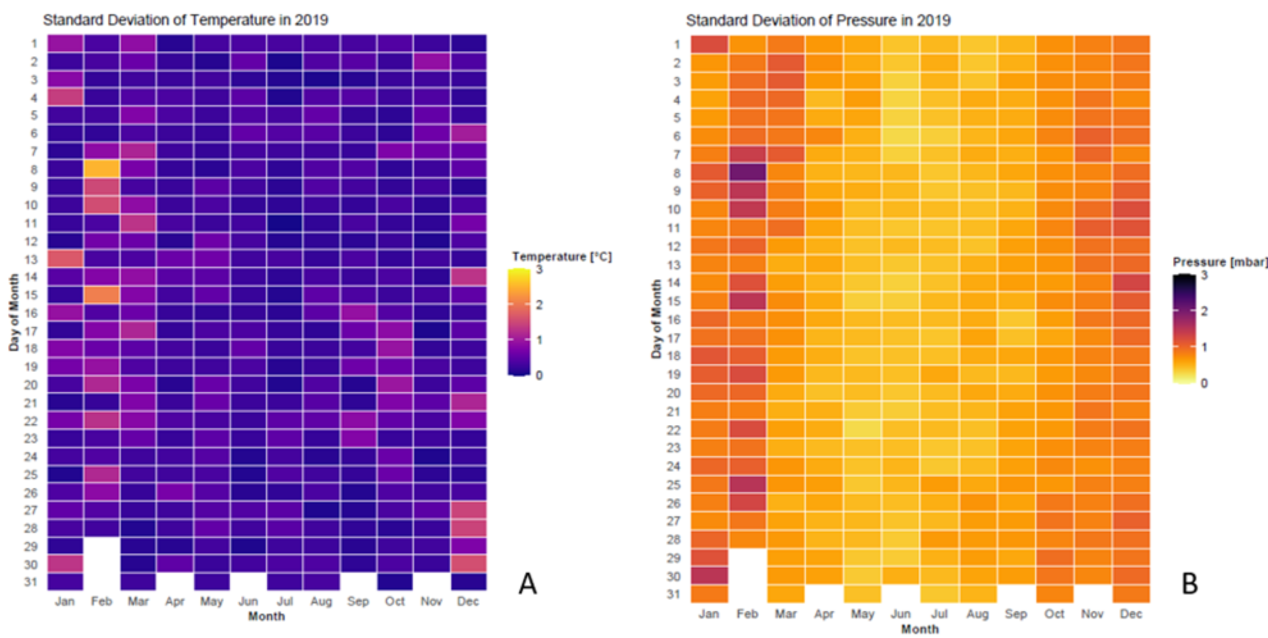

Figure 3. Panel A. The standard deviation of air temperature at four meteorological stations is used to demonstrate the spatial variability of the variable at OFN in 2019. The day of each month is represented by the x-axis, while each month is the y-axis. The colour represents the change in the variable. Panel B. The standard deviation of barometric pressure at four meteorological stations that is used to demonstrate the spatial variability.

The variability of air temperature across the four stations is shown in Figure 3. Standard deviation of temperature ranges between 0 and 3 °C during the year, with the greatest variability observed during the winter months. Between April and November, variability between the stations is below 1 °C. April through November air temperature variation is significantly less ($p < 0.001$) than that in January-March and December combined. Overall, air temperature recorded at the four sites show no statistical difference ($F = 0.103$, $p = 0.748$).

The most significant observation of the spatial variability of air temperature is the substantially increased variability in winter. Elevation across the study are varies by ~100 m and may explain this increased variability during cold conditions. Cold, dense air settling in low areas (eg, Station 4) may explain these observations. At the same time, stations located at local topographic high points (eg, Station 3) may experience greater winds which maintain a relatively snow free surface (Pomeroy et al., 1998), exposing the lower albedo soil and vegetation below, leading to increased daytime surface temperature.

Barometric pressure is related to air temperature, with denser air exhibiting a higher pressure (Ahrens and Henson, 2018), and therefore there are similarities between the air temperature

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observations shown in Figure 3 and the barometric pressure observations ($r = 0.478$, $p < 0.001$) (Fig. 5). For example, on February 8, the high spatial variability of air temperature is accompanied by a high variability of pressure. The longer-term seasonal variability also matches between the two variables, with the greatest variation observed during the winter months. Similarly, there is no statistical difference in air pressure between the four sites ($F = 0.010$, $p = 0.919$)

3.3 Wind speed & wind direction variability

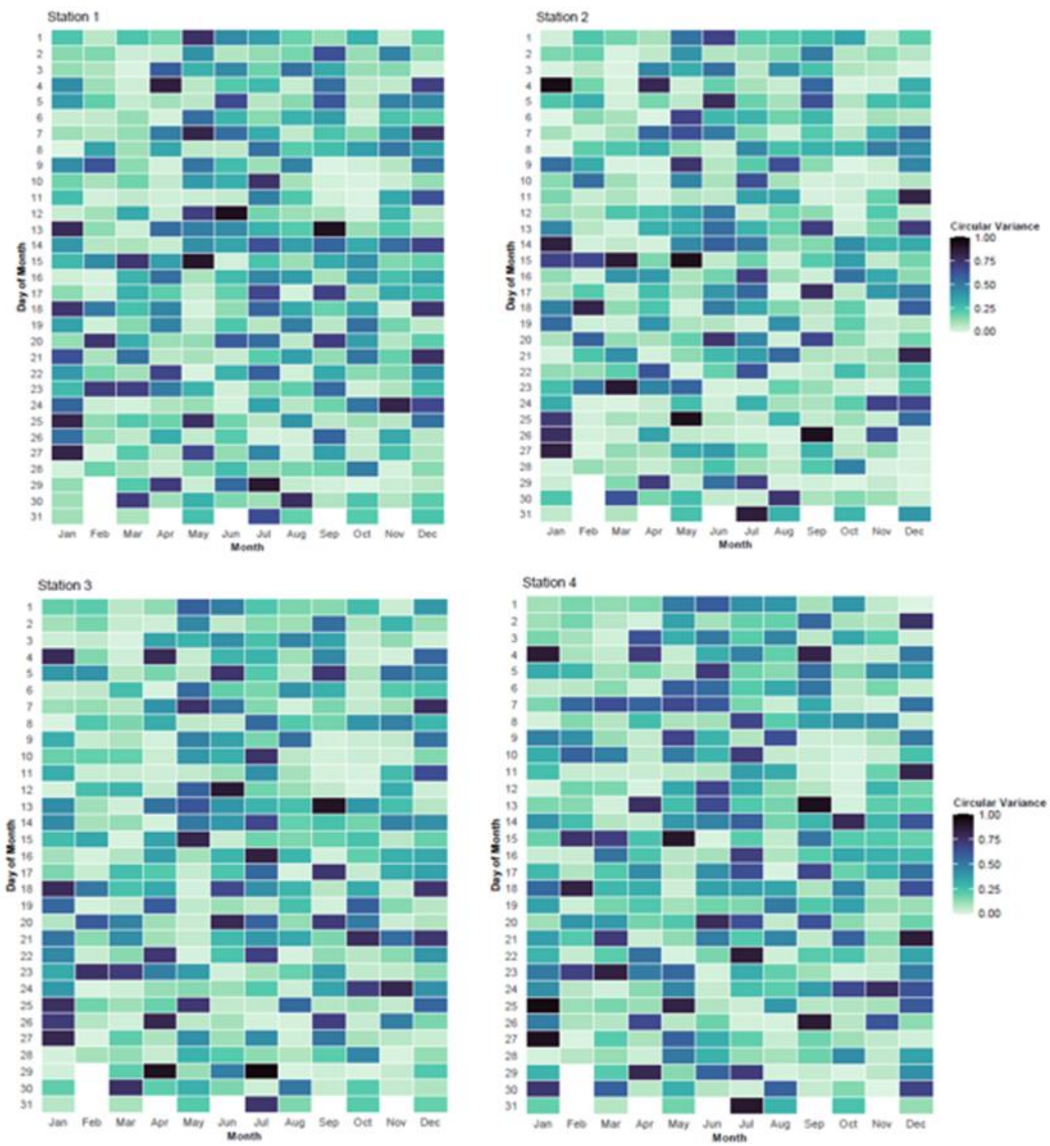

Figure 4. The circular variance of wind direction at four meteorological stations is used to demonstrate the spatial variability of the variable at OFN in 2019.

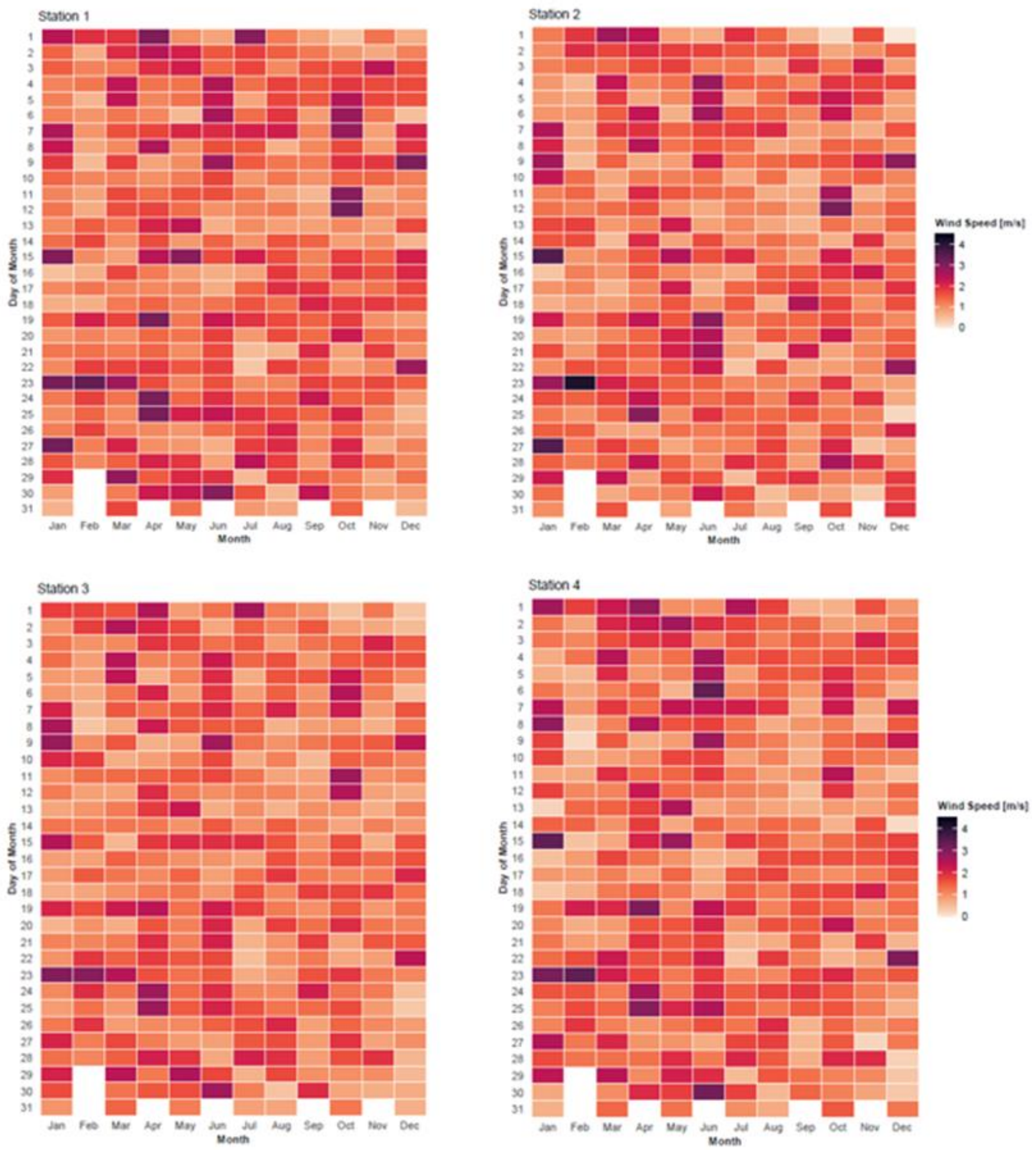

Figure 5. The standard deviation of wind speed at four meteorological stations is used to demonstrate the spatial variability of the variable at OFN in 2019.

Figure 4 displays the circular variance for each station for 2019. Circular variance approaches 0 when all wind vectors point in approximately the same direction while circular variance approaches 1 when the wind vectors point in opposite directions. For example, a day with consistent wind direction would yield near-zero circular variance, while a day which experiences a significant shift from southerly to northerly flow would yield a near-one circular variance. Between the four stations, wind direction variation tends to be consistent throughout the year, though there are some differences between individual stations. For example, the January 13-15 period shows substantial variability between the stations. Similarly, stations 1 and 3 (westernmost) exhibit high directional variation on June 12, while stations 2 and 4 exhibit substantially less. Overall, stations 1 and 3 exhibit the most similar circular variance (r = 0.882, p < 0.001) while stations 3 and 4 are least similar (r = 0.788, p < 0.001).

The variability of wind speed from each station is displayed in figure 5. Each station looks similar but displays different magnitudes of wind speed deviation. A pattern discerned from the graphs is that during spring and summer months the wind speed deviation is at its greatest from station to station. Although it appears that wind speed variability is common throughout the whole year. Stations 1 and 4 display the most similar wind speed deviation (r = 0.882, p < 0.001), while stations 2 and 4 are the least similar (r = 0.729, p < 0.001). The resolution of the wind speed sensor is 0.5 m/s which plays a role in the heat map above because the maximum deviation that is shown is about 4 m/s. This means that the majority of deviation that is shown could be affected by how precise the wind speed sensor can measure that change in wind speeds. With respect to mean wind speed, we find statistical similarities between station 1, 2, and 3 (0.085 < p < 0.973), but station 4 is statistically different from all others (2.0×10^{-7} < p < 0.007).

3.4 Relative humidity variability

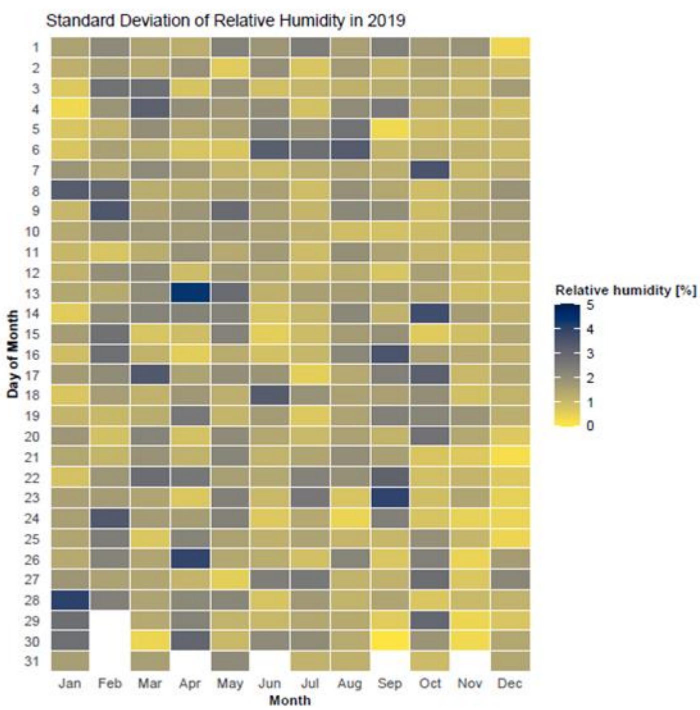

Figure 6. The standard deviation of relative humidity at four meteorological stations is used to demonstrate the spatial variability of the variable at OFN in 2019.

The spatial variability of relative humidity is the least seasonally consistent of all the weather variables presented here (Fig. 6). Variability of relative humidity as controlled by changes in temperature are well known, as is the influence of local moisture supply (eg, evapotranspiration) (Ahrens and Henson, 2018). Overall, though, relative humidity does not vary more than 5% between the four stations, and such variability can be observed at all times of the year. Over the full year, correlation between the stations is high (0.975 < r < 0.997, p < 0.001) and an analysis of variance confirms that these stations are observing the same relative humidity (F = 0.301, p = 0.583).

At OFN, the four stations spread across 220 km^2 exhibit spatial variability amongst the studied weather elements. Most outstanding is station 4, located in the eastern part of the study site and experiencing the least amount of rain and the greatest variability in wind speed and direction when compared to the other stations. Station 4 is also the lowest elevation station, resulting in the concentration of dense air in winter leading to higher variability in air temperature and pressure in the winter months. This suggests that one or two stations are necessary at OFN. Elements like relative humidity, pressure, and temperature did not demonstrate significant variability across all four stations. Grouping these variables into one station located centrally would produce similar results. However, rainfall, wind speed, and wind direction do vary between the stations suggesting that a separate station at site 4 contributes valuable observations of the spatial variability of weather elements at OFN.

4.Conclusion

The purpose of this study was to determine the merit of four meteorological stations at Okanese First Nation. Through analysis of heat maps and correlation/ANOVA statistics it was determined that temperature, relative humidity, and pressure showed minimal differences, while rainfall and wind speed/direction exhibited higher spatial variability between stations. Station 4 exhibited significant differences in weather measurements when compared to the other stations.

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