Trees and their impact on carbon storage and surface temperature, a comparative study

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2. Abstract

Urban trees play a key role in carbon storage and surface temperature regulation. This study quantifies and compares carbon storage at two university campuses, Universidad Nacional del Comahue (Argentina) and University of Texas at Tyler (USA), as well as in an urban planted forest, a park, and a native Araucaria Forest. Additionally, it evaluates the relationship between canopy cover and surface temperature and assesses differences between ground-based and satellite-derived tree height measurements.

Field data collection included tree height and circumference measurements using the GLOBE Observer App. Biomass and carbon storage were estimated through allometric equations. Surface temperature was measured seasonally, under different canopy cover conditions on sunny and cloudy days, using an infrared thermometer. Satellite data from ICESat-2 and GEDI were compared with ground-based tree height measurements.

Results indicate a negative correlation between canopy cover and surface temperature, mainly in spring and summer, when tree shade reduces solar radiation impact. Araucaria forests stored more carbon per tree, but the highest carbon stock per square meter was in a eucalyptus-dominated urban park. While UT Tyler trees were taller, UNCo exhibited higher carbon stock per square meter, likely due to tree density differences.

These findings emphasize the need for ground-based measurements to improve tree height and carbon stock estimates. They also highlight the importance of urban and peri-urban forests in temperature regulation and carbon sequestration, supporting regulations that balance urban development and tree conservation.

Keywords: Urban trees, carbon storage, surface temperature, canopy cover, remote sensing

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3. Research Questions

The role of urban trees in carbon capture and storage represents an area of growing scientific interest. In this context, this research paper addresses the quantification and comparison of carbon storage in two university campuses: Universidad Nacional del Comahue (Argentina) and the University of Texas at Tyler (United States), located in different geographical, climatic and cultural contexts.

The questions that were sought to be answered throughout this research work were the following:

1. How much carbon do urban trees store on the campuses of the National University of Comahue and the University of Texas at Tyler?
2. What are the differences in carbon stock per square meter and tree biomass between the campuses of the National University of Comahue and the University of Texas at Tyler?
3. Are there differences in height and carbon storage between trees in a native araucaria forest and an urban implanted forest, a park, and university campuses, considering both the carbon stored per tree and per square meter?
4. How do trees contribute to surface temperature moderation, and what influence does cloud cover have on this process?
5. Is there a difference in tree height measurements measured in the field and from satellites?

4. Introduction & Review of Literature

Climate change, driven mainly by greenhouse gas emissions, represents one of the most pressing environmental challenges globally (Baek et al., 2022). Urban areas, with high concentrations of population and industrial activity, are significant sources of carbon emissions, highlighting the need for effective mitigation and adaptation strategies. In this context, urban trees play a key role in carbon storage and sequestration, helping to reduce the concentration of greenhouse gases and mitigate climate change (Nowak et al., 2013).

Urban forests have a unique ability to influence carbon circulation and improve environmental quality. Through photosynthesis, trees absorb CO_2 and store it in their biomass and in the soil. In addition, they offer ecosystem services such as microclimate regulation, air purification, reduction of rainwater runoff, and increased biodiversity (Nowak et al., 2013). These benefits not only contribute to environmental sustainability but also have a positive impact on the quality of urban life.

Despite these benefits, the role of urban trees in carbon capture and storage remains underestimated due to a lack of accurate data on their carbon sequestration capacity and their interaction with the environment (Lee et al., 2019). Assessing how tree cover influences surface temperature and its relationship with factors such as cloud cover can improve urban planning and management of green spaces, allowing them to maximize their potential as carbon sinks.

This study addresses these questions by estimating carbon storage in urban trees from different environments and species, as well as assessing the impact of tree cover on temperature. Tree height data are collected to estimate carbon biomass following the protocols of the GLOBE Program (GLOBE Program, 2024). Study sites include the campuses of the University of Comahue (Neuquén, Argentina) and the University of Texas (Tyler, United States), as well as a forest planted on the coast of the Limay River (Plottier, Neuquén) and an araucaria forest in Lanín National Park. These measurements are complemented by temperature, land cover and cloud cover records, using the GLOBE Observer Land Cover and GLOBE Observer Clouds applications.

Understanding the role of urban trees in carbon sequestration and temperature moderation is crucial for the development of sustainable urban strategies. In addition, forests located far from cities also offer indirect benefits to urban areas, such as regulating climate and air quality, protecting watersheds, and conserving biodiversity that is key to urban ecosystems (Wilson et al., 2022).

5. Research Methods

Figure 1: Location of the National University of Comahue (Argentina) and University of Texas at Tyler (United States)

This research was conducted as part of the 100K Strong in The Americas initiative, which funded the exchange of students and faculty from the National University of Comahue, Argentina, and the University of Texas at Tyler, United States. The main study sites correspond to the university campuses of both universities (Figure 1).

5.1. Methodology

Tree height, land cover and cloud data were recorded using the GLOBE Observer App (GLOBE Program, 2024b) following the biosphere (Biometry: Tree Height and Circumference, Carbon Cycle and Land Cover Classification) and atmosphere (Surface Temperature and Clouds) protocols of the GLOBE Program (2024d). In addition, manual tree height measurements were compared with information obtained from ICESat-2 and GEDI LiDAR (Light Detection and Ranging) sensors, with the aim of reducing uncertainties and improving the interpretation of forest structure (Enterkine et al., 2022; Campbell, 2021). ICESat-2 uses the ATLAS (Advanced Topographic Laser Altimeter System) instrument, which emits green laser pulses (532 nm) and allows altimetry profiles of vegetation to be obtained by the difference between the return of the canopy and the soil (Neuenschwander & Pitts, 2019). GEDI, a LiDAR system mounted on the International Space Station, emits pulses in the near-infrared (1064 nm) and generates sampling sites 25 m in diameter to reconstruct the vertical structure of forests (Dubayah et al., 2020).

Figure 2: The line indicates the different sections of sidewalks where surface temperature records were taken. In addition, land cover was recorded at each corner with GLOBE Observer Land Cover.

To quantify the surface temperature throughout the seasons of the year and in different weather conditions (sunny and cloudy days), a digital infrared thermometer with a measurement range of -50° to 300°C was used. In Argentina, surface temperature sampling was carried out on the sidewalks of the buildings of the Faculty of

Engineering and the Faculty of Economics of the National University of Comahue, in the areas of circulation of people (Figure 2).

These measurements were complemented with land cover and cloud type and cover records, using the GLOBE Observer Land Cover and GLOBE Observer Clouds applications, respectively. The classification of land cover was carried out using the MUC (Modified UNESCO Classification) system. (Bourgeault et al., 1998; GLOBE, 2024). In addition, in Argentina, air temperature data from the INEUQU23 weather station (Weather Underground, 2025), located near the campus of the National University of Comahue, were incorporated.

For the analysis of changes in land cover, Landsat satellite imagery (Gorelick, et al., 2017) and Sentinel (Esri, 2024) were used. The Köppen-Geiger climate classification was used to characterize the climate (Beck et al., 2023; Kottek et al., 2006; National Geographic, 2024). Tree sampling was performed at non-standard sites on both university campuses and standard sites in the implanted forest and natural forest. The height and circumference of the trees were measured with the GLOBE Observer Trees app and tape measure.

To estimate carbon biomass, the carbon cycle protocols of the GLOBE Program were followed. (GLOBE Program, 2024d). The DBH (Diameter at Breast Height) was calculated from the tree circumference measurement using the following formula:

$$DBH\ (cm) = Circumference\ (cm) \div \pi$$

To estimate the biomass of each tree (Aboveground Biomass), the allometric model was applied based on the equation proposed by Jenkins et al. (2003):

$$Biomass = exp(B_0 + B_1\ ln(DBH))$$

Where:

- *ln* is the natural logarithm.
- *DBH* is the Diameter at Breast Height (cm).
- *B0 and B1* are specific coefficients obtained from the study by Jenkins et al. (2003) for different tree species. For the *Araucaria araucana* species, specific coefficients proposed by Kutchartt et al. (2021) were used.

Once the biomass was obtained, the stored carbon was estimated assuming that 50% of dry biomass is carbon.

$$Biomass\ (g/m^2) \times 50\% = Carbon\ storage\ (gC/m^2)$$

Where:

- *Biomass (g/m²)* represents the amount of biomass in grams per square meter.

- *Carbon storage (gC/m²)* is the amount of carbon stored in biomass within an area of 1 square meter, expressed in grams of carbon per square meter.

5.2. Study sites

5.2.1 Sites in Argentina

5.2.1.1 National University of Comahue

Location: 38º 56' 26"S and 68º 03' 23"W. Altitude 315 masl. Sampling area: 86,565.72 m^2 (Figures 3 and 4).

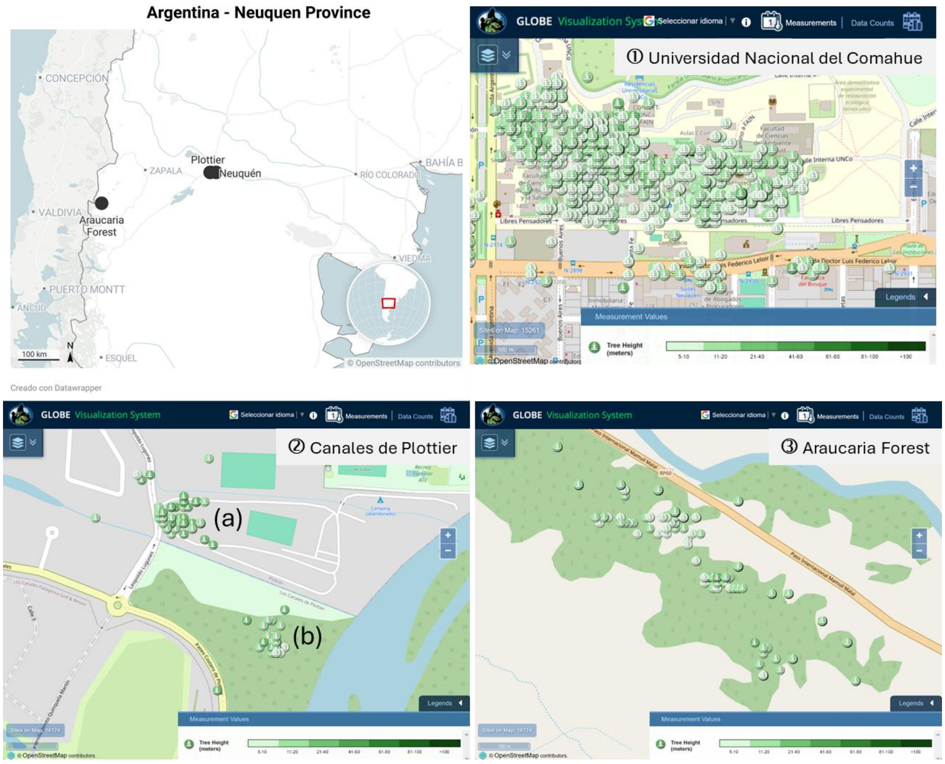

Figure 3: Sampling sites in Argentina: (1) National University of Comahue. (2) Plottier Canals: (a) Park - (b) Forest. (3) Araucaria forest.

The study site corresponds to the University's campus located north of the city of Neuquén, one of the most populous in the Patagonian region of Argentina, with 289,712 inhabitants (INDEC, 2022). This city is experiencing rapid growth driven by its economy, which is mainly based on the oil industry. According to the MUC classification, the area belongs to the MUC 94 category (urban area). The climate is classified as BWk (Cold desert climate). Since it is a non-standard site, a survey of all the trees on campus was carried out, totaling 792 individuals. All the trees were planted during the construction and expansion of the university campus and correspond to species of pines and cypresses, mostly, and in smaller quantities: ash, elms, poplars, casuarina, eucalyptus, acacias and others. For the analysis of carbon storage, the coefficients calculated for pines were considered and the rest of the species were considered as medium-hardness wood (Jenkins, et al., 2003). These species are exotic to this region.

5.2.1.2 Plottier channels

Location: 38° 57' 57.80"S and 68° 13' 6.78"W. Altitude: 279 masl. Sampling area: 31,554.17 m^2 (Figures 3 and 4).

Figure 4: Sampling areas: 1) National University of Comahue: 86,565.72 m^2 - 2) Plottier Canals: a) Park 6,582.45 m^2 - b) Planted Forest: 31,554.17 m^2 - 3) Araucaria Forest: 184,150.76 m^2.

The site corresponds to canals derived from the Limay River on the waterfront south of the city of Plottier. This city, located 16 km from Neuquén, has a population of 16,046 inhabitants (INDEC, 2022). The study site covers a forest implanted between the canals and the coast of the Limay River. A sampling was carried out in a park (50 trees) and in an implanted forest (21 trees) in addition to other trees in the center of the city, recording a total of 92 trees corresponding to various species of poplars, acacia, and eucalyptus. In the implanted forest, sampling was carried out in an area of 30 x 30 m, whose data were extrapolated to the total forest area. Since poplars are the dominant species and acacias are codominant, the site was classified as MUC 12b (broadleaf deciduous trees). As for the climate, it corresponds to the same as the city of Neuquén BWk (Cold desert climate).

5.2.1.3 Araucaria Forest

Location: 39° 37' 1.78"S and 71° 20' 50.70"W. Altitude: 979.11 masl. Sampling area: 184,150.76 m^2 (Figures 3 and 4).

The study site corresponds to a pure araucaria forest (*Araucaria araucana*). However, in a nearby area, this species shares habitat with the mountain cypress (*Austrocedrus chilensis*) and several species of *Nothofagus sp*. in a mixed forest. The araucaria is an endemic species of northwestern Argentine-Chilean Patagonia. (Veblen et al., 1995, Sanguinetti et al., 2023). This forest is located within the Lanín National Park. As it is a standard site, 205 trees were sampled, and the data were extrapolated to the total forest area. According to the MUC classification, the site falls into the MUC 11n category (evergreen trees with needle-like or scale-like leaves). The climate of the area is classified as Csb (Temperate with warm, dry summers).

5.2.2 Site in the United States

The campus of the University of Texas at Tyler is located at 32º 18' 53" lat. N and -95º 15' 07" long. Or. The climate is classified as Cfa (Humid subtropical climate).

Given the wide extension of the campus and the variability in tree density in its different sectors, it was decided, for reasons of time, to carry out sampling in the area with the lowest tree density (Figure 5).

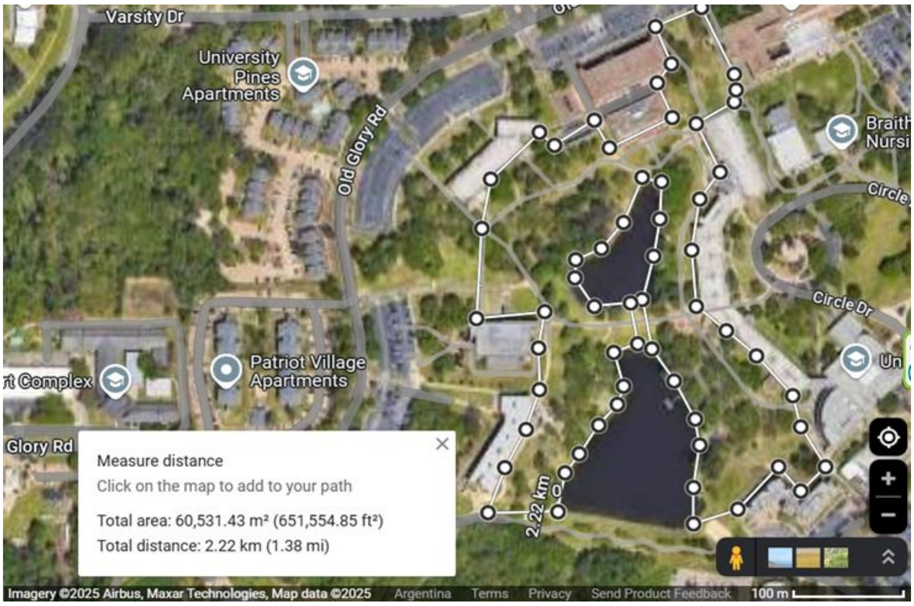

Figure 5: Sampling area at the University of Texas at Tyler: 60,531.43 m^2.

6. Results

6.1 Changes in land cover

In Argentina, the cities of Plottier and Neuquén, changes in land cover recorded through satellite data from Sentinel Images show the great advance of urbanized areas over green areas in the region (Figure 6). In the time period analyzed, this expansion is mainly observed in the city of Plottier, where the construction of neighborhoods has been the main cause of urban expansion.

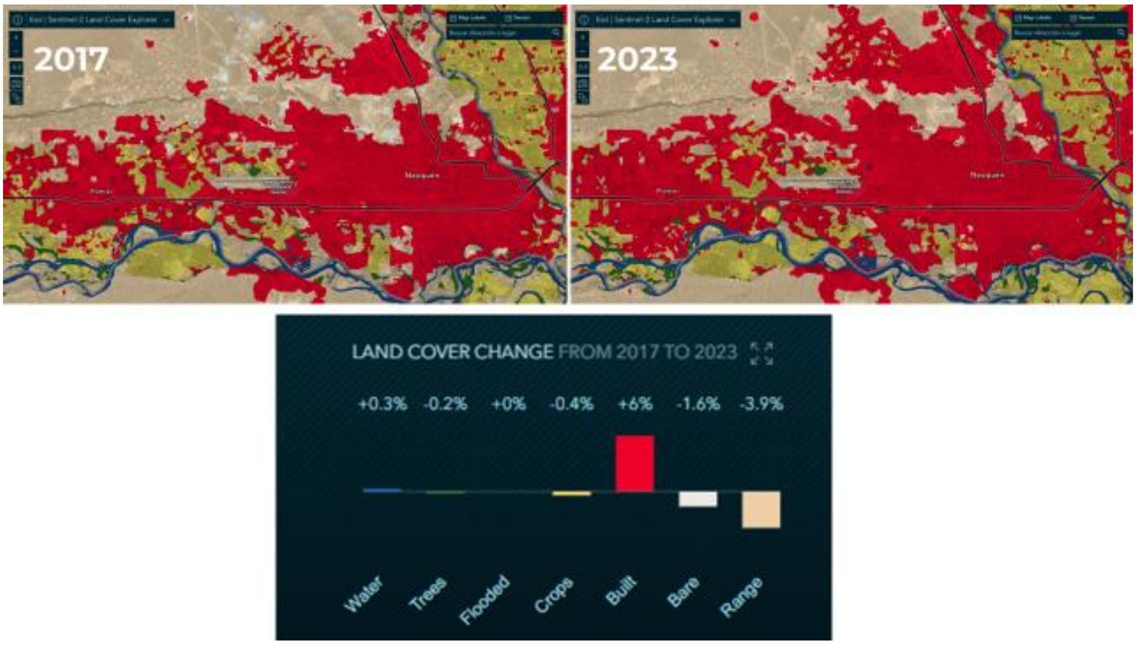

Figure 6: Argentina: Percentage of changes in land cover between 2017 and 2023. Sentinel images. ArcGIS [Living Atlas]

Figure 7. Seasonal changes in land cover. Photos of land cover were taken in the corners of the selected area.

The site that evidences the greatest urban expansion is the coast of the Limay River in the city of Plottier. In the case of the city of Neuquén, there is an increase in the growth of the urban area of the city to the north and northwest, but without affecting tree cover.

It is observed that the percentage of change in tree cover between 2017 and 2023 was -0.2%, while the percentage of urbanization was 6%, reflecting the increase in the size of the cities previously analyzed.

Figure 7 highlights the variation in the intensity of solar radiation and the shade of the trees in the different seasons of the year.

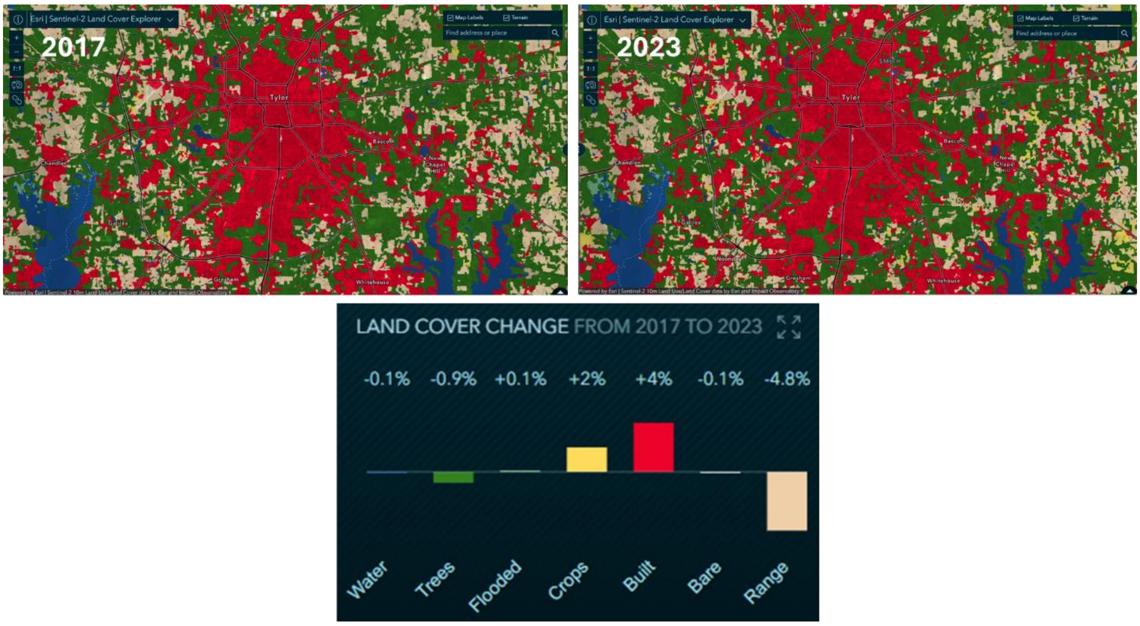

Figure 8: United States: Percentage of changes in land cover between 2017 and 2023. Sentinel images. ArcGIS [Living Atlas]

In the United States, the city of Tyler has experienced land cover changes between 2017 and 2023, with a 4% increase in built-up areas and a 2% expansion of agricultural land, while tree cover has declined by 0.9%, according to Sentinel images (Figure 8).

6.2. Carbon and Biomass Storage

6.2.1 Argentina

For the study of the importance of trees in carbon storage, four different study areas were selected in Argentina, Neuquén province. The first corresponds to the campus of the headquarters of the National University of Comahue in the city of Neuquén, the second is a park in the city of Plottier, the third an area of forest implanted in the city of Plottier and the fourth a native forest in Junín de los Andes (Figure 4). Given the heterogeneity of the first and second sites, the measurement of the trees was carried out individually, unlike zones 3 and 4, where the measurement was made by estimation. The height and trunk circumference of a total of 1068 trees were measured between the four sites.

6.2.1.1 National University of Comahue

Table 1: Data for the UNCO campus

UNCo Trees - Total					
	Elevation (masl)	Tree Heights (m)	Tree circumference (cm)	Tree Aboveground Biomass (kg)	Tree Aboveground Carbon Storage (g C)
Mean ± SD (Max – Min)	315 ± 4 331 - 268	11 ± 5 37 - 3	91 ± 47 381 - 18	540 ± 910 12,532 - 6	269,777 ± 455,190 6,265,780 – 3,197
N	792				

MASL: (meters above sea level)

Table 2: Biomass and carbon storage results in trees with medium-density wood.

Table summarizing the tree data – Total UNCo (Medium Wood Density Species and Pine)	
	Total Aboveground
Total Biomass (g/total area)	427,327,256
Total Carbon Storage (g C/total area)	213,663,628
Biomass (g/m^2)	4,936
Carbon Storage (g C/m^2)	2,468

Biomass g/m^2: biomass in grams per square meter
Carbon Storage (g C/m^2): Carbon storage in grams of carbon per square meter.

On the campus of the University of Comahue, 792 trees were measured, the average height and circumference was 11 ± 5 m and 91 ± 47 cm respectively, and the tallest tree reached 37 m (Table 1). The predominant species in this sector are pine and medium-density wood trees. The calculations of biomass and carbon stored per m^2 from the circumference data are shown in Table 2, where we find a calculated biomass of 4,936 g/m^2 and the stored carbon is 2,468 gC/m^2.

6.2.1.2 Plottier

6.2.1.2.1 Plottier Forest

Table 3: Data for the Plottier Forest

Plottier Forest					
	Elevation (masl)	Tree Heights (m)	Tree circumference (cm)	Tree Aboveground Biomass (kg)	Tree Aboveground Carbon Storage (g C)
Mean ± SD (Max – Min)	281 ± 3 284 - 277	18 ± 8 37 - 8	105 ± 83 418 - 30	498 ± 635 2,592 - 23	249,036 ± 317,471 1,295,950 - 11,368
N	21				

MASL: (meters above sea level)

Table 4: Biomass and carbon storage results in trees with medium-density wood in the Plottier Forest.

Table summarizing the tree data below – Plottier Forest (a planted forest) (Medium Wood Density Species)	
	Total Aboveground
Total Biomass (g/total area)	9,961,449
Total Carbon Storage (g C/total area)	4,980,724
Biomass (g/m^2)	388,054
Carbon Storage ($g\ C/m^2$)	194,027

Biomass g/m^2: biomass in grams per square metre.
Carbon Storage ($g\ C/m^2$): Carbon storage in grams of carbon per square meter.

A total of 21 trees were measured in this area. The predominant species are poplars, where we find that the average height was 18 ± 8 m and the tallest tree is 37 m, the average of the measured circumference was 105 ± 83 cm. (Table 3) The calculated biomass was 388,054 g/m^2 and the stored carbon 249,036 gC/m^2 (Table 4).

6.2.1.2.2 Park in Plottier

Table 5: Data corresponding to Plottier Park.

Plottier Park					
	Elevation (masl)	Tree Heights (m)	Tree circumference (cm)	Tree Aboveground Biomass (kg)	Tree Aboveground Carbon Storage (g C)
Mean ± SD (Max – Min)	280 ± 1 281 - 277	19 ± 6 30 - 9	171 ± 92 546 - 57	2712 ± 4701 30,626 - 110	1,355,897 ± 2,350,297 15,313,198 - 54760
N	50				

MASL: (meters above sea level)

Table 6: Biomass and carbon storage results in trees with medium-density wood in the Plottier Park.

Table summarizing the tree data below – Plottier Park (Medium Wood Density Species)	
	Total Aboveground
Total Biomass (g/total area)	78,413,945
Total Carbon Storage (g C/total area)	39,206,973
Biomass (g/m^2)	11,913
Carbon Storage (g C/m^2)	5,956

Biomass g/m^2: biomass in grams per square meter
Carbon Storage (g C/m^2): Carbon storage in grams of carbon per square meter.

This recreational area is mainly home to eucalyptus and poplars, with eucalyptus standing out as the dominant species, which stand out for their remarkable trunk diameter and height. The highest value recorded for the circumference of the trees corresponds to a eucalyptus, with a measurement of 546 cm, while the average value is much lower in values of 171 ± 92 cm. In terms of height, the species that reaches the largest size is again eucalyptus, with a height of 30 m, while the average height is

19 ± 6 m (Table 5). Table 6 shows the calculation results of biomass with a value of 11,913 g/m^2 and stored carbon 5,956 gC/m^2

6.2.1.3 Araucaria Forest

Table 7: Data from the araucaria forest

Araucaria forest						
	Elevation (MASL)	**Tree Heights (m)**	**Tree circumference (cm)**	**Tree Aboveground Biomass (kg)**	**Tree Aboveground Carbon Storage (g C)**
Mean ± SD (Max – Min)	979 ± 48 1447 - 963	13 ± 5 30 - 4	195 ± 105 657 - 17	3,058 ± 4,195 38,360 - 5	1,528,914 ± 2,097,450 19,180,167 - 2,600
N	205				

MASL: (meters above sea level)

Table 8: Results of biomass and carbon storage in araucarias (Araucaria araucana)

Table summarizing the tree data		
	Total Aboveground	**Total Aboveground**
Total Biomass (g/total area)	626.854.613	651.940.932
Total Carbon Storage (g C/total area)	313.427.306	325.970.466
Biomass (g/m^2)	3.404	3.540
Carbon Storage (g C/m^2)	1.702	1.770
	Calculation with Araucaria coefficients. Kutchartt, et al., 2021	Calculation with Mixed Hardwood coefficients. Jenkins, et al., 2003

Biomass g/m^2: biomass in grams per square meter
Carbon Storage (g C/m^2): Carbon storage in grams of carbon per square meter.

In the native forest, the most relevant species is the araucaria (*Araucaria araucana*), a slow-growing tree (between 5 and 8.2 centimeters per year in height and between 2.34 and 2.7 millimeters per year in diameter) that can reach 50 meters in height (Kutchartt et al., 2021; Sanguinetti et al., 2023). In the measured area, the araucarias have an average diameter of 195 ± 105 cm and an average height of 13 ± 5 m, with the maximum height found for this species being 30 meters (Table 7). The calculation of biomass and stored carbon was performed using the coefficients for Araucaria determined by Kutchartt et al. (2021) and compared with the coefficients for Mixed Hardwood obtained by Jenkins et al. (2003), which were applied in all estimates in this work. The results of the biomass and stored carbon calculations are presented in Table 8, where it is observed that the values obtained from both coefficients do not show significant differences.

6.2.2 United States: University of Texas at Tyler

Table 9: Data corresponding to the UTT campus

UTT Trees - Total					
	Elevation (masl)	Tree Heights (m)	Tree circumference (cm)	Tree Aboveground Biomass (kg)	Tree Aboveground Carbon Storage (g C)
Mean ± SD (Max – Min)	179 ± 2 187 - 175	17 ± 7 42 - 4	133 ± 62 288 - 12	1,293 ± 1,299 6,254 - 2	646,467 ± 649,498 3,127,154 - 1,168
N		192	125		

MASL: (meters above sea level)

Table 10: Biomass and carbon storage results in trees with medium-density wood.

Table summarizing the tree data – Total UTT (Medium Wood Density Species and Pine)	
	Total Aboveground
Total Biomass (g/total area)	161,616,777
Total Carbon Storage (g C/total area)	80,808,388
Biomass (g/m^2)	2,670
Carbon Storage (gC/m^2)	1,335

Biomass g/m^2: biomass in grams per square meter
Carbon Storage (g C/m^2): Carbon storage in grams of carbon per square meter.

On the University of Texas at Tyler campus, 192 trees were measured in a low-density sector. The average height and circumference were 17 ± 7 m and 133 ± 62 cm, respectively, with the tallest tree reaching 42 m (Table 9). The predominant species in this sector are medium wood density trees. Biomass and carbon storage per square meter, calculated from circumference data, are presented in Table 10, showing an estimated biomass of 2,670 g/m² and carbon storage of 1,335 gC/m².

6.3 Tree cover and surface temperature

The site chosen corresponds to an urban area within the campus of the National University of Comahue, characterized by a single type of land cover (cement) on its perimeter (Figure 2). This selection allowed us to evaluate the role of trees as thermal regulators by minimizing the influence of other surface variables such as grasses, bare soil, etc. In addition, accessibility to the site was prioritized to ease periodic measurements. The measurements were made with regular distance intervals (two steps) and were repeated in each season of the year, under various cloudy conditions.

Land cover estimation was made using GLOBE Observer's Land Cover protocol at solar noon, which allowed the recording of surrounding shade-generating elements such as tree leaves and buildings.

To analyze the relationship between tree cover and temperature, the site was divided into four sections (1, 2, 3 and 4) with a total perimeter of 305.37 m. facilitating the comparison of the data obtained (Figure 2).

6.4 Surface temperature

6.4.1 Surface temperature in different seasons of the year

Table 11: Variations in surface temperature in the different seasons of the year.

		Autumn (Overcast)	**Winter (No clouds)**	**Spring (Broken)**	**Summer (No clouds)**
Land Surface Temperature (°C)	Mean ± SD (Max – Min)	8.6 ± 1.0 (10.8 - 6.5)	4.8 ± 2.4 (10.4 - 0.2)	27.5 ± 8.6 (48 - 14.6)	47.9 ± 10.3 (69.0 - 33.6)
Air Temperature (03:00 pm) INEUQU23	(°C)	13.0	10.6	25.5	38.3
N		183	183	183	183

Table 11 shows the average surface and air temperature data corresponding to the different seasons of the year 2024 and summer of 2025. In autumn (cloudy) an average surface temperature of 8.6°C was observed and an air temperature of 13°C was recorded. When comparing air temperatures with the maximum surface temperature, a difference of 2.2°C is detected. In winter (clear) an average surface temperature of 4.8°C was observed and an air temperature of 10.6°C was recorded. In this case, the difference between the maximum surface temperature and that of the air is only 0.2°C, therefore it could be said that in this season there were no great differences in temperature. In spring (isolated clouds) an average surface temperature of 27.5°C was observed and an air temperature of 25.5°C was recorded. In this station there is a difference of 22.5°C compared to the air temperature 25.5°C and the maximum surface temperature 48°C, which denotes an important difference with respect to the previous stations. In summer (clear) an average surface temperature of 47.9°C was observed and an air temperature of 38.3°C was recorded. Note that the maximum temperature recorded on the surface was 69.0°C (belonging to mostly asphalted sectors and without trees around) showing a difference of 31.5°C when compared to the air temperature, this being the difference of greater magnitude of the four seasons. This shows the relevance of trees in the regulation of surface temperature.

6.4.2 Surface Temperature vs. Tree Cover

In section 1 (Figure 9), 60 m long, surface temperatures were recorded in autumn and winter with differences of less than 10.5°C, both in the presence and absence of trees. On the other hand, the differences in surface temperatures are greater than 30°C when comparing spring and summer. Figure 9 shows a decrease in surface temperature, greater than 20°C, in spring and summer in areas with tree shade.

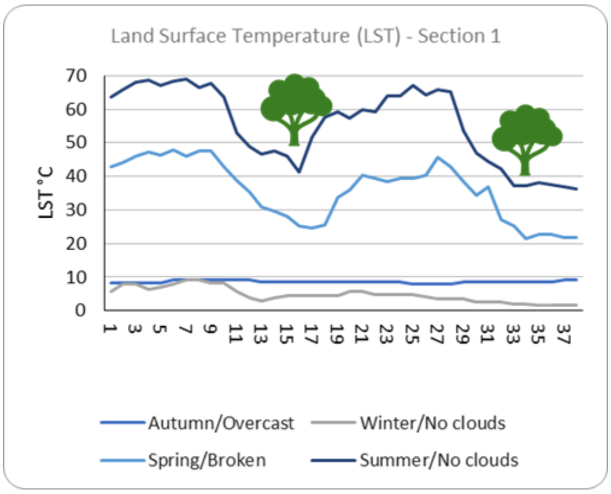

Figure 9: Surface temperature measurements along section 1.

In section 2 (Figure 10), 90 m long, a greater presence of trees is observed along the perimeter, which is reflected in the temperature fluctuations recorded. Again, the impact of tree cover has a similar behavior to section 1. However, in winter it is observed that surface temperatures reached 0.2°C (Table 11, Figure 10) and also remained in a specific section of the perimeter covered by trees.

In summer, in areas of continuous tree cover, the temperature can be maintained at a value around 35°C (Figure 10).

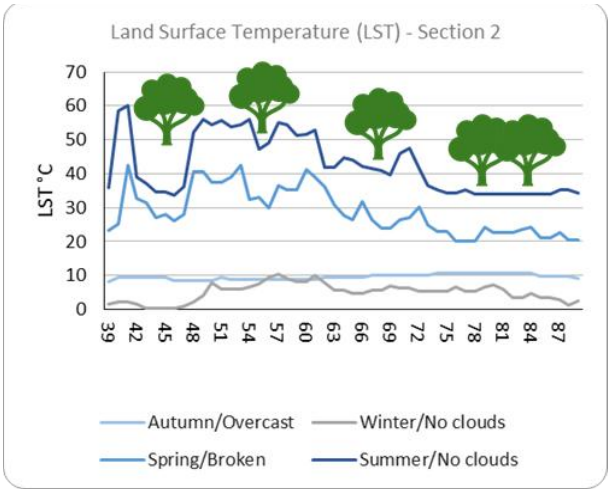

Figure 10: Surface temperature measurements along section 2.

In section 3 (Figure 11), 60m long, similar results to the previous sections are observed: at the beginning of the section there is a marked decrease in surface temperature influenced by the presence of trees, however, it then increases due to their absence although the presence of buildings contributed to decrease and maintain temperatures again.

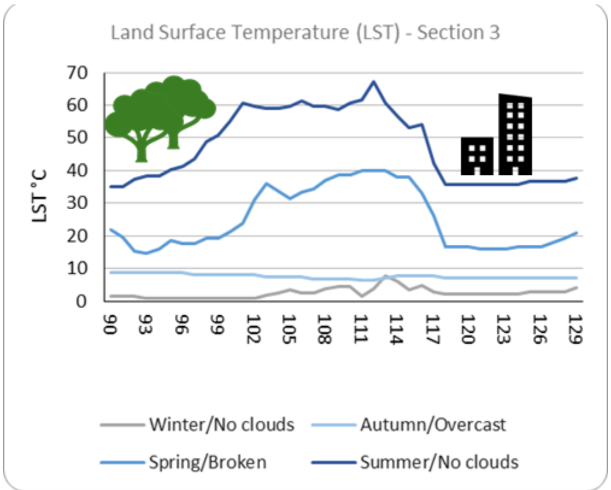

Figure 11: Surface temperature measurements along section 3.

Finally, in section 4 (Figure 12) of around 90 m in length, surface temperatures fluctuated constantly due to the presence and absence of trees along the entire perimeter, with this variation being most noticeable in the summer. The presence of buildings also reflected a maintenance and decrease in surface temperatures.

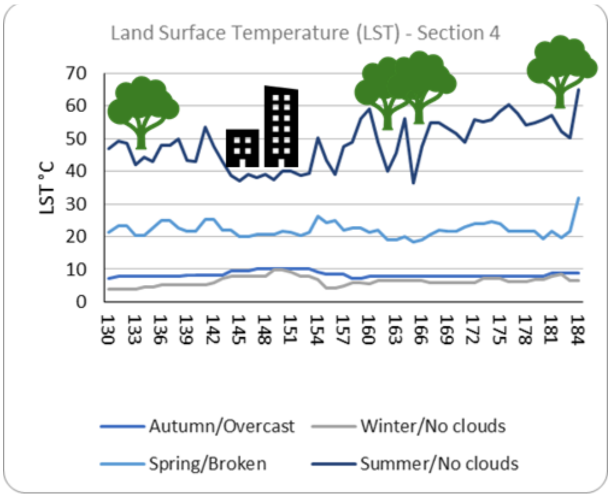

Figure 12: Surface temperature measurements along section 4.

Figure 13 shows the tree cover percentages for each section in the form of pie charts. Section 2 stands out as the most covered of the four (81% coverage), which allowed summer surface temperatures to remain around 35°C. In contrast, section 1, with only 12% tree cover, reached temperatures of up to 69°C in summer, with few stretches of temperatures below 40°C. In sections 3 and 4, the presence of buildings that, together with the tree cover, kept surface temperatures constant is observed as a common characteristic. In section 4, 72% of tree cover was observed.

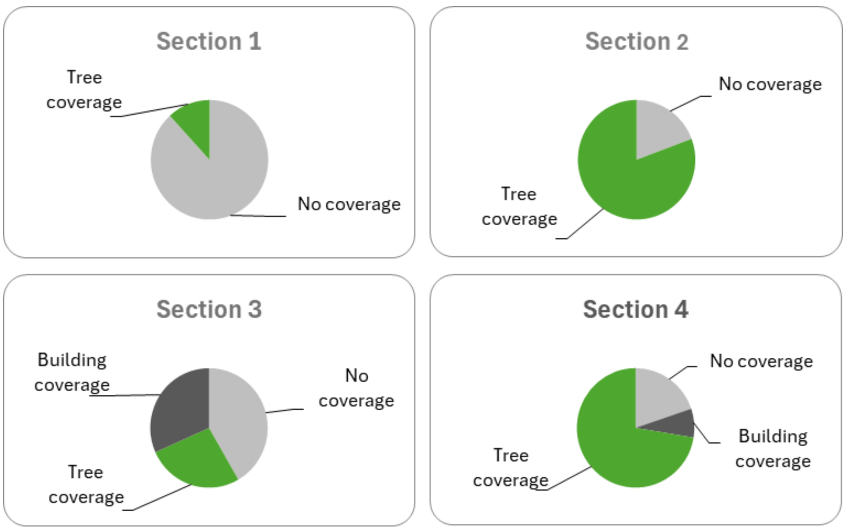

Figure 13: Tree cover percentages for each section.

6.4.3 Sunny Day vs Cloudy Day Comparison

Table 12 shows the results of the surface temperature measurements for each section studied. In this case, we sought to obtain data from a cloudy day and then a sunny day in summer to evaluate the impact of clouds on surface temperature and the role of tree cover under each situation.

When analyzing Table 12, a smaller range of thermal amplitude on the cloudy day can be seen compared to the sunny day: the minimum thermal amplitude of the cloudy day was found in section 1, with a value of 8.7°C, while the maximum amplitude was found in section 3 with a value of 22.0°C. These values contrast with what was obtained for the sunny day, where the minimum thermal amplitude is 26.9°C (section 1), three times higher than that obtained for the sunny day. The maximum thermal amplitude for the sunny day is 35.6°C and was recorded in section 3. Comparing both days, the importance of tree cover can be appreciated, mainly on sunny days, where temperatures can reach values of up to 66.6°C in those areas directly exposed to the sun, while the presence of trees can decrease the temperature on the surface to 26.9°C.

Table 12: Surface temperature cloudy day and sunny day.

	Cloudy 11/12/24			
	Section 1	**Section 2**	**Section 3**	**Section 4**
Mean ± SD Max – Min	33.6±2.7 (36,5-27,8)	27.1±4.5 (35,5-19,2)	29.7±5.0 (40,0-18,0)	28.1± 2.7 (34,3-21,5)
Thermal amplitude	8,7	16,3	22,0	12,8
	Sunny 3/1/2025			
	Section 1	**Section 2**	**Section 3**	**Section 4**
Mean ± SD Max – Min	59.4±7.3 (66,6-39,7)	38.5±10.1 (59,7-26,9)	45.3±12.2 (64,6-29,0)	42.0±7.9 (59,1-30,3)
Thermal amplitude	26,9	32,8	35,6	28,8

Figure 14 shows the impact of tree cover along each section. Cloudy days show a homogeneity in temperatures both in areas with tree cover and those areas that do not, so the impact is less in this situation.

Figure 14: Section 1 to 4 surface temperatures (left to right, top to bottom) for sunny days and cloudy day.

6.4.4 Temperature and shade cover (trees and building)

Finally, in Figure 15 the shade in sections 1, 2 and 4 comes mainly from the cover of the trees, which impacted the results obtained and previously analyzed. The presence of buildings is notable in section 3, which affected the measurements obtained.

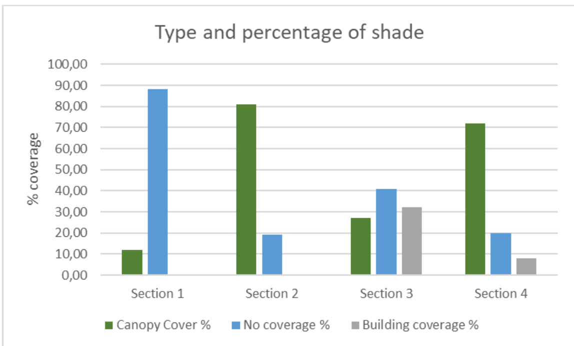

Figure 15: Origin of the shadow of each section and associated percentage.

6.5. Contrast the height of trees with satellites

6.5.1 Measurement error using GLOBE Observer

To determine the error in the measurement of tree height and circumference using the GLOBE Observer Mobile Application, a tree was chosen as the object to be compared among the measurements made by each member of the Argentine exchange group (Figure 16), with a total of six measurements (N=6). As a result, a mean circumference of 67.8 ± 1.3 cm and a mean height of 10.1 ± 0.6 m were obtained, where the uncertainty for both measurements was the standard deviation. The standard deviation was used as uncertainty in all trees measured in the field, while in satellite measurements their own associated uncertainty was considered.

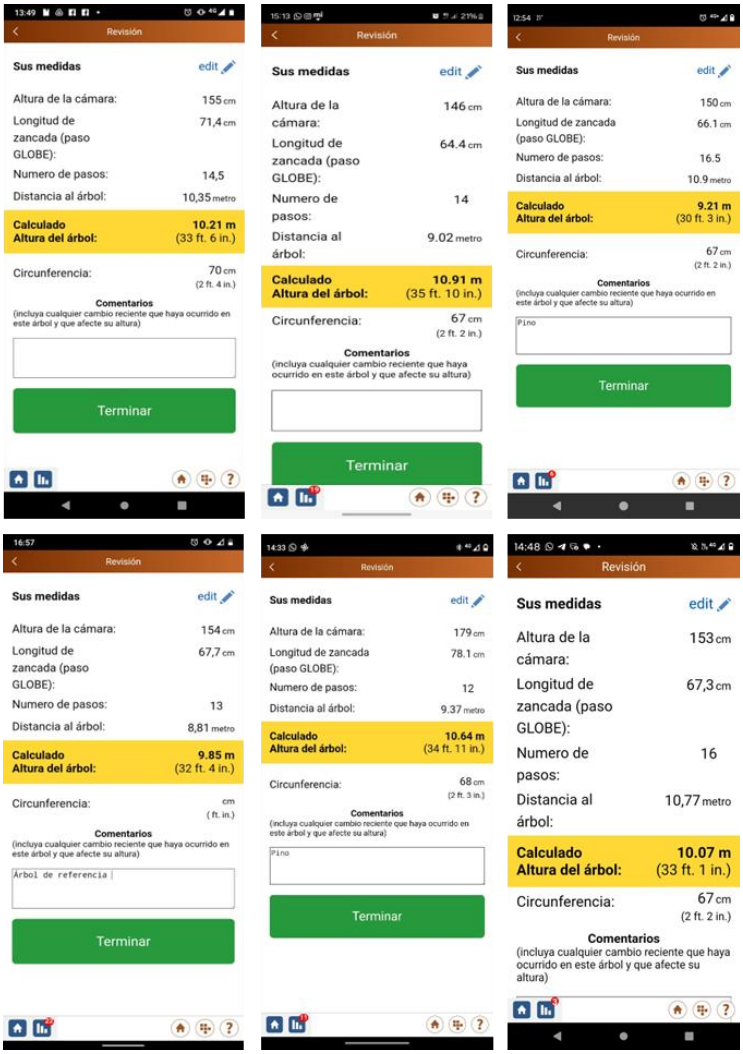

Figure 16: Determination of uncertainty in the measurement of tree height and circumference using the GLOBE Observer Application.

To contrast tree heights measured on the ground at the different study sites, satellite images and data from GEDI (Global Ecosystem Dynamics Investigation), Landsat ARD (Landsat analysis-ready data time-series) (Potapov et al. 2020), and ICESAT-2 satellite data obtained from Open Altimetry were used.

6.5.2 ICESAT-2

Another methodology to contrast the measurements in the field was carried out using ICESAT-2 data. Historical information on orbits that crossed the campus of the National University of Comahue was searched and a particular tree was identified (Figure 17). This tree was measured in the field five times by different people using GLOBE Observer and compared with what was recorded by ICESAT-2.

6.5.2.1 UNCO

The IceSat measurement result was 8.12 m, while the measurements using GLOBE Observer were 7.7 m, 8.35 m, 7.1 m, 6.68 m and 6.91 m respectively, with an average of 7.3 ± 0.6 m.

Figure 17: Tree height measured by ICESAT-2 compared to on-the-ground measurements with GLOBE Observer.

6.5.3 GEDI & LANDSAT ARD

For this comparison, the average height of the tree sectors measured in the terrain and the average satellite data obtained by GEDI were used. GEDI's tree height measurements were finalized in 2019 generating a global mapping with pixels of thirty meters on a side with a sensitivity of ±1 meter. For comparisons of the following sectors, 5 m was used as the minimum height with an overall accuracy of 87.8% (Potapov et al., 2020). Since it is not possible to know for sure which tree was measured in the pixels, the average heights of trees measured in the terrain were analyzed.

6.5.3.1 UNCO

Figure 18 shows the sector of the campus of the National University of Comahue where the GEDI measurements were obtained.

Figure 18: Sector of the campus of the National University of Comahue where the height of trees was analyzed: 1) Pixels taken from GEDI of 5 m (light green) and 6 m (dark green) of tree heights. 2) Sector in GLOBE Observer.

Once the sector was recognized, the measurements made in it were searched with the help of the GLOBE Visualization System (Figure 18). The average of the tree height measurements on the ground were 11.3±5.5 m, while the average measured by GEDI was 5.5± 1 m.

Table 13: Comparison of field measurements with GLOBE Observer and GEDI.

UNCo sector Trees GEDI vs. GLOBE		
Data sources	**Tree Heights (m)**	
[GEDI]	Mean (Max – Min)	5.5 6 - 5
[GLOBE]	Mean ± SD (Max – Min)	11.3 ± 5.5 30,62 - 3,81

6.5.3.2 PLOTTIER

In the same way, the measurements made in Plottier, in the sector of the Plottier canals (Figure 19), were conducted.

Figure 19: Sector in Plottier where tree height was analyzed: 1) Pixels taken from GEDI of 5 m (light green) and 6 m (dark green) tree heights. 2) Sector in GLOBE Observer.

The average height of the trees obtained with GLOBE Observer in the selected sector was 17.8 ± 7.5 m. The average measured by GEDI was 8.5 ± 1 m and it is noted that in this sector heights of 12 m maximum were recorded.

Table 14: Comparison of field measurements with GLOBE Observer and GEDI.

Plottier sector Trees GEDI vs. GLOBE		
Data sources	**Tree Heights (m)**	
[GEDI]()	Mean (Max – Min)	8.5 12 - 5
[GLOBE]()	Mean ± SD (Max – Min)	17.8 ± 7.5 39.3 - 8.2

7. Discussion

The results of this study reveal a clear influence of canopy cover and shade on surface temperature, answering our initial question about the role of urban trees in mitigating the heat island effect. A negative correlation was observed between tree cover and surface temperature, indicating that areas with higher vegetation cover experience lower temperatures. This effect is particularly pronounced in spring and summer during sunny days, when the shade provided by trees reduces the incidence of direct solar radiation and decreases surface warming.

This research has shown that trees in urban and peri-urban environments play a crucial role in carbon sequestration and surface temperature regulation. In addition, it was observed that carbon storage capacity varies according to the tree species, its age, and forest density, highlighting those native forests, such as araucarias, have a higher long-term capture capacity compared to implanted forests or young urban trees (Loguercio, et al., 2024; Pregitzer & Euskirchen, 2004)

On the campus of the National University of Comahue, the diameters of the trees are smaller with respect to the trees of the Plottier Park and the Plottier Forest (urban) and the araucaria forest (National Park), which reflects the environmental variations that influence the growth of the trees.

Variability in carbon storage was observed between the different sites studied in Argentina. The park in Plottier, with large eucalyptus, has the highest carbon storage per square meter, while the araucaria forest shows a lower value in comparison. However, when comparing storage by tree, araucarias contain a higher amount of carbon per individual, possibly due to the age of the forest.

When comparing carbon storage in the evaluated areas of both university campuses, it is observed that, although the trees at the University of Texas at Tyler are taller on average, the campus of the National University of Comahue presents a higher carbon storage per square meter. This difference could be due to a higher density of trees or the presence of species with a higher capacity to capture carbon.

Certain limitations were identified when comparing terrestrial and satellite data. Chief among them was the scarcity of satellite data matching trees measured on the ground. In addition, GEDI completed the sampling in 2019 and the trees were measured in the field in 2024, so the difference in height may be due to the growth of the trees during that period. On the other hand, ICESat-2 has not completed the global survey of tree height and only information was obtained from one tree in the area studied. These limitations highlight the importance of field measurements to obtain accurate and up-to-date data on tree height, which is critical in forestry and carbon storage studies. However, having satellite data allows for carbon storage estimates (Yang et al., 2024; Gülçin & van Den Bosch, 2021), which is useful for studying remote, inaccessible, or large areas.

Our results on carbon storage in urban trees are consistent with what has been reported in scientific literature. (Ariluoma et al, 2021; Choudhury et al., 2020)

Finally, considering the growing urbanization of the city of Neuquén Capital, whose economy is mainly based on the oil industry, it would be pertinent to address the discussion of how to promote urban growth without compromising tree cover. This could be achieved through the implementation of laws and regulations that regulate the balance between development and conservation.

8. Conclusion

-No significant differences are found between the height and circumference of the trees measured in the different sites

-Trees play a crucial role in reducing surface temperatures, as they provide shade and release water vapor through transpiration, which helps mitigate the heat island effect especially in urban areas.

-In semi-desert regions such as the city of Neuquén, the scarcity of vegetation and accelerated urbanization make the presence of trees even more valuable to mitigate extreme heat, underscoring the need to conserve and increase urban green areas.

-Native or planted forests have a greater impact on climate regulation and carbon storage than urban plantations, as they have a higher density and size of trees, which allows them to store more carbon and generate a more significant climate effect.

-The joint use of GLOBE Observer, ICESat-2 and GEDI improves the accuracy of carbon stored estimates.

-There are geographical and temporal limitations when comparing measurements of tree height in the field with satellite measurements

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Badges

I AM A DATA SCIENTIST

In this research, data was used to analyze carbon storage and temperature regulation in different types of forests and urban environments. Field measurements were made and then compared with satellite data (ICESat-2 and GEDI). In addition, statistical analyses were applied to make comparisons. Allometric equations were used to estimate carbon storage and biomass. Data from canopy covers and surface temperature were used to assess the impact of trees on temperature.

I AM A COLLABORATOR

This research was possible thanks to interdisciplinary collaboration between scientists, students and experts from different institutions. They worked as a team to collect and analyze data in the field and satellites. Knowledge, tools and methodologies were shared. Working collaboratively in an international team allowed us to strengthen bonds beyond work.

I WORK WITH A STEM PROFESSIONAL

This research was conducted in collaboration with scientists from both universities. We received the support of NASA scientists and Mentor trainers from the GLOBE Program who provided knowledge and tools that allowed sampling and subsequent analysis of data. Satellite data specialists (ICESat-2 and GEDI) helped to obtain information and analyses it by comparing it with data obtained from field measurements.