Exploring the Urban Heat Island (UHI) Trend in Taiwan's Capital

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Abstract

Studies on the urban heat island (UHI) effect in Taiwan primarily focus on short-term analysis, typically covering a period of about one month. Additionally, many references do not clearly define the distinction between urban and rural areas.

We analyzed the UHI index in Taipei City from May 2020 to December 2023, calculated using the monthly average temperature from the Taipei Station of the Central Weather Administration (CWA) minus the monthly average temperature from HTSH DAVIS Station. We then incorporated gridded surface station data to compensate for areas without meteorological stations. The second version of the TCCIP gridded dataset was selected, and grid points above 100 meters in elevation were removed to prevent altitude from affecting temperature estimations. Within the urban area below 100 meters, the highest and lowest temperature grid points were selected to calculate UHI intensity.

Our findings indicate that 2020–2023 surface station data showed a declining trend in the UHI index, while 1960–2022 gridded data exhibited an increasing trend. This discrepancy led us to further investigate the possible causes. At the same time, we hope to increase the density of meteorological stations to make the data more reflective of everyday life.

Introduction

In our GLOBE class, the teacher introduced the concept of the urban heat island (UHI) effect. During our daily observations, we also noticed that the temperature at our school differs from that in the city center, which sparked our interest in this topic. We became curious—is the UHI effect intensifying under the influence of global warming?

To explore this question, we collected temperature data from HTSH DAVIS Station and the Taipei Station of the Central Weather Administration (CWA) for comparison. By analyzing the trend of UHI intensity changes, we aim to identify the factors affecting the UHI effect. Our goal is to contribute insights that can serve as a reference for urban climate adaptation policies in Taiwan.

Research Objectives

1. To analyze the changes in the urban heat island (UHI) from July 2020 to December 2023.
2. To examine the UHI trends and characteristics in Taipei City over a 63-year period from 1960 to 2022.
3. To compare the advantages and limitations of gridded data and surface station data.

Data Analysis Methods and Process

1. Definition of the Urban Heat Island (UHI)

The urban heat island effect refers to the phenomenon where urban areas experience higher temperatures than their surrounding rural areas due to human activities, climate factors, vegetation cover changes, and building material modifications. The UHI is a metric used to quantify the intensity of this effect, calculated as follows:

UHI index = Urban Temperature - Rural Temperature【Howard, L. (1833)】

2. Defining Urban and Rural Temperature Locations

- Urban temperature: Monthly average temperature from the Taipei Station of the Central Weather Administration (CWA).
- Rural temperature: Monthly average temperature from HTSH DAVIS Station (located at an elevation of approximately 15 meters).

Figure 1: HTSH DAVIS Station at Hsintien High School

3. Data Collection and Processing

We used temperature data from May 2020 to December 2023, collected from meteorological stations. To eliminate altitude-induced temperature variations, we only analyzed data from locations below 100 meters in elevation. We verified that Hsintien High School is situated below this threshold.

Following the definition of the UHI index, we calculated:

UHI index = Urban temperature - Rural temperature, which is obtained by subtracting the monthly average temperature of HTSH DAVIS Station from the monthly average temperature of the Central Weather Administration's Taipei station.

This allowed us to assess the intensity of the urban heat island effect in Taipei City.

Station Locations

Figure 2: Location of Taipei City

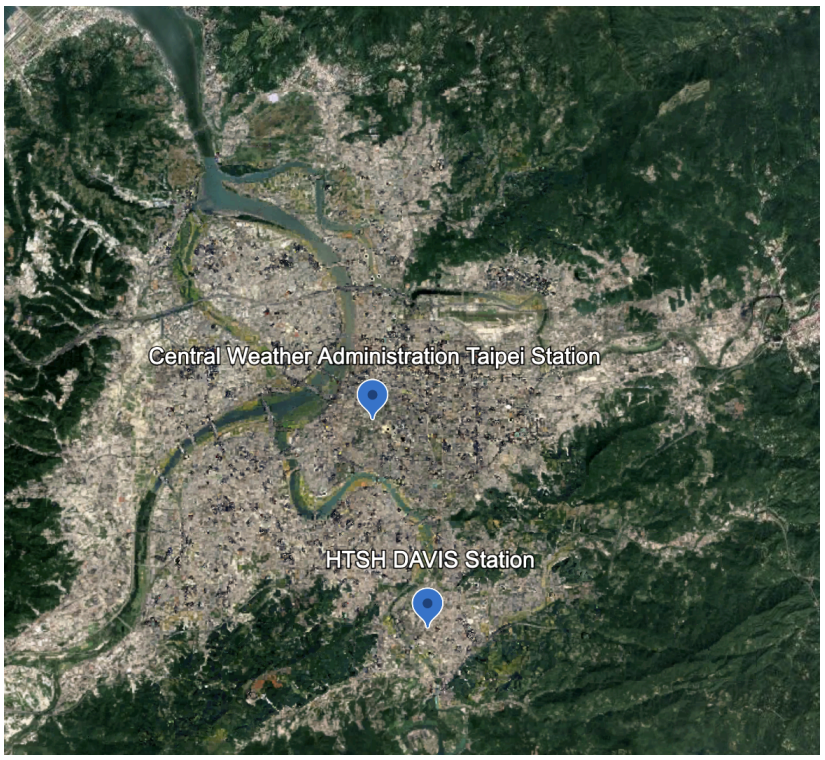

Figure 3: Station placement map

Software and Tools

1. Microsoft Excel and spreadsheets:
   Utilized to organize data, perform various calculations, and create line charts, allowing direct comparisons between different datasets to gain deeper insights into trends and correlations.
2. Taiwan Climate Change Projection and Information Platform (TCCIP):
   Daily gridded temperature data (1960-2022) was obtained from the Taiwan Climate Change Projection and Information Platform (TCCIP) website. The grid size is 1 km × 1 km, with the grid height representing the center elevation of each grid. A total of 164 grids were used, with each grid represented by its central latitude and longitude, covering an area of 0.01° × 0.01°.
3. QGIS Geographic Information System:
   Used to visualize point coordinates on a map, helping facilitate discussions and better understanding of the research content.
4. PHP programming language:
   Utilized to efficiently remove grid points above 100 meters in Taipei City and convert daily average temperatures into monthly averages for analysis.

5. Atmospheric Science Research and Application Databank (ASRAD):
   Used to obtain meteorological data from the Taipei Station.
6. HTSH DAVIS Station:
   Used to collect campus temperature data from Hsintien High School.

Research Results

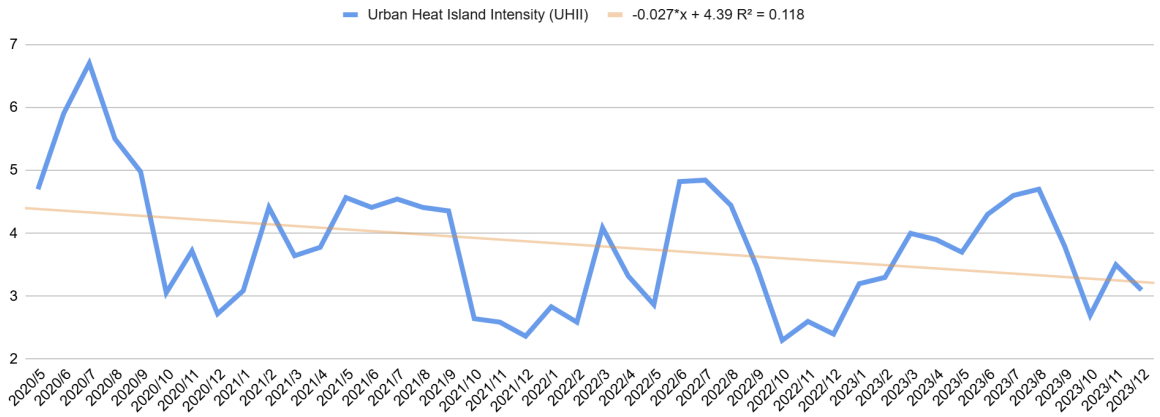

Figure 4: Changes in the Urban Heat Island (UHI) from July 2020 to December 2023

According to Figure 4, the trend of the UHI index from May 2020 to December 2023 is shown. The blue line represents the actual UHI index, while the orange line illustrates the overall trend. The trendline equation is y = -0.027*x + 4.39, with an R^2 value: 0.118

Table 1: UHII for Each Month of the Year

	Years			
Months	2020	2021	2022	2023
1		3.1	2.8	3.2
2		4.4	2.6	3.3
3		3.6	4.1	4.0
4		3.8	3.3	3.9
5	4.7	4.6	2.9	3.7
6	5.9	4.4	4.8	4.3
7	6.7	4.5	4.8	4.6
8	5.5	4.4	4.4	4.7
9	5.0	4.4	3.5	3.8
10	3.1	2.6	2.3	2.7
11	3.7	2.6	2.6	3.5
12	2.7	2.4	2.4	3.1
Average	4.7	3.7	3.4	3.7

This table reveals that the UHI is higher in summer and weaker in winter. Notably, in July 2020, the UHI reached its highest value of 6.7. Additionally, 2020 had the highest annual average temperature, while 2022 had the lowest annual average temperature.

Discussion

The research results indicate that the UHI from May 2020 to December 2023 shows a downward trend. This differs from our initial expectation of an increasing trend, prompting us to further investigate the long-term changes in the UHI in Taipei City.

For this extended analysis, we utilized gridded data, which helps address the issue of areas lacking meteorological stations. We selected the second version of the TCCIP gridded observation dataset. However, directly using this dataset to select the lowest temperature as the rural temperature might lead to the selection of mountainous regions. To prevent altitude from influencing temperature measurements, we excluded grid data above 100 meters in elevation and retained only temperature data below this threshold. Within this urban range (below 100 meters), we selected the highest and lowest temperatures from the gridded data to estimate the UHI intensity.

1. Data Analysis Methods and Process

A. Defining Urban and Rural Temperature Locations

Urban Temperature : The grid point with the highest monthly average temperature within the urban area below 100 meters in elevation.

Rural Temperature : The grid point with the lowest monthly average temperature within the urban area below 100 meters in elevation.

B. Data Collection and Processing

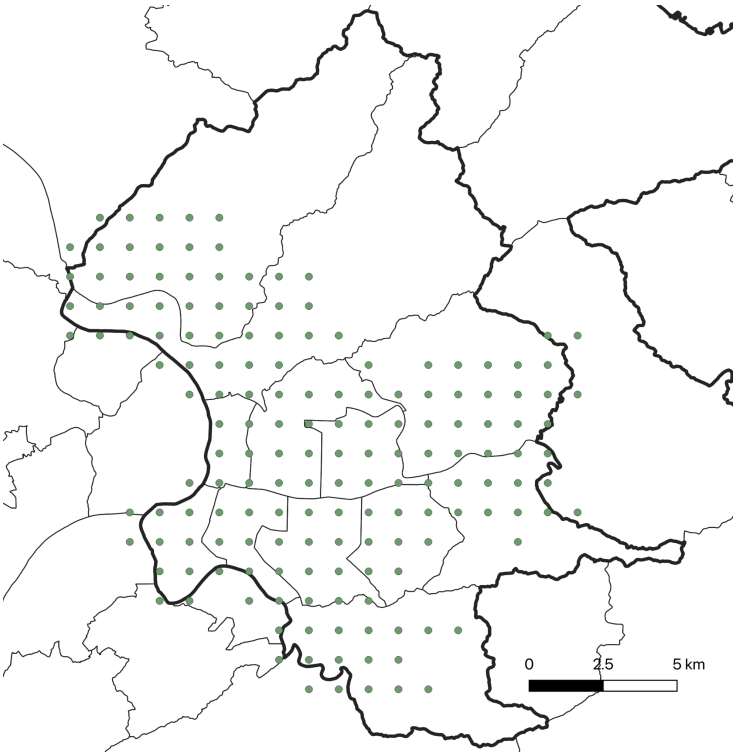

Figure 5: Location of Grid Points Below 100 Meters in Taipei City (A total of 164 grid points were selected, covering a study area of approximately 164 km²)

We used gridded temperature observation data (daily average temperature) from 1960 to 2022. To prevent altitude from affecting temperature measurements, we first removed grid points above 100 meters in elevation, reducing the impact of altitude-related temperature decreases that could otherwise misrepresent rural areas.

Next, we developed a program to calculate the monthly average temperature for each grid point each year. From the monthly temperature dataset, we identified the highest and lowest temperatures, defining the highest temperature as the urban temperature and the lowest temperature as the rural temperature. By subtracting these values, we obtained the urban heat island (UHI).

To refine our analysis, we calculated the five-month moving average of the UHI. Finally, we integrated the processed data and visualized it as a line chart for further analysis.

Table 2: Partial Calculation of the Urban Heat Island (UHI)

	Grid	January	February	March	April	May	June	July	August	September	October	November	December
121.46	25.1	15.9	16.8	20.3	20.4	23.8	27.2	29.1	27.3	27.5	23.8	21.3	16.6
121.46	25.11	15.9	16.8	20.2	20.4	23.7	27.2	29.1	27.3	27.5	23.8	21.3	16.6
121.46	25.12	16.0	16.8	20.3	20.4	23.7	27.0	29.1	27.2	27.3	23.6	21.2	16.6
121.46	25.13	15.9	16.7	20.3	20.3	23.6	27.0	29.0	27.2	27.2	23.6	21.2	16.6
121.47	25.1	15.9	16.7	20.2	20.3	23.7	27.1	29.0	27.2	27.4	23.8	21.2	16.6
121.47	25.11	16.0	16.8	20.3	20.3	23.7	27.0	29.1	27.2	27.3	23.6	21.2	16.6
121.47	25.12	15.9	16.8	20.3	20.3	23.7	27.0	29.1	27.2	27.3	23.6	21.2	16.6
121.47	25.13	15.9	16.7	20.3	20.3	23.6	27.0	29.0	27.2	27.2	23.6	21.2	16.6
121.47	25.14	15.8	16.6	20.1	20.1	23.5	26.8	28.9	27.0	27.1	23.4	21.0	16.4
121.48	25.03	15.8	16.7	20.2	20.3	23.7	27.1	29.0	27.2	27.4	23.7	21.2	16.5
121.48	25.04	15.8	16.7	20.2	20.4	23.7	27.1	29.0	27.2	27.5	23.8	21.2	16.6
121.48	25.1	16.0	16.8	20.3	20.3	23.7	27.0	29.1	27.2	27.3	23.6	21.2	16.6
121.48	25.11	16.0	16.8	20.3	20.3	23.7	27.0	29.1	27.2	27.3	23.6	21.2	16.6
121.48	25.12	16.0	16.8	20.3	20.3	23.7	27.0	29.1	27.2	27.3	23.6	21.2	16.6
121.48	25.13	16.0	16.8	20.3	20.3	23.7	27.0	29.1	27.2	27.3	23.6	21.2	16.6
121.48	25.14	15.6	16.4	19.9	19.9	23.3	26.6	28.7	26.9	26.9	23.3	20.9	16.2
121.49	25.01	15.9	16.7	20.3	20.4	23.7	27.2	29.1	27.3	27.5	23.8	21.2	16.6
121.49	25.02	15.9	16.7	20.3	20.4	23.7	27.2	29.1	27.3	27.5	23.8	21.2	16.6
121.49	25.03	15.8	16.7	20.2	20.3	23.7	27.1	29.0	27.2	27.4	23.7	21.2	16.5
121.49	25.04	15.9	16.7	20.2	20.4	23.7	27.2	29.1	27.3	27.5	23.8	21.2	16.6
121.49	25.09	16.0	16.8	20.3	20.3	23.7	27.0	29.1	27.2	27.3	23.6	21.2	16.6
121.49	25.1	16.0	16.8	20.3	20.4	23.7	27.0	29.1	27.3	27.3	23.7	21.3	16.6
121.49	25.11	15.9	16.7	20.3	20.3	23.6	27.0	29.0	27.2	27.3	23.6	21.2	16.6
121.49	25.12	16.0	16.8	20.3	20.3	23.7	27.0	29.1	27.2	27.3	23.6	21.2	16.6
121.49	25.13	16.0	16.8	20.3	20.3	23.7	27.0	29.1	27.3	27.3	23.7	21.3	16.6
121.6	25.07	15.9	16.7	20.2	20.1	23.5	26.9	28.9	27.0	27.2	23.4	21.1	16.5
121.6	25.08	15.9	16.8	20.2	20.2	23.5	26.9	28.9	27.1	27.2	23.5	21.2	16.6
121.6	25.09	15.9	16.8	20.2	20.2	23.5	26.9	28.9	27.1	27.2	23.5	21.2	16.6
121.61	25.03	15.9	16.7	20.2	20.1	23.4	26.9	28.9	27.0	27.2	23.4	21.1	16.5
121.61	25.04	15.8	16.7	20.1	20.1	23.4	26.8	28.8	27.0	27.1	23.4	21.0	16.4
121.61	25.05	15.9	16.7	20.1	20.1	23.4	26.8	28.8	27.0	27.1	23.4	21.1	16.5
121.61	25.06	16.0	16.8	20.3	20.2	23.6	27.0	29.0	27.1	27.3	23.5	21.2	16.6
121.61	25.07	15.9	16.7	20.2	20.1	23.5	26.9	28.9	27.1	27.2	23.5	21.1	16.5
121.61	25.08	15.7	16.5	19.9	19.9	23.2	26.6	28.7	26.8	27.0	23.2	20.9	16.3
121.61	25.09	15.6	16.4	19.9	19.9	23.2	26.6	28.7	26.8	26.9	23.3	20.8	16.3
121.62	25.04	16.0	16.8	20.3	20.2	23.6	27.0	29.0	27.1	27.3	23.5	21.2	16.6
121.62	25.05	16.0	16.9	20.3	20.3	23.6	27.0	29.0	27.2	27.3	23.6	21.2	16.6
121.62	25.06	16.0	16.9	20.3	20.3	23.6	27.0	29.0	27.2	27.3	23.6	21.3	16.7
121.62	25.07	15.9	16.8	20.2	20.2	23.5	26.9	28.9	27.1	27.2	23.5	21.2	16.6
121.62	25.08	15.7	16.5	19.9	19.9	23.2	26.6	28.7	26.8	27.0	23.2	20.9	16.3
121.62	25.09	15.9	16.7	20.1	20.1	23.4	26.8	28.9	27.0	27.1	23.4	21.1	16.5
121.62	25.1	15.7	16.5	20.0	20.0	23.3	26.7	28.7	26.9	26.9	23.3	20.9	16.3
121.63	25.04	15.8	16.6	20.1	20.0	23.4	26.8	28.8	26.9	27.1	23.3	21.0	16.4
121.63	25.08	15.7	16.6	20.0	19.9	23.3	26.7	28.7	26.9	27.0	23.3	20.9	16.3
121.63	25.1	15.9	16.7	20.1	20.1	23.4	26.8	28.8	27.0	27.1	23.4	21.1	16.5
	Maximum temperature	16.0	16.9	20.4	20.4	23.8	27.2	29.1	27.3	27.5	23.8	21.3	16.7
	Minimum temperature	15.6	16.4	19.9	19.9	23.2	26.6	28.6	26.8	26.9	23.2	20.8	16.2
	Heat Island Index	0.4	0.5	0.5	0.5	0.5	0.6	0.5	0.5	0.6	0.6	0.4	0.4

2. Trend of Urban Heat Island (UHI) Changes in Taipei City

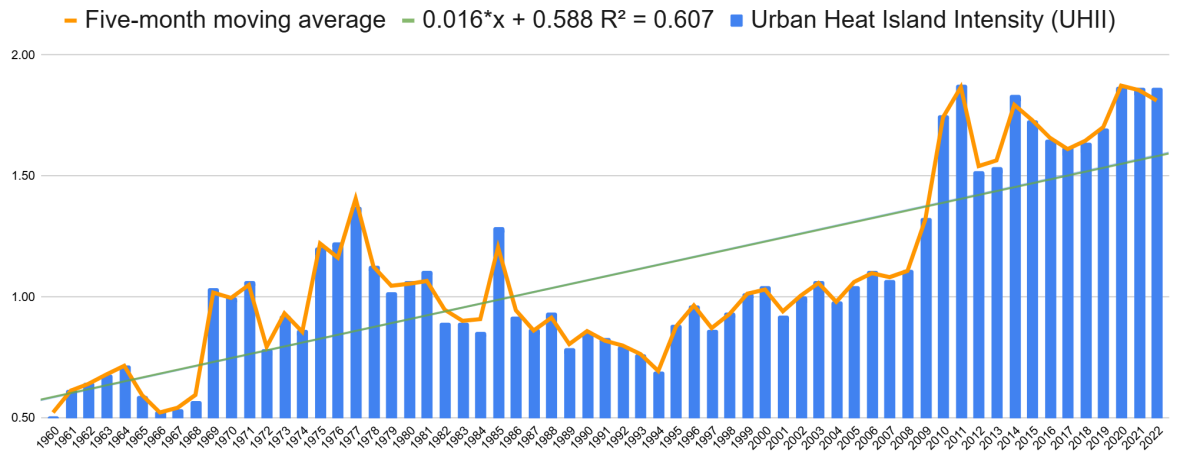

Figure 6: Annual Average Urban Heat Island (UHI) and Five-Month Moving Average in Taipei City (1960-2022)

In Figure 6, it is evident that the UHI in Taipei City has shown an overall increasing trend from 1960 to 2022, with values ranging between 0.42 and 2.38. The bar chart illustrates annual variations and fluctuations, where the UHI remained relatively low between 1986 and 2008 but began to rise around 2009, with a faster growth rate compared to previous decades.

The linear regression equation for the trendline is $y = 0.016x + 0.588$, with an R^2 value of 0.607, indicating a moderately strong correlation. This suggests that the intensity of the UHI effect has increased by approximately 1.6°C per century.

3. Comparison of the Advantages and Limitations of Gridded Data and Surface Station Data

Surface station data provides direct measurements of local temperatures, making it more suitable for small-scale observations. However, a single station's readings can be influenced by its surrounding environment. For example, in our case, the school’s weather station is placed on the rooftop. If the station were relocated to a grassy area, next to a classroom, or near a sports field, the recorded temperature might differ significantly.

On the other hand, gridded data helps reduce environmental influences by averaging temperature values over a spatial grid. It also compensates for areas without meteorological stations, making it more appropriate for large-scale studies and long-term climate research. While surface station data is essential for detailed, localized monitoring, gridded data is better suited for analyzing broader temperature trends and urban climate changes over extended periods.

4. Discussion on the Differences in Overall Trends Between Station Data and Gridded Data

The gridded data aligned with our expectations, as we believe that the urban heat island (UHI) effect should intensify with global warming. However, the UHI derived from station data showed a decreasing trend. The station data covers a relatively short time scale, reflecting only the trend over the past three years.

We believe that the recent decline in the UHI is due to Taipei's urban development

reaching saturation, leading to population migration to surrounding areas. For instance, Hsintien has experienced population growth and increased vehicle emissions, contributing to rising temperatures. Additionally, in recent years, the government has actively promoted green buildings in urban areas. These buildings can reduce the absorption of solar radiation, which has contributed to a slight cooling effect in Taipei.

Conclusion

1. The average rate of change in the UHI based on 2020–2023 surface station data indicates that the urban heat island effect in Taipei City has decreased by approximately 2.7°C per century.
2. The average rate of change in the UHI based on 1960–2022 gridded data shows that the urban heat island effect in Taipei City has increased by approximately 1.6°C per century.
3. The monthly average temperature at Taipei Station is consistently higher than that at HTSH DAVIS Station.
4. We hope to continue collecting temperature data from Hsintien High School to further investigate whether the urban heat island effect is intensifying under global warming.
5. We also hope to increase the density of automatic weather stations in the future, allowing for more detailed and practical temperature data analysis relevant to daily life.

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Appendix

Supplementary Program Code for Data Processing

```
public function csvStep1($input) {
    $heightDataOfCity = $input['heightDataOfCity'];
    $cityName = $input['city'];
    $startYear = $input['startYear'];
    $endYear = $input['endYear'];
    $heightLimit = $input['heightLimit'];


    $filePathTaiwan = storage_path('app/public/taiwanInfo_' . $heightDataOfCity . '.csv');
```

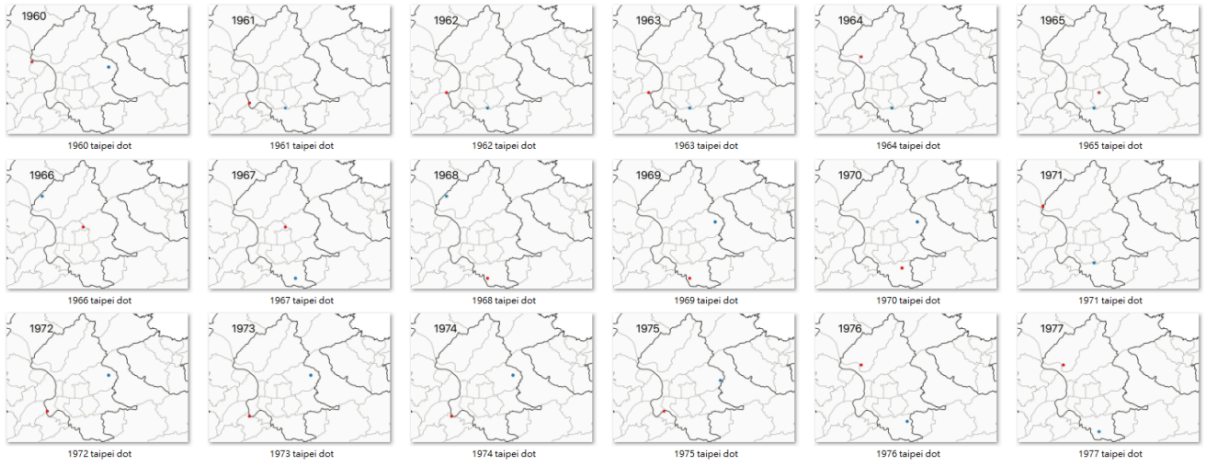
```
        $taiwanCsv = array_map('str_getcsv', file($filePathTaiwan));
        unset($taiwanCsv[0]);

        $taiwanList = array();
        foreach ($taiwanCsv as $key => $info) {
            $taiwanList[] = [["LON" => $info[0], "LAT" => $info[1]], ["HEIGHT" => $info[2]]];
        }

        for ($year = $startYear; $year <= $endYear; $year++) {

            $filePathCity = storage_path('app/public/' . $cityName . '/' . $cityName . 'Info_' . $year .
'.csv'); // 檔案路徑
            $cityCsv = array_map('str_getcsv', file($filePathCity));
            unset($cityCsv[0]); // 移除標題

            $cityList = array(); // 台中「經緯度」列表

            foreach ($cityCsv as $key => $info) {
                $cityList[] = ["LON" => $info[0], "LAT" => $info[1]];
            }


            $searchResult = array(); // 這裡存的是台灣csv的key值
            foreach ($taiwanList as $key => $info) {
                if (in_array($info[0], $cityList)) {
                    $searchResult[] = $key;
                }
            }

            $cityRequiredList = array();
            foreach ($searchResult as $key => $searchKey) {
                if ($taiwanList[$searchKey][1]['HEIGHT'] > $heightLimit) {
                    continue;
                }
                $cityRequiredList[] = $taiwanList[$searchKey];
            }
            $result = array();
            foreach ($cityRequiredList as $key => $info) {
                $keyInCityCsv = array_search($info[0], $cityList) + 1;
```

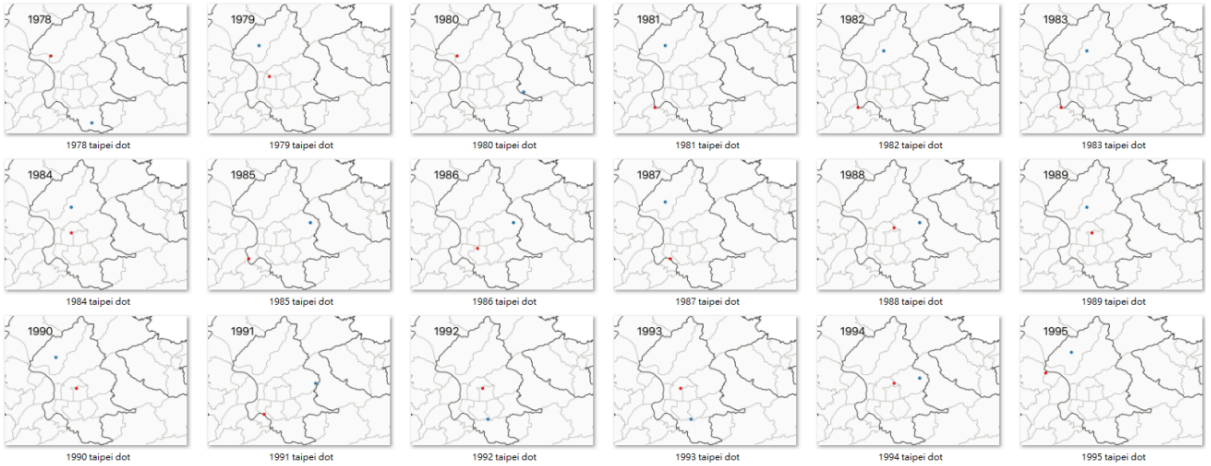
```
            if ($keyInCityCsv) {
                unset($cityCsv[$keyInCityCsv][0]);
                unset($cityCsv[$keyInCityCsv][1]);
                $result[] = ["Location" => ["HEIGHT" => $info[1]["HEIGHT"], "LON" =>
$info[0]["LON"], "LAT" => $info[0]["LAT"]], "Temperature" => $cityCsv[$keyInCityCsv]];
            }
        }


        $this->csvHelper->ganerate($cityName, $cityName . "_" . $year);
        $multiRowData = array();
        foreach ($result as $resultInfo) {
            $rowData = array();
            // $rowData[0] = $resultInfo["Location"]["HEIGHT"];
            $rowData[1] = $resultInfo["Location"]["LON"];
            $rowData[2] = $resultInfo["Location"]["LAT"];
            for ($i = 2; $i < count($resultInfo["Temperature"]) + 2; $i++) {
                if($resultInfo["Temperature"][$i] == -99.9){
                    $rowData = array();
                    break;
                }
                $rowData[$i + 1] = $resultInfo["Temperature"][$i];
            }
            if(count($rowData) > 0){
                $multiRowData[] = $rowData;
            }
        }
        // $outputData = array_map(null, ...$multiRowData); // 矩陣反轉

        $outputData = $this->calMonthAverage($multiRowData, $year); // 計算月平均

        $this->csvHelper->setMultiRowData($outputData);
        echo $this->csvHelper->finish();
    }
  }
  public function calMonthAverage($multiRowData, $year) {
    $outputData = array();
    $outputData[0][0] = "";
    $outputData[0][1] = "網格";
```

```
        $outputData[0][2] = "月份 1";
        $outputData[0][3] = "月份 2";
        $outputData[0][4] = "月份 3";
        $outputData[0][5] = "月份 4";
        $outputData[0][6] = "月份 5";
        $outputData[0][7] = "月份 6";
        $outputData[0][8] = "月份 7";
        $outputData[0][9] = "月份 8";
        $outputData[0][10] = "月份 9";
        $outputData[0][11] = "月份 10";
        $outputData[0][12] = "月份 11";
        $outputData[0][13] = "月份 12";
        foreach ($multiRowData as $data) {
            $daysInMonth = 0; // 每個月有幾天
            $startIndex = 2; // 從第幾個索引開始算平均溫度
            $rowData = array(); // 每筆網格對應的12個月份月均溫
            $rowData[0] = $data[1]; //
            $rowData[1] = $data[2];
            for ($month = 1; $month <= 12; $month++) {
                $daysInMonth = Carbon::create($year, $month, 1)->daysInMonth;
                $averageTempInMonth = array_sum(array_slice($data, $startIndex, $daysInMonth)) /
$daysInMonth;
                $startIndex += $daysInMonth;

                $rowData[$month + 1] = $averageTempInMonth;
            }
            $outputData[] = $rowData;
        };
        $onlyAverageTempData = $outputData;
        $columnLength = count(array_column($onlyAverageTempData, 0));

        $outputData[$columnLength + 1][0] = "";
        $outputData[$columnLength + 1][1] = "最高溫";
        $outputData[$columnLength + 2][0] = "";
        $outputData[$columnLength + 2][1] = "最低溫";
        $outputData[$columnLength + 3][0] = "";
        $outputData[$columnLength + 3][1] = "熱島指數";

        for ($monthIdx = 2; $monthIdx <= 13; $monthIdx++) {
```

```
        $column = array_filter(array_column($onlyAverageTempData, $monthIdx), 'is_numeric');

        // 計算最大值與最小值及列長度
        $maxValue = max($column);
        $minValue = min($column);

        $outputData[$columnLength + 1][$monthIdx] = $maxValue;
        $outputData[$columnLength + 2][$monthIdx] = $minValue;
        $outputData[$columnLength + 3][$monthIdx] = $maxValue - $minValue;



    };
    return ($outputData);
  }
```

1960 – 2022 Taipei Urban and Rural Point Coordinates





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