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WIND FIELDS AND TEMPERATURE PATTERNS IN LISBON (PORTUGAL) AND THEIR MODIFICATION DUE TO CITY GROWTH

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Abstract: Summer wind regimes at Lisbon airport are presented and the prevalence of N, NW and NE winds is showed. Subsequently, two thermal patterns related with different summer wind fields over Lisbon are analysed. To show urban influence, wind profile referring to the 1980s is compared with the one that has probably occurred over the site of Lisbon, before the presence of the city. Estimated wind profiles for 2020 reveal that between the 1980s and 2020, the greatest changes of wind speed are predicted at the 10m level over the city centre (40% reduction) as high buildings are being constructed in the northern districts (lying on the windward side of the city in 75% of summer days).

Key words: wind, Lisbon, summer, city growth

1. INTRODUCTION

The present paper has two main purposes. First, to show wind control on summer canopy layer thermal patterns of Lisbon in the 1980s. Secondly, to analyse how the growth of the city in its windward side has been modifying wind characteristics, and to foresee what will happen in the near future.
Lisbon is located at 38º 43' latitude N and 9º 9' longitude W and has approximately 800,000 inhabitants. The city lies 30 km to the east of the Atlantic seashore (fig.1), and is situated right on the Tagus estuary. It has a Mediterranean type of climate, with a dry warm season, classified as *Csa* according to Köppen system. Inside the city perimeter, altitude does not go higher than 160m, but it is a highly topographic differentiated area. The oldest city districts lie near the river. From the 19th century onwards the city began to expand northwards. Unlike some other cities, the highest buildings are concentrated on Lisbon's north and northwest limits.

2. DATA AND METHODOLOGY

The analysis presented is based on field measurements, thermograph and anemograph records and a wind database from Lisbon airport (1971-2000). The WAsP Program from Risø National Laboratory was used to estimate the wind profiles. WAsP condenses and transforms the original data into a set of values that contains the A parameter (related to wind speed) and the K parameter (shape) of the corresponding Weibull distribution. The research was carried out in the frame of CLIMLIS Project [1]

3. WIND REGIME

At 500 hPa, western winds prevail all the year round (Alcoforado, 1992). Surface wind flow remains the same during the cold half of the year, but it comes mostly from the north, northwest and northeast in spring and summer. Wind roses from different meteorological stations reveal that in winter winds blow mostly from SW, W and NW, but from March onwards, there is a great increase in the frequency of northerly winds (Alcoforado, 1992). At the airport, N, NW and NE winds prevail from May to September. Only daytime summer situations are dealt with here.
The analysis of the frequency of summer winds at the airport (fig.2) for the period 1981-2000 shows that the winds blow from the NE, E, SE, S and SW circa 40% of the cases at noon; at 18:00h hardly any winds blow from the aforementioned directions. Moreover, N and NW winds, which together come to 52% at noon, increase their frequency up to 77% at 18:00h. The results of an earlier work help to understand that this is a Tagus/Ocean breeze system and to give some more light to daytime succession of wind directions (Alcoforado, 1987). North (and northwest) winds blow continuously all day long in at least 45% of the occasions when there is a very strong pressure gradient between an anticyclone over the Atlantic and a low pressure to the east. On 35% of the days, northern winds are interrupted (for one to 5 hours) by thermally induced eastern (north-eastern or south-eastern) estuary breezes and/or south western sea breezes. It seems that during the morning hours the breeze is a local phenomenon, blowing from the Tagus estuary towards the city (eastern and south-eastern winds that reach the airport at noon, fig.2), which is then warmer than the surrounding water. Later during the afternoon, a stronger

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[1] CLIMLIS: Prescription of Climatic Principles in urban planning. Application to Lisbon, POCTI/34683/GEO/2000, financed by the *Fundação para a Ciência e a Tecnologia*. Portugal

and more developed sea breeze blows across the western hills and reaches Lisbon's western and southern districts. Later in the evening even faster N winds blow once more.

4. WIND AND THERMAL PATTERNS

Comparing two city-sites (where thermographs were located during the 1980s) with the airport at the northern border of Lisbon, we concluded that the frequency of positive differences is higher by night than by day. At the southern districts of Lisbon, 35% of the daytime situations correspond to a 'negative heat island' (Alcoforado, 1986). On summer days, there is a very complex relationship between temperature and wind conditions. On one hand, the mesoscale winds are thermally induced: a system of estuary and sea breezes develops on account of air temperature differences over the continent and over the Tagus estuary and the Atlantic Ocean. On the other hand, as the breeze continues to blow, urban air temperature of riverside districts decrease (fig 3a). When north winds blow then the same districts that were cooled by the breeze become the warmest in town due to a shelter effect (fig. 3b). The latter may either occur after the former in the same summer day or north wind may blow continuously; as a result, Lisbon riverside districts may be sheltered and consequently warmer all day long (+4ºC than at the airport), as shown in fig. 3b.

5. GROWTH OF THE CITY AND WIND CLIMATE CHANGE

The influence of the city in wind profiles will be analysed from a "historical" perspective. First, it will be assumed that only topography has an influence on wind fields and Lisbon will be considered a "site" with no constructions at all. Secondly, the roughness characteristic of the 1980s will be taken into account. Finally, the wind profile of the next decades will be presented considering the possible and probable growth of the northern districts by high buildings as it is already happening in the NW and NNW city boundaries. This problem can grow worse because plans are underway for the airport (location on fig.1) to move from the north of the city and this area could be occupied by a new generation of high buildings, completing the north urban barrier to the prevailing wind.

5.1. The roughness map of Lisbon

The accuracy of the wind speed estimation depends on the quality of data related to roughness length (z_0). When working on a microclimatic scale, one can easily determine roughness lengths by measuring the elements of a restricted area. In a mesoclimatic study (i.e. the whole city) some generalisations must be made. In this study, the same z_0 values were assigned to areas that have the same general urban morphology or computed through the *formulae* given by Mortensen *et al*. (1993). The roughness classes are presented in figure 4.

5.2. Average wind speed decrease in the 1980s

The estimated wind profiles (fig.5) reveal an average decrease of wind speed with the growth of the city. As expected, the great relative changes in summer are predicted at 10m high (reduction of almost 30% wind speed) and around 20% above it. Figure 6 shows the differences in the wind at 10m high in the 1980s as compared with the previous situation (absence of the city). As can be seen, the greatest changes are observed over the city centre. Obviously, the reduction of the wind speed occurs in areas where, throughout the ages, the city has grown more compact. The north of Lisbon does not reveal great changes due to the low construction until the 1980s and there is clearly a northwest/southeast differentiation in wind speed changes.

5.3. Prediction of future trends of wind speed

Based on empirical knowledge of Lisbon's expansion, an attempt to predict future changes of the wind speed was conducted in a down-town district ('Baixa'). The task consisted of transforming the original data of 1971/80 into a new wind data set, assuming that the roughness will change from 0.01 (airport) to 1.5 (typical roughness of a city that increases in height and volume), using the WAsP software. Results are shown in figure 5. As suspected, there will probably be a wind speed reduction, specially affecting the first 100m of the atmospheric boundary layer. When compared to the 1980s, the surface wind speed will be reduced up to 40% (Weibull A, 4.4 m/s in the 1980s, and 2.5m/s estimated for the next 20 years) and will decrease 10% at 100m high (respectively, 8m/s and 7m/s).

6. Conclusion

It is quite probable that all northern Lisbon districts are becoming an enormous barrier to the north wind, which blows on 75% of summer days and 50% of winter days. Until now, the north wind has proved effective in removing pollutants and as a thermal comfort regulator. Such a buffer (with an estimated roughness length greater than 1.5m), will certainly increase the occurrence of pollution critical peaks (with a greater incidence of associated diseases), human discomfort and the intensity of heat waves.

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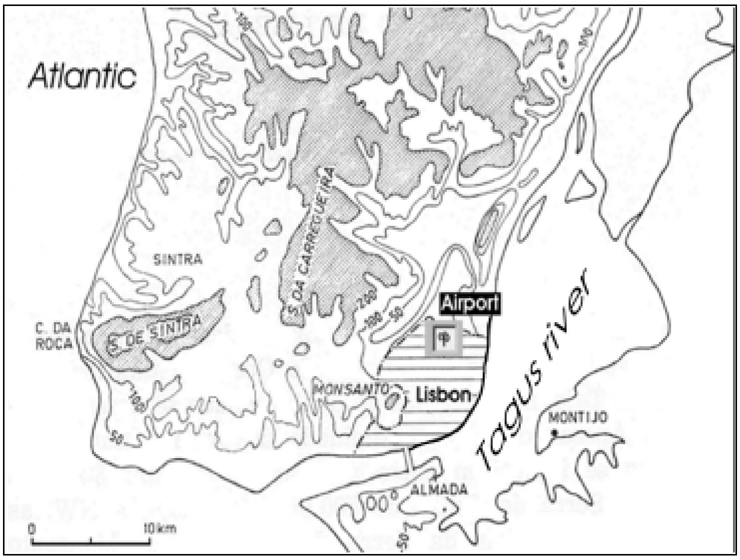
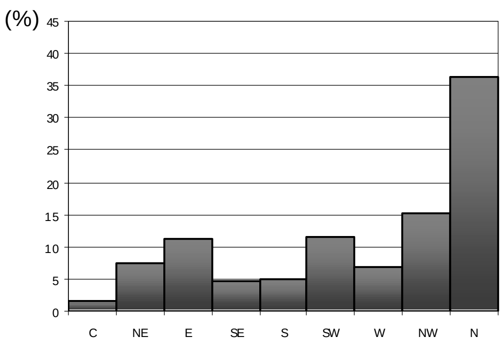


Fig 1 – Lisbon and its environments



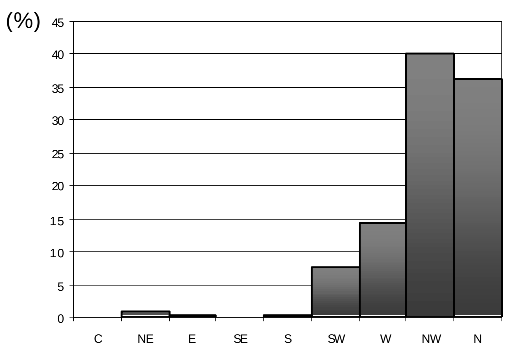


Fig. 2 – Wind direction in summer (June to August) at Lisbon airport (1971-2000)

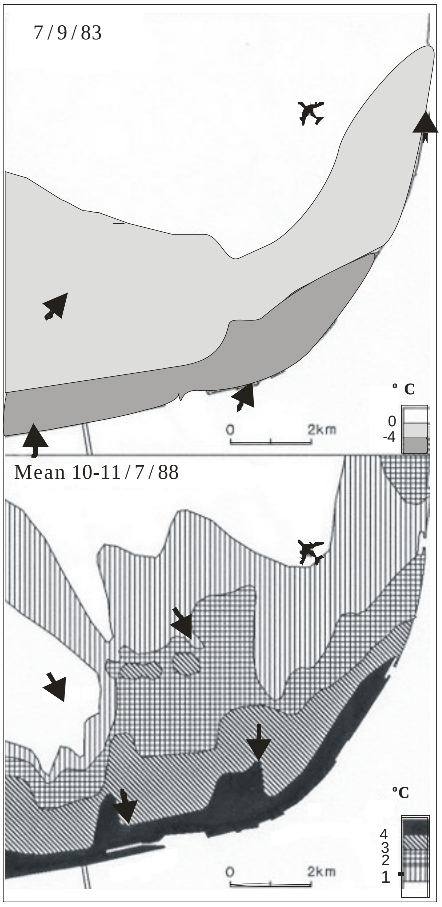


Fig. 3 – Temperature deviation from the airport
a) – breeze day b) – mean from 2 north wind days.

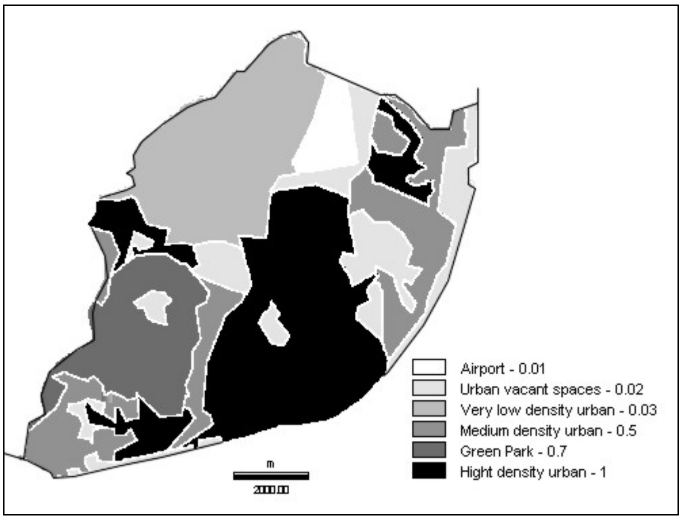


Figure 4 - Lisbon roughness length map (z_0 in m) in the eighties:

1.0 - Centre of the city;
0.7 - Woods of Monsanto;
0.5 - Urban areas with “suburban” characteristics;
0.03 - Open spaces with some houses and green areas and residual ancient farmland;
0.02 - Open spaces with no particular soil occupation (vacant spaces);
0.01 - airport area;
0.0 - River Tagus (WAsP recognise this value as "water").

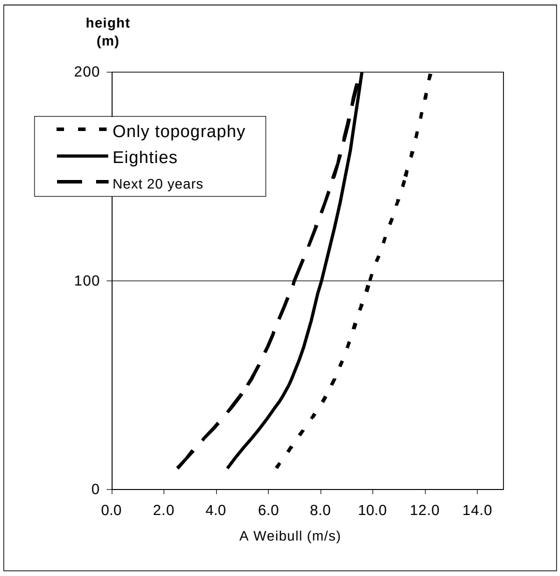


Fig. 5 – Estimated wind profiles for the ‘Baixa’ considering the roughness of the surface at three different periods in Summer.

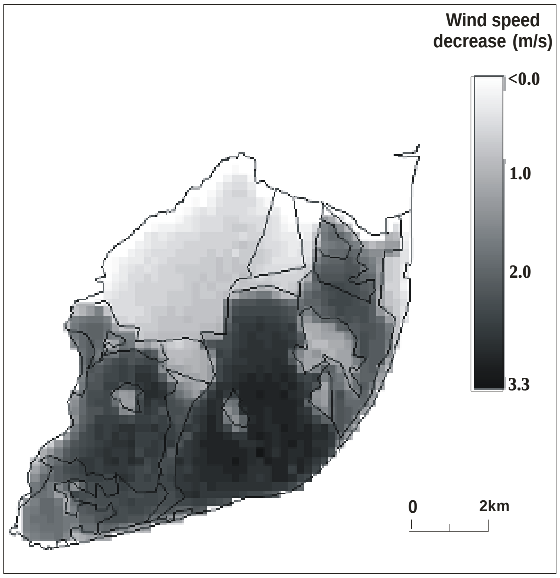


Fig. 6 – Wind speed decrease with Lisbon’s growth at 10m height until the 1980s (the highest figures show the greatest decreases)