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Urban Heat Islands modeling

Project Assignment

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1 Deviations from the proposal

In the actual litterature, research on urban heat islands is very wide, with a lot of complex 3D models. It is quite difficult to know what we are able to compute with our begginer programmation skills and as we wanted to collect accurate (satellite) data as input to calculate some temperatures, we quickly realize that this was the purpose of a further course in our bachelor.

We aimed to be able to use a complex model (Calculation of Land Slides Temeratures) in the project proposal but we got stopped by the use of the NDVI datas in the equation that we dont know for the moment how to use.

Thus, we bent toward a very simplistic approach : calculating temperatures with a basic aerial picture. This include a bit of image manipulations but it is much more within our reach. This is why we also choosed Python instead of Mathlab for the image manipulations, where we already had basics

2 Introduction to the problem

In a 2014 report on global urban trends[2], the United Nations highlighted that more than half of the world's population was already living in urban areas. According to experts, this proportion is expected to rise significantly, reaching almost two-thirds of the population by 2050. This rapid urbanization will inevitably lead to an increase in construction activities, particularly for expanding cities.

Such growth presents both opportunities and challenges. While urban expansion can bring economic development and improve access to services (public transports, education, hospital), it also has an impact on environment, and by extension on the quality of life. As a result, it is essential that the emerging parts of cities can be designed considering carfully teh actual and future challenges. These include reducing carbon emissions, managing energy and water resources efficiently, and creating resilient infrastructures capable of adapting to climate change.

Even though the 2023 voted law on the climate is quite general [4], the will of the population to figure out solutions to fight the climate change is clear. A clear part of combating global warming evidently occurs in agglomerations and this is where we focused on for our project.

In every urban complex (already existing or being built) solutions against high temperatures have to be taken into account in order to create viable spaces within cities, especially in a climate change context. Therefore we wanted to create a tool easily usable so that in every neighbourhood a quick and precise analyse of the temperatures can be made in order to elaborate solutions instantaneously.

Therefore, we come up with the idea to compute a basic tool to visualize heat islands within a neighbourhood of a city With such a tool, we also think that it could give a bit of responibility to the city executive, without relying on slow and expansive engineering analysis.

3 Approach

At our level, calculating temperatures with all the parameters influencing this one is a Herculean task. We chose to reduce the complexity to a 2D simulation so we can use a very accessible input : an aerial image. Then we can estimate two parameters (albedo and emissivity) to finally calculate the surface temperature.

3.1 Model used

For that we use an ajusted version of Stefan's law that estimates the surface temperature (in Kelvin) from a simplified radiative balance. It first computes the effective atmospheric emissivity using Brutsaert's empirical relationship,

$$\varepsilon_a = 1.24 \left(\frac{e_a\,[\mathrm{mb}]}{T_a\,[\mathrm{K}]} \right)^{\frac{1}{7}}, \quad 0 \leq \varepsilon_a \leq 1,$$

where e_a is the vapor pressure and T_a is the air temperature ; ε_a is then constrained to the physical range $[0, 1]$. The downward longwave radiation is parameterized as

$$L_\downarrow = \varepsilon_a\, \sigma\, T_a^4 \quad [\mathrm{W}\,/\mathrm{m}^2],$$

with σ the Stefan-Boltzmann constant. The net incoming energy at the surface combines absorbed shortwave and atmospheric longwave,

$$(1 - \alpha)\, S_\downarrow + \varepsilon\, L_\downarrow,$$

with α the surface albedo, ε the surface emissivity, and $S_\downarrow$ the incoming shortwave radiation.

$$T_s = \left(\frac{(1 - \alpha)\, S_\downarrow + \varepsilon\, L_\downarrow}{\varepsilon\, \sigma} \right)^{\frac{1}{4}}.$$

We fixed values for T_a = 298 K, $S_\downarrow$ = 800 W/m^2 and e_a = 1500 Pa that are realistics values during summer in urban places.

3.2 Classification

Surface Type	**Albedo**
Vegetation	0.25
Water	0.05
Concrete	0.30
Asphalt	0.15
Metal	0.60

TABLE 1 – Albedo values

Surface Type	**Emissivity**
Vegetation	0.98
Water	0.96
Concrete	0.92
Asphalt	0.93
Metal	0.60

TABLE 2 – Emissivity values

Stefan's law only uses the albedo and emissivity of the picture, so we defined a function that classifies pixels following specific criteria. We set a table with realistic albedo and emissivity values (e.g. vegetation albedo = 0.25 and emissivity = 0.98) [1]. Then we create two files (`emissivity_matrix.csv` and `albedo_matrix.csv`) containing all pixel values on the map that can be processed later in the program.

3.3 Pixellisation

Initially, a precise input is necessary to get an interpretable result. We applied a pixellisation to reduce the impact of the shadow zones ($\alpha \to 1$) and disstort the picture to a 100x100 pixels which is way easier to use in a C file.
From this 100x100 map, we can then calculate the emissivity and the albedo value of each pixel and create two .csv files (emissivity_matrix.csv and albedo-matrix.csv)

FIGURE 1 – Satellite picture of Plaine de Plainpalais in Geneva

FIGURE 2 – pixelated map

4 Results

4.1 Temperature map

The goal of the project is to see graphically where are the zones that are likely to become heat islands so the progamm computes two different maps : the first one is a temperature map. Each pixel is a value in the file *temperature_matrixe.csv* and represents the temperature calculated in the C file following Stefan's law. The file *overlay.py* computes each value on a map (*tempmap.png*) and returns a map with heat zones. A gaussian filter is used to smooth the whole thing and have a more realistic rendering.

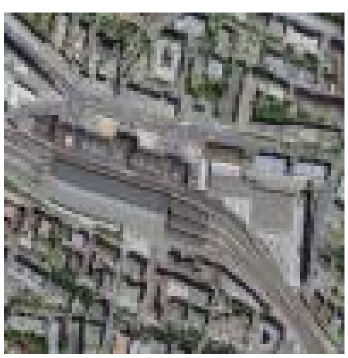

FIGURE 3 – Pixelated map of Lausanne trainstation

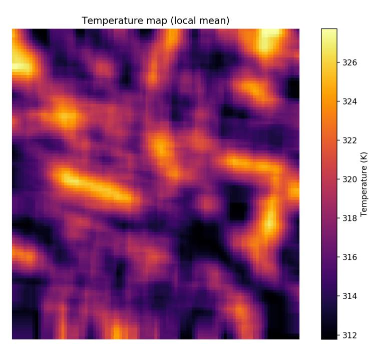

FIGURE 4 – Temperature map of Lausanne trainstation

4.2 Overlaying

The second image is an overlay of the chosen map (i.e plaine de Plainpalais in Geneva) and the outlines of potentials heat islands. To achieve this, the code reuses the temperatures values from the CSV file and calculates the mean temperature. With this, it can identifies areas that are above the 85th percentile which are potential heat islands. This method provides a clear visual representation of thermal contrasts and highlights critical zones that require attention. By combining the thermal map with the satellite image, the result becomes more intuitive and easier to interpret. Such analysis is particularly valuable for urban studies, as it helps pinpoint regions where heat tends to accumulate.

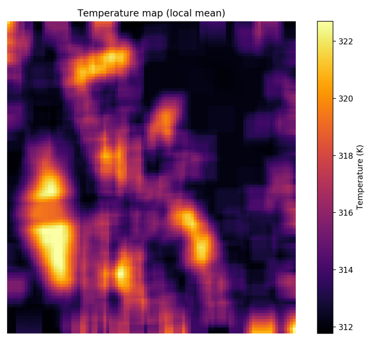

FIGURE 5 – Temperature map of Plainpalais

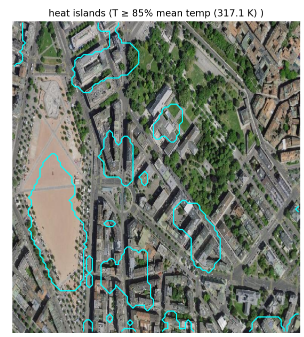

FIGURE 6 – potential heat islands in Plainpalais

4.3 Discussion

The absorption of incident solar radiation can be influenced by many different factors : impervious surfaces, insufficient green spaces, reduced air circulation due to the density of the built environment or poor building orientation. This accentuates warming during the day and significantly reduces nighttime cooling. The effect is most pronounced a few hours after sunset and gradually diminishes during the night.[3]

The results here are unambiguous. Areas with a high vegetation coverage are cooler than others made of concrete or asphalt. This differences can be explained by the physical properties of the coverage materials.

Dark, impervious surfaces such as asphalt and certain types of concrete have a low albedo and a high capacity to absorb solar radiation. Therefore they trap heat and it ends up with the temperature increasing at the given place but also among the surroundings.

Vegetation covered areas are less likely to retain heat, helped by their middle range albedo. Dense and large green areas have a more powerful impact on reducing the surrounded heat than isolated trees or small grass gardens.

5 Conclusion and outlook

Even though the results are quite concrete, this model is very simplistic and it presents a few inconvenients which might be good to relevate in order to interprete the results with caution.

5.1 2D model

Considering a 2D model for a 3D situation logically gives unprecise results. Nevertheless, giving boudaries conditions to use the model can be acceptable. It obviously depends on the size of the buildings. For sure we can say that the model treat flat and aerated surfaces better than a skyscratter city with a high building density.

5.2 Approach based on colors

The input is a image with colored pixels taken by a satellite. The resolution and the quality of the image will directly influence the results because we based our calculations on the color of each pixel. Therefore if the image has am inadequate lightning (many dark areas on the image) or if the image is edited, the colors might be disorted which will affect the result.

5.3 Pixelization

Pixelizing the picture was our choice for practical reasons. First, the idea was to obtain an average view of the colors, without analyzing each pixel (time conuming and more sensible to isolated colored pixels). Then is was vey interesting to have a fix pixelization size when we got into reading a *.csv* file in C. We made this choice knowing that the image will be compressed, which could be a problem for larger areas as inputs.

5.4 Surface temperature

The temperature calculation were not very accurate at the begining, so we added a constant (-50 K) that is based on terrain mesures in order to calibrate the model. This calibration is necessary to do before using the code. Furthermore, as a matter of technical skills, we used the Stefan-Boltzmann relation to calculate the temperature in our examples. This relation is based on radiative exchanges but urban heat islands are way more complicated than that. To be as accurate as possible, we should have taken many other parameters such as convection (wind), conduction (energy storage), anthropic heat, road traffic or even evapotranspiration but we realised that the major part of errors comes from the vegetation. As we saw before, the model works well when vegetation areas are separate from built-up areas (ex. plaine de plaipalais), but when they are intertwined, it tends to interpret vegetation as black zones, leading to an overestimation of heat. Indeed it only takes into account albedo and emmissivity based on RGB (which are very high for vegetation) but neither the cooling effect from tree's transpiration nor the fact that the shadows under keeps the areas cooler than in other places. To fix this, the best manner is to modify the programm and use NDVI values instead of RGB and so modelise with way more precision the potential heat islands. The use of NDVI allows the use of Calculation of Land Slides Temperatures model that we aimed to compute or other more complexes but way more accurates models.

5.5 Conclusion

In conclusion, this project allowed us to discover the structure of a program related to a concrete topic in connection with our studies. The modeling of an environmental subject convinced us of the usefulness of our field and the possibilities related to current climate issues. Despite the relative reliability of the program, it is easy to realize the untapped potential in the field of research.

6 Authorship statement

Writers and editors : Diego Dellamula, Nicolas Egger

7 References

[1] *Albedo - MeteoSwiss*. en. URL : `https://www.meteoswiss.admin.ch/weather/weather-and-climate-from-a-to-z/albedo.html` (visité le 16/12/2025).

[2] Nations Unies, éd. *World urbanization prospects, the 2014 revision : highlights*. eng. ST. ESA 352. New York : United Nations, 2014. ISBN : 9789211515176.

[3] Office fédéral de l'environnement OFEV et Office fédéral du développement territorial ARE. *Quand la ville surchauffe ; Bases pour un développement urbain adapté aux changements climatiques*. Rapp. tech. 2018.

[4] Confédération Suisse. *Loi fédérale sur les objectifs en matière de protection du climat, sur l'innovation et sur le renforcement de la sécurité énergétique (LCl)*. 2023.