Learning activities around understanding the spatial variability of key weather elements

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ABSTRACT

Understanding the spatial variability of weather elements is a critical component of understanding the physical processes which generate them. At Chappell Marsh Conservation Area in Saskatoon, Canada, air/soil temperatures, rainfall, and wind speed were observed to vary in response to vegetation controls. Field data collection was performed by students as part of their undergraduate learning experience. Providing opportunities to measure such environmental variability is an invaluable component of developing their understanding of environmental processes in general and preparing for their future careers.

1. Introduction

In the environmental sciences, spatial variability is of central concern for a wide range of physical processes (e.g., Grünzweig et al., 2003; Brocca et al., 2012; Maier et al., 2020). Providing undergraduate students with the opportunity to examine such spatial variability is important to the continued promotion and development of this field of environmental research. Undergraduate research has been demonstrated to benefit students' learning in several ways (Seymour et al., 2004; Auchincloss et al., 2014) and has been called a "high-impact" educational practice by the Association of American Colleges and Universities (Kilgo et al., 2015). However, providing field-based and/or instrument-based research opportunities to large numbers of students is a challenge with high travel and equipment costs and instructor/supervisor/mentor time typically limited (Graves, 2021).

This paper presents a summary of research outcomes from a course-based and field-based undergraduate research opportunity that examines the spatial and temporal variability of important weather phenomena. While a primary goal of this research is to quantify variability of weather phenomena, it will also describe the students' approaches and successes in observing these phenomena.

2. Methods & Data

Chappell Marsh Conservation Area (CMCA; near Saskatoon, SK, Canada; Fig. 1) is situated on ~1.5 ha of restored prairie wetland habitat. The site hosts a mix of grassland, forest, and dried pond-bed sediment landscapes (open water pond dried out in 2020). Since 2018, the University of Saskatchewan has offered the senior undergraduate course GEOG 390: Methods in

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Hydrometeorology at CMCA. In addition to access to an established meteorological station, students are provided with a selection of sensors and a set of research questions based on observing and recording the spatial variability of key weather elements: temperature, rainfall, and wind. Working in groups, students identify the necessary sensors, develop a research plan and sensor deployment strategy, collect the relevant data, complete data analysis using ArcGIS and/or R/Excel, and produce research reports for each variable. In September/October 2022, students completed three concurrent projects following this process:

1. Temperature: air and soil temperatures were recorded at two locations at CMCA – the exposed pond bed and within the forest. Air temperature was recorded with a CS500 (Campbell Scientific, Inc.) probe within a radiation shield installed 1.5 m above the ground. Soil temperature was recorded with a 107 thermistor (Campbell Scientific, Inc.) installed 10 cm below the ground. Data were acquired from all sensors at 15-minute intervals.
2. Rainfall: rainfall gauges were installed in pairs around a large shrub at CMCA, with a goal of measuring the impact that proximity to vegetation has on gauge catch. Pairs of gauges were installed at each cardinal direction (i.e., north, east, south, west) around the shrub, with one sensor immediately adjacent to the vegetation and the other 2 m away from the vegetation edge. Rain gauges were installed 1.8 m above the ground surface. Rainfall catch was recorded manually at a weekly interval.
3. Wind: wind speed was measured with a handheld anemometer at various locations around CMCA, including at the 8 rainfall gauges describe in 2. above. Wind speed was measured at the instrument height (i.e., 1.8 m) and at ground level (15 cm) to capture the influence of surface roughness. Wind speed was measured at 10-second intervals and then averaged over 1 minute.

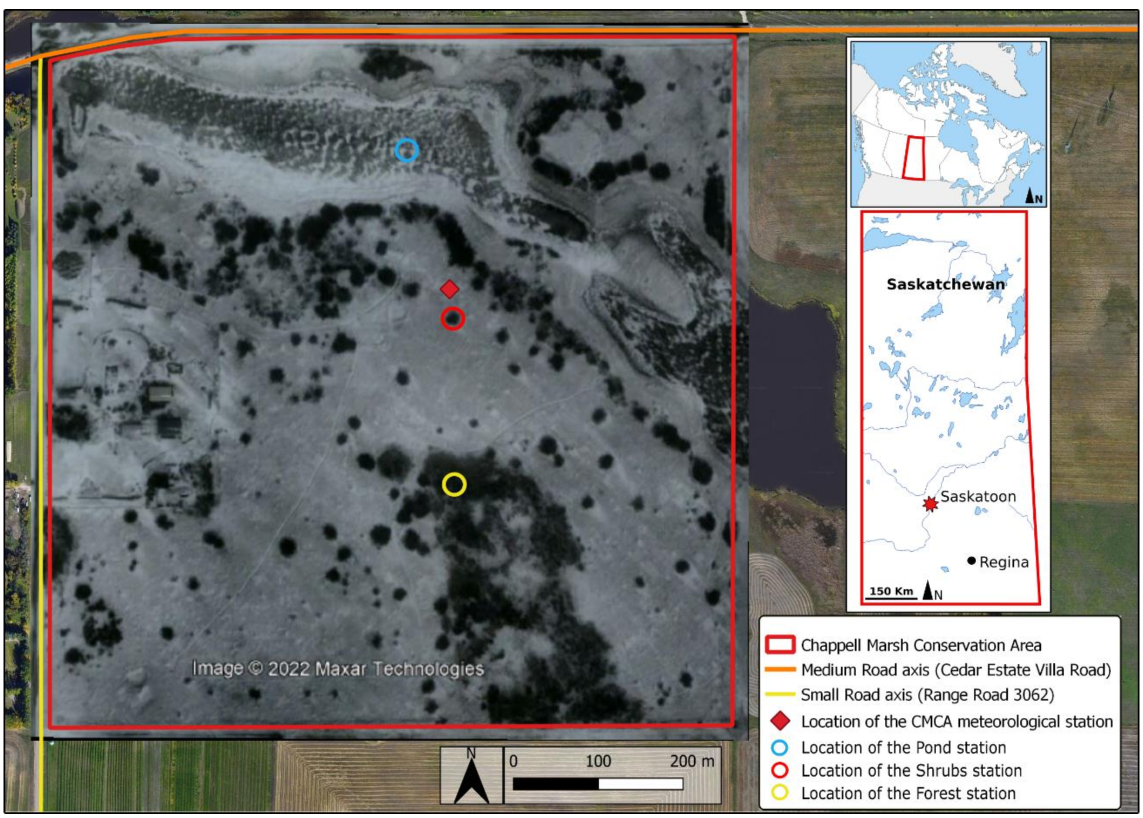

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Figure 1: Chappell Marsh Conservation Area, near Saskatoon, SK, Canada.

3. Results & Discussion

A summary of the results of the three research projects are describe below. Student-prepared written reports revealed both successes and challenges in identifying and describing the variability of each of the weather elements.

3.1 Air temperature variability

The pond and forest sites represent different surface and canopy characteristics at CMCA. Students immediately identified the important role of land surface cover as a controlling factor of the surface energy balance and ultimately air and soil temperatures, thus targeting these different environments to observe temperature variability. Results show that, while diurnal temperature variations track similarly at both sites (Fig. 2A), the pond site generally experiences colder nighttime temperatures. However, during days with small diurnal temperature change, the two locations do not vary. Daytime temperatures are consistent between the two sites throughout the monitoring period. At 10-cm below ground (Fig. 2B), soil temperature variations demonstrate substantial differences in diurnal amplitude and magnitude. The forested site experiences less diurnal variability than the pond site throughout the monitoring period. At soil temperatures greater than 10 °C, the pond soil is warmer than the forest, however, below 10 °C the forest soil is warmer than the pond.

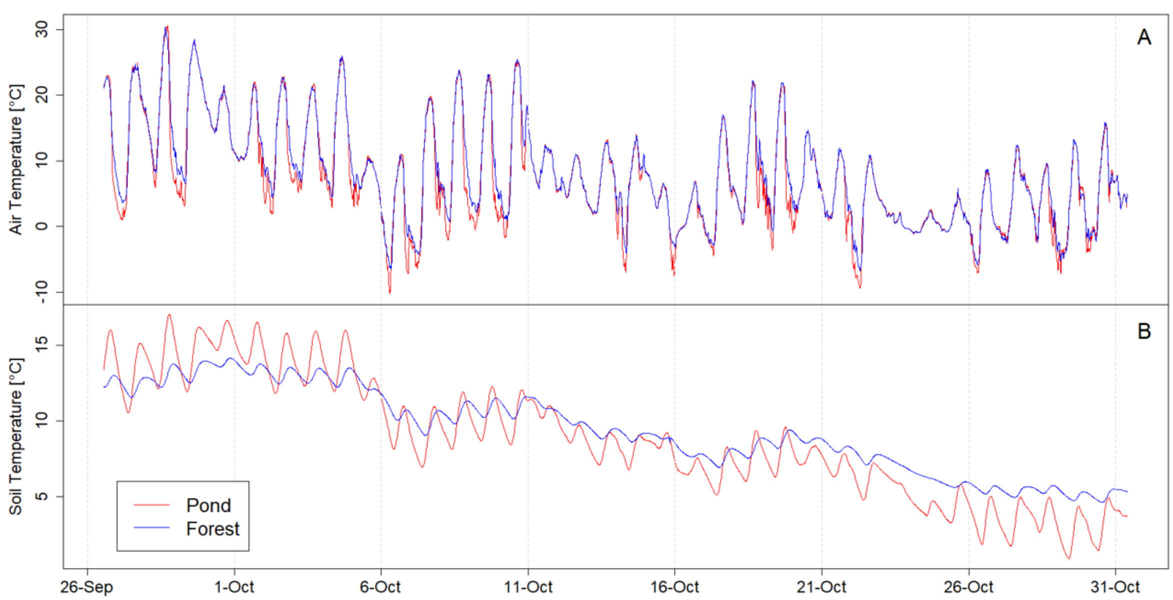

Figure 2: 15-minute interval air (A) and 10-cm depth soil temperature (B) variability between the pond and forest sites at Chappell Marsh Conservation Area.

While these results conform to previous studies (e.g., Al-Kaisi et al., 2017), they provide a clear example of air and soil temperature spatial variability. Students sought to observe variation between these sites and that goal was realized. Thus, students demonstrated an ability to combine their previous knowledge of the surface energy balance acquired through classroom instruction with new skills in sensor programming and deployment, and overall environmental observation. In their reports, students focused on the challenges of the latter as opposed to further developing the former, though this may be related to the learning objectives of the course which are focused on the technical side of environmental observation.

3.2 Rainfall variability

Rainfall measurements recorded by eight gauges surrounding a 10-m diameter shrub reveal the variability of rainfall catch as influenced by proximity to vegetation (Table 1.). During the rainfall event on October 23/24, wind direction was from the NNW – N at an average speed of 3.3 m s^{-1} and gusts as high as 7.6 m s^{-1}. Rainfall catch was consistently higher at the edge of the vegetation compared to 2 metres away from the edge on all sides except for the south, the leeward side during this event; in this case catch was equal at both distances. The difference in catch between the paired gauges was greatest on the north side, most directly in line with the incoming wind.

Table 1: Variability of rainfall catch at gauges surrounding a large shrub. Gauges were oriented on the north, east, south, and west sides of the shrub. Gauge measurements are presented in millimetres.

Rainfall collected [mm]	N	E	S	W
at vegetation edge	4.6	5.0	7.4	4.2
2 m from edge	3.6	4.4	7.4	3.8

In their efforts to assess the causes of the observed rainfall variability, students made clear connections between rainfall catch totals and dominant wind direction during the particular event and correctly identified the role of obstructions that reduce wind speed and enhance rainfall catch on the lee side of the obstruction. Again, students successfully combined knowledge of physical processes with the practical aspects of observing environmental variability. However, students were challenged by how to visualize such variability in four dimensions (3 spatial + 1 temporal) and produced several different types of figures (Fig. 3). This range of visualizations, none of which fully captured the variability, underscores the need to connect spatial data analysis skills (e.g., ArcPro, R) with field-based learning; an ability to measure and observe variability must be supported by the ability to convey the information to others.

3.3 Wind speed variability

Similar to the rainfall measurement described above, students identified vegetation as an important factor in modifying wind speed in the field. From a teaching perspective, describing the thickness of the boundary layer where such surface roughness factors play an important role in meteorology can be challenging since it varies greatly between locations. For example, students understood that wind speed tends to increase with height above the land surface, the result of moving away from a rough surface, but understanding how fast wind speed changes with distance provided a new learning opportunity. The variability of wind speed was measured at each of the eight rainfall gauges as described above in Section 3.2, at the gauge height and at ground level. During the measurement period, wind was coming from the SE at 3.1 m s^{-1}. Overall, wind speed was greatest on the windward side of the shrub at both heights and lowest on the leeward side. Wind speed measurements at 1.8 m above ground were consistently higher than those at ground level. In all cases, wind speed is greater at 2 m distance from the shrub.

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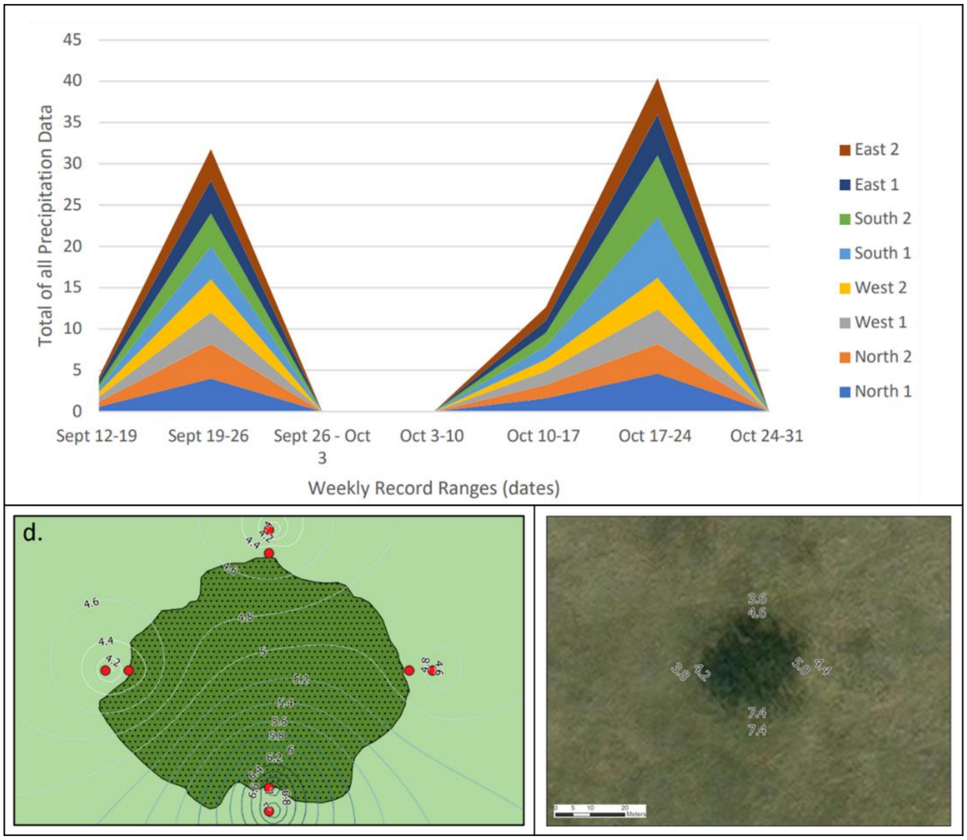

Figure 3: Examples of student attempts to document the spatial and temporal variability of rainfall catch around a vegetation obstruction at CMCA, October 23/24, 2022. The bottom images are selected from a collection of similar images reflecting the weekly sampling interval.

Table 2: Variability of wind speed around a large shrub. Wind speed (m s^{-1}) was recorded at eight locations around the shrub, at both ground level and at 1.8 m above the ground.

Wind speed [m s^{-1}]	N (ground / 1.8 m)	E (ground / 1.8 m)	S (ground / 1.8 m)	W (ground / 1.8 m)
at vegetation edge	0.2 / 0.3	0.6 / 2.5	0.5 / 2.8	0.0 / 0.6
2 m from edge	0.7 / 0.8	0.8 / 3.0	1.3 / 3.0	0.0 / 1.1

Again, like the precipitation measurement, students struggled to visualize the spatial variability of wind speed. In their reports, students clearly understood what they were observing and why it was happening but were unable to clearly describe the patterns in their writing or graphics. However, students were able to observe and measure wind speed variability at distances less than 2 m. This project also provided students with the greatest flexibility in developing a research design to acquire wind speed data. While the measurement itself was straightforward, students needed to develop a plan to consistently measure wind speed (a highly temporally variable weather element) such that the full set of results were directly comparable. This requires a great deal of foresight and teamwork, important soft skills in the training of environmental scientists.

3.4 Field-based learning about spatial variability of environmental data

The results described above certainly conform to results presented elsewhere (e.g., Ash and Wesson, 1983; Szkordilisz and Zöld, 2016; Al-Kaisi et al., 2017) and typically support the well-founded understanding of basic weather processes (e.g., Ahrens and Henson, 2018), and therefore are easily transferable to a traditional classroom-learning setting. However, the benefits of course-based research and field-based learning are well documented as beneficial to students, offering subject-specific, social, and "transferable" skills. (e.g., Oliver et al., 2018). In GEOG 390, students brought their prior knowledge of meteorological elements as acquired from previous courses and built upon that foundation by observing weather phenomena in real time. As described by one student: "Working with a real-world example was much more engaging than reading lectures about a site and analyzing random data". In the words of another student: "It is one thing to be taught this in a classroom setting but to have the experience of going out into the field and observing this relationship in person allows for the concept to be internalized". Clearly, students recognized the benefits of field-based learning as a component of the overall undergraduate learning experience.

One of the goals of GEOG 390 is to provide students with the opportunity to record their own observations of weather elements as opposed to being taught the relevant processes and patterns. To do so, students learn how to use the technology necessary to observe environmental variability, such as data loggers and a range of different sensors. Research planning and teamwork are also important skills developed concurrently with the technical skills. As one student describes, their knowledge of the relevant sensors allows them to "know exactly what we are talking about and we can often push the analysis further". Therefore, students are learning about the spatial variability of weather elements while also gaining the skills to deepen their learning. Furthermore, a student reported that they learned "practical skills which are essential in our future professions". When describing the opportunities to observe and measure weather variability *in situ*, one student commented that "[t]his type of experience is invaluable".

From a teaching perspective, conducting weekly field trips, each based on measuring a different weather element, is logistically complex and requires more planning and organization time than a classroom-based course. Environmental challenges (i.e., weather) also play a substantial role in dictating the success or failure of an individual project or the course as a whole. The local field site is an important component of the course and provides for weekly access. This also promotes accessibility and inclusion for students, as course fees are minimized, and it demonstrates that local, accessible areas are also valuable research sites (Tinsley, 1996). Although the results of the student research may not be on the frontiers of the science, they are valuable in strengthening students' learning experiences across several courses. The benefits of such increased teaching efforts are great. As described by Tinsley (1996), self-directed undergraduate fieldwork projects are "intellectually challenging, highly motivating, promote increased self-confidence, and provide a vehicle for the demonstration of a wide range of skills". In other words, for the sake of supporting students as they develop into environmental scientists or other professionals, it is well worth the effort.

4. Conclusion

At Chappell Marsh Conservation Area, near Saskatoon, SK, Canada, the spatial variability of key weather elements was observed and documented through a series of student-led research projects. Air and soil temperature, rainfall, and wind speed are all impacted to a greater or lesser degree by proximity to vegetation, height above the surface, and overall land surface type. Such understanding is well documented in past research and is translated to undergraduate students through a variety of classroom activities. However, by providing students with field-based activities focused on the observation of such variability, students gain a deeper insight into the spatial variability of these phenomena. Students report that such experiences are "invaluable" and "essential" to their education and future careers. While undergraduate field-based research is known to be logistically challenging, the efforts are worthwhile in providing a "high-impact" learning experience.

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