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Avanços na caracterização dos eventos de vento forte no Uruguai

Advances in the characterization of high wind events in Uruguay

Valeria Durañona[1,a], Andrés Guggeri [1,b] e Sofía Orteli [1,c]

[1]Institute of Fluid Mechanics and Environmental Engineering, School of Engineering University of the Republic, Montevideo, Uruguay
[a] valeriad@fing.edu.uy, [b] aguggeri@fing.edu.uy, [c] sofiao@fing.edu.uy

Resumo

Uruguai encontra-se na região com a segunda maior frequência de ocorrência de tempestades severas no mundo, que inclui também o sul do Brasil, o nordeste da Argentina e parte do Paraguai; e na região da América do Sul que apresenta a frequência mais alta de ciclogênese intensa. Ambos os fenômenos atmosféricos produzem ventos intensos no país. Apesar de sua intensidade, o último estudo a nível nacional sobre ventos intensos foi conduzido há mais de 30 anos, durante o desenvolvimento do código nacional de ventos ainda em uso corrente. A instalação em anos recentes de uma rede de estações meteorológicas automáticas que realizam medições continuamente com boas resolução temporal, distribuição geográfica e controle de qualidade ofereceu informação adequada para dar início a uma caracterização e nova análise destes eventos. A análise destes dados mostrou claramente que a maioria dos episódios de ventos intensos (definidos como aqueles com rajadas de vento a 45 m de altura = 22.2m/s) são não-sinóticos e geralmente ocorrem durante atividade convectiva severa. Os ventos mais fortes e a maior frequência de ventos intensos são encontrados no noroeste do Uruguai. Por outro lado, cerca de 70% dos episódios de ventos intensos ocorrem durante a primavera e o verão.

Palavras-chave: *Ventos não-sinóticos intensos; clima de ventos intensos; Uruguai; atividade convectiva severa.*

Abstract

Uruguay belongs to the second most prone region of the world to the occurrence of severe convective storms, which also includes the south of Brazil, north-eastern Argentina and part of Paraguay; and to the region of South America that presents the highest frequency of occurrence of intense cyclogenesis events. Both meteorological processes produce high winds in the country. In spite of its strength, the last study at national level of high winds in the whole country had been conducted more than 30 years ago, during the development of the national wind code still in use. The installation along the last years of a network of automatic meteorological stations that measure continuously with a good temporal resolution, geographical distribution and data quality offered adequate information to start a characterization and new analysis of these events. The analysis of their data clearly showed that most high wind events (defined as those with wind gust speeds at 45m height ≥ 22.2m/s) are non-synoptic and usually occur during severe convective activity. Higher winds and more frequent high wind events are found to the northwest of Uruguay. On the other hand, around 70% of the high wind events occur during spring and summer.

Keywords: *Non-Synoptic High Winds; Extreme Wind Climate; Uruguay; Severe Convective Activity.*

1 Introduction

Uruguay is located in the south eastern region of South America (SESA), between the latitudes of 30° and 35º south and the longitudes of 53º and 58º west. It belongs to the second most prone region of the world to the occurrence of severe convective storms, and to the region of South America that presents the highest frequency of occurrence of severe cyclogenesis events (Nascimento and Doswel, 2006; Gan and Rao, 1991).

Being part of the mid-latitudes, Uruguay experiences a wide variety of fast changing weather, as cold air masses from the poles and warm air masses from the tropics can travel to these latitudes and sometimes alternate within hours of each other. As a result, severe convective activity, weather fronts and extra-tropical cyclones produce severe winds in the country (Celemín, 1984).

In spite of the intense extreme wind climate of Uruguay, the only study at national level of the occurrence of high winds in the whole country had been conducted more than 30 years ago, during the development of the national wind code (UNIT: 50-84, 1984) still in use. This study was a statistical analysis of basically one wind gust data series of dubious quality (Durañona, 2014), which assumed that the flow during these high wind events was of the boundary layer type.

The gradual installation since 2008 of a network of automatic meteorological stations that measure continuously with a good temporal resolution, geographical distribution and data quality allowed to start analyzing with more detail the characteristics of the atmospheric flow during high wind events in Uruguay (e.g. Durañona, 2013; Durañona, 2015b). In this paper, updated information until June, 2015 on the characterization of these events is presented.

2 Description of the network of automatic meteorological stations

In 2008, the National Administration of Power Stations and Electrical Transmissions (UTE), began installing a network of automatic meteorological stations. These stations are distributed across the country, and measure with a sampling frequency of 1Hz a series of meteorological parameters at heights between 10 and 100m. Mean, standard deviation and maximum and minimum values of wind speed, wind direction and temperature are registered every 10 minutes, with some stations also registering relative humidity and solar radiation.

Among the available stations, those placed in open and level terrain and without significant obstacles in their surroundings were selected for the analysis of high wind events. By the time of this study, 28 stations from this network complied with these criteria. Most of them were surrounded by rural terrain, and their main characteristics are indicated in Table 1. The columns of this table show, for each station, its number and name, the analyzed measurement period, the corresponding number of complete years of measurements, and the measurement heights for each type of sensor. In the case of the anemometers (3-cup anemometers NRG #40C), the number of sensors at each height or the orientation when there was only one anemometer is shown in brackets. As this table indicates, the measurement periods of these stations ranged from 1 to 7 complete years at June, 2015. Altogether these data series represented 1440 months of measurement of each meteorological parameter every 10min.

The location of the stations listed in Table 1 is identified with their number codes in Figure 2. This figure also indicates the main topographic features of Uruguay, with the height scale at its upper right corner. As this scale shows, the highest point of Uruguay is around 500m above sea level.

The characteristics of this network of stations allow the description of the evolution in space and time of mesoscale and synoptic weather systems that produce high winds while they move across Uruguay, as well as the analysis of high wind events in specific sites, with a degree of detail that was not possible before.

Table 1: Main characteristics of the selected automatic meteorological stations.

Nº	Station	Analyzed period	Complete years	Anemometers heights (m)	Wind vanes heights (m)	Thermometer heights (m)	Hygrometer heights (m)	Solarimeter height (m)
2	Bonete	31/7/2008 – 30/7/2014	6	48.3(2), 25(2), 10(E)	50, 25	4	-	9
4	Peralta	6/5/2008 – 5/5/2015	7	75.2(2), 42.6(W), 10(W)	74.5, 41.5	4	-	-
5	Valentines	13/5/2008 – 12/5/2015	7	77.6(2), 42.7(2), 10(E)	77.6, 42.7	8	-	-
7	Rosario	28/5/2008 – 27/5/2013	5	64.3(2), 44.9(2), 10(W)	64.3, 44.9	4	-	7
8	Artilleros	18/6/2008 – 17/6/2013	5	46.1(2), 27.7(E), 11(S)	45.7, 26.9	6	-	-
9	Piedras de Afilar	1/7/2008 – 30/6/2014	6	62.2(2), 36.6(2)	62.2, 36.6	8	-	-
10	Arroyo Cañas	10/7/2008 – 9/7/2013	5	64.9(2), 41.1(2)	64.9, 41.1	5	-	-
11	Pintado	15/7/2008 – 14/7/2013	5	87.3(2), 71.4(2), 42.7(2)	85.5, 42.7	13	-	-
12	Cerro Colorado	25/7/2008 – 24/7/2014	6	81.5(2), 39.2(2)	79.1, 36.8	8	-	-
14	Andresito	20/8/2008 – 19/8/2014	6	89.9(2), 40.1(2)	92, 42.1	4	-	-
16	Pampa	8/10/2008 – 7/10/2014	6	91.3(2), 87.1(2), 34(2)	90.1, 34.3	5	-	-
17	Buena Unión	9/10/2008 – 810/2014	6	78.4(2), 33.6(2)	67.6, 33.6	13	-	11
18	José Ignacio	18/10/2008 – 17/10/2013	5	54.4(2), 24.9(2)	54.4, 24.7	8	-	-
20	Rocha	2/7/2009 – 1/7/2014	5	74.3(2), 32.6(2)	68.9, 32.6	7	-	-
23	Mc. Meekan	13/11/2010 – 12/11/2014	4	58.9(2), 39.7(2)	59.1, 39.1	7	-	-
24	César Mayo	26/11/2010 – 25/11/2014	4	90.1(2), 67.9(2)	89.8, 67.3	18	-	-
25	Rosendo Mendoza	3/12/2010 – 2/12/2014	4	59.5(2), 39.7(2)	59.5, 39.7	4	-	-
30	Aparicio Saravia	22/12/2011 – 21/12/2014	3	101.5(2), 80.4(2), 60.8(2)	101, 60.8	2	-	-
31	Colonia Rubio	9/12/2011 – 8/12/2014	3	101.5(2), 81.1(2), 63.4(2)	101, 63.4	3	-	-
33	Baltasar Brum	16/2/2012 – 15/2/2015	3	74.5(2), 39.7(2)	73.9, 39.1	72	-	6
34	J. Otamendi	16/3/2012 – 15/3/2015	3	101.6(2), 80.8(2), 60(2)	100.6, 60.2	100	-	5
35	C. Eulacio	30/3/2012 – 29/3/2015	3	101.8(2), 81.8(2), 60.8(2)	100.8, 60.8	100	-	-
36	Colonia Terra	1/6/2012 – 31/5/2015	3	54.3(2), 35.3(2)	54.3, 35.3	53	-	-
37	Arerunguá	22/11/2012 – 21/11/2014	2	101.5(2), 79.5(2), 60.3(2)	100.3, 60.1	2	-	-
39	Palomas	1/2/2013 – 31/1/2015	2	99.3(2), 79.4(2), 60.3(2)	98.2, 60.6	4	-	-
40	Arroyo Negro	25/9/2010 – 24/9/2011	1	75(S), 55(2), 20(S)	75	75	3	-
41	Egaña	4/7/2011 – 3/7/2012	1	72(S), 55(2), 21(S)	73.3	73	3	-
42	Lascano	27/9/2010 – 26/9/1012	2	72.3(2), 55(S), 20(S)	73.3	73	-	-

3 Objectives and general methodology

The principal aim of the research presented in this paper was the identification and description of the main characteristics of the high wind events that occur in Uruguay.

A high wind event was defined as one that presented a wind gust speed that exceeded 80km/h (22.2 m/s), and its analysis covered the previous and following 5 hours from the time the maximum wind gust speed was recorded. This wind speed value was identified as the threshold for wind damage to start being reported in the country (Durañona, 2015b).

When a high wind event was identified at a station, gust and 10min mean wind speeds data series were analyzed at each measurement height, together with wind direction and temperature, and solar radiation and humidity data when these last measurements were available.

For conclusions on the monthly distribution of high wind events in Uruguay, their wind roses and geographical characteristics, complete years records from the stations listed in Table 1 were analyzed, in order to take into account the probable seasonality of the occurrence of high wind events. With the same aim of obtaining homogeneous results among the different stations, wind speed measurements were interpolated at 45m height, as most of the stations measured above and below this height, as indicated in Table 1.

At each station, the monthly frequency of occurrence of high wind events and their most frequent wind direction were analyzed. In addition, a higher threshold wind gust speed value (29 m/s) was chosen to analyze the annual frequency of occurrence of these higher wind events and their most frequent wind direction.

4 Analyses and results

The analysis of wind gust speeds measured during the 1440 months records from the 28 stations indicated in Table 1, interpolated at 45m height, identified 1388 high wind events.

It was found that most of these events were non-synoptic, i.e., the time scale of their increase and decrease in wind speed was less than few hours, and usually occurred during severe convective activity. The non-synoptic high wind events usually presented sudden increases in wind speed accompanied by temperature drops and wind direction shifts. As discussed in Durañona, 2015a and 2015b, these characteristics are typical of wind gusts generated by severe convective activity. A number of these events were selected for analysis with satellite imagery, which confirmed that severe convection was usually taking place at the time and place where these events were measured. During these non-synoptic high wind events, gust and 10min mean wind speeds showed similar time evolution at different heights, many presented higher gust factors (U_{gust} /U_{10min}) during or around the 10min interval when the highest wind gust was measured, and significant drops in temperature (up to around 10-15 ºC) were not uncommon.

At each station, non-synoptic high wind events accounted for most of the high wind events and for the highest measured wind gust speed values. In other words, dominance of non-synoptic over synoptic high winds was found in all the stations.

Most of the non-synoptic high wind events displayed one of these typical behaviors:

(a) Their wind gust speeds presented very pronounced peaks (increase and decrease in half an hour or less), generally associated with temperature drops and abrupt wind direction changes;

(b) Their wind gust speeds presented pronounced peaks (increase and decrease in one hour or less), also associated with drops in temperature and generally abrupt wind direction changes, but with usually a more gradual return to the original wind direction;

(c) Their wind gust speeds presented abrupt increases, while the decrease was gradual and spanned several hours, also generally associated to temperature drops, some of them quite significant;

(d) Their wind gust speeds presented increases and decreases that generally took between 1 and 3 hours each.

The following cases are examples of the typical behaviors of non-synoptic high wind events described above:

Case (a): Station 8 – Artilleros, on 07/02/2010 at 10:00 hs, with $U_{gust\ 45m}$ = 36 m/s.

Case (b): Station 11 – Pintado, on 04/04/2012 at 23:20 hs, with $U_{gust\ 45m}$ = 40 m/s.

Case (c): Station 4 – Peralta, on 20/02/2009 at 16:00 hs, with $U_{gust\ 45m}$ = 41.4 m/s.

Case (d): Station 40 – Arroyo Negro, on 12/10/2011 at 22:40 hs, with $U_{gust\ 45m}$ = 29.3 m/s.

where $U_{gust\ 45m}$ stands for wind gust speeds interpolated at 45m height.

Case (a) and (c) registered an increase in wind gust speed from 10 to around 40m/s in consecutive intervals of 10min, while the increase in wind gust speed for case (b) (also from around 10 to 40m/s) occurred along 20 to 30min. The increase in wind gust speed for case (d) was from around 12 to 30m/s and took place in almost 1 hour.

In all these cases, wind gusts measured at different heights presented similar behaviors, and the same occurred with the 10min mean wind speeds.

Also, the gust factor value did not vary much at each height, but it tended to increase around the 10min interval when the maximum wind gust was recorded. For example, in case (a), the gust factor reached a value of 2.5 at 46.6m height during the 10min interval when the maximum wind gust was registered; in case (b), it took values around 2 at the three heights and in case (c), values around 2.3 at the three heights. Case (d) yielded the minimum gust factors of these four cases: it took values between 1.3 and 1.5 for the three heights at the 10min interval when the maximum wind gust was registered. These last values are similar to those expected for Atmospheric Boundary Layer (ABL) flows over rural terrain at these heights (Choi, 1999), while the corresponding values of the first three cases are clearly higher. For example, according to Wieringa, 1973, a gust factor of 1.42 can be estimated for rural terrain and a gust wavelength of 2.6m at 45m height, while according to Cook, 1985, a gust factor of 1.37 would be expected for rural terrain at 45m height, in this last case, assuming that the relation between hourly wind speed and 10min mean wind speed is around 1.1.

Another differences between cases (a) – (c) and case (d) are the behavior of the temperature and wind direction around the time the maximum wind gust is registered. The first three cases showed temperature drops when the wind gust increased; the largest one corresponding case (c), with a sharp decrease in temperature of around 10°C in 20min at 4m height; while in the last case, there was a slight increase in temperature. In relation to wind direction, the three first cases showed abrupt to moderate changes of wind direction at the 10min interval when the maximum wind gust occurred, while in the last case, the change in wind direction when the maximum wind gust was registered is not clear.

Looking at satellite images of GOES 12 from CPTEC (Center for Weather Prediction and Climate Studies, from Brazil), one difference between these events is that convective activity seemed to be higher in the first three, showing lower temperatures for the top of the clouds at the sites and times corresponding to cases (a) – (c) than those corresponding to case (d), meaning that these clouds would have reached higher altitudes, and therefore, convection would have been more intense.

Case (d) might have been related to the passage of a warm front, which implies an increase in temperature. The passage of these fronts over Uruguay tends to be slower than those of cold fronts (Celemín, 1984), fact which might explain why the wind speed did not increase so fast in this case.

The events with $U_{gust\ 45m} \geq 22.2$m/s presenting the behavior illustrated by case (d) (wind gust speed increase and decrease taking between 1 and 3 hours each) accounted for relatively few events from the 1388 events identified, meaning that the general characteristics of most of the non-synoptic high wind events would mainly fall into the other three categories, and would be mostly related to severe convective activity, with a tendency to produce higher gust factors than those expected for ABL flows.

The monthly distribution and wind rose of the 1338 events that presented $U_{gust\ 45m} \geq 22.2$m/s are presented in Figures 1(a) and (b).

The maximum $U_{gust\ 45m}$ was registered at station 4-Peralta, with a value of 49m/s (176km/h).

Analysis of the available wind records at 10m height shown in Table 1, i.e., stations 2, 4, 5, 7 and 8, also indicated that severe convective activity would cause the highest wind gust speeds and most frequent high wind events at 10m height. The maximum U_{gust} registered at 10m height ($U_{gust\ 10m}$) at those stations was 40m/s at station 5-Valentines. Three of the four events that registered $U_{gust\ 10m} \geq 40$m/s at stations with anemometers installed at 10m high presented $U_{gust\ 10m}$ values similar to $U_{gust\ 45m}$ values.

Figure 1(a) clearly shows the high seasonality of high wind events in Uruguay. The months from October to February show a clear higher frequency than the rest of the months. The months from April to July would be the months with fewer events. Spring (Oct-Nov-Dec) would be the season presenting the greatest frequency of occurrence of events with $U_{gust\ 45m} \geq 22.2$m/s, with around 40% of them, followed by summer (Jan-Feb-March), with 27% of the events. These first results are in accordance with results from regional research (Natalini, 2011) and with seasonal characteristics of severe convection in SESA (CLIVAR, 2013).

Figure 1(b) shows that most of these high wind events presented wind directions from the SW quadrant, with the highest frequency from the SSW direction. Around 17% of came from the SSW; 14%, from the SW; approximately 12%, from the S, and 10% from the WSW. The W direction accounted for around 7-8% (6%) of the cases, while the three directions between the NNE and ENE registered about 12% of these events.

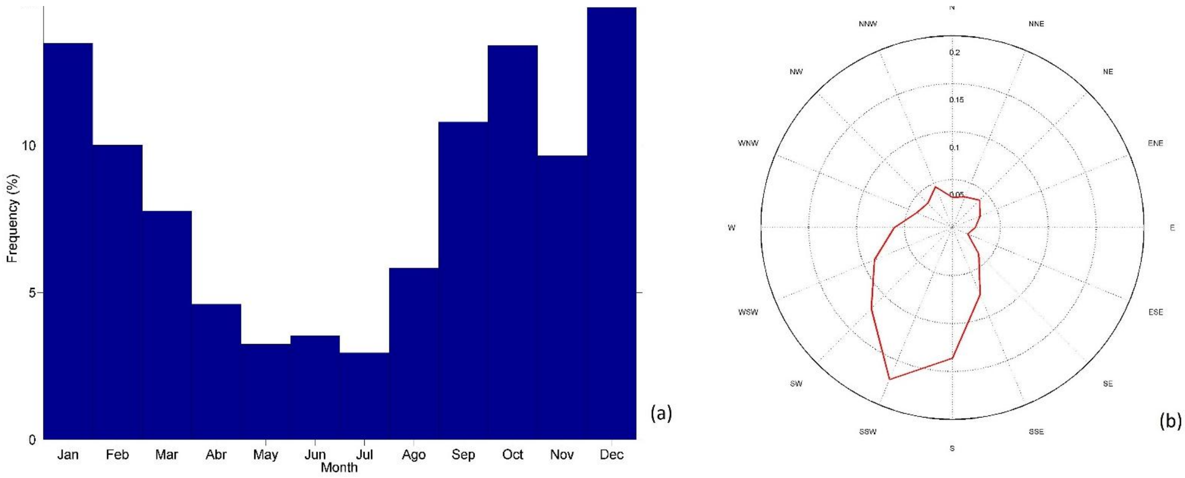

Figure 1. (a): Monthly distribution of the events with $U_{gust\ 45m} \geq 22.2$m/s. (b): Wind rose of the events with $U_{gust\ 45m} \geq 22.2$m/s.

The analysis of the geographic distribution of high wind events in Uruguay illustrated their strong tendency to occur mostly between October and February in the whole country, and suggested that in the south and east of the country they would occur more frequently in spring, especially during October and November. To the northwest of the country, more events are found in warmer months (December, January, February).

In relation to typical wind directions, high wind events tend to present wind directions usually from the southwest quadrant, and in particular from the SSW. This wind direction is the typical direction exhibited by the passage of cold fronts in the region.

The average number of events per month with $U_{gust\ 45m} \geq 22.2$m/s at each station ranged between 0.5 and 1.06; implying that in average, one potential damaging wind event (at 45m height) occurred every one to two months at each of the analyzed stations. The highest rate of occurrence of events with $U_{gust\ 45m} \geq 22.2$m/s was found to the northwest of Uruguay; in particular, two stations, stations 16-Pampa and 4-Peralta, presented in average one event per month.

Figure 2 characterizes the events that presented $U_{gust\ 45m} \geq 29$m/s over a map of Uruguay. The modulus of each arrow shown represents the mean of the wind gust speed of the events that presented $U_{gust\ 45m} \geq 29$m/s at each station. This value is also indicated in m/s next to each station. The direction of each arrow represents the most frequent wind direction of these events at each station; and the color, the most frequent season when these events occurred at each station. The bar scale to the right of this figure indicates the color corresponding to each season. Another number next to each station indicates the average number of events per year that presented $U_{gust\ 45m} \geq 29$m/s recorded at each station.

This figure illustrates the strong tendency of the events with $U_{gust\ 45m} \geq 29$m/s to occur mostly during summer and spring in the whole country. In the south of the country there would be relatively more events in spring, and in some cases, in autumn. It can also be seen that the preferred wind directions during these events are from the south-west quadrant, and that their frequency of occurrence is higher in the northwest of Uruguay.

and of the simultaneous behavior of these meteorological variables.

In addition, it could also be seen that in the northwest of the country, higher and more frequent wind gust speeds would occur than in the rest of the country.

A trend to have more high wind events in summer (January to March) and spring (October to December) than in the rest of the seasons in Uruguay could also be shown. This result might be explained by e.g. Salio, 2007, which observe that the SALLJS (South American low level jet stream), which favors the development of mesoscale convective systems in SESA, presents an intense maximum during spring, and with those from e.g. CLIVAR, 2013, that observes that in South America, convection shifts gradually northward toward the equator between March and May, and that during April and May, the southward flow of tropical warm and humid air from the Amazonia, which fuels severe convection in SESA, weakens, as more frequent incursions of drier and cooler air from mid-latitudes begin to occur over the interior of subtropical South America.

The geographic and seasonal distributions of extreme winds found during this research would be in accordance with studies carried out in the region. For example, in northeastern Argentina, Natalini, 2011 studied damaging wind events that occurred between 2006 and 2010, and found that around 56% of them took place in spring and 35% in summer, and that strong winds are mainly caused by severe convective activity, produced by mesoscale convective complexes or the passage of either cold fronts or squall lines. According to Riera, 2013, in central-southern Brazil extra-tropical cyclones would be associated with the highest wind speeds of low recurrence period (around 10 years, depending on the area), while for longest recurrence periods, severe convective activity would be responsible for the highest wind speeds. Therefore, in the long term, convective activity would cause the dominant extreme winds in that region. Uruguay may be then considered as an intermediate region, with its extreme wind climate relatively more dominated by convective activity than center-southern Brazil, but less than northeastern Argentina, and relatively more dominated by intensifying extra-tropical cyclones than northeastern Argentina, but less than Brazil (Durañona, 2015).

Despite the impact of severe convective events in different regions of the world, in terms of the damage they produce, the available information and characterization of these events worldwide is still relatively scarce. For example, in the field of wind engineering, it is of interest to describe their typical wind speed profile with height, the relationship between the maximum wind gust recorded and the mean wind speed (defined along a suitable time interval), the temporal variation of wind speed, direction and temperature, the expected wind gust speeds for different return periods, their geographic distribution and its variation throughout the year, among other relevant parameters. All these characteristics are different from those of synoptic winds, and can vary depending on the analyzed region.

In particular, due to the high intensity and frequency of severe convective events in SESA, region that includes northeastern Argentina, part of Paraguay, southern Brazil and Uruguay, it would be important to continue these studies with a regional and multidisciplinary approach.

In summary, this paper presented an updated characterization of high wind events that take place in Uruguay with meteorological information available since 2008, emphasized the significance of non-synoptic high wind events in the extreme wind climate of Uruguay, and the necessity of continuing this line of research, if possible with a regional approach.

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