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ORIGINAL ARTICLE

A climatology-based wind speed map for NBR 6123

Mapa de isopletas para a NBR-6123 com base em abordagem climatológica

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Abstract: Updating the basic wind speed map of NBR 6123 –-Wind loading on buildings – is one of the duties of the committee responsible for the revision of this code. Traditionally such maps are elaborated by means of extreme value wind speed data collected at meteorological stations, use of statistical methods for data characterization, and application of mathematical regression to elaborate the territorial maps. However, the spatial distribution of the atmospheric phenomena responsible for strong winds cannot be disregarded. This work presents a proposal for a new wind speed map for NBR 6123 combining a climatological approach and wind speed data recently compiled from hundreds of meteorological stations. A climatological wind map was first produced considering the phenomena which cause strong winds, and used as a basis to draw the isopleths of the basic wind speed map, considering the measured wind speed data. The resulting map shows basic wind speeds ranging from 30 to 48m/s.

Keywords: extreme winds, basic wind speeds, climatology, Gumbel distribution, NBR 6123.

Resumo: A atualização do mapa de isopletas da norma NBR 6123 – Forças devidas ao vento em edificações – é um dos aspectos tratados no âmbito do trabalho da comissão encarregada da revisão da citada norma. Tradicionalmente estes mapas são elaborados por meio de análises de valores extremos das velocidades do vento registradas em estações meteorológicas, da aplicação de métodos estatísticos para caracterização dos dados, e de interpolação matemática para geração do mapa. Entretanto, a distribuição espacial dos fenômenos atmosféricos responsáveis por ventos fortes no Brasil não pode ser desconsiderada. Este trabalho apresenta uma proposta para um novo mapa de isopletas da velocidade básica do vento para a NBR 6123 elaborado com base em uma abordagem climatológica e em recente pesquisa incluindo novos dados de centenas de estações meteorológicas. Inicialmente foi desenvolvido um mapa de regiões climáticas associadas aos fenômenos que produzem ventos fortes, a partir do qual o mapa de isopletas foi traçado. Resultaram isopletas associadas a velocidades de vento variando entre 30 e 48m/s.

Palavras-chave: ventos extremos, isopletas, velocidade básica do vento, climatologia, distribuição de Gumbel, NBR 6123.

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1 INTRODUCTION

In NBR 6123 [1] the so-called “basic” wind speed V_0 is defined as the average speed over three seconds (wind gust), which is exceeded on average once every 50 years, measured 10m above ground in open and flat terrain. Based on annual maximum wind gusts obtained in 49 weather stations of Brazilian airports, a wind speed map was drawn [2], [3], [4], which served as a basis for the current basic wind speed map of NBR 6123 [1]. In this map (Figure 1), values between 30 and 50 m/s are observed, as well as a large, hatched region in central Brazil, for which data was not available at the time, and for which the “minimum” value of 30 m/s was adopted.

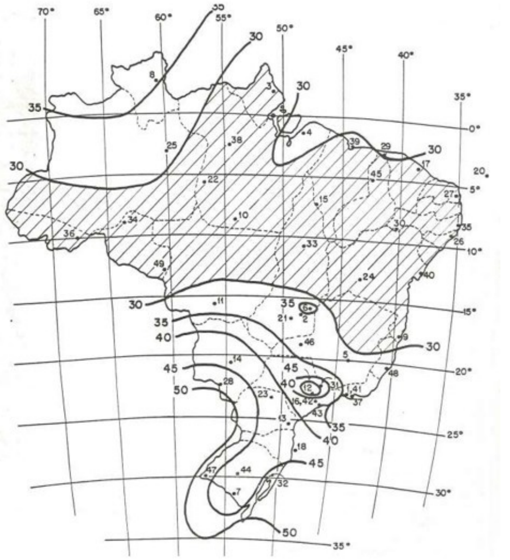

Figure 1. Isopleths map of current NBR 6123 [1]. V_0 values in m/s shown at tips of isocurves; numbers associated to dots identify the weather stations.

Recent research on the topic includes Almeida [5], Beck and Correa [6] and Vallis [7], who proposed maps based on mathematical regression. More recently, Kriging regression/interpolation was also proposed [8]. Vallis [7] also presented a V_0 map for Brazil in zone format. The author [7] developed algorithms to classify the events which cause strong winds in Brazil in synoptic and non-synoptic (definitions in Section 2). Vallis [7] concluded that non-synoptic winds dominate and define extreme winds in most parts of the Brazilian territory. Before that, other works pioneered identification and classification of winds in stationary synoptic and non-synoptic [9], [10].

The meteorological phenomena which produce extreme winds in Brazil have distinct characteristics in different parts of the country [11]–[14]. Recognizing this fact leads to the proposal of a climatological approach to the basic wind speed map, in opposition to purely mathematical regression. The purpose of this manuscript is to present and justify the proposal of a climatology-based basic wind speed map for NBR 6123. A climate zone map of Brazil is first proposed, focusing on the dominant atmospheric phenomena which typically cause strong winds. In the sequence, a literature review is conducted, addressing past literature proposing V_0 maps for Brazil. Finally, the climatology-based basic wind speed map for NBR 6123 is proposed and justified.

2 BRAZILIAN CLIMATOLOGY: SPATIAL DISTRIBUTION OF THE ATMOSPHERIC PHENOMENA RESPONSIBLE FOR STRONG WINDS

2.1 Types of atmospheric phenomena and their scales

Extreme winds in Brazil are generally caused by two types of meteorological phenomena which can also occur simultaneously: extratropical cyclones and local convective storms [12], [13], [15]. The winds originated in extratropical cyclones are better known and studied and serve as the basis for the design criteria and aerodynamic coefficients present in current wind codes worldwide.

Extratropical cyclones belong to the synoptic scale of atmospheric phenomena, with horizontal dimensions of the order of hundreds of kilometers and duration of up to a few days. From this scale of motion originates the term ‘synoptic wind’ employed in wind engineering. Other extreme winds are associated to local convective storms, which belong to a different atmospheric scale, called mesoscale (or convective scale, more specifically) [15]. Local convective storms have a horizontal scale of the order of 10 km and duration of the order of one hour. In the convective scale are the winds known as TS (thunderstorm), as well as the general ‘non-synoptic winds’ of wind engineering. Among the most intense TS winds are those associated to strong downward currents (or downbursts) and tornadoes.

2.2 Characteristics of non-synoptic winds relevant to structural engineering

The term ‘downburst’ was coined by Fujita [16], and is understood as a dense column of cold air associated with which is a convective-scale downward current (or downdraft) that eventually reaches the earth´s surface, giving rise to a ‘burst’ of highly divergent winds. In terms of horizontal scale, a downburst can be classified as a microburst when the radius of the divergent motion spreads no more than 4 km from the central downdraft, and as a macroburst when this radius exceeds the 4 km threshold [17], [18].

Figure 2 shows photos of the leading edge of a ‘supercell’ storm (i.e., a convective storm that exhibits rotation) over the city of Porto Alegre, RS, in the 29th of January, 2016 from which strong downdrafts and accompanying gusts (non-synoptic winds) originated. The schematic illustration shows the short horizontal scale of the event. Due to their local character, many non-synoptic wind events are not adequately registered by operational surface weather stations, implying that the non-synoptic wind speeds, being poorly sampled, could be significantly stronger than those actually measured by the anemometers at weather stations.

The characteristics of the horizontal flow originating from the convective downdrafts are complex, and their detailed discussion is out of the scope of this manuscript. However, some aspects relevant to structural engineering should be discussed.

In terms of vertical structure, the mean velocity profiles of downbursts (as they spread laterally) are significantly different from those typically observed for winds originated from extratropical cyclones (atmospheric boundary layer profiles, or ABL), as illustrated in Figure 3 for profiles corresponding to V_0 equal to 40 m/s. The mean velocity profile illustrated for the downburst was obtained from Vicroy’s model [20], considering maximum velocity at a height of 40 m, as in ref. [21]. In this case, the load effect on buildings with heights between 10 and 120 meters is more intense than for winds originated from extratropical cyclones, for the same value of V_0. The opposite occurs for buildings higher than 150 m. However, the height at which the maximum downburst wind speed occurs can be higher than 40 m (even reaching 120 m), increasing considerably the height of buildings for which the downburst profile would be more favorable than the ABL profile.

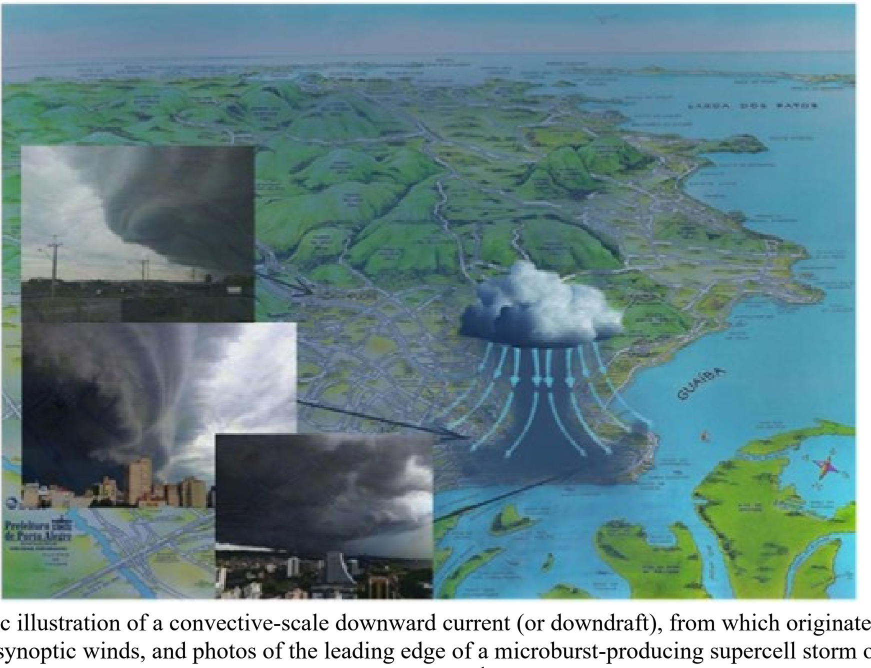

Figure 2. Schematic illustration of a convective-scale downward current (or downdraft), from which originates a type of intense non-synoptic winds, and photos of the leading edge of a microburst-producing supercell storm over the city of Porto Alegre, RS on 29th of January, 2016 [19].

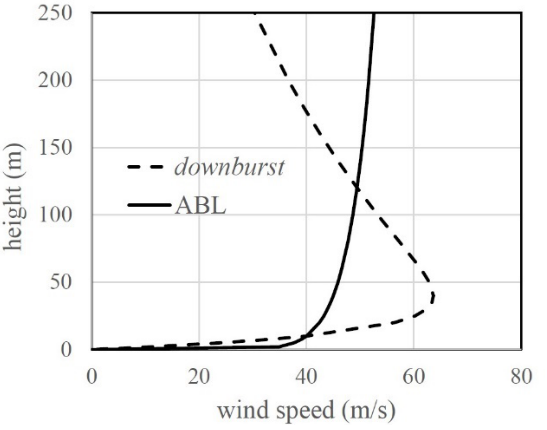

Figure 3. Mean wind profile corresponding to V_0 equal to 40 m/s for atmospheric boundary layer winds (full line) and downburst-like winds (dashed line, with maximum at height of 40 m) during its horizontal divergence at low-levels, based on Vicroy model [20].

Importantly, non-synoptic winds can occur simultaneously to synoptic winds. Such occurrences are quite frequent, for example, during the progression of a cold front, due to frontally-induced local convective storms. This combination of meteorological events changes wind flow patterns, as illustrated in Figure 4, leading to the classification of downbursts in stationary and non-stationary. Following Li et al. [22], non-stationary downbursts occur more often.

Figure 5 is a representation of horizontal flow patterns that arise from the combination of forcing mechanisms that belong to distinct scales of atmospheric motion (most notably, synoptic and sub-synoptic scales). The figure refers to the Northern Hemisphere and was elaborated by Fujita and Wakimoto [23] based on observed damage produced by the distinct wind types. Figure 5a) shows the flow associated with an anticyclone (synoptic winds) and also identifies the cold front zone. Figure 5b) provides a close-up view along a section of the cold front and illustrates the formation of the gust front associated with convective storms (TS) aligned with the cold front. Some of these storms can occasionally produce downburst winds. Figure 5c), which is a zoomed-in view of panel 5b), shows the flow patterns associated with a downburst. Finally, Figure 5d), on the 1 km scale, shows that inside a downburst there are more intense gust swaths, which lead to non-uniform wind patterns.

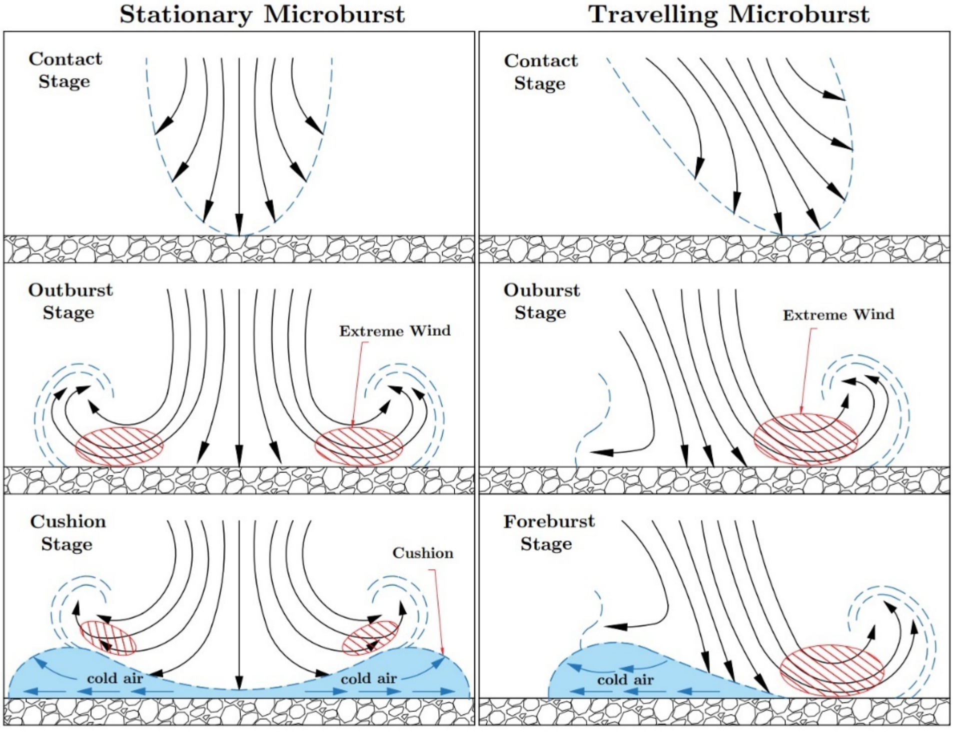

Figure 4. Schematic vertical cross-sections displaying the time evolution of the atmospheric flow across a stationary downburst (left column), and a typical moving or non-stationary downburst (right column) (based on Fujita [17]).

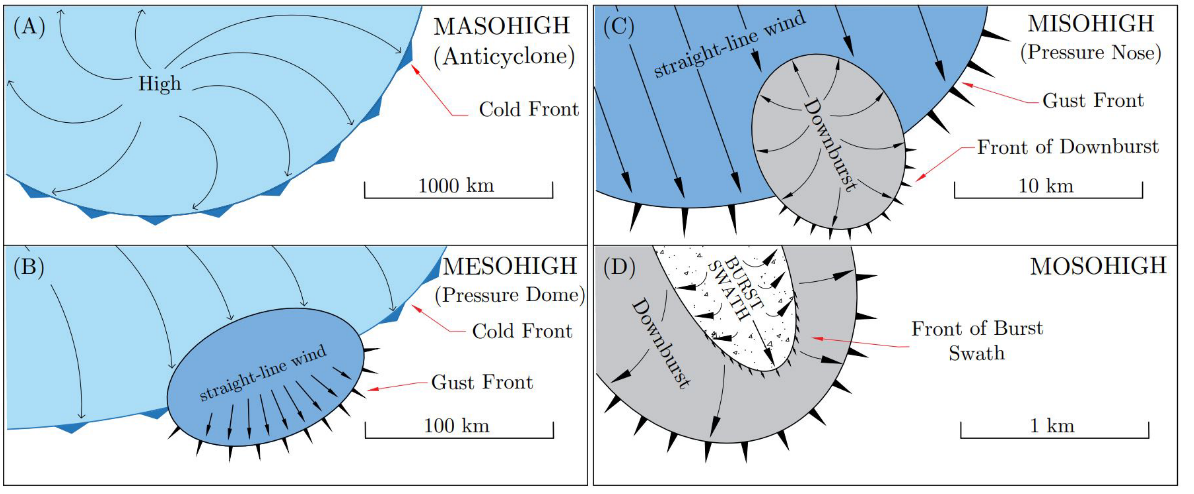

Figure 5. Schematic charts for the Northern Hemisphere displaying close up views of horizontal flow patterns originating from the combination of synoptic and non-synoptic winds forced by atmospheric processes belonging to different scales of motion. From (a) to (d), panels depict flow patterns at ever shorter horizontal scales (based on [17]).

Figure 6 illustrates, in a schematic way, the passage of a non-stationary downburst by a building [24]. It is evident that the building is subject to winds of different intensity and directions. This is one of the reasons why wind directionality cannot be used to reduce design wind speeds.

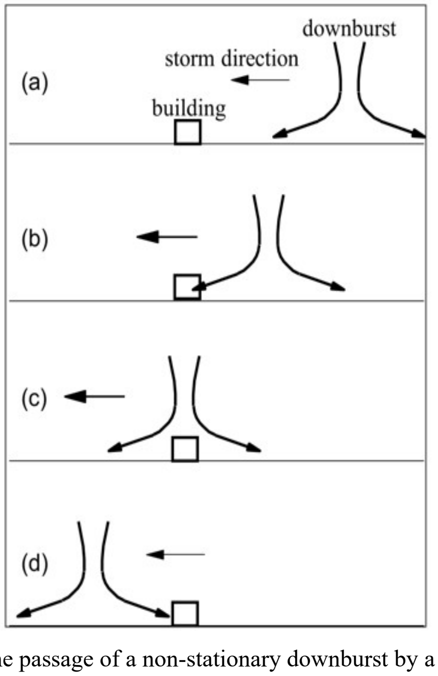

Figure 6. Schematic illustration of the passage of a non-stationary downburst by a building (based on Chay et al. [24]).

2.3 Climatology of non-synoptic winds

Figure 7 shows results of a recent study [25] that indicates the estimated frequency (in terms of the mean number of hours per year) of atmospheric conditions in South America which favor the occurrence of convective storms in general (left panel) and severe convective storms in particular (right panel); warm colors indicate higher frequencies. In this context, severe convective storms are the ones that generate hailstones with diameter greater than 2 cm, or tornadoes, or non-tornadic wind gusts above 50 kt (slightly over 90 km/h), representing, thus, characteristics that are particularly relevant to wind engineering. The conditions conducive to general convective storms are more frequent in the Amazon Basin, especially over northwestern Brazil (Figure 7a). In contrast, the atmospheric conditions that lead to severe storms are more frequent over the La Plata Basin including subtropical Brazil (Figure 7b).

Even though the La Plata Basin is recognized as the South American hot spot for severe local storms, this does not exclude the potential for damaging TS winds in the Amazon River Basin. In fact, Figure 7b) does indicate that conditions for severe storms occur with reasonable frequency over far northwestern Brazil (see sector with yellow-orange colors). Second, there is physical evidence of destructive wind gusts of convective nature in the Amazon Basin. A number of studies report the sudden appearance of irregularly-shaped clearings in the rainforest, which are not related to human activity. These clearings are associated with intense wind gusts originated by local convective storms.

To illustrate that, Figure 8 highlights some key results from these studies, consisting of the identification of damage inflicted to the vegetation cover via high-resolution remote sensing using environmental satellite imagery [26]–[28]. Figure 8 shows that fall of large trees caused by natural factors are more frequent in the center-west and in the extreme east of the Amazon Basin. The fallen tree mapping in Figure 8 can be compared with the frequency map of convective storms over the Amazon Basin, Figure 4 of [28]. The color shading in Figure 4 of [28] indicates the frequency of convective storms based on the annual number of days with precipitation surpassing 20 mm (warm colors corresponding to greater frequency). A strong correlation can be identified between these independent sources of information, with a greater frequency of forest clearances occurring precisely where the convective activity is more frequent.

Going back to south-central Brazil, several studies using different methodologies confirm the frequent occurrence of severe storms in this region, including those generating strong winds. One example is shown in Figure 9, which illustrates a map of occurrences of wind gusts of convective nature greater than or equal to 25 m/s in southern Brazil (as measured by the operational network of automated weather stations maintained by INMET – National Institute of Meteorology) between 2005 and 2015 [29]. Figure 9 shows a general tendency for strong convective gusts to be more frequent in the south-west sector of southern Brazil, which matches reasonably well with the climatological map produced by Taszarek et al. [25] for the same sector (Figure 7b). Great part of the local storms producing destructive gusts in southern Brazil, such as supercells and severe quasi-linear convective systems, originate in northeastern Argentina or in southern Paraguay, before advancing to the east towards the Brazilian territory. This essentially accounts for the geographical distribution shown in Figures 7b and 9. With respect to Figure 9, it is important to point out that the density of INMET´s network of surface automated weather stations was not originally conceived to adequately detect wind gusts on the convective scale (i.e., of short duration and small horizontal extension). This means that one can safely state that the map shown Figure 9 provides an underestimation of the actual number of convective events that produced wind gusts equal to or larger than 25 m/s in southern Brazil.

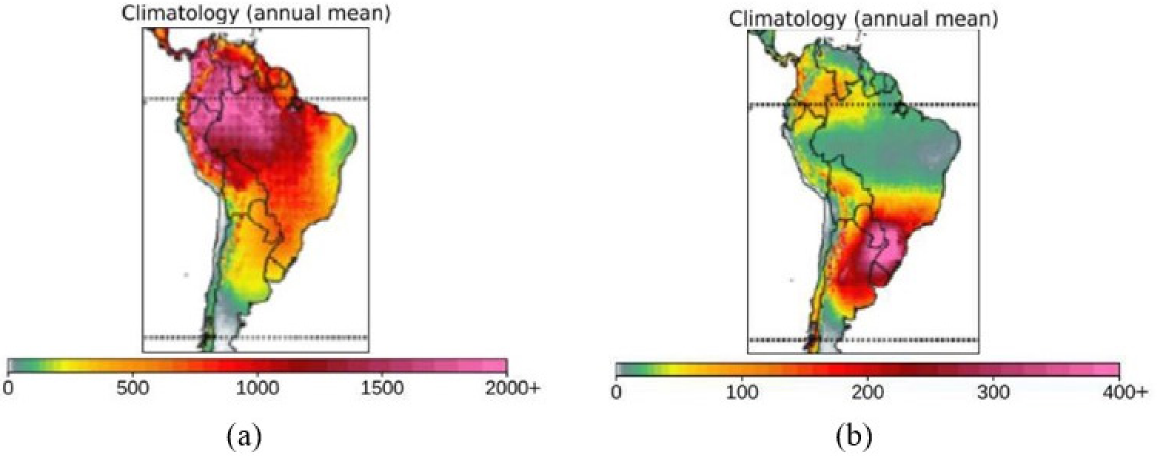

Figure 7. Annual frequency, in terms of the mean number of hours per year (see color convention), of atmospheric conditions that are favorable to the occurrence of (a) convective storms in general, and (b) severe convective storms, in South America. The climatology refers to the 1979 to 2019 period and is based on the 5th Generation of the European Center for Medium-Range Weather Forecasting reanalysis (ERA5) dataset. (Adapted from Taszarek et al. [25]).

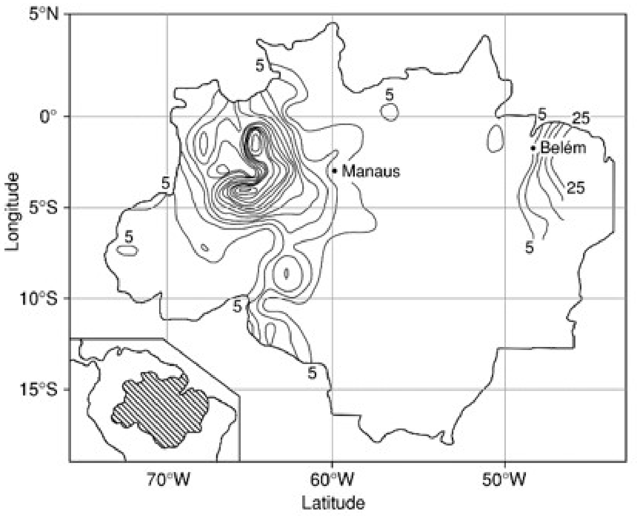

Figure 8. Distribution of large forest clearings due to natural causes in the Amazon region (adapted from [26]).

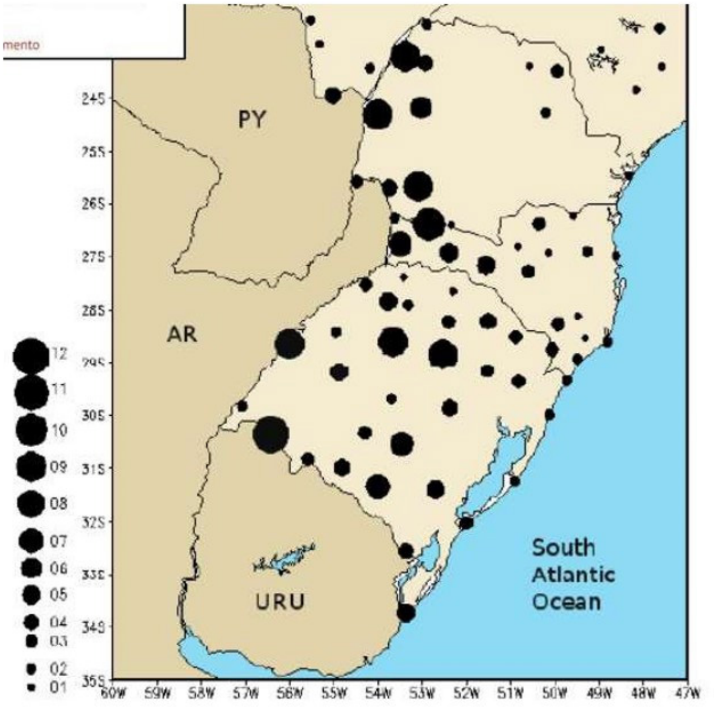

Figure 9. Climatology of wind gusts generated by severe storms in southern Brazil, based on measurements from the national network of INMET automated surface weather stations between 2005 and 2015. Diameters of the black circles are proportional to the number of occurrences of convectively-induced wind gusts equal to or greater than 25 m/s; see convention in ref. [29].

2.4 Climatology of synoptic winds

Apart from gusts produced by local convective events, synoptic scale winds can also occasionally reach destructive intensity in some regions of Brazil. Figure 10, taken from [30], shows the climatology of surface cyclogenesis over South America, in the period between 1979 and 2005. In the Brazilian context, cyclogenesis refers to formation of extratropical (and sometimes, subtropical) cyclones. These synoptic scale events, when formed over land or close to the shore, produce intense winds which typically last for at least a couple of hours, and which cover much wider areas when compared to local convective storms.

Among the three regions with frequent cyclogenesis in South America, two of them (RG1 and RG2 in Figure 10) affect coastal areas in southern Brazil. In South America, winds of destructive magnitude associated with synoptic-scale cyclones are observed in middle and subtropical latitudes; therefore, the northeast of Brazil is not shown in Figure 10.

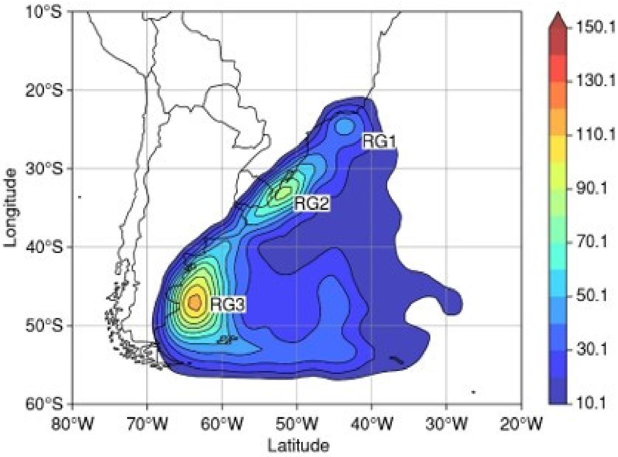

Figure 10. Mean annual density of surface cyclogenesis per km^2 (see color convention) detected between 1979 and 2015 based on the ERA-Interim reanalysis and the Climate Forecast System reanalysis. The three regions with more frequent cyclogenesis frequency are indicated as 'RG' (based on [30]).

2.5 Climate regions associated with strong winds in Brazil

The brief climatological description presented above serves as support to characterize the Brazilian regions which share common atmospheric conditions, leading to meteorological phenomena capable of producing wind gusts of destructive potential. Based on the above, the map of climate regions illustrated in Figure 11 is proposed by the authors to guide wind engineers. This climatological map, to be used in addition to the measured wind data (to be described later), is the basis for the technical sketch of isopleths of the basic wind speed map proposed for NBR 6123. Details of the climatology map are discussed in the sequence.

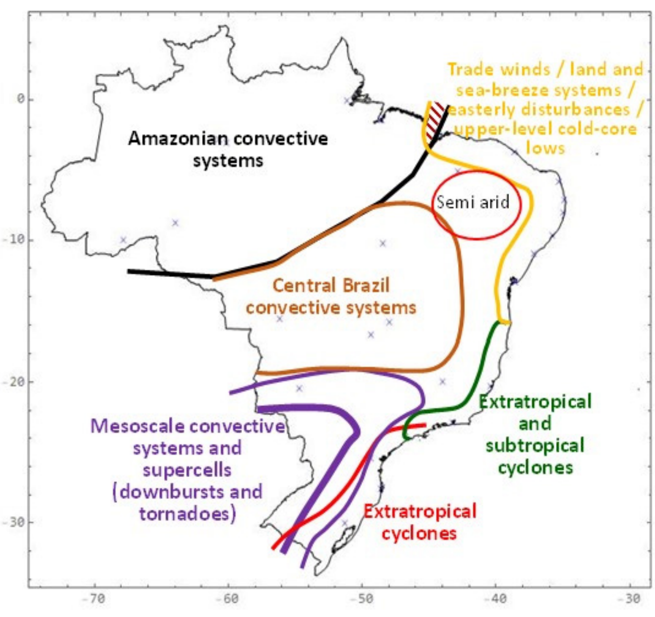

Figure 11. Geographical delineation of regions that share similar regimes of atmospheric phenomena that generate intense surface winds in Brazil.

The wind regions shown in Figure 11 are quite large and their delineation is not influenced by non-natural factors such as cities or administrative boundaries. This is in clear contrast with the exaggerated and artificial localized details of the current basic wind speed map [ref. [1], Figure 1], like the strong gradients (concentration of isopleths) over the cities of Brasília and Campinas. The large size of the climatology-based wind regions in Figure 11 is also evidence against some localized details of more recent maps, like the strong gradients over the west of Santa Catarina in [7], [8], and over other seemingly arbitrary small regions in [8]. Some regions, like the south of Brazil, can experience intense winds of synoptic-scale as well as from TS events

3 BASIC WIND SPEED FOR BRAZIL: PREVIOUS WORK

Pioneering work dedicated to identify and classify winds in synoptic and non-synoptic include Riera and Nanni [9], who studied annual maximum velocities registered at four towns in the state of Rio Grande do Sul. The authors have shown that, taken separately, winds originating in each type of storm can be better adjusted by a Gumbel or Type I extreme value distribution, than by a Type II or lognormal distribution. At the same time, a mixed series containing synoptic and non-synoptic winds does not adjust very well to Type I, but can be represented by a Type II (Frechet) distribution, as observed in the initial studies leading to the basic wind speed map of NBR 6123 [31].

More recent studies like Almeida [5], Beck and Correa [6], Vallis [7] and Pires et al. [8] employed the Gumbel distribution to adjust annual maximum velocities. Mixed wind series were considered in [5], [6] and [7]; classified and mixed wind series were considered in [7], [32]. In refs. [5]–[7], conventional mathematical regression was used to draw the V_0 isopleths map. Pires et al. [8] used Kriging, which is a powerful regression and interpolation tool, but which puts too much weight on the measured wind speed data.

The work of Vallis [7] is commended for the detailed analysis of the quality and homogeneity of the meteorological data [32], and for the large size of the database (a total of 692 weather stations were considered, as shown in Figure 12). One of the relevant results of [7], [32] was the classification of meteorological events into synoptic and non-synoptic. The authors found that, for a mean return period of 50 years, non-synoptic winds originated in TS storms dominate over the largest part of the Brazilian territory. After developing algorithms and criteria to identify and remove spurious data, to classify winds into synoptic and non-synoptic, and homogenize the wind speed time series, the author [7] performed the extreme value analysis for V_0 at each weather station. The extreme value analysis was performed for separated synoptic and non-synoptic winds, as well as for the mixed series. Figures 13 and 14 show examples of the Gumbel distribution fit for the mixed wind series in the cities of Florianópolis and Belém, respectively. In these figures, the vertical axis corresponds to wind velocities, and the horizontal axis is a transformed variable dependent on the return period T. For the 50-year return period (T=50), this variable equals 3.9 in the horizontal axis. The diamond markers indicate individual extreme events recorded; the continuous purple line shows the linear model corresponding to a Gumbel distribution fit to the mixed series; and the black line is an envelope of the distribution for the classified synoptic (blue line) and non- synoptic (red line) annual maximum winds. The data collected by Vallis [7], as well as the distribution fit for every weather station, can be checked at www.windytips.com.

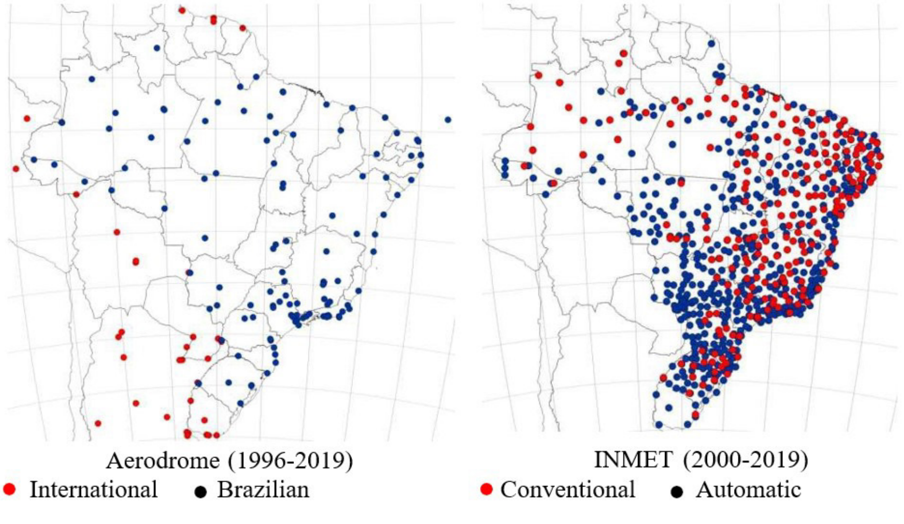

Figure 12. Network of meteorological weather stations with wind speed data processed by Vallis [7].

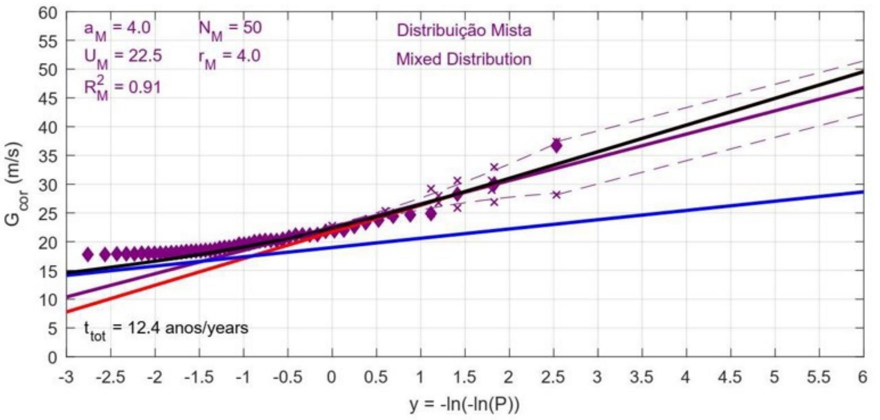

Figure 13. Distribution fit and data for maximum annual wind speeds at station A86 in Florianópolis, SC [7].

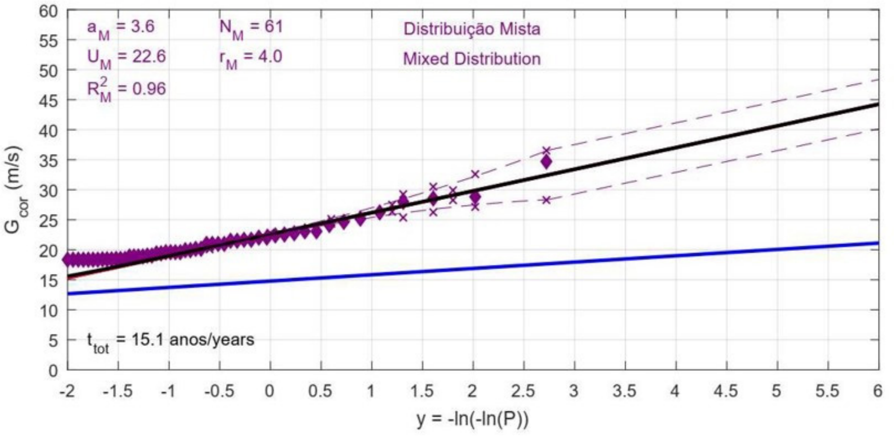

Figure 14. Distribution fit and data for maximum annual wind speeds at station SBBE in Belém, PA [7].

Figure 15 shows one of the proposals presented in [7] as basic wind speed map for NBR 6123, where the format of zones with the same basic wind speed is considered. However, the definition of these zones did not take into account the climatological aspects. Figure 16 shows the V_0 map proposed by Vallis [7], which was generated by mathematical regression from local mean V0 values determined at so-called dominant weather stations. Selection of these stations was done by a process of filtering, starting from a grid of nodes spaced roughly 50×50 km. The selection process begins with the eight stations closer to the node to be considered, by evaluation of the weighted mean of V_0 at these stations, with sample weight being the time-length of each time series. From the eight stations around each node, those with V_0 value lower than the local mean minus 3 m/s were removed.

In section 8.3 of his PhD thesis, Vallis [7] points some risks and shortcomings to be considered before adoption of the proposed the map in NBR 6123. The main points stated by the author are:

a) the elaborated map does not consider potential occurrence of tropical cyclones, like hurricane Catarina, which hit the coast of Santa Catarina in 2004, but which was not registered by the weather stations used by the author [7], [32], [33];
b) some weather stations produced V_0 values significantly larger than those of the proposed map (Figure 16); for instance, the stations with long time-series records SBBE in Belém (17 years of record) and SBEG in Manaus (19 years of record), with differences of 25 and 20%, respectively.
c) issues like the large differences between V_0 values of the current basic wind speed map [ref. [1], Figure 1] and the map elaborated by Vallis [ref. [7], Figure 16]; for instance, in the cities of Campinas, SP (reduction from 45 to 38 m/s) and the central region of Mato Grosso (increase from 30 to 38 m/s) which can also induce changes in the proposition.

In terms of data processing, the following limitations of the work of Vallis [7] can be identified:

i. small length of the wind speed time series in several stations, which does not warrant reliability of the 50-year mean return wind speeds (V_0);
ii. limitation of parameters to identify and separate synoptic and non-synoptic winds;
iii. several problems found in the database used and corrections implemented;
iv. the Gumbel distribution used does not adjust itself very well to the data for several stations; for instance, that illustrated in Figure 13, as pointed out by Riera [31] and Riera and Nanni [9]. Typically, these stations are located at zones subject to mixed origin and/or combined (synoptic and non-synoptic) winds.

Figure 15. Zone map for non-synoptic winds proposed by Vallis [7].

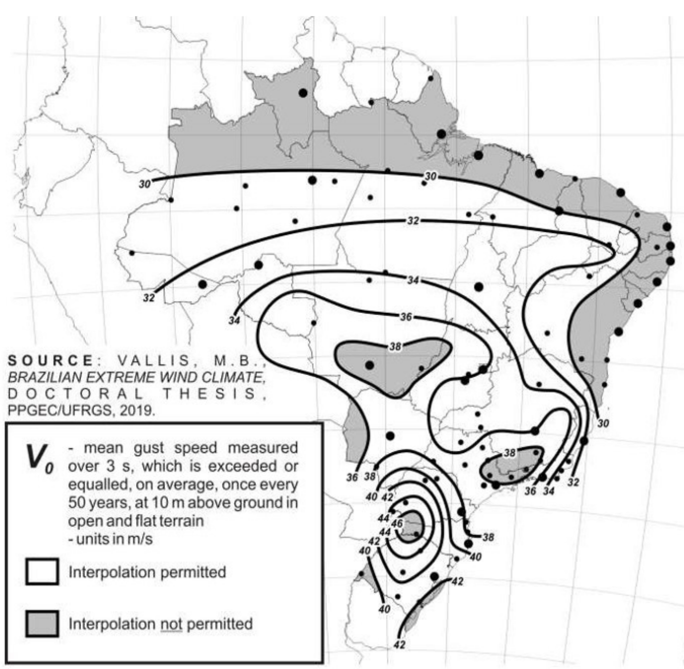

Figure 16. Basic wind speed map proposed by Vallis [7].

Despite the limitations mentioned above, the work of Vallis [7] is an important advancement of knowledge, within the research lines developed at Universidade Federal do Rio Grande do Sul (UFRGS) in partnership with Universidade Federal de Santa Maria (UFSM) and Instituto de Aeronáutica e Espaço / Departamento de Ciência e Tecnologia Espacial (IAE/DCTA).

4 PROPOSITION OF A CLIMATOLOGY-BASED BASIC WIND SPEED MAP FOR BRAZIL

4.1 Premises

From the observation that non-synoptic meteorological events determine extreme wind speeds in the majority of the Brazilian territory, and considering that design criteria and aerodynamic coefficients given in current wind codes were developed considering synoptic winds, a question arises about the possibility of establishing separate design procedures and maps for synoptic and non-synoptic winds. The specialized literature [34], [35], however, points to the impossibility of such division at present time, due to the lack of analytical models of universal acceptance which correctly represent the flow characteristics of non-synoptic events, and of their interactions with constructions. Moreover, as pointed out above, in the same meteorological event the mutual occurrence of synoptic and non-synoptic winds is possible, increasing the difficulty for separate consideration of these wind types. Another issue to be considered is the necessity to significantly increase the reliability of the wind speed data collected in the country before separate basic wind speed maps can be produced. The short length of wind time series at most weather stations [7], [32] also precludes, or reduces the reliability, of projecting the 140-year mean return wind, or the wind with 30% probability of occurrence in 50 years, as advocated by NBR 8681 [36].

Considering the above, the current proposition of a basic wind speed map for NBR 6123 is a 50-year return wind, without separation of meteorological events. We point out, however, that work is currently in progress, with the targets of separating these wind regimes in the future and adopting longer return periods. In this setting, the current proposition of a V_0 map for NBR 6123 is called 'transition code'.

The basic wind speed map proposed herein, to be adopted in the 'transition code', was build considering the climatic regions shown in Figure 11, and the V_0 values obtained and processed by Vallis [7]. Special attention was given to the possible occurrence of tropical cyclones in the coastal region of south Brazil, as hurricane Catarina registered in 27/03/2004 [37]. The proposed map uses the format of isopleths (a line on a map connecting points having equal incidence of a specified meteorological feature; in the present case, wind speeds).

In this work, subsets of weather stations and corresponding V_0 data were selected, among those processed by Vallis [7], to support drawing of the basic wind speed isopleths. These subsets are representative of the extreme winds to be expected at each climatological region (Figure 11). The selection of weather stations privileged those with higher V_0 values, and this is plainly justified by the localized characteristic of TS storms (see Figure 2), which leads to significant subsampling by the network of meteorological stations, as addressed in Section 2. In brief, non-synoptic winds may be captured by one station but not registered at a neighboring station, situated at a distance larger than the spatial scale of the phenomenon. Other events may not be registered at all. From this understanding, it can be concluded that Vallis's [7] procedure of taking the average of the V_0 values among neighboring stations, to obtain a representative value for one location, introduces a flagrant contradiction with the nature of the physical phenomena, particularly its reduced dimensions, with respect to the density of weather stations.

To compose the database of V_0 values to support drawing of the map, we selected weather stations which V_0 values are larger than a minimum for each climatologic region. These values, shown in Table 1, were defined by considering the current basic wind speed map (Figure 1).

Table 1. Range of V_0 values used in selecting weather stations to compose the database for the proposed map.

Geographical Region*	Climate region (colors refer to Figure 11)	Basic velocity V_0
Norte (Amazônia)	Amazonian Convective Systems	$V_0 > 30$m/s
Sul	Mesoscale Convective Systems / supercells (thick purple line), extra- tropical cyclones VS	$V_0 > 40$m/s
Centro-Oeste and Sudeste	Mesoscale convective systems (thin purple line) in MS and SP	$V_0 > 36$m/s
Centro-Oeste	Convective systems of central Brazil	$V_0 > 33$m/s
Sudeste (coast)	Extratropical / subtropical cyclones VS	$V_0 > 34$m/s
Nordeste	Trade winds / land and sea breeze systems / easterly disturbances	$V_0 > 30$m/s
Nordeste	Semi-arid	$V_0 > 33$m/s

*Own names kept in Portuguese.

This procedure is also backed by the fact that V_0 values published by Vallis [7] were obtained from data selected using rigorous criteria with respect to the parameters of the homogenization phase. Hence, the data selected to support our map cannot be questioned for the single fact of being higher than the remaining ones. Moreover, due to the rigorous data processing, it is possible that non spurious values originated from real events have been excluded.

Figure 17 shows a panorama of the database used to support drawing of the map proposed herein. The V_0 values shown in the map refer to each weather station following Vallis [7].

Figure 17. Overview of selected weather stations and corresponding V_0 values (m/s) processed by Vallis [7].

4.2 Drawing of isopleths and final map

Having selected V_0 values to support drawing of the map, and looking at the climatic regions of Figure 11, we proceeded to draw the isopleths. The regions with well-defined atmospheric characteristics were considered first, leaving boundary regions with mixed climate for the last steps. We started by the Amazon region, following with the south and the northeast coast, concluding with the center and south-east. In general, the V_0 value for each curve was chosen based on more frequent (modal) values. For certain regions, in addition to the local climatology and V_0 values, other criteria were applied, such as physical evidence of destructive wind action, the possibility of occurrence of tropical cyclones and the imprecise fitting of the Gumbel distribution applied to the data. These will be explained for each region, as follows.

The analysis of few V_0 data in the Amazon region revealed an interesting correlation with the results shown in Figure 8. The cities of Coari (AM) and Belém (PA), highlighted by red circles in Figure 17, are found inside the contours shown in Figure 4 of [28] associated to higher frequency of intense storms and distribution of large areas of forest devastated by wind action (Figure 8). The V_0 values are 37.2 m/s and 36.7 m/s for the cities of Coari and Belém, respectively. The mentioned areas were associated to an isopleth of 36 m/s, whereas in the region between these, an isopleth of 33 m/s was drawn, as shown in Figure 18. Towards east, closing of the 33 and 36 m/s lines follows the boundaries of the Amazon climatic region, as shown in Figure 11.

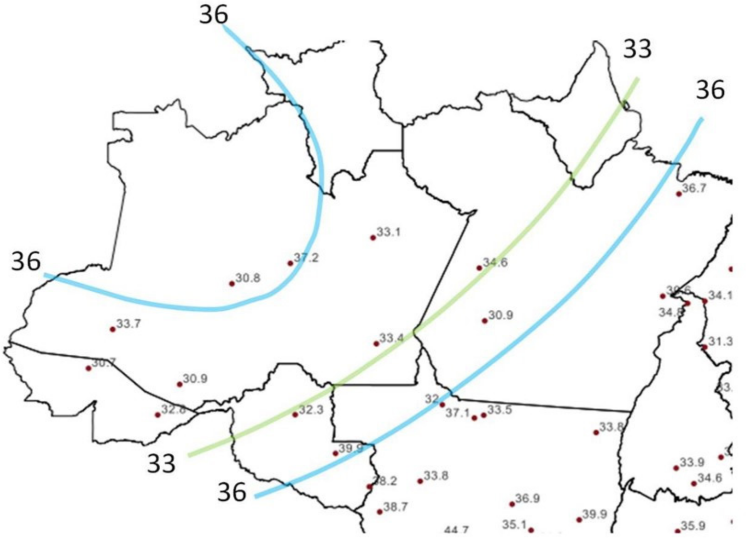

Figure 18. Amazon climate region and proposed isopleths, V_0 in m/s.

Figure 19a shows a detail of the south region of the map in Figure 11, where one observes the region of occurrence of severe TS storms, as described in Section 3. In this region, several stations show V_0 values in the range between 47 and 49 m/s, with the station of Chapecó (SC) showing V_0 =50.8 m/s. Hence, the V_0 value of 48 m/s was chosen for this region (Figure 19b). Progressing towards north and east, the V_0 values are reduced, and the isopleths of 45 and 42 m/s were drawn. This last line meets the coast near the boundaries between the states of São Paulo and Paraná, such that the coast of the states of Santa Catarina and Paraná have values between 42 and 45 m/s, also having in mind the known occurrence of tropical cyclones in this region, for which no measurements are available. Moreover, as a region subject to the simultaneous occurrence of synoptic and non-synoptic winds, the imprecise fit of the Gumbel distribution and the statistical treatment were also considered (see Section 3).

The northeast region presents the climate regions shown in detail in Figure 20a). In the coastal areas, almost all weather stations registered data leading to V_0 values lower than 30 m/s, such that the isoline of V_0 =30 m/s was drawn, following the boundary of the climate zone (see Figure 20b). In the semi-arid climate region, the V_0 values are higher, reaching 35 m/s, whereas at the Ouricuri station (PE) the value is 40.6 m/s.

The 'Centro-Oeste' climate region is characterized as shown in Figure 21a), and 'Sudeste' region shows large areas of transition between well characterized climate zones. As the last climate regions to be treated, a compatibility between previously drawn isopleths is sought. An extensive area including the states of MS and SP, and the south of the states of MT, GO and MG shows V_0 values between 38 and 42 m/s. In this region we inserted a 40 m/s isopleth following the thin purple line in Figure 21a) towards the west, and the curvature of this line towards the state of MG. More to the north, the isoline associated to 38 m/s and the adjacent 36 m/s line approach the northeast boundary of the region characterized as 'Central Brazil Convective systems' (Figure 11) and follow towards the coast of 'Sudeste' region. The three central lines associated to 36 m/s form a closed area with constant V_0.

With the methodology just described, the complete map shown in Figure 22 was obtained, and has been proposed for adoption in the next edition of NBR 6123. In the hatched areas interpolation is not permitted.

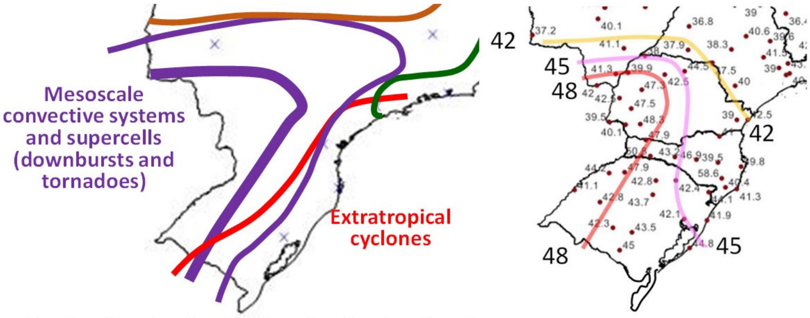

Figure 19. South region: a) climatic regions; b) proposed isopleths (V_0 in m/s).

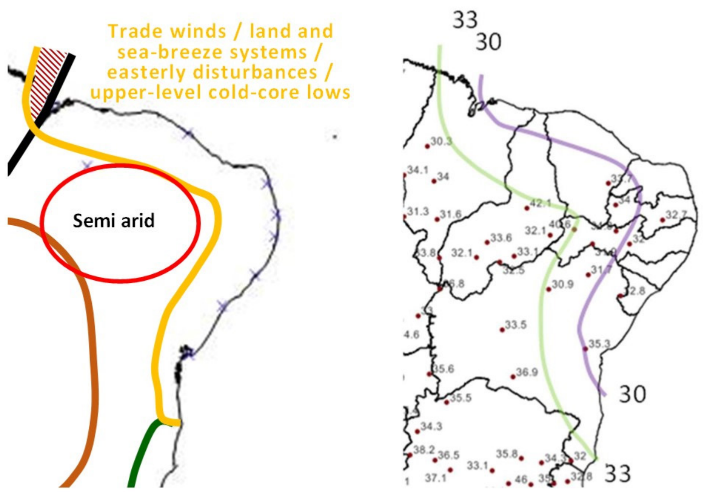

Figure 20. Northeast region: a) climatic regions; b) proposed isopleths (V_0 in m/s).

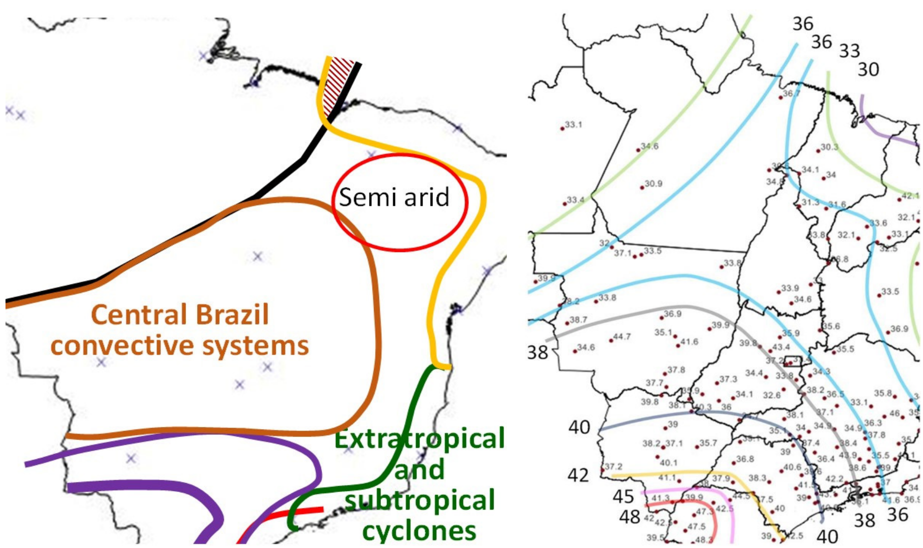

Figure 21. Center and southeast region: a) climatic regions; b) proposed isopleths (V_0 in m/s).

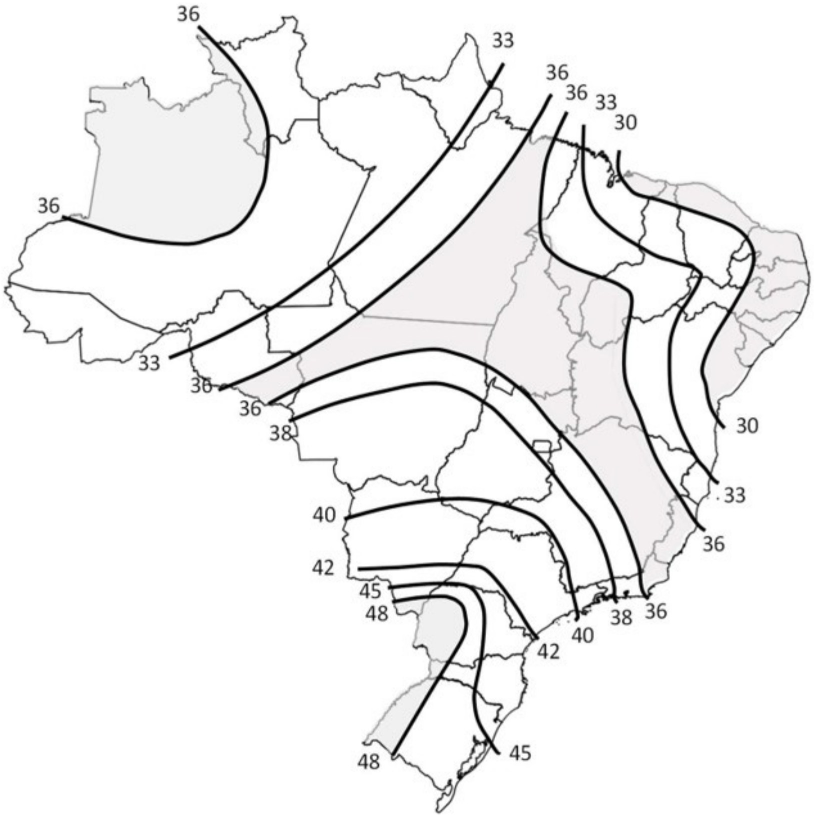

Figure 22. Final basic wind speed map proposed for NBR 6123 (isopleths with V_0 in m/s).

5 CONCLUDING REMARKS

In this manuscript a new basic wind speed (V_0) map, proposed for adoption in NBR 6123, is presented and justified. The novel approach to this map is the definition of characteristic climate zones producing strong winds in Brazil. These climate zones were used as a guide for the manual technical drawing of the wind speed isopleths. The V_0 values characterizing each climate zone and giving support to the isopleths were obtained from data categorized and processed by Vallis [7]. Unfortunately, due to limitations in the length of wind speed time series available in Brazil, the adoption of a return period longer than 50 years was not found possible at this time.

The proposed map, shown in Figure 22, has basic wind speeds ranging between 30 and 48 m/s. The climatological approach took into consideration the physical characteristics of the phenomena leading to strong winds in Brazil. This is in contrast with, and a significant improvement in comparison to, the pure mathematical regression approaches used in other maps. We expect that the adoption of the proposed map will increase the reliability of structural design in Brazil, with a proper balance between constructions and expected failure costs.

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