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ACTUALIDAD TECNOLÓGICA

Variabilidad de temperatura a corto plazo en una ciudad andina tropical Manizales, Colombia

Short-term temperature variability in a tropical andean city Manizales, Colombia

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Resumen

En La variabilidad climática en las zonas tropicales andinas es alta, tanto espacial como temporalmente, y su análisis se debe realizar tanto en el corto plazo como en el largo plazo, dependiendo de la información disponible. Este tipo de análisis conjunto espacio-temporal proporciona herramientas para la planificación y la gestión ambiental en las zonas urbanas, dada la alta complejidad que se presentan en la zona. Esta investigación se centra en un diagnóstico del ciclo diurno y el análisis de la estructura mensual de la temperatura en 13 estaciones localizadas en la ciudad de Manizales, Caldas (Colombia). El comportamiento encontrado se corresponde con lo definido previamente por otros autores para la zona andina, es decir la temperatura en la ciudad presenta patrones muy estables, pero a nivel intra-diario se aprecian variaciones importantes en la amplitud de la temperatura a lo largo y ancho de la ciudad y durante el día.

Palabras clave: Ciclo diurno; ciclo mensual; ciudad tropical andina.

Abstract

The climatic variability in the Tropical Andes area is high, both spatially and temporally, and its analysis must be carried out both in the short and long term depending on the available information. This type of spatial-temporal analysis provides tools for planning and environmental management in urban areas, given its high complexity. This investigation focuses on a diagnosis of the diurnal cycle and the analysis of the monthly temperature structure in 13 stations located in the city of Manizales, Caldas (Colombia). This applied research aims to understand the behavior of the temperature in a tropical Andes city in Colombia, where the spatial-temporal complexity of this variable improves the urban and hydrological planning strategies. Results correspond to what has been previously defined by other authors for the Andean zone: city temperature shows very stable patrons, yet important variations in temperature range across the city are appreciated during the day.

Keywords: Day-night cycle; Monthly cycle; tropical Andean city.

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1. Introducción

Temperature is one of the most important climate variables used by planners and decision makers. Different indicators such as extreme values of temperature, its average or range are used. For instance, average temperature trends have been used to analyze climate change over long terms, while changes in extreme temperatures are used to plan activities such as engineering, agriculture, energy generation, etc. Average values are analyzed through anomalies, that is, values above or below the norm, in order to monitor the appearance of cold or hot waves. These have numerous implications for society and living things, such as diseases development, plant productivity, livestock development, and risk assessment. These analyzes are performed over different time periods (e.g., intra-annual or intra-daily), to know the impact that causes temperature changes over each period.

In tropical regions, temperature is considered one of the most important mechanisms in the global hydrological cycle and in determining evapotranspiration in one place [1], [2]. The processes that intervene in temperature dynamics in the tropics are complex and more so in the Andean areas of Colombia, since the meteorological processes are of high spatial and temporal variability in some areas. Because Colombia is located in the tropical zone, the average temperature behavior on the surface is strongly conditioned by the height above the sea level.

The analysis of this variability can be carried out in a short term, when the data lapses from few years ago and has a high resolution, or in a long term, when the information dates from many years back. Both analyses help characterize and know the time and space consistencies in climatic variables. In the short-term, understanding the intra-daily and intra-annual cycle of temperature is important for many reasons, mainly due to the fact that the amplitude and phase of this cycle is the result of the interaction between the dynamic and radioactive processes. The success degree in explaining these processes is a useful measure for understanding atmospheric physics at these time scales [3].

The intra-annual temperature cycle is important because in tropical areas there are precise cycles that should theoretically take place each year (warm and cold seasons). However, monthly fluctuations may occur and affect the activities programmed in the economic and biotic system of a region. One way to analyze monthly temperature fluctuations above or below normal ones is through anomalies, which is applied in this study to observe temperature changes during each year from 2010 to 2018. The anomaly represents deviation in degrees Celsius above or below the norm. High anomalies may be related to the occurrence of dry periods due to the El Niño South Oscillation, ENSO [4].

The daytime temperature cycle is a fundamental factor in the formation, development and intensity of deep convection, a very important mechanism in the genesis of tropical rain. Rain and cloudiness strongly influence surface (by net surface radiation) and atmospheric (by latent heat release) temperatures [5]. Some factors that directly affect local atmospheric dynamics and cause changes in diurnal temperature cycles are orography, solar radiation, and thermodynamic cloudiness [6]; highly variable factors in Colombia. Temperatures typically decrease with altitude increase; however, the opposite can occur under certain conditions. For instance, some authors mention the influence of heat stroke, inversion, catabatic winds and cold air drainage over the temperature gradient in mountainous areas [7]–[10]. Thus, the temperature gradient is highly variable in mountains according to studies conducted in areas with average altitudes between 1200 and 5000 masl, ranging between 0.3-0.9°C/100m [7], [11]–[17]. The changes that occur in daytime cycles should be added to this complexity, due to the urban areas from which local climate areas are generalized, as has been widely documented [18]–[22]. The high heterogeneity of the physical processes in the cities can be attributed to the variability of the urban surface. In Colombia, there have been multiple studies on the daytime precipitation cycle and some on temperatures [1], [23], [24], [24]–[30]. Numerous international studies have also been carried out on the matter, yet there is still a lack of studies that explain all aspects of daytime temperature cycles for all tropical zones, for which further research is required [31], [32].

The aim of this study is to characterize the daytime temperature cycles in the city of Manizales, a tropical Andean city, considering the hydrometeorological data of the city stations in the *Red de la Unidad de Gestión de Riesgo* during 2010-2018 [33]. This network belongs to the *Sistema de Monitoreo Integrado Ambiental de Caldas* (Caldas Integrated Environmental Monitoring System - SIMAC), which has been working to improve meteorological information to perform this type of analysis. SIMAC is a recent system and now has 124 hydrometeorological stations installed; yet only 13 allow the last 9 years to be analyzed simultaneously. The interannual and multiannual analysis of climatic variability in the long term was not carried out in this investigation basically because there aren't long enough series to carry out a rigorous and detailed analysis in Manizales. Even so, the information is relevant because it contributes to the understanding of spatio-temporal variability in the short term in a tropical mountain city, which, due to the lack of measurements, could not be carried out previously.

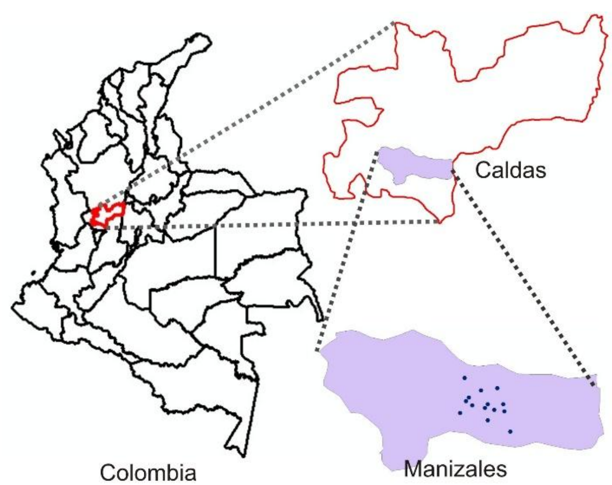
2. Materials and Methods

2.1. Study area

The study takes place in the city of Manizales, capital of the department of Caldas, located in the central western region of Colombia, over the extension of the Andes. It has proper mount characteristics such as its average pendant 25% and an average altitude of 2153 masl. Given its geographical location, Manizales has a bimodal climate, and each year there are two winter and two dry seasons, typical of the Intertropical Confluence Zone ITCZ [32], [34]. Due to Manizales's geographical location and to its orography of large slopes there are snow, woods, mountains and valleys, and so on. That is, the city's relief is especially mountainous. The city has eight microclimates in an urban area, with an average temperature of 18°C with a bimodal climate. For the rainiest months, precipitation reaches values between 100 and 500 mm, and for the less rainy months, precipitation ranges between 100 and 300 mm, with an inverse relationship between temperature and rain [35].

Twelve meteorological and one hydrometeorological station, all distributed in the urban area of the city of Manizales, Caldas and monitoring the flood with Davis sensors with a resolution of 0.1°C will be used. Figure 1 shows the stations from the landslide-risk management used in this study. Its temperatures are recorded and managed every five minutes by the Universidad Nacional de Colombia in Manizales. Their data are available at a call center (Centro de Datos e Información Ambiental de Caldas or CDIAC) [36]. The most ancient station was installed in 1997 and the overlapping years between stations were 2010-2018, thus, it was the lapse chosen for analysis.

Figure 1. Location of the city of Manizales and of the hydrometeorological stations used in the study.



Fuente: elaboración propia.

2.2. Methodology

Table 1 shows a summary of the temperature records of each station used in the research. Data is collected each five minutes and the Bosques station perform the highest missing data but due to resolution, it was included in the study.

Table 1. Summary of the temperature records for Manizales' monitored network.

Station	N° data	Mean (°C)	Missing data (%)
Alcázares	926784	18.57	7.85
Aranjuez	946656	18.25	11.83
Bosques	946656	17.38	21.60
Carmen	946656	17.50	10.48
CHEC	811584	19.81	13.19
EMAS	946656	18.35	14.80
La Nubia	946656	17.31	12.53
Hospital	946656	17.34	13.38
Milán-Planta Niza	946656	17.72	5.63
La Palma	946656	18.45	13.29
Posgrados	946656	16.98	4.13
Yarumos	946656	16.16	12.55
Ruta 30	946656	17.64	4.42

Fuente: elaboración propia.

From the temperature data with a five-minute temporal resolution T_i the average hourly values $\overline{T_h}$ are obtained for each hour. From them $\overline{T_h}$, the monthly mean values of each hour ***h*** are obtained for each year ***a*** $\overline{Thm}$, m (m=1,….,12), *a* (*a*=1,…,na) averaging daily values for each year.

$$\overline{Thma} = \frac{1}{365}\sum_{d=1}^{365} Thma_d \quad (1)$$

These values helped obtain the multiannual monthly hourly mean values $\overline{Thm}$, as the average of the previous values for all years at (*a*=1,…,*na*).

$$\overline{Thm} = \frac{1}{9}\sum_{a=1}^{9} Thma_a \quad (2)$$

The monthly mean values for each year were obtained as the average of the hourly values of each month, averaging all the hours of each month.

$$\overline{Tma} = \frac{1}{24}\sum_{h=1}^{24} \overline{Thma_h} \quad (3)$$

The multiannual monthly average values $\overline{Tmma}$ were obtained as the average of the monthly values of each year (a = 1,…, na).

$$\overline{Tmma} = \frac{1}{9}\sum_{a=1}^{9} \overline{Tma_a}$$

The maximum $\overline{T_x}$ and minimum $\overline{T_m}$ schedules were obtained, from the temperature data with a five-minute time resolution $T_{i,}$, obtaining the maximum and minimum values of each hour, each day *d*, each month *m*, of each year *a*, values that were averaged in turn. Each previous analysis is shown in graphs that show the space and time variability of the temperature with respect to spatio-temporal analysis, which will serve as a tool for planners' decision making in the city of Manizales.

The possible relationship with elevation is explored by performing a temperature correction for which the methodology by [37] was used. The methodology consists in eliminating the effect of altitude on temperature values by standardizing them with respect to a reference value according to the equation:

$$T_{DET} = T_h + \left(\Gamma \cdot (Z_{DET} - Z_{REAL})\right)$$

Where T_{DET} is the standardized temperature, T_h is the average real temperature at a given time (°C), Γ is the slope that is obtained with the linear correlation equation, Z_{DET} is a reference height chosen in masl (in this case 1900 masl) and Z_{REAL} is the actual height of the station. For this methodology to give reliable results, the correlation must be greater than 80%. This spatial analysis identifies aspects such as heat island.

3. Results and Discussion

One of the predominant characteristics of the annual distribution of temperatures during the year shows a small bimodal regime for most of the Andean region [38], which is consistent with the presence of ITCZ.

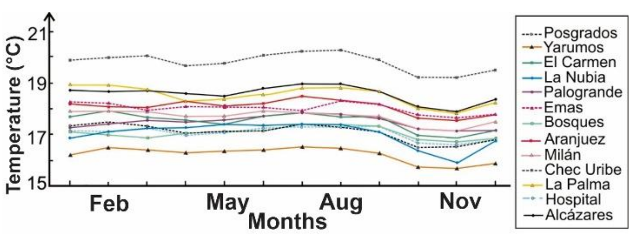
3.1. Annual cycle

The results of multiannual average values for the period 2010-2018 are shown in Figure 2. In each of the stations, bimodality is evidenced in the annual temperature cycle, that is to say that there are two seasons of 3 months, each one of low and high temperatures respectively, where the months with the highest temperature of the year are June to August (JJA) being the hottest season and from December to February (DJF); and those of lower temperature from March to May (MAM) and from September to November (SON), where the second season has lower temperatures, which coincides with what is reported in the literature [31], [32].

The temperature in the city varies between 12.9 ºC recorded in Yarumos and 22.8 ºC in Chec Uribe, which evidences that the city has a high variability in monthly averages. There is also high variability in temperatures in some seasons, where temperature gradients can be up to 10°C in Posgrados, Yarumos and Ruta 30.

The behavior of the average values throughout the year is quite homogeneous, with very few variations (around 1° for most stations) and with a maximum variation of 2°C in the La Nubia station.

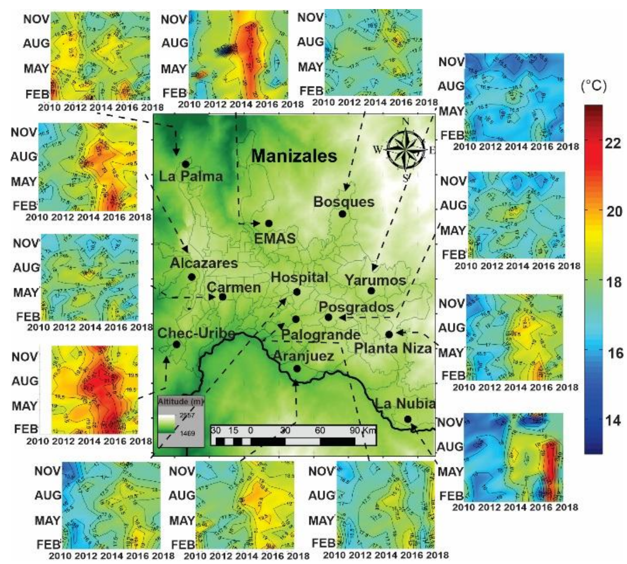
Figure 2. Multiannual monthly average temperature for hydrometeorological stations used in the study.



Fuente: elaboración propia.

When discriminating the previous behavior by years (see Figure 3), the years 2010-2011 and 2017-2018 were much colder than normal, especially in November for almost all the stations analysed (except La Palma, El Carmen, Posgrados and Yarumos for the first period, and Alcázares, Aranjuez, La Nubia, Hospital, Milán-Planta Niza and Ruta 30 for the second). According to IDEAM in 2010 during the months of May and June, conditions close to the neutrality of the El Niño - Southern Oscillation ENSO prevailed, but then, specifically in July, there was a rapid change towards the cold phase (La Niña, or cold phase of ENSO), a month after which the Oceanic Niño Index (ONI) certifies the occurrence of La Niña, which lasted until May 2011. That period became one of the coldest and rainiest in general for the Colombian Andean area, practically eliminating the dry mid-year season and the second rainy season was one of the strongest winters in Colombia, generating numerous events triggered by the rains (landslides and floods) [4].

Figure 1. Annual average monthly temperature for hydrometeorological stations used in the study.



Fuente: elaboración propia.

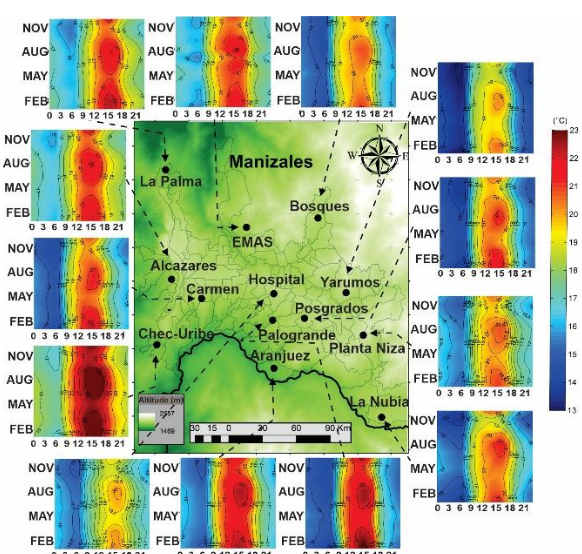
Figure 3 also shows that the year 2015 had a positive anomaly in all seasons (higher temperatures than normal), especially high in Emas where it was 113% for that year (20.73°C/18.39°C). This period was preceded or followed by another year of positive anomaly in all stations, that is to say alternating between 2014-2016 between stations and in the case of Alcázares, Aranjuez, Hospital de Caldas and Milán-Planta Niza said trend continued until 2018. In fact, this behavior was sustained in the following years for some of those stations such as Aranjuez, La Nubia, Milán-Planta Niza and Alcázares. This behavior highlights the Yarumos station, where temperatures have remained within the normal range, as well as Posgrados, both stations located near wooded areas.

If the behavior of the temperatures is observed taking the altitude into account, the areas that register the highest temperatures during the year are Chec-Uribe (1940 masl), Alcázares (2057 masl) and La Palma (1967 masl) because they are lower in altitude and they are to the west of the city, followed very closely by Emas and Aranjuez while those that register the lowest temperatures are Yarumos (2195 masl, located to the northeast), Posgrados (2179 masl, located in the center), and La Nubia (2091 masl, located east of the city) all at similar altitudes and with large forest cover to its surroundings.

3.2. Day-night cycle

The diurnal cycle of the temperature in the city (see Figure 4) has a unimodal behavior throughout the day, due to the incidence of sun hours between 6:00 a.m. and 6:00 p.m. and night hours between 6:00 p.m. to 6:00 a.m, with small variations due to the tropical condition in the city. The hours of minimum average temperature are from 4:00 am to 6:00 am and those of maximum between 10:00 am to 6:00 pm. for the entire period analyzed.

Figure 4. Multi-annual hourly average temperature for each month for sliding management in each station.

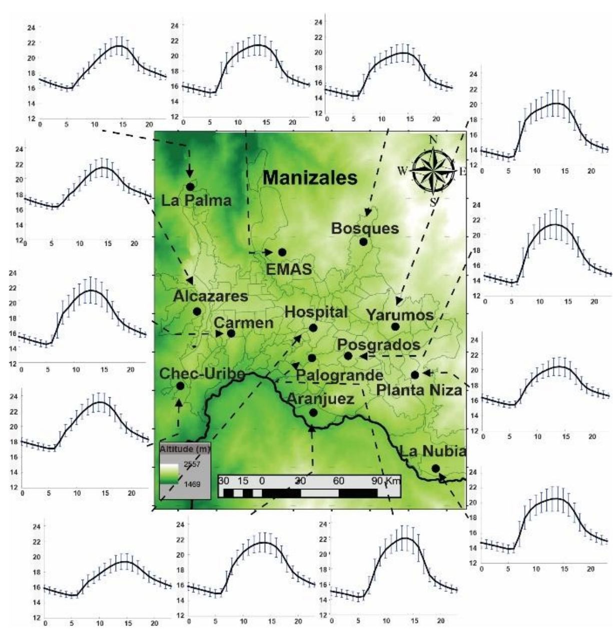


Fuente: elaboración propia.

The station that shows the highest maximum temperatures is Chec-Uribe, followed by Aranjuez and Q. Palogrande Ruta 30 near 23°C, while the stations with the lowest maximum are Hospital de Caldas, Milán-Planta Niza, Los Yarumos and Bosques (~ 20°C). The lowest minimum values were at Los Yarumos and Posgrados stations, followed by Q. Palogrande Ruta 30, La Nubia and Bosques.

This behavior was analyzed with the variation between the maximum and minimum hourly values for each station as shown in Figure 5. The graphs for all the stations show the behavior of the diurnal temperature cycle. Early morning is a moment with temperature decreases, which reaches a minimum towards 6:00h, coinciding with the sunrise time for Manizales. This period is followed by a long period of heat until reaching the point of maximum temperatures T_{max} that occur approximately around 3:00 p.m., after which the temperatures decrease again.

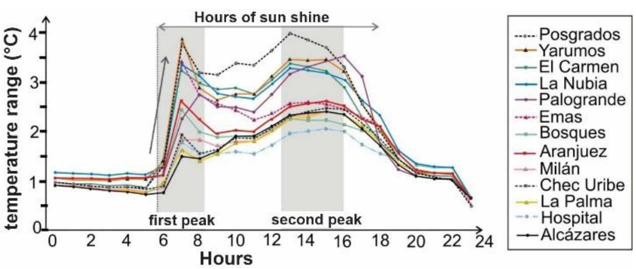
Figure 2. Minimum, average and maximum hourly temperature for stations selected for the study.



Fuente: elaboración propia.

Figure 5 shows that the temperature range is not homogeneous throughout the city, with maximum values at the Posgrados stations, Q. Palogrande-Ruta30, Yarumos and El Carmen with a maximum daily amplitude close to 10°C. The stations with the lowest daily temperature range are Hospital de Caldas (5.8°C), Milán-Planta Niza (6.5°C) and Alcázares (6.7°C). A more detailed review of the hourly temperature ranges (see Figure 6) allows concluding that the greatest hourly temperature ranges occur at noon with the same spatial variability indicated above. The maximum values in the amplitude vary between 1°C and 4°C per hour, the latter is considered an important change from one hour to another, as seen between 6:00 and 7:00am, otherwise it happens at sunset with a smoother, presumably due to the heat island effect in the city, also reported by Roncancio (2013).

Figure 3. Temperature range for the hydrometeorological stations used in the study.



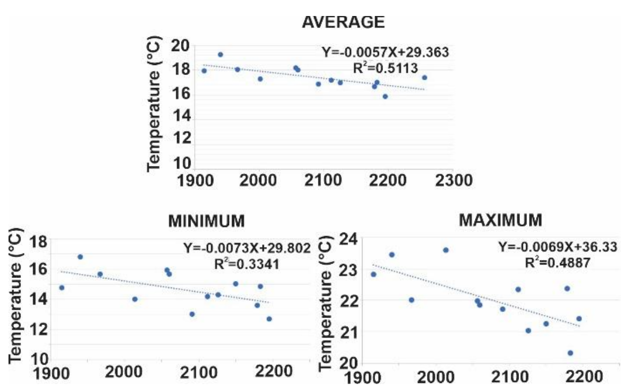
Fuente: elaboración propia.

Figure 6 shows two gradient peaks during the day, the first at 7:00 am, which is more pronounced at the Yarumos and Posgrados (~ 3.7°C), followed by La Nubia, Emas and El Carmen (~ 3.3°C) and then for the following stations the first gradient peak decreases. It is notable that the rate at which said gradient changes for Posgrados, Yarumos, Emas, La Nubia, El Carmen and La Nubia stations is quite considerable (~ 1.2°C/h) as highlighted by the increasing gray strip in the Figure 6. The second peak occurs between 1:00 p.m. - 4:00 p.m. for the different seasons, where the highest gradients are in Posgrados, Yarumos, El Carmen and La Nubia with values much higher than in other stations. Palogrande-Ruta 30 stands out, which has the same two peaks in the hourly temperature gradients, but displaced one or two hours with respect to the rest of the stations, which can be explained by being a hydrometeorological station located in the trough of the Palogrande creek. Almost all stations that have high temperature gradients in the first peak have similar gradients in the second peak with the exception of Emas, which remarkably changes the gradient with respect to 7:00 am, first with 3.4°C difference and then 2.6 °C.

3.3. Temperature gradient with altitude

Altitude standardization showed correlations of 0.5, 0.3 and 0.5 with the mean, minimum and maximum values and gradients with the elevation of -0.57, -0.73 and -0.69°C/100 m respectively (see Figure 7), values found within the reported literature [39]. This supports the high variability of these gradients in mountain areas, and it is also observed that the variation for the minimum temperature is much higher than for maximum and average values. This behavior has also been documented in cities where several authors report increases in minimum temperatures due to the effect of urbanization [21].

Figure 4. Temperature-elevation Ratio (T-E) for the considered stations.

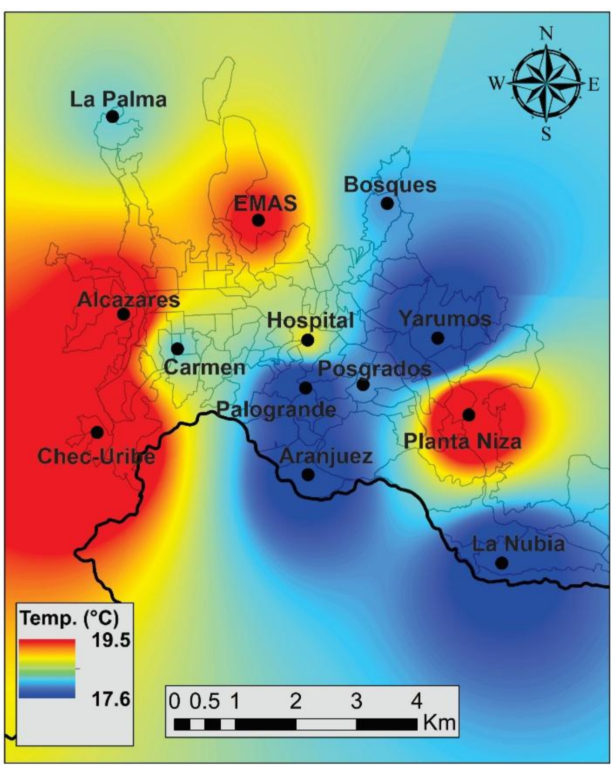


Fuente: elaboración propia.

With the temperature maps corrected by altitude (see Figure 8) the existence of the heat island effect that had been reported by Roncancio (2013) is shown, where the temperature is higher in the center and outside of the city to the west. From the Hospital station located in the geographic center towards the west, a warming of the city is observed, with very intense points at Emas (north-west), Alcázares (west) and Chec (south-west) stations. The latter was not identified by Roncancio's study because he considered 7 stations only. According to Roncancio's findings, whose maximums are within the urban area in the commercial center of the city (former transport terminal, Villapilar clinic), this effect is due to the high concentration constructions in that sector and that the winds do not manage to dissipate the heat accumulated in the day. 6.23% of the commercial area was presented for the year, in addition to the historical, political center (the Department and the Mayor's Office of Manizales), religious (Cathedral) and the financial district [40].

Higher temperatures are difficult to explain in the Chec-Uribe station that corresponds to a peri-urban area and where, according to the literature, temperatures should drop [21], although there is an electrical substation, which could be an explanation.

Figure 5. Homogenized annual multiannual temperature at 1900m for landslides-risk management in each station of Manizales.



Fuente: elaboración propia.

The intra-hour effect of heat island is also observed, which shows that the temperature is lower in the morning hours, before sunrise, on the outskirts of the city. However, the distortion of the Chec-Uribe station, which is greatly influenced by its elevation, stands out again, as well as the lower temperature amplitude at noon due to the heat island effect, clearly observed in the Hospital de Caldas area.

4. Conclusions

In this article, a spatial and temporal description of the temperature in the city of Manizales is made, which is located on the slopes of the Central mountain range heavily influenced by the orography, where variations for the diurnal cycle are observed for a relatively small area, monthly and throughout the city. The density of temperature monitoring stations is very high according to international recommendations, but these results justify the monitoring density given the variability observed.

In the maximum, average and minimum temperatures, bimodality is evident in the monthly cycle consistent with the ITCZ reported by various studies as identified in the introduction. Therefore, higher temperature months coincide with the rainiest months (MAM and SON) and, on the contrary, those of lower temperature with less rain (JJA and DJF). The change is relatively small month to month (~ 1°C) which indicates a low temporal variability, but on the contrary the spatial variability is quite high with gradients of up to 10°C between extreme points of the city.

On a daily level, the temperature responds to the thermodynamic conditions imposed by the radiative heating exhibiting a unimodal behavior in the hourly cycle, which was also reported in the literature, with the greatest gradients towards noon, and maximum in the period 12:00- 2:00 p.m. As for the spatial distribution of this behavior, the intraday temperature gradient in some stations is quite pronounced with daily amplitudes close to 10°C, with two temperature peaks changes during the day, the first, very pronounced, between 6:00 and 8:00 and the second between 12:00 and 16:00.

Temperature analysis with the altitude corroborates the linear relationship between these two widely supported variables. This correlation stands out for the stations analyzed because they are weak in the city (R^2 = 0.5) due to the short range of elevations, but it can be noted that the stations that have the lowest peaks are south-east or south of the city, presumably due to the effect of the humid air masses that come from the Cauca river valley located to the west and that ascent in precipitation in this area, lowering temperatures. Even so, the temperature-altitude gradients found (-0.5°C/100 m to –0.7°C/100 m) have been reported in different studies carried out in mountain areas.

Additionally, these results coincide with the heat island effect in other studies for the urban area of the city of Manizales, confirming the existence of this phenomenon in the city for the central and western zone.

Knowing the diurnal cycle and the intra-annual structure of precipitation and temperature becomes a planning tool for the territory and a reference input for builders in the city. For example, works in the city of Manizales may schedule their concrete or pavement emptying at the most convenient times of the day or in the months of the year to guarantee construction efficiency.

Finally, this analysis should be updated as more information becomes available and serves as a baseline for the city of Manizales in different future studies, such as heat island analysis, climate change and climate analysis and evapotranspiration studies in urban areas, among many other aspects.

5. Data availability statement

The data that support the findings of this study are available in Caldas environmental information and data center (CDIAC because of its name in Spanish) at http://cdiac.manizales.unal.edu.co/inicio/, reference number [14,15]. These data were derived from the following resources available in the public domain: http://cdiac.manizales.unal.edu.co/inicio/

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