Assessing Ground Freezing Depth Variability During an El Niño Winter: A Frost Tube Approach

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Abstract:

El Niño is a periodic climate phenomenon marked by warmer than average sea surface temperatures in the Pacific Ocean, which can influence weather patterns in Southeast Michigan, potentially causing warmer winters with less snowfall and unusual precipitation patterns. El Niño events have implications greater than warmer weather, such as pest control. For example, mosquitoes need only a few centimeters of standing water to breed, and El Niño events generally stimulate insect outbreaks. This research utilized frost tube methodology to investigate the possible impact of **El Niño** winter conditions on ground freezing dynamics. At the study site, a frost tube was placed to monitor ground freezing depth throughout the winter season. Data on air temperature, surface temperature, snowpack depth, and other parameters were collected to assess relationships with ground freezing dynamics. The study focused on highlighting how El Niño winters possibly impact **ground freezing depth**, recognizing possible implications on infrastructure management and specie interactions in urban environments. Inverse relationships were observed between air temperature and freezing depth, freezing depth and surface temperature, and snowpack depth and air temperature. In contrast, direct relationships were observed between snowpack depth and freezing depth. These findings suggested snowpack insulation, considering any time a snowpack was present, the ground freezing depth was >0 centimeters. However, further analysis is required to fully understand the underlying mechanisms and implications of those mechanisms. Future research should aim to expand the scope of inquiry by incorporating additional variables and extending data collection across multiple winter seasons across multiple sites.

Key Words: El Niño, Ground Freezing Depth, Surface Temperature.

Research Question:

"How do variations in air temperature, snowpack depth, and surface temperature during the winter of 2023-2024 impact ground freezing levels in Southeast Michigan?"

Null Hypothesis:

Changes in air temperature, snowpack depth, and surface temperature collectively do not influence ground freezing levels in Southeast Michigan.

Introduction and Review of Literature:

When taking into consideration the infrastructure and environment of temperate regions, like Southeastern Michigan, the ground freezing levels are crucial to take into account. Many aspects of society require understanding ground freezing levels, such as construction, pest management, and water resource management. On a regular basis, the areas near the equator experience their normal weather and climate patterns; however, during El Niño events, warmer sea surface temperatures have been documented in the Pacific Ocean. This leads to disruption of global weather patterns. This also includes changes in precipitation patterns, warmer air temperatures, and decreased storm activity (See Figure 1). Although many studies have investigated the drawbacks of El Niño winters, few have discussed its implications on ground freezing dynamics, especially in southeastern Michigan.

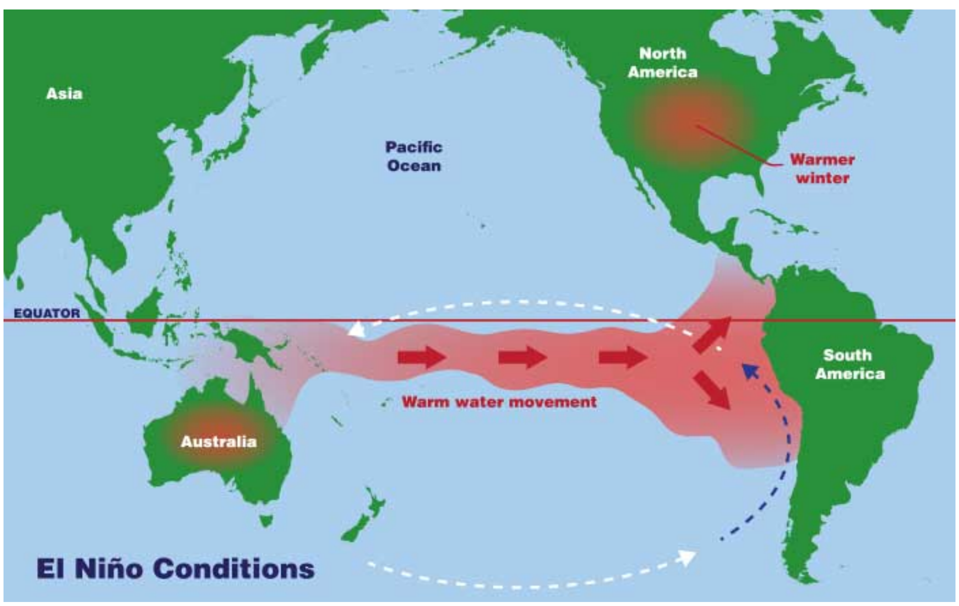


Figure 1: Map illustrating sea surface temperature anomalies (red) during an El Niño event. Source: NOAA 2020.

Studies investigating correlations between El Niño events and ground freezing dynamics sparse yet increasing. Research by Yu et al. (2012) showed that El Niño events may lead to warmer winters, which in turn causes more shallow ground freezing depths. Previous findings suggest that snowpack depth, air temperature, and surface temperature during El Niño events all contribute to the dynamics of ground freezing level. Although the contributions are made clear, the mechanisms that drive these changes are not fully clarified. In a study conducted by Power et al. (2020) in the midwestern region of the United States, the mechanisms which induced the drastic change in ground freezing levels during El Niño events were stated to be precipitation patterns and temperature. These mechanisms led to less snowpack collection and earlier melting of snow, which ultimately caused unusual ground freezing levels. Overall, these studies strengthen the idea that multiple variables must be considered to understand the complex dynamics of ground level freezing. Furthermore, recent advancements in remote sensing technologies, including satellite imagery and ground-based sensors, have paved the way for a better understanding of the changes in ground freezing dynamics during El Niño events. For instance, Li et al. (2021) used satellite-derived data to assess changes in snow cover and surface temperature in regions affected by El Niño, displaying the potential for remote sensing techniques to improve our understanding of ground freezing processes. Overall, while available research suggests a possible link between El Niño and ground freezing dynamics, more research is necessary in order to expose the underlying mechanisms and to assess the implications for regions such as Southeast Michigan. By addressing the lack of knowledge, we can better prepare for and understand the effects of climate on ground freezing depth in temperate regions.

Research Methods:

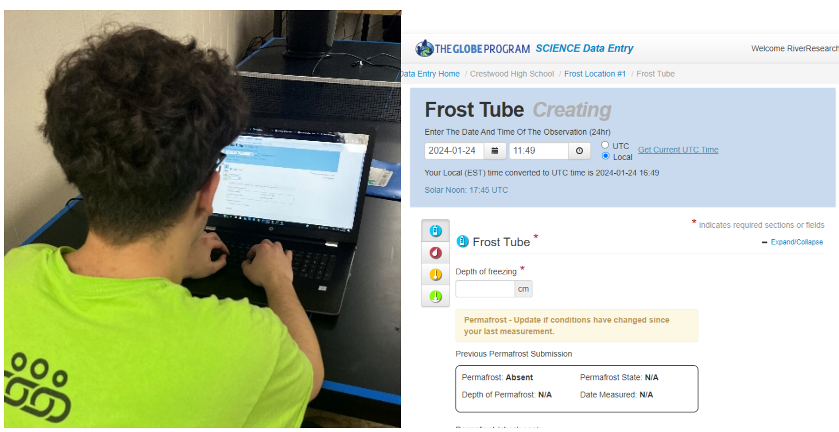
To investigate winter months, our research was planned to take place from early November through late February. However, although this period of time was selected so our data would be taken during some of the snowiest months, substantial snow did not fall until early January likely due to higher average temperatures as a result of El Niño conditions. Consequently, our research period took place from early January to mid-February. The site selected was in a local backyard. Our site's location was precisely determined using GPS coordinates. This site had not been previously defined as a GLOBE site. Before moving forward, the site had to be carefully established. Our team sampled a total of 32 times between January 10th and February 11th, once a day. Samples were taken at roughly the same time of day near evening. Following GLOBE protocols, we immediately measured surface temperature, using the ETEKCITY LASERGRIP 774 Infrared Thermometer, snowpack depth, using a measuring tape, and ground freezing depth, using the frost tube. The thermometer was calibrated prior to taking the measurements. All data was determined at the site using approved instruments. Three representative measures of temperatures were obtained and averaged in order to achieve a more representative result.

Figure 2 (Left); Visualization of site. Figure 2 shows the site where the frost tube data was collected. The figure shows the Backyard site (42°19'07"N 83°17'39"W), Google Earth 2022. Proximity to buildings and any vegetation can be seen. The site exactly is marked in red.

We were fortunate to receive a frost tube from Dr. Czajkowski of NASA Mission Earth-University of Toledo to use as a template for the device we made. We noted that his leaked fluid, so we created the same type using similar materials but made sure that no leakage occurred. To determine ground freezing data, a frost tube was assembled (Figure 3) using a 2-Meter, 20-Millimeter diameter PVC tube, 2 PVC caps, PVC cement, a 2-Meter, 7-Millimeter diameter clear tubing, a lighter, water, and food coloring. In constructing our Frost Tube for ground freezing level measurement, our team followed the systematic process outlined on the GLOBE website. Firstly, we estimated the below-ground length of the Frost Tube, considering factors such as frost depth or permafrost thickness in our research area (1 meter). We then determined the total length of the Frost Tube by adding 1 meter to the estimated below-ground length. Using PVC cement, we sealed the bottom of the outer PVC tube with a PVC end plug or cap. Next, we filled the clear inner tube with colored water, leaving approximately 15 cm from the top, and sealed both ends using a gas burner. After marking the inner tube every centimeter from ground level down, carefully, we inserted the sealed inner tube into the outer PVC tube, ensuring it reached the bottom. After placing the cap on top of the outer tube to seal it, we installed the Frost Tube assembly in the ground at the estimated depth, marking the soil surface on the outer tube for reference (Figure 5). To prevent external elements from entering, we securely fastened the cap on top of the Frost Tube, and with PVC cement over the cap on the end in the ground (Figure 4).. This meticulous process ensures the accurate measurement of ground freezing levels using our Frost Tube assembly in our research endeavors.

Figures 3, 4, & 5. Frost tube. Finished frost tube above ground (left), Installed Frost Tube (center), and Installing of the frost tube (right).

After all parameter measurements were obtained, the results were collected and averaged if needed. The data was compiled and entered in a spreadsheet then uploaded directly into the GLOBE website database. The data was then analyzed and interpreted for trends and/or patterns (Figures 6 & 7).



Figures 6 and 7. GLOBE data entry. All data that was obtained using GLOBE protocols was entered into the GLOBE database. The data that was submitted was on Air temperature, Surface temperature, Snowpack depth, and ground freezing depth.

Results:

Each of the frost tube parameters that we measured were graphed in order to visualize trends over the time period that data was collected. In our findings, all data was graphed in spreadsheets, and inputted into the GLOBE database.

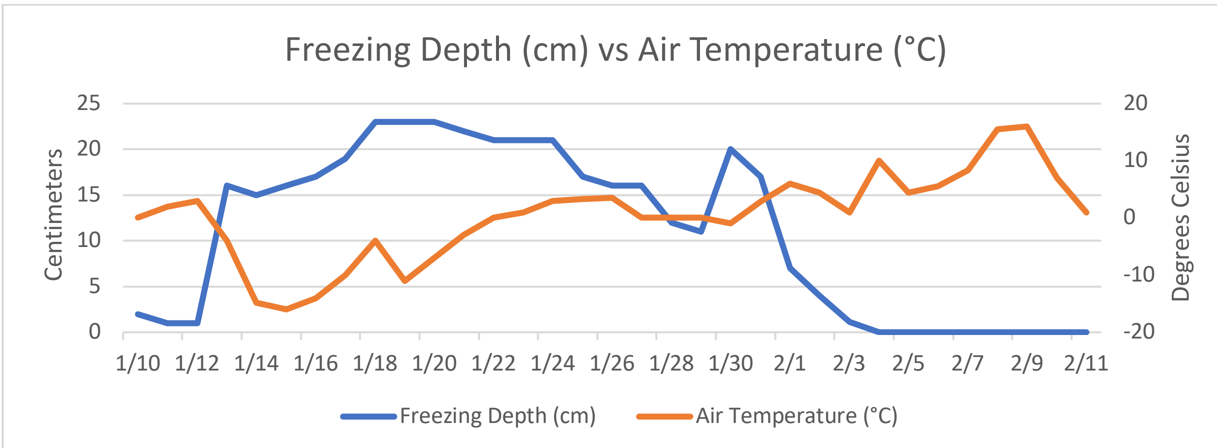


Figure 8. Freezing depth vs Air temperature. The graph above displays freezing depth (blue line) versus air temperature (orange line) in degrees Celsius. The graph displays depth in cm, and temperature in degrees Celsius. In the graphs, freezing depth and air temperature displayed clear inverse correlation. Typically, as air temperature decreased, freezing depth levels increased.

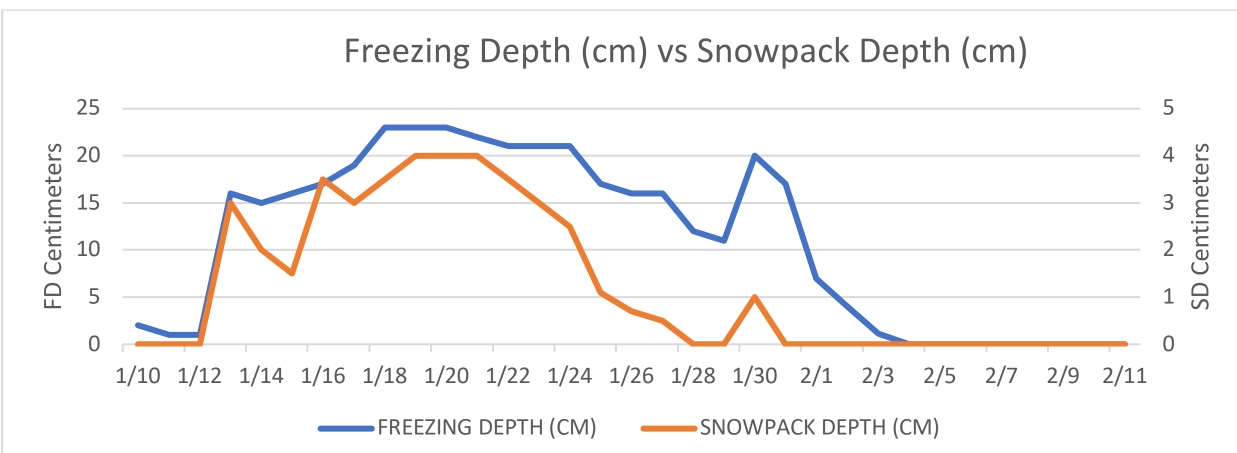


Figure 9. Freezing depth vs Snowpack Depth. The above graph displays freezing depth (blue line) versus snowpack depth (orange line). The graph displays depth in centimeters. Freezing depth and snowpack showed a direct correlation. Additionally, at any time a snowpack depth value was observed as >0, there was a freezing depth. This demonstrated the insulating effect of snowpack on ground freezing.

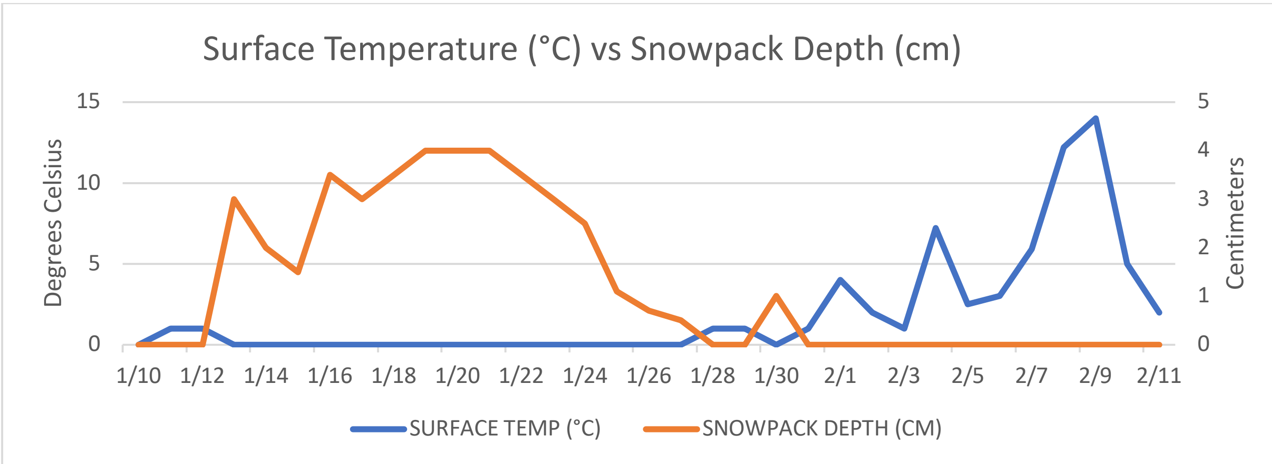


Figure 10. Surface Temperature vs Snowpack depth. The above graph displays surface temperature (blue line) versus snowpack depth (orange line). The graph displays depth in centimeters and temperature in degrees Celsius. Surface temperature and snowpack showed an inverse correlation. Additionally, at any time a snowpack depth value was observed as >0, the surface temperature was 0.

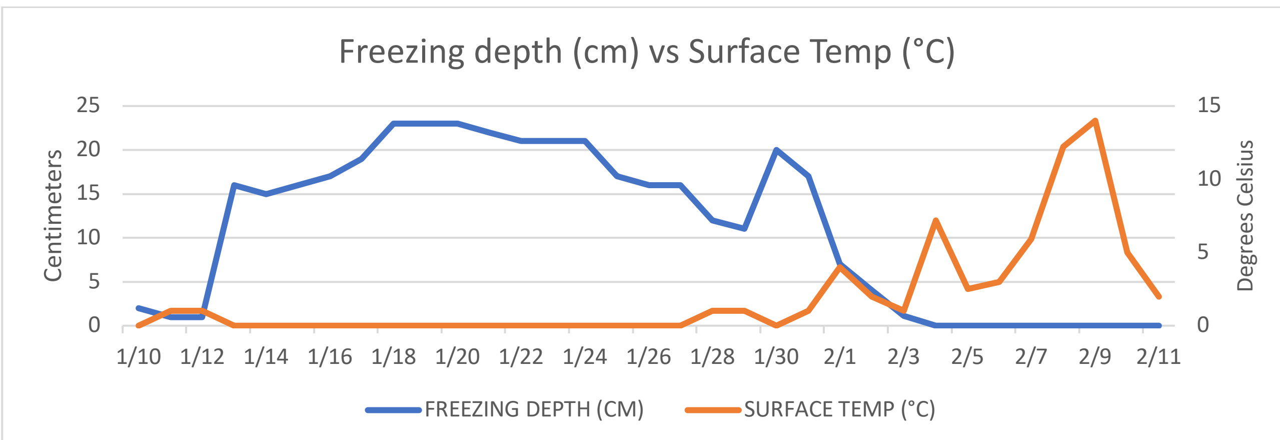


Figure 11. Freezing depth vs Surface Temperature. The above graph displays freezing depth (blue line) vs surface temperature (orange line). The graph displays depth in centimeters and temperature in degrees Celsius. Freezing depth and surface temperature showed an inverse correlation. Additionally, at any time a surface temperature value was observed as 0, there was a freezing depth value >0.

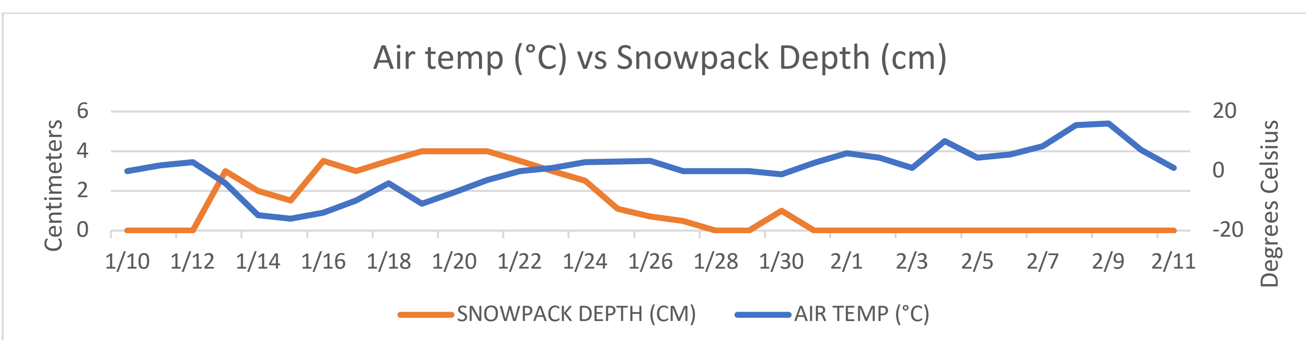


Figure 12. Air Temperature vs Snowpack depth. The graph above displays snowpack depth (orange line) versus air temperature (blue line) in degrees Celsius. The graph displays depth in cm, and temperature in degrees Celsius. In the graphs, snowpack depth and air temperature displayed clear inverse correlation. Generally, as air temperature decreased, snowpack depth levels increased, and vice versa.

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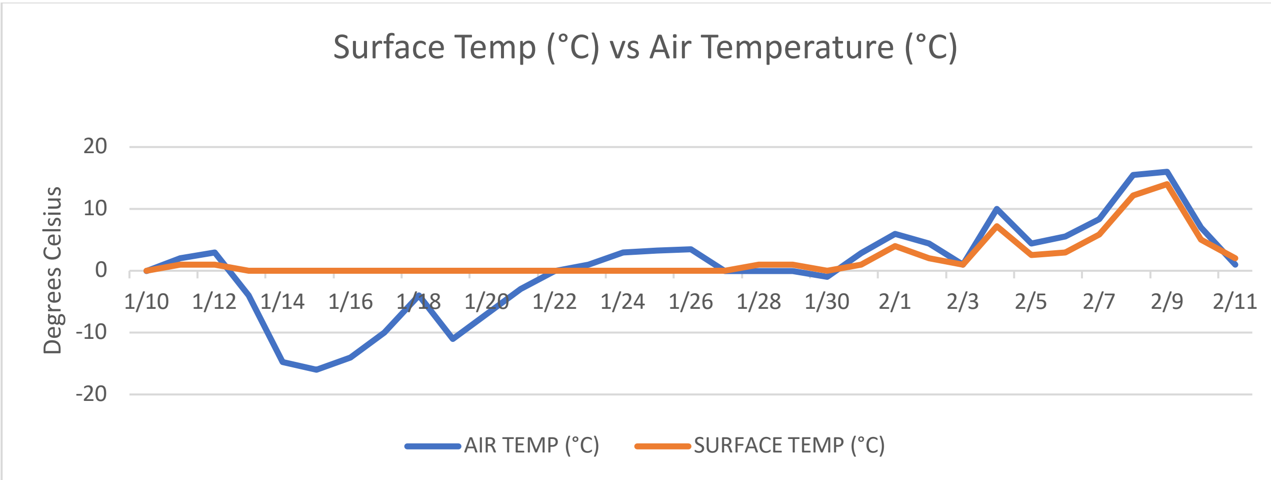

Figures 13. Surface Temperature vs Air Temperature. The above graph compares surface temperature to air temperature. Surface temperature and air temperature were both measured in degrees Celsius. These parameters displayed a direct correlation. As air temperature increased, so did the surface temperature; and vice versa. However, the surface temperature never dropped below 0 degrees, as fresh snow, at its coldest, is 0 degrees Celsius.

Discussion:

During our research on freezing depth during an El Niño winter in Southeast Michigan, we observed correlations between various parameters, with our data displaying significant correlations between air temperature, snowpack depth, surface temperature, and freezing depth, illustrating the dynamics of ground freezing processes. First, we identified an inverse relationship between air temperature and freezing depth. As air temperatures decreased, the freezing depth levels increased. This relationship highlights the direct impact of El Niño conditions on ground freezing dynamics. On the contrary, we observed a direct relationship between snowpack depth and freezing depth, displaying the insulating effect of snow on ground freezing. The presence of snowpack occurred simultaneously with observable freezing depth, revealing the role of snow cover in moderating ground temperatures. Furthermore, our observations highlighted an inverse relationship between surface temperature and snowpack depth. As snowpack depth increased, surface area temperatures would decrease. This highlights the cooling aspect of snow cover on surface temperatures, adding to the freezing in the ground layers. In addition, we observed an inverse relationship between freezing depth and surface temperature. When surface temperatures decreased to freezing levels, the freezing depths would increase, displaying the direct effect of surface conditions on ground freezing dynamics. Moreover, our research highlighted a pattern in the relationship between air temperature and snowpack depth. We found that snowpack depth had an inverse relationship with air temperature. As air temperatures decreased, snowpack depth increased, and vice versa. This observation emphasizes the complex interaction between atmospheric conditions and snow accumulation, which ultimately influences ground freezing processes. The data analysis provides valuable understanding into the dynamics of ground freezing during an El Niño winter in Southeast Michigan. By revealing these relationships, our study adds to a deeper understanding of the factors influencing ground freezing dynamics in temperate regions. However, it is important to note potential sources of error, including measurement inaccuracies and unusual weather conditions, which may have altered our findings. Additionally, human error, especially during the beginning stages of data collection, may have contributed to inaccuracies in measurements. Inexperience with the apparatus as well as difficulties in field calibration procedures could have influenced the reliability of our data. This potential error establishes the importance of constant monitoring and long-term data collection to verify our findings and highlight the dynamics of ground freezing in the region. The data analysis revealed significant relationships among parameters, indicating the effect of seasonal transitions and precipitation on freezing depth dynamics during an El Niño winter in Southeast Michigan. Finally, we reject our null hypothesis. Our findings refute the idea that changes in air temperature, snowpack depth, and surface temperature collectively have no influence on ground freezing levels in Southeast Michigan. Instead, our findings highlight significant relationships between these variables and freezing depth dynamics, revealing their connection in shaping ground freezing processes.

Conclusion:

Initially, we attempted to observe the ground freezing patterns during El Niño winters in Southeastern Michigan; however, due to the lack of snow and cold conditions between the times of Novermber 2023 to February 2024 this posed a challenge to our original plan. With our analysis, we accumulated 32 observations of cold weather events, but this, we concluded, would not be enough to provide a solid interpretation of ground freezing dynamics. Therefore, we decided to begin our research from the first major snowfall event to examine snowpack depth, air temperature, and surface temperature all in regards to ground freezing levels. With these observations we came across an intricate relationship that these variables posed on ground freezing levels in southeastern Michigan. With this, we concluded that to accurately understand ground freezing levels in southeastern Michigan many factors must be put into consideration. After analyzing our research, certain areas of improvement could be made in future research attempts. Expanding the sites of data across more areas in southeast Michigan is an aspect of our research that could be enhanced. Using areas which include rural or suburban could better allow us to understand the variables that must be considered when investigating ground freezing levels. In conclusion, we hope our research will lead to the further understanding of the effects that El Niño winters have on ground freezing levels in Southeastern Michigan. Although we ran into limitations, including but not limited to limited periods of snow fall, our studies aimed to highlight the importance of considering multiple factors when assessing ground freezing levels. Moving forward we hope to inspire the younger demographic of researchers to take on research regarding the frost tube, hopefully expanding the areas of study. The expansion of our sampling sites, enhancement of our materials, and growth of our knowledge will be crucial in bettering our understanding of the ground freezing level dynamics and progressing the environment and infrastructure of southeastern Michigan.

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Photo "El Nino diagram" NOAA 2020 Copyright

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BADGES:

I am a Data Scientist: Over a 1-month period, we tested a local site and collected data of parameters and how they are affected by environmental factors associated with fluctuations in the environment. Apart from data collected by our group, we utilized data from the NOAA. We then analyzed the data gathered with tools, utilizing Excel Spreadsheets, and making graphs to examine relationships among parameters. We found numerous patterns between the factors of temperature and precipitation, and the parameters of snowpack and ground freezing depth. The data collected and analyzed from our own collection and other sources allowed us to effectively draw conclusions and answer our research questions.

I make an Impact: Ground freezing levels are critical to analyze due to their significant impact on infrastructure stability, agricultural practices, ecological systems, water resources, and climate dynamics. Understanding the depth and duration of ground freezing is essential for engineers and planners to design resilient infrastructure that can withstand seasonal freeze-thaw cycles. Farmers rely on knowledge of ground freezing to optimize planting and harvesting schedules, while changes in freezing patterns can disrupt ecosystems and biodiversity. Ground freezing also influences groundwater recharge rates and water movement through soil, affecting water availability and quality. Additionally, ground freezing serves as an indicator of broader climate trends, making it valuable for climate research and understanding the effects of climate change on terrestrial systems. Overall, our analysis for freezing levels provides crucial insights for managing environmental resources and mitigating the impacts of changing climatic conditions.

I am a STEM Storyteller: Rami Eter, a GLOBE researcher on our team, founded a grassroots local environmental organization, "The Green Project", earlier in 2022. In the time since, Rami created an Instagram account in order to best share local and global environmental news, information, and other content to the community. In order to creatively share what was learned by the group, Rami and the other group members decided to share a post with the community, through an Instagram post on the account. This post highlighted the story of our research, and what was learned, in a creative, well-designed way. The post can be viewed on

Instagram on the account @thegreenproject_dh.