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**Heat Fluxes from Landsat Images:
A Contribution to Lisbon
Urban Planning**

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Heat Fluxes from Landsat Images: A Contribution to Lisbon Urban Planning ⁽¹⁾

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ABSTRACT

The urban structure is a modeller of wind fields and an active modifier of radiation conditions, trapping, reflecting and shadowing much more than the rural areas. In a smaller scale the different albedos and the heat capacity of the materials are also able to modify the thermal patterns. The main purposes of this work are to create a land use/urban structure map for climatic purposes and to estimate heat fluxes with numerical modelling and Landsat images are. We also want to contribute to Lisbon's urban planning by creating several cartographic documents as part of the project: *"Prescription of climatic principles in urban planning. Application to Lisbon"*.

1 INTRODUCTION

The urban climate of Lisbon is dominated by three local factors: the vicinity of the Atlantic Ocean to the west and south-west, the Tagus river (large estuarine area to the south-east and a 2 km large channel to the south of the city) and finally its topography (fig.1). This determines a

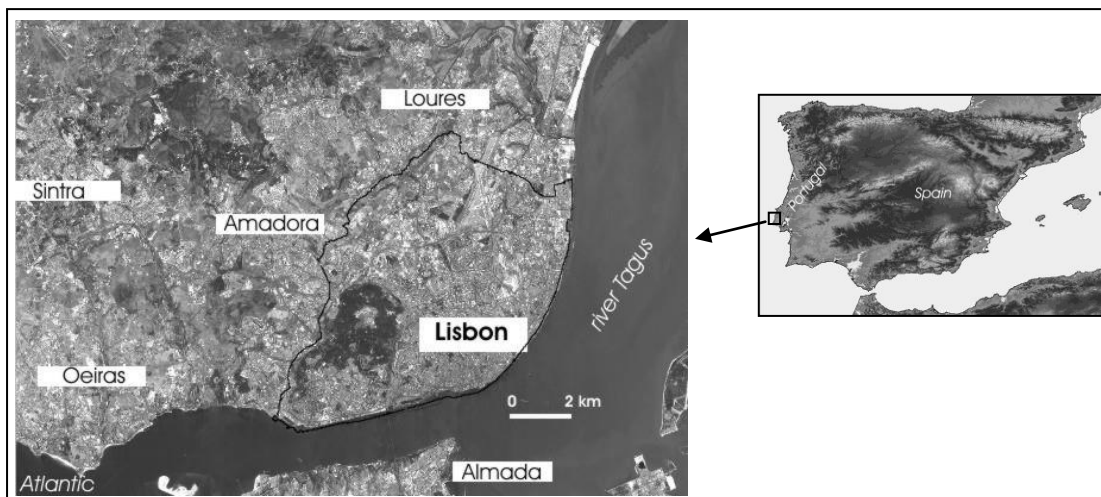


Figure 1. Lisbon and its suburbs.

1 Comunicação apresentada durante o *2nd International Symposium on Remote Sensing of Urban Areas*, Regensburg, Alemanha, em Junho de 2001

very complex urban climate. The relation between the complex multiplicity of spaces and structures built by man in a city and the atmospheric environment is a matter of our days an up-to-date problem. With more exigent citizens, policymakers and politicians must use the scientific knowledge to improve urban planning.

If we exclude the synoptic macroscale circulation, the known thermal patterns in the city are induced by major local factors such as local and regional wind, urban structure, building materials and air pollution. The wind speed varies according to the roughness produced by the buildings and depends on construction density and the presence of gardens, industrial spaces, open spaces, etc. Therefore the urban structure (the height and the width of the buildings, and the orientation of the streets) is a modeller of wind fields and wind profiles. The urban structure is also an active modifier of radiation conditions, trapping, reflecting and shadowing much more than the rural areas. In a smaller scale the different albedos and the heat capacity of the materials are also able to modify the thermal patterns and to induce urban climatic phenomena, which the urban heat island is only an example.

The aims of this work are:

- a) To create a land use/urban structure map for climatic purposes.
- b) To model heat fluxes in certain atmospheric conditions and times of the year from Landsat images.

Besides the methodology to estimate heat fluxes presented by several authors, we use here a new concept to create a land use/urban structure classification for climatic purposes. The concept is based on roughness lengths, since urban ventilation is one of the major forces that conducts climate patterns.

This work is a contribution to Lisbon's urban planning through remote sensing imagery and it is a part of a project recently approved by the *Fundação para a Ciência e Tecnologia* (Science and Technology Foundation of Portugal), entitled: "Prescription of climatic principles in urban planning. Application to Lisbon".

2 LISBON THERMAL PATTERNS STUDIES.

Since the eighties, the Lisbon climate has been studied from remote sensing images. Alcoforado (1986 and 1992) interpreted a night-time thermal image obtained by a radiometer *Deadalus* onboard of a Portuguese Airforce plane. The author noted several warm nucleus in the older part of the city, near the Tagus river and along the main avenues from the centre to the north of the city. Several industrial areas eastwards of the city centre (nowadays replaced by the EXPO 98 site) were warmer than the surroundings. Even apart from the centre, at 8.00 p.m., the main streets with SW and West exposed façades presented this warmer pattern. The cold areas corresponded to the bottom of the valleys in the eastern part of the city. These patterns are in agreement with the measurements of air temperature and reveal the Urban Heat

Island (UHI): air temperatures in the cities are normally several degrees higher than the surroundings. After a lack of twelve years Andrade and Lopes (1998) created a model to predict surface temperatures from a Deadalus infrared image, and Lopes (current work) used daily NOAA-AVHRR images to recognise surface UHI. With this kind of images we have a good temporal coverage but a very poor ground resolution to recognise several local and microscale thermal patterns.

But high surface temperatures do not always coincide with high air temperatures (Parlow, 1998). The Urban Heat Island is therefore one of the recurrent themes in urban Climatology, and some effort has been made to carry out new approaches to this field study.

3 DATA AND METHODS

The estimation of radiative and heat fluxes are quite complex. Several numerical models and algorithms with a GIS were made to prosecute this work. Image interpretation was also an important method to confirm *in situ* observations. When possible we tested several ways to obtain intermediate data and we compared the final results.

Accuracy must be therefore checked in every step of this method and the results were compared with other papers, in several cities.

3.1 NET RADIATION

Net all wave radiation (Q^*) balances short-wave (solar) radiation ($K^*=K\downarrow-K\uparrow$) and the long-wave radiation from Earth and atmosphere ($L^*=L\downarrow-L\uparrow$) (Oke, 1987, p.22-23). Because solar irradiance ($K\downarrow$) in inclined surfaces depends on several factors, namely the angle between surface normal and the direction towards the sun, we calculate slopes and aspects from a DTM of Lisbon and solar elevation and azimuth angle at satellite overpass on August 19, 1994. The main difficulty to estimate solar irradiance is related to the total extinction to which the solar radiation is subjected in the atmosphere. The Link Turbidity Factor (LTF) is the suitable extinction measure that "specifies the optical thickness of a turbid and moist atmosphere and a multiple of the clean dry atmosphere" (VEREIN DEUTCHER INGENIEURE-VDI, 1994, p.16). We can simulate integrated hourly clear sky irradiation values in a horizontal surface taking account with LTF. The average value of August in Lisbon is 5.4 according to the "Ecole des Mines de Paris, Centre d'Énergétique, Groupe Télédétection et Modélisation (<http://www-helioserve.cma.fr>), the site used to make the calculations of $K\downarrow$ in a horizontal surface. After that we made the correction for inclined surfaces using the slopes and aspects maps and the VDI (1994) formulation in a raster GIS (IDRISI).

The short wave reflection was calculated from the albedo (α - fig.2) of the surface ($K\uparrow=K\downarrow \alpha$) Oke, 1987, p.22). For that purpose, we first made the necessary corrections to transform

Landsat 5 Digital Number (DN) successively to calibrated spectral radiance (using lookup tables of gain and offset setting), and finally to exoatmospheric reflectance or in-band planetary albedo (EOSAT, 1986). Figure 2 shows the centre of the city (1) with values of albedo in a range between 12 and 18%, and the woods of Monsanto (2) with values much lower than that (<10%). In other unoccupied areas (3) and in the airport in the North, the values exceed 25% showing higher reflection in this areas and consequently high short-wave radiative loss.

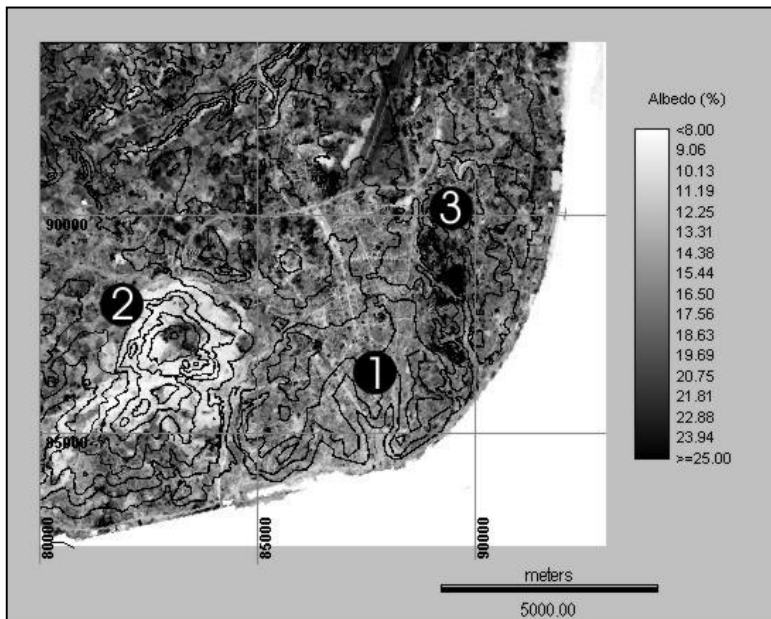


Figure 2 Lisbon albedo on 19 August 1994.

The surface thermal map (fig. 3) at satellite overpass time, about 10.00 a.m., shows the tree canopy of *Monsanto* (2 in figure 2) much fresher than the surroundings, with temperatures values (T_s), lower than 300 K. In the north-western areas T_s reaches 320 K. The city presents a

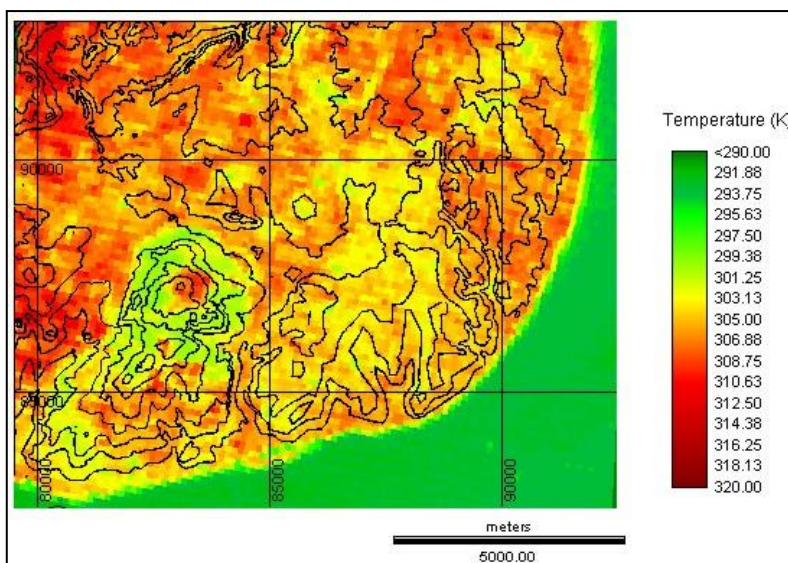


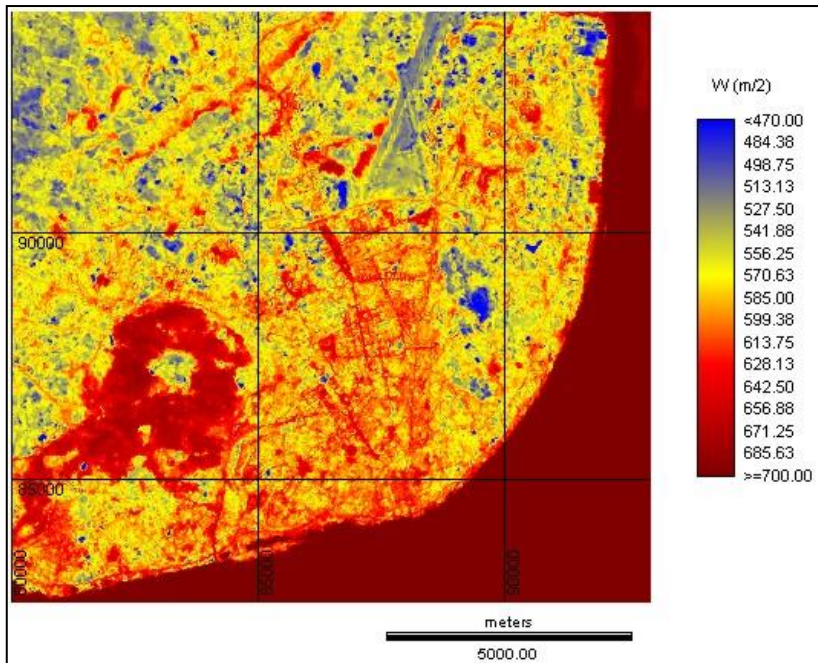
Figure 3. Lisbon surface temperatures (T_s) on 19 August 1994.

Both long-wave radiation (Earth $L\uparrow$ - or terrestrial emission and atmosphere $L\downarrow$ - or atmospheric counter radiation) were derived from Stefan-Boltzmann law. We assumed that atmosphere is formally a grey body (VDI, p.26) and we used air temperature at 2 m for the estimation of $L\downarrow$. For $L\uparrow$ we considered typical emissivity values close to the unit. Surface temperatures (T_s) were estimated from Landsat thermal band.

contrast between *Baixa* (down town: 1 in figure 2) and the eastern part, where the temperature is 4 K higher than in the centre.

The spatial distribution of net radiation (fig. 4) shows that the woods of *Monsanto* and the centre of the city receive more than 600 Wm^{-2} , whereas the airport area and some open spaces from the eastern part of

the city and north-west suburbs gain less than 400 Wm^{-2} . A regression analyses between surface temperature and net radiation (fig. 5), reveals a good agreement in those variables. Low



net radiation is the consequence of high surface temperatures (long-wave radiative loss) and high albedo (short-wave radiative loss), as it was noticed by Parlow (1998), for an industrial area in the Rhine region.

Figure 4 Net all wave radiation (Q^*) computed from numerical models and a Landsat image on 19 August 1994

3.2 URBAN STRUCTURE CLASSIFICATION FOR CLIMATIC PURPOSES

The storage heat flux (Q_G) is one part of the available energy that balances net radiation (the other two are latent and sensible heat fluxes, that for several reasons are not included in this paper, but will be parameterised in the future). After Parlow (2000) the basis inputs to compute Q_G are the NDVI (figure 8) and urban, rural and forest areas.

The “traditional” land-use classes derived from satellite images are complex aggregates, reflecting not only different physical surface properties, but also socio-economic aspects of

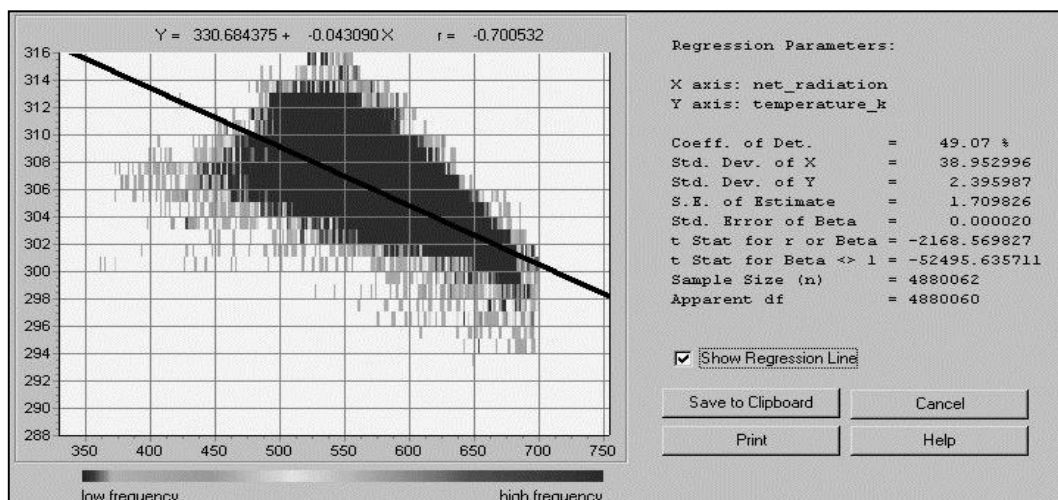


Figure 5. Regression analysis between surface temperature and net radiation.

land-use. Generally they are not very useful for climatological purposes, because, as it was referred to before, the height and the width of the buildings, and the orientation of the streets are effective modellers of wind fields and therefore important in thermal patterns.

The main question is: what can we use in addition to reflectance measured by satellites (materials properties) that give the influence of the city morphology?

In this work we present a different approach to create a land use/urban structure map, based on roughness length classes combined with Landsat and SPOT images. To achieve this urban structure map, several attempts were made, in order to get the most accurate one. The goal was to experiment different types of classification and see which one was more similar to the roughness map.

As referred to above the first input was the roughness map of Lisbon (fig. 6), where the city is divided in several areas with the same roughness. The classes were derived from the building heights and the width of the streets. The final map (fig. 7) has 6 different classes according to the estimated roughness lengths. Each class entered as a training site for several supervised classifications of the Landsat and SPOT, from different periods. The Landsat images

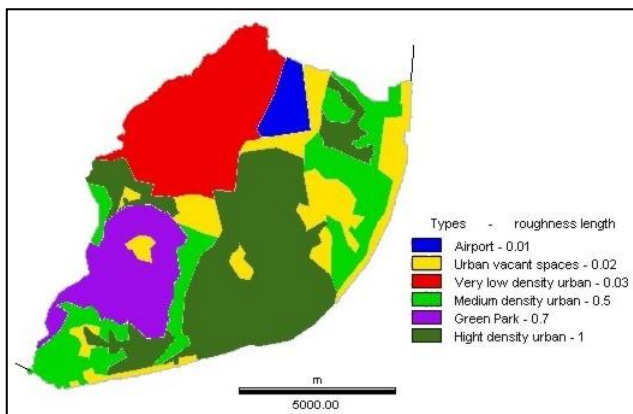


Figure 6. Roughness lengths taken from the building heights and the width of the streets. Training sites for the supervised classification were derived from these classes.

were from February 1992 August 1994 and July 1997; one SPOT image from July 1991 was also used. The following classifiers were tested: the minimum distance (raw and normalised), the maximum likelihood (with 0% and 1% to exclude), and the parallelepiped one (by Min/Max and by the Z-Score).

The next step was to calculate the error associated to each classification observing the values of the error matrixes, in order to choose the most accurate one. Once we know the error associated to each classification, we can choose the most accurate classification. Comparing the result with previous works, observations made in the field and former knowledge by the authors, we considered the maximum likelihood classification of the Landsat 1992 to be the most accurate classification of all.

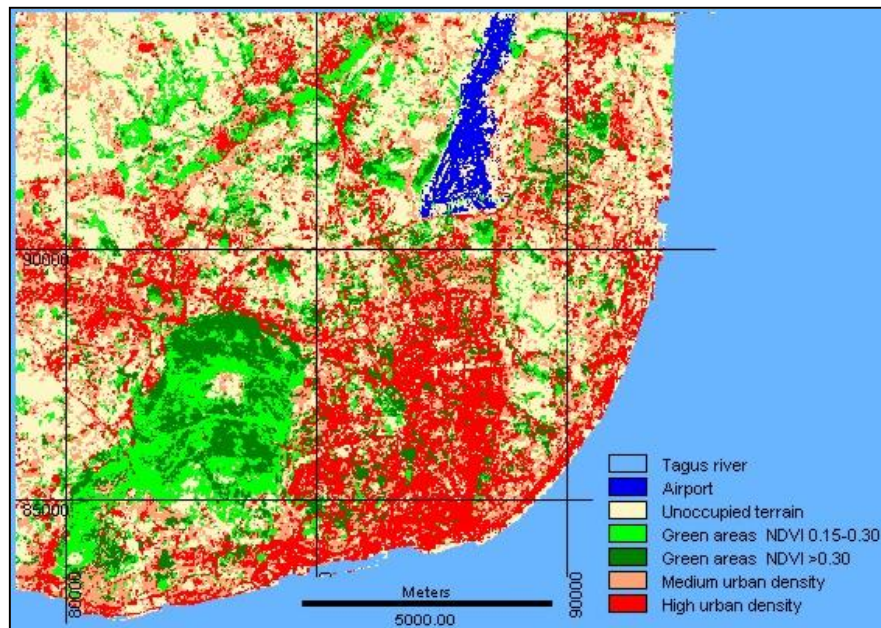


Figure 7. Land use/urban structure map of Lisbon for climatic purposes.

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Comparing the results with the city roughness map we concluded that there is a good correspondence for the overall map. The most difficult areas to classify were those with low urban density characterised by a great mixture of elements. The best agreement was the large green areas, the airport and the medium to dense urban areas.

3.3 STORAGE HEAT FLUX

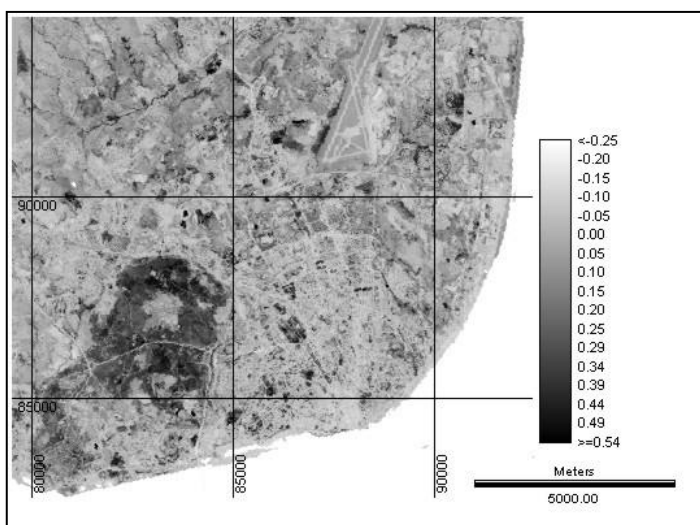


Figure 8. Normalised Difference Vegetation Index (NDVI) derived from Landsat image on 19 August 1994

Many authors applied NDVI (fig. 8) and net radiation to estimate the storage heat flux. The density of the vegetation (related to NDVI) acts as a resistance for the storage flux (Parlow, 2000). According to this author most employed equations cannot be used for both rural and urban surfaces, mainly because urban environment Q_G can reach up to 60 % of net radiation. He

proposes formulas to compute Q_G separately for urban, rural and forest areas. In the present work we join the urban areas (low, medium and high density), and we considered the green park as "forest" and the open spaces as rural "areas". The ratio Q_G/Q^* shows the differences between heat storage and net radiation in those areas.

4 RESULTS AND DISCUSSION

This summer image shows that urban and especially wood areas have the highest net radiation and as a consequence they are cooler than the surroundings. The Urban Heat Island is therefore not present in the morning. It was shown that the short-wave radiation loss (high albedo) and the high surface temperatures are related to the lowest net radiation values.

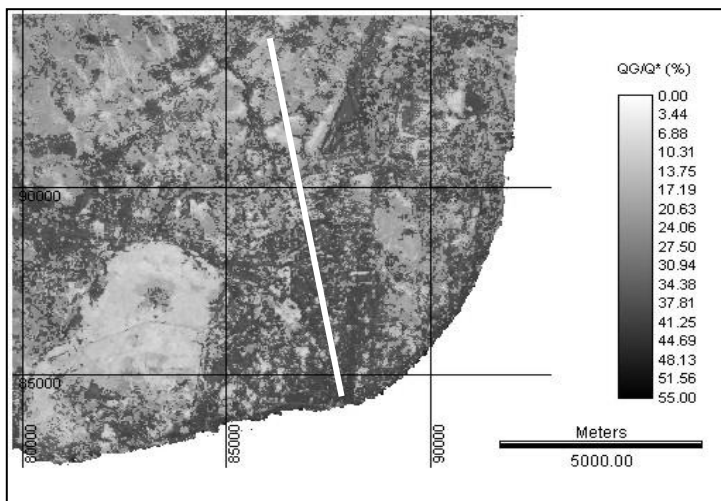


Figure 9. Ratio between the net storage flux Q_G and the net radiation Q^* , on 19 August 1994. The white line represents the profiles in figure 10.

The storage flux Q_G can be expressed as a ratio of the net radiation Q^* (Q_G/Q^* , fig. 9). During this clear sky summer day, woods present values less than 15 %. This value increases in urban areas. This means that urban surfaces (roads, buildings, etc.) store more than 40% of their net balance (fig. 10).

The results should not be static in time. By comparing Landsat images of different dates we can evaluate modifications of radiation and heating conditions within the city. In the future we expect to evaluate also the modifications of these parameters and to correlate them with the growing of Lisbon.

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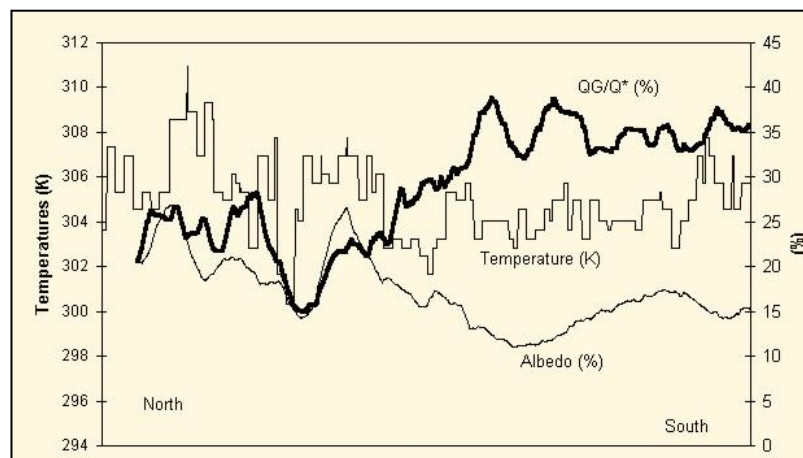


Figure 10 Surface temperatures, heat and radiation fluxes in a profile shown in fig. 9.

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