WA^{s}P software - application for data analysis of wind over a city

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1. Introduction

Large cities can be thought as included in two different groups on its genesis: old and new cities.

The first group can typically be defined from an old settlement (some centuries) that must present conditions related not only with the comfort but also with the safety (defence) of the neighbouring populations. The second group includes the more recent cities (a couple of centuries of history) settled in conditions where defence is not a mandatory condition. For the first ones the nucleus is “old”, normally in hilly and slopy terrain, and their expansion along the centuries is made occupying the farm lands (plain terrain) around that nucleus; the new cities were as a rule established in plain terrain normally with hilly boundaries that are now being invaded by the urban expansion.

Both of them have a common background that supports their settlement and development along time: they need water and good air quality. In what concerns this last aspect we now know that man does not like to settle in places where mean yearly wind velocities are above 5 to 5.5 m/s and the standard deviation is low (above 25%-30% of the mean velocity).

2. The Methodology and Procedures

This article focuses on the study conducted for the city of Campinas/SP/Brazil. It is located on the southeast of the state of São Paulo/Brazil, 100km from its capital (geographical coordinates S 22°53'20", W 47°04'40"); its altitude is about 680m above sea-level and it is about 150 km from the sea (Atlantic).

22.5° S is in the limit of the tropical zone (Capricorns tropic 23.5/ S) and so though well inland the wind regimes are expected to be dominated by the trade winds global pattern.

The city was founded in the last quarter of the 18th Century as a simple outpost in the way to Minas Gerais and Goiás. Only in the middle of the 19th Century with the development of cultures like sugar cane, coffee and cotton the city small town began to grow though only by the end of the 30’s of last century with the beginning of industrialization and the construction of the first Brazilian highways the real urban “explosion” begins. Campinas municipality urban ground now holds about 1.1 million, a population that almost doubles when the urban areas of the adjacent municipalities collapse together in the “larger Campinas”. Most of the original vegetation existent in the city, the “*Mata Atlântica*”, was devastated along the years and the city now suffers a severe environmental stress.

Thus Campinas is a city typical of the second group defined previously (established in the plain as a small nucleus and then growing, occupying the involving hilly - soft slopes - terrain). The Master Plan divides the city in nine macro-zones. These were created due to the heterogeneity of the areas of the city of Campinas and their definition took into consideration physical-territorial, socio-economic and environmental aspects (SEPLAMA, 2012).

The climate is tropical (Köppen type Cwa) mitigated by elevation (Campinas - a large prairie in Portuguese - is located in the transition between “*Depressão Periférica Paulista* and *Planalto Ocidental*”), with lower rainfall in winter and annual average temperature of 21.3 C, with dry and mild winters (rarely too cold) and rainy summers with warm to hot temperatures. Fall and spring are transitional seasons. The average annual rainfall is 1424.5mm and the driest month in August, when there are only 22.9mm. In January, the rainiest month, the average is 280.3mm, CEPAGRI (2010).

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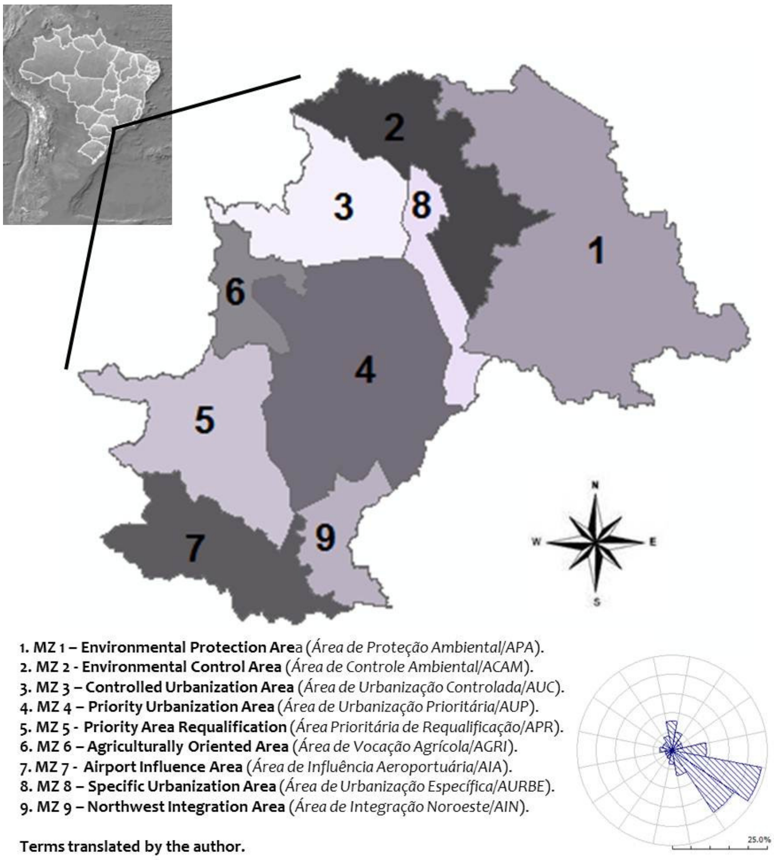


Fig. 1 Macro-zones / Master Plan city of Campinas/SP/Brazil.

The methodology proposed for the analysis of the wind urban climate (a sensible parameter the importance of which is increasing as cities grow) follows the following steps:

- Collect the information on the city and its involving areas topography;
- Collect the information from meteorological stations with a minimum of credibility (airport data in most cases) and for an extended period (some years if possible);
- Adopt a (simple) software model that incorporates at the same time the topography of a large area, the characteristic of terrain occupancy (roughness) and the integration of the data: WA^{s}P software was considered, and its advantages and drawbacks discussed. The WA^{s}P software - Wind Atlas Analysis and Application Program (Mortensen et al., 1993), developed by Denmark's Wind Energy Department – Riso National Laboratory, was used to estimate the height profiles and wind fields, given the topography and an equivalent roughness;
- Run the software for the present terrain occupation condition considering the data from the most credible station, built the site specific wind rose (including not only the wind rose but the statistical distribution of wind velocity from the different directions) and the wind regimes for the whole area considering the present occupation of soil (roughness) namely the wind profiles;
- Assess the information for the site at a height above ground where the effect of roughness can be ignored;
- Rebuild the wind regimes with the roughness removed (roughness corresponding to the conditions before settlement) over the area of the whole city and its surroundings again at a certain height above the terrain;
- Compare results from both runs at specific sites, namely at those sites where meteorological stations with credible data are installed;
- Treat the data and provide a detailed comparison (same period of time) for the results obtained following the former steps of the methodology;
- Justify differences between "estimated" and real data based on specific site conditions.

Procedures were defined to collect the information: general maps of the terrain from official authorities, Figure 2a; general lay-out of roughnesses in the city, as supported by observation of Google-generated image, (in this first stage, for the sake of simplicity, general values for roughness - built /not built - were adopted), Figure 2b; and contacts with entities like the airport administration to obtain wind data and verify its consistency.

For this article data from three weather stations in Campinas/SP were obtained: Viracopos airport (Southeast area of the city - lat. -22,81º; long. -47,13º, alt 660m); Instituto Agronômico de Campinas - IAC (Central area of the city - lat. -22,86º; long. -47,07º, alt 668m) and Centro de Pesquisas Meteorológicas e Climáticas Aplicadas à Agricultura - CEPAGRI/Unicamp (lat. -22,81º; long. -47,06º, alt. 619m), Figure 2d). For all the stations the data analyzed is for the period from Jan/2000 to Dec/2010. A file was created with columns containing dates, times, velocities and directions of the average wind. For WAsP simulation, the data used was that from the Viracopos station.

Figure 2c presents the line plotted between the stations at Viracopos airport and Cepagri/Unicamp, cutting through the central area of the city. Although the vertical scale of the terrain profile seems to vary widely, along 23km the slope values were typically around 10% (notice that vertical and horizontal scales are different), making it – thus – possible to use the WAsP software.

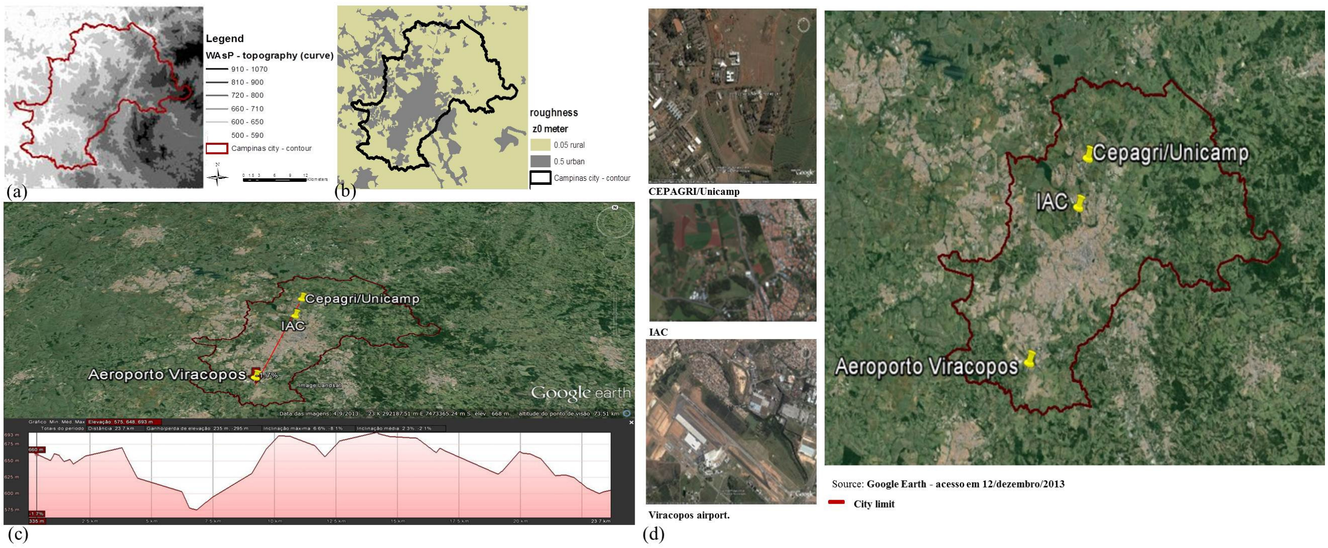


Fig. 2 Macro-zones / Master Plan city of Campinas/SP/Brazil.

The following reasons justify WAsP adoption:

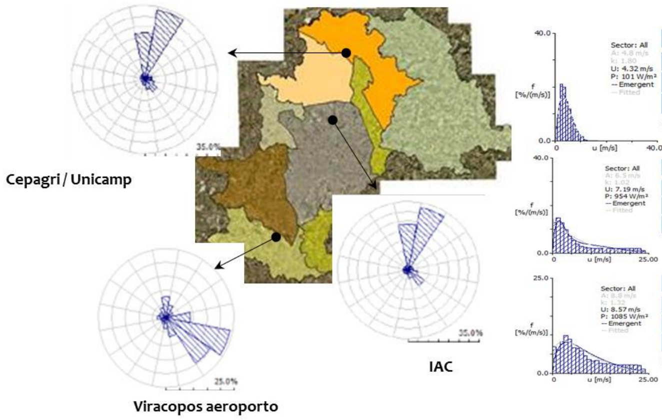
1. it can cover a large area to estimate wind conditions from data from a single meteorological station;
2. a 40x40 km area centered on the weather station can be considered - as the effects of the Coriolis force can be considered small for lengths over the earth surface at mid latitudes less than 20 km;
3. terrain maps can be imported into the software from a large type of data bases;
4. roughness maps can be superimposed (after a definition by the user) directly on the terrain representation;
5. hilly terrains are not a problem for the fluid mechanics models adopted, if gradients are not to high – even downhill flow can be reasonably described by the model if slopes are below 6º (meaning ~10% gradient) (Figure 2c) and;
6. statistical treatment means that some lack of data does not demand adoption/development and application of a procedure for “building” the missing information.

3. Results and Discussion

For results and discussion the simulations below were considered:

1. Analysis of climate data for the three stations, for verification of values A and k for each wind orientation. Based on the climate data and use of WAsP software, Figure 3 shows the history series of the three stations, as well as the wind roses, average velocities and values A and k for each wind direction. For Viracopos, k>2 values on quadrant 90 to 157.5 degrees are typical of trade winds coming from this direction (main direction 120 to 150 degrees). Values of k<2 from the other directions are typical of continental patterns. The Rayleigh distribution (k=2, maritime regime) in this case represents the transition between the two first regimes. This distribution is compatible with what is known on the climate of the site.

2. Drafting a map of mean year velocities (at 10 m) superimposed on the topography map of the area (without the city), with wind data from Viracopos.



	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
A	4.2	3.9	3.3	3.0	3.4	5.7	6.4	6.0	4.0	3.5	3.5	3.4	3.6	3.9	3.9	4.2
k	2.01	1.72	1.87	1.96	2.26	2.49	2.38	2.03	1.63	1.68	1.63	1.58	1.89	1.80	1.89	1.98
U	3.68	3.48	2.90	2.68	2.97	5.08	5.68	5.32	3.56	3.17	3.12	3.08	3.17	3.50	3.43	3.70

Viracopos airport

	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
A	10.5	13.2	2.8	2.3	2.3	3.5	4.4	3.2	2.3	2.3	2.1	2.2	2.1	2.2	2.5	2.9
k	1.49	2.00	1.94	1.62	1.53	1.57	2.06	1.68	1.57	1.62	1.56	1.72	1.74	1.92	1.65	1.65
U	9.52	11.66	2.48	2.09	2.03	3.10	3.90	2.90	2.06	2.05	1.93	1.97	1.87	1.93	2.19	2.60

Instituto Agronômico de Campinas - IAC

	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
A	11.9	13.3	3.8	4.0	4.8	6.3	7.7	7.4	5.7	4.5	4.1	4.7	5.3	5.1	5.5	5.5
k	1.75	2.05	1.57	1.46	1.41	1.65	1.81	1.75	1.40	1.36	1.37	1.48	1.64	1.66	1.76	1.79
U	10.62	11.80	3.41	3.59	4.35	5.66	6.85	6.58	5.22	4.09	3.74	4.27	4.72	4.59	4.92	4.93

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Fig. 3 Values A e k for the weather stations.

3. Drafting a map of mean year velocities (at 10 m) superimposed on the topography and roughness maps of the area, with wind data from Viracopos.

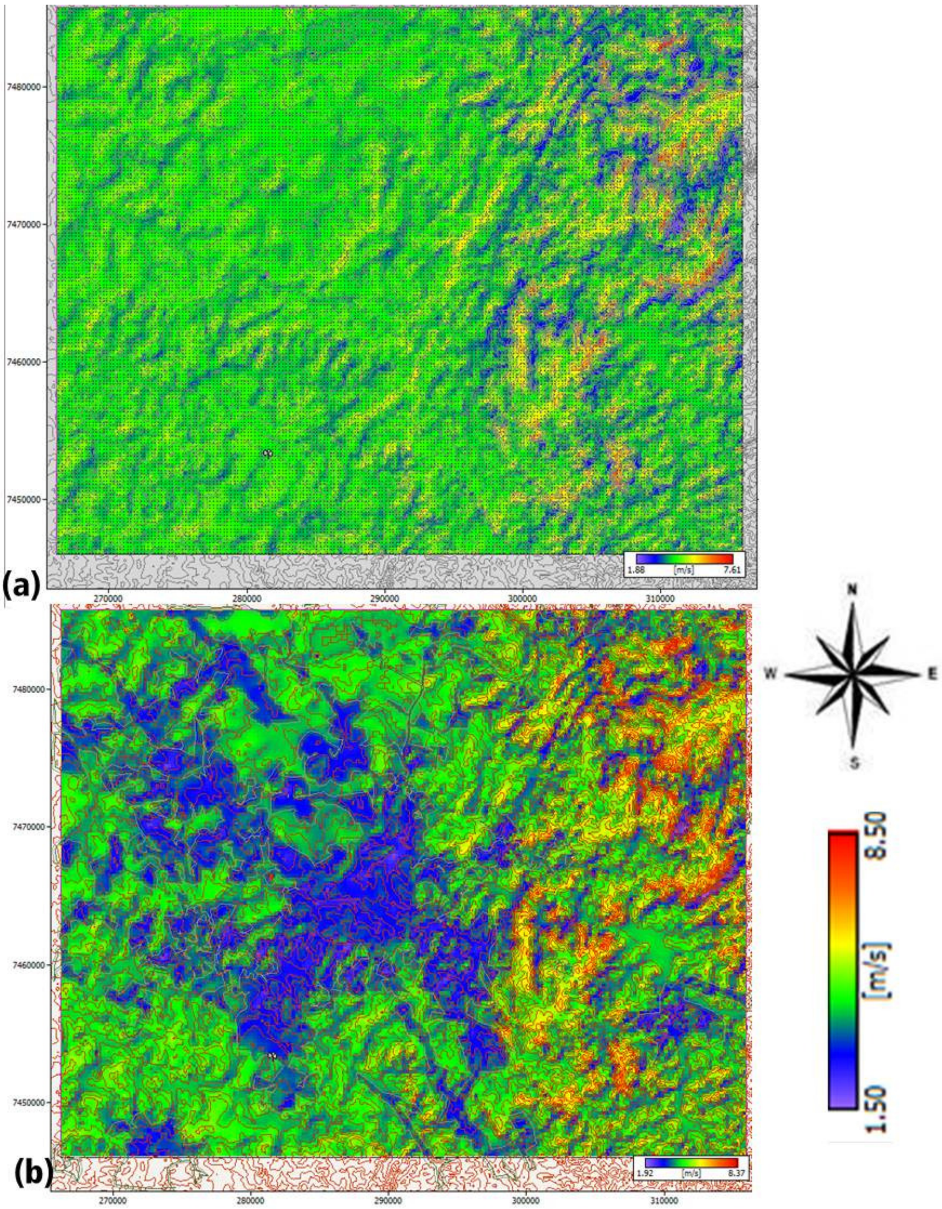

Fig. 4 Wind Atlas map (a) topography and (b) adopted roughness (rural and urban).

These last two simulations aim at verifying whether or not there are changes and what influence roughness has on the results found.

Figure 4(b) shows an increase in wind velocity with the insertion of roughness values in the model, compared to what is seen on the topography-only scenario (Figure 4(a)).

On the first simulation it's clearly seen the influence of the anemometer height on k values.

As expected the average velocity values are typically below 5 m/s. Based on the results presented, it can be stated that WAsP is a good tool for verification, in global terms, of wind behavior (only velocity is considerate though the same procedure can be used for direction) in urban scenarios.

The results from the climate data present A and k values which support wind patterns over the city (verification of combinations of trade winds, atmospheric circulation of the depression centered in Central Brazil and the entrance of cold fronts from the South; and the atmospheric flows from the North/West quadrant, typical of the small percentage of winds coming from "the continent").

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