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Wind-induced Damage in Two Regions of Argentina

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Abstract: Information on wind-induced damage to civil structures in Argentina is scarce. In this paper, general trends regarding both meteorological conditions and patterns of damage when damage occurred in two regions of Argentina are presented. The regions under study were the north-east of Argentina (NEA) and the north-Patagonia. This research is based on a collection of data comprising field surveys conducted after the passage of destructive storms, NCEP/NCAR Reanalysis, a Global Data Assimilation System model and other secondary sources like emergency services, local press, local councils and the National Weather Service. It is shown that both regions have similar problems of vulnerability, even though they have different meteorological environments. Topics that must be addressed to reduce the vulnerability of civil structures have been identified.

Key words: Wind, damage, buildings, field survey, reanalysis.

1. Introduction

Argentina is a country of the South-American subcontinent that it is particularly vast in the latitudinal direction. Its septentrional and meridional borders are at 22º and 55º S latitudes, respectively. Intense winds are recorded in the entire territory, which are due to different meteorological environments of mesoscale and synoptic scale, according to the region of the country. The characteristics of strong winds were studied by several authors, among them Labraga [1] focused in the Austral Patagonia (between 44º and 55º S), Lassig et al. [2] characterized north-Patagonia (from 36º to 42º S) and Schwarzkopf [3] studied tornados and severe storms in the whole country. Schwarzkopf determined that tornados occur from the septentrional border (22º S) to north-Patagonia (38º S).

At a global level, the losses caused by wind or wind-related phenomena, when they are evaluated over relatively long periods of time, are similar or even greater (depending on the source) to the ones caused by seismic action. Concerning Argentina, it is not possible to quantify the significance of the phenomenon due to lack of exhaustive information on the subject. Apart from the regulations on structural safety, which are of limited enforcement, and the early warnings regularly issued by the Servicio Meteorológico Nacional (SMN)(Argentina National Weather Service), there are no further mitigation efforts of the government towards wind-related disasters. Historical factors, like the late development of Wind Engineering in Argentina, explain that strong winds are considered a kind of natural hazard that is not worth of much attention.

During the last year, a number of research groups working in National Universities started to pay attention to the damage caused by strong winds. They intend to produce information to ground public policies concerning mitigation of wind damage. At the same time this information should be adequate for guiding the formulation of research projects. Even though there is not a formal framework yet, some of the groups are already working in collaboration on different subjects at different levels. The present work is the outcome of the joint work of two of these groups. The UNNE group is based in the north-east of Argentina, in the province of Chaco, and the Comahue group is based in the province of Neuquén, in the northern part of the

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Patagonia area. They are settled 1500 km further apart from each other.

A database on wind-induced damage, comprising information coming from different sources, is presently under construction. Field surveys have been conducted in the provinces of Chaco, Formosa and Neuquén, after the passage of destructive storms. Secondary sources, such as government emergency services, local press, local councils and the SMN have also provided valuable information. Finally, in some cases of particular interest, the synoptic conditions during the events were determined through NCEP/NCAR Reanalysis and a Global Data Assimilation System (GDA) model.

At the moment, it is not possible to obtain adequate funding to base a proposal to quantify the phenomena at the usual level required in risk modelling, due to lack of a minimum of information. The same problem hampers any possible dialogue with the government. For these reasons the scope of the present study is to establish general trends regarding both meteorological conditions and patterns of damage when damage occurs. The methodology follows in general lines, the works of Menzies [4] and Buller [5]. In this way it has been possible to progress with a low budget and a small team.

One of the issues of concern is whether there is any correlation between the kind of meteorological phenomenon and the pattern of damage. In this paper, some recent findings on this topic are presented and discussed.

2. North-East Region

The provinces of Chaco and Formosa lie in the north-east of Argentina (NEA) between the latitudes of 22.5º and 28º S and between the longitudes 57.5º and 63.5º W. Main causes of strong winds are convective storms that are produced by mesoscale convective complexes (MCCs) or the passage of either cold fronts or squall lines. Sometimes these convective storms end up in tornados. The duration of these strong winds are the typical ones of mesoscale, which is from a few minutes to a couple of hours at most. The intrinsic local nature of the storms, which occur in a large area where there are only two anemometers of the SMN, makes the certain determination of the wind speeds during the events impossible. Thus, the quantification of the damage through vulnerability curves is not possible yet.

2.1 Chaco

Thirty-four wind events causing damage were observed in Chaco during the period between July 2006 and November 2010. After twelve of the events, field surveys were conducted. Information from secondary sources, mainly the local press, was available in the remaining twenty-two cases. Criteria were established to count the number of events. In many cases, the damage occurred over large areas in the midst of generalised bad weather conditions. In these cases, if the damage in different villages was caused by strong winds that started at the same time, the damage had been considered to be due to a single event. Otherwise, the damage was counted as the result of different, but correlated events. According to these criteria, only nineteen events were independent.

Nineteen events (56%) took place in the spring, twelve (35%) in the summer, one (3%) in the autumn and two (6%) in the winter. Clearly, spring is the most hazardous season, followed by summer. Information regarding the duration of the storms was available in fifteen cases. In all of them, but in three of the cases, the damage occurred during periods of strong winds that lasted from four minutes to half an hour. In the other three cases, the storms lasted more than 1 hour. In some situations, the strong winds corresponded to a more intense phase of a longer storm, whereas in others, the phenomenon was an intense short-lived storm.

There is not significant difference between the number of damaging storms that occur between sunset and dawn and between dawn and sunset; 55% occurred in nighttime hours and 45% in daylight hours. Strong winds occurred simultaneously with rain in 50% of the cases, with hail in 3% of the cases, and with both rain and hail in 29% of the cases. 18% were events of wind with no rain or hail.

As regards to the extent of and level of destruction associated with the cases, it is difficult to quantify both factors using the available information. We can assert that two of the events were widespread destructive events, meaning that the government had to provide significant assistance to the population and that wind-induced damage was clearly visible to passers-by. In six cases, the only damage was to isolated structures, with the surrounding area unaffected. Between these two extremes there were cases in which the damage was widespread but mainly localised to background damage (damage to poorly built structures or poorly maintained structures). There were also four cases in which the government provided significant assistance to victims without specifically denoting whether the people were affected by strong winds, floods or hail.

The most frequently affected structures were dwellings. Damage to dwellings was reported in twenty-three cases (68%), being affected about one thousand five hundred homes in total. The predominant kind of dwelling that was affected is self-built, non-engineered houses with masonry walls and light metallic roofs, which is the most common style among poor people, who most of the time can only afford bricks and steel sheets. In the vast majority of cases the roof is lost while walls, windows and doors remain safe and sound.

Large roofs of non-engineered warehouses and canopies with light structures collapsed in thirteen events (38%). In all of these cases the structures were completely destroyed. Here the problem is directly related to a low-strength lattice made with steel rods, like the lattice used in small antenna masts. The manufacture of columns and trusses with this light lattice is characteristic of the local building culture. They are cheap, easy to build and massively used in Argentina and Paraguay. Balbastro and Sonzogni [6] reported the same problem of vulnerability of these structures in the province of Santa Fe. There have been some attempts in the past to improve the safety of them [7–9] but their construction is presently out of control.

Electricity lines—or, more appropriately, their supporting poles—are the only kind of engineered structures that were vulnerable. There are records of failures of virtually every kind of line, comprising any voltage and typology of poles, but a close inspection of the records shows frequent failures of two poles: creosote-treated timber poles used in low-voltage lines and the metallic trussed towers of 132-KV lines. Creosoted poles also support telephone lines. Low-voltage lines failed massively in 53% of the events. High-voltage electricity transmission lines were damaged in six cases (18%), which comprise the failure of twenty-four metallic towers of 132-KV lines, in four events. All twenty-four were suspension towers. These failures are a matter of concern for the different electricity service providers of NEA. The causes of the vulnerability of these kinds of poles have not been systematically studied yet.

Both rural and urban areas were affected at the same time in 32% of the cases. Comparatively, only urban areas were affected in 42% of the cases, and only rural areas were affected in 26%. The number of victims was surprisingly low: only eleven people suffered minor injuries in a total of three cases. Twenty-eight events produced no casualties (82%), whereas the remaining three cases lacked sufficient information to determine whether they involved injuries.

2.2 Formosa

Four events that happened in Formosa between 2008 and 2010 called the attention of the authors of this paper. The patterns of damage of three of these cases were similar to those observed in the fourteen cases surveyed in Chaco, (let us call them the conventional cases). But one of the Formosa cases was clearly different, and it was a case of damage caused by a tornado.

Every year, non-qualified eye witnesses report the occurrence of tornados, principally in rural or forest areas. But on 21st of October, 2010, at 6 p.m. local time (21:00 UTC), a tornado demolished the village of Pozo del Tigre (24.9º S; 60.32º W), in broad daylight. Hundreds of eyewitnesses sighted the movement of at least one tornado funnel. The tornado entered the village through the SW boundary and then drifted towards the NE, crossing through the village. The whole process took less than 15 minutes. According to eyewitnesses, the funnel had a diameter between 20 and 50 metres at ground level, which is consistent with the observed footprint. There were 852 heavily damaged homes and 2215 people (out of a population of 4000) who were affected, of whom 395 had to be evacuated. Four large canopy roofs and one railway warehouse were completely destroyed. Four people were killed under the rubble of masonry walls. Hospitals assisted 200 people with injures and bruises caused by the fall of masonry walls, debris and an intense and dense hail, which became a lethal factor when combined with the strong winds.

Several factors took part on the formation of the 21st of October tornado. The inflow of a warm, humid mass of air from the north (Fig. 1a) was activated on the surface by a low pressure system positioned on the Bolivian Altiplano that extended to the south (Fig. 1b). Together with the presence of an upper-level subtropical jet stream (Fig. 1c), they contributed to the formation of a very intense convective cell (Fig. 1d).

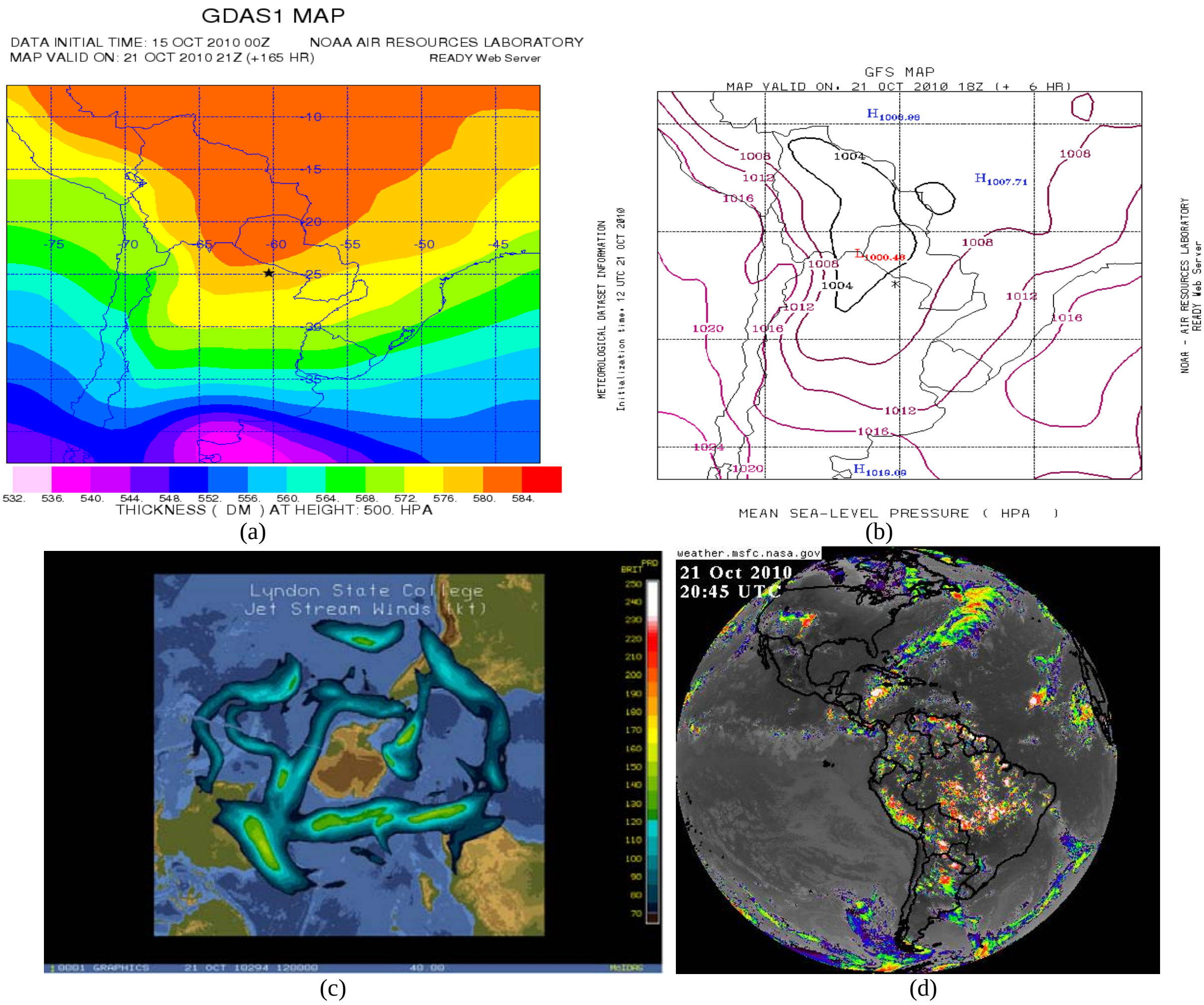

Fig. 1 21st of October tornado. (a) thickness map showing the inflow of warm air into Formosa area. (b) sea-level pressure isobars chart where it can be seen a low centre situated NW of the area of development of the tornado. (c) jet stream over the area. (d) GOES image showing an intense convective cell over the area, fifteen minutes before the event.

The occurrence of this tornado is particularly interesting because on 9th of November, 2008, another storm caused widespread damage in the same village, being the features of the damage coincident with a conventional case. In that opportunity, the damage was caused by a downburst originated in the formation of a MCC and the case was described by Natalini et al. [10].

2.3 Patterns of Damage

In the conventional cases, the damage is evenly distributed over a given area and demonstrates a predominant wind direction. In a typical case, many instances of unroofed dwellings, uprooted trees, falling of a substantial portion of the low-voltage net, a collapse of at least one large roof (warehouse or canopy), collapse of one or two masts belonging to local FM radio stations and damage to a variety of poorly built auxiliary structures can be expected. It is also useful to look at what is not damaged in these conventional cases. Apart from electricity lines, engineered structures are rarely damaged. It must be acknowledged that engineered structures are typically part of the minority in the area, except for social housing. It can be also expected a few people with minor injures only in one out of three events and fatal victims in none of them.

Conversely, after the passage of the tornado through the town of Pozo del Tigre, a non-uniform distribution of damage was observed, due to the migration of the funnel. Unharmed buildings remained standing right next to completely destroyed ones with similar vulnerability. Although the tornado drifted towards the north-east, the structures were blown away in every direction, including the south-west. Engineered structures were damaged as frequently as non-engineered ones. Thus, apart from all of the typical structures that were damaged by conventional storms, social housing, public buildings and engineered large roofs were also affected. One of the most outstanding features was the commonly occurring collapse of masonry walls, which killed four people and wounded many more. However, masonry walls reinforced with concrete resisted satisfactorily in most cases. The collapse of masonry wall plus the combination of debris, intense hail and wind caused injuries to about 200 people (out of a population of 4000 people).

Reanalysis and GDA modelling were applied to seven case studies, which showed in all cases that the origin of the strong winds was intense convective activity [10]. This is consistent with some characteristics of the thirty-four events reported in section 2.1, like the short duration of the strong winds and the seasonality; most of the events occurred in the period of the year when large masses of warm, humid unstable air gather on the area. Although the number of case studies is too small to achieve statistical significance, considering the consistency of the cases in section 2.1, it can be concluded that virtually all of the events of strong winds that caused damage to civil structures in Chaco and Formosa corresponded to storms caused by intense convective activity. This is a distinctive characteristic of the region.

In all seven case studies, there were two factors that acted upon the instability of the masses of air: (1) the existence of a low pressure system in the north-west of Argentina, which extended to neighbouring countries, producing a persistent advection of warmer and more humid air in NEA, and (2) the presence of a jet stream in the upper troposphere, which, for dynamic reasons, impinges an increased vertical ascending movement contributing in this way to the instability. With regards to the meteorological mechanisms causing damage in the seven case studies, one case was a tornado, two cases were MCCs and four cases were convective activity associated to frontal system or to instability lines. No dependence between the different kinds of atmospheric conditions causing storms and the values of the Convective Available Potential (CAPE) and the Standard Lifted Index (SLI) was observed. As for the relationship between meteorological phenomena and the severity of damage, the analysis of the cases suggests that MCCs produce higher losses than the convective cells that accompany frontal system or instability lines (synoptic systems), while tornados are devastating. However, seven cases is too a low number to be conclusive.

3. Neuquen (North-Patagonia)

3.1 Overview

This region is under the influence of the Pacific Subtropical Anticyclone and the passage of extra-tropical low pressure systems over the Drake Passage. In a few occasions, some of these depressions break through the continent, producing strong isobaric gradients on surface that cause intense winds of durations between 12 to 72 hours (synoptic scale), which have a large superficial extension. They can occur in any season.

Eight events of strong winds that caused damage during 2010 are listed in Table 1. A particularly destructive event in 1995 that was studied by one of the authors is also included. Among the nine events mentioned in the table, seven were caused by the aforementioned strong isobaric gradients. Unlike the cases studied in NEA, there were meteorological stations in all of the places where damage was reported. The gust speeds appearing in Table 1 are maxima 3 seconds gust speeds at 10 m over ground level. The names in the first column correspond to the urban centres where the storms reached its maximum intensity. However, it must be noted that these storms acted over large areas. A typical example of this kind of events occurred on 12th of January, 2010, when the passage of an extra-tropical low pressure system off the south coast of Tierra del Fuego Island induced a pronounced shrinking of the isobars over the continent in Patagonia (Fig. 2). Another similar event occurred in winter, on June 23rd, 2010. In the first case, the affected area was the centre and south-east of the province of Neuquén; in the second case, the centre and north-west. In both cases, damage was caused in places as far as 200 km and gusts of about 44 m/s were recorded.

When the gust speeds did not exceed the 40 m/s, the kind of buildings and infrastructure affected was roughly the same as the one that it has been described in the previous section about conventional storms in NEA. But the gust speeds of more than 45 m/s caused the kind of damage that has been observed only in the tornado in Pozo del Tigre. This could provide an indication of the wind speeds experienced during the tornado event. However, it must be noted that both regions have different degrees of development and consequently, to some degree, different ways of building. The fashion on which some constructive

Table 1 Nine events of strong winds that caused damage in Neuquén.

Location	Meteorological phenomenon	Date	Gust speed (m/s)	Observed damage
Las Lajas	Strong isobaric gradient	22/06/1995	47.2	Unroofing of dwellings. Failure of walls. Unroofing of hospital and school. Failure of satellite antenna.
Viedma	Convective storm	03/01/2010	27.8	Unroofing.
El Chañar	Strong isobaric gradient	11/01/2010	30.6	Unroofing. Trees uprooted.
Cutral co	Strong isobaric gradient	12/01/2010	44.7	Unroofing of gymnasium.
Choele Choel	Convective storm	22/01/2010	25.0	Failure of domestic TV antennas. Trees uprooted.
Rio Colorado	Strong isobaric gradient	23/03/2010	25.0	Failure of telephone line. Damage to cars.
Rincon de los Sauces	Strong isobaric gradient	23/06/2010	44.4	Unroofing. Trees uprooted. Wooden shanty houses demolished from the basements. Damage to auxiliary structures.
Viedma	Strong isobaric gradient	11/07/2010	29.7	Unroofing. Failure of low voltage electricity lines. Trees uprooted.
Huinganco	Strong isobaric gradient	03/08/2010	27.8	Separation of roof sheathing. Trees uprooted. Damage to the street light system.

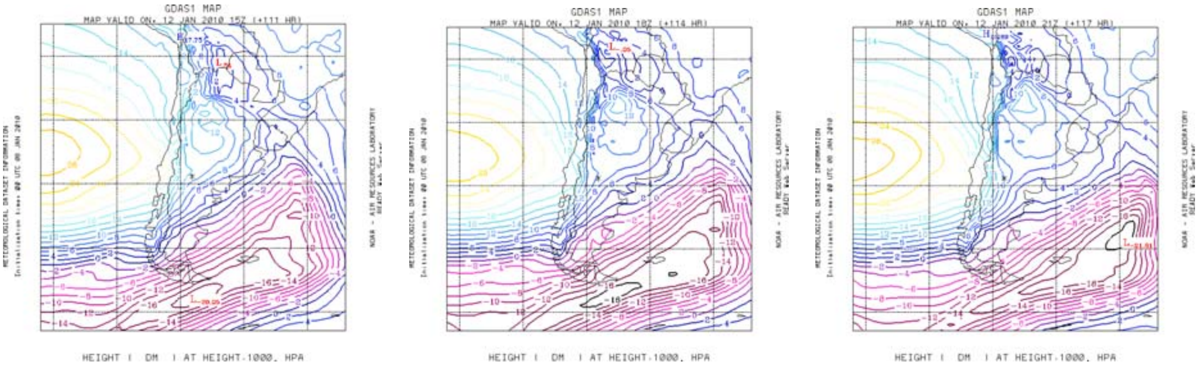

Fig. 2 12th of January, 2010. Sequence of geopotential height contours at 1000 hPa shrinking over Patagonia. Left, 15:00 (UTC), centre 18:00 (UTC) and right 21 (UTC). It can be seen the squeezing of the contours between the Pacific Subtropical Anticyclone and the extra-tropical low pressure centre in the South Atlantic Ocean.

Damage			
Uprooting of tree	Separation of roof sheathing	Unroofing	Failure of masonry wall
			
20	30	40	50
Gust speeds (m/s)			

Fig. 3 Typical level of damage observed in Neuquén according to the speed of the wind gusts.

details are made might modify the vulnerability in regard with the infrastructure of NEA, being this issue something that will have to be addressed in the future. Fig. 3 associates wind speeds with images of damage. It has been also observed some phenomena that are absent in NEA. In dry season, the long duration of storms results in large clouds of dust, which turns out in disruption of the traffic and even crashes. Strong gusts generate crashes and overturns in roads. Fires, when existing, are enlivened by the wind, obstructing the work of fire fighters.

3.2 Vulnerability of Dwellings

Even though the wind speeds during the events of Neuquén are known, the volume of information that is available is not enough to produce vulnerability curves, since the quantification of the Mean Damage Ratio requires detailed information about both the cost of repairing all the damaged buildings in a location and the total value of the buildings in that location. However, a simple exercise to illustrate the vulnerability of dwellings is presented here. First, the dwellings have been grouped in three typical categories: (1) **Social housing**: engineered houses with metallic roof and masonry walls reinforced with concrete; (2) **Self-built houses**: non-engineered houses with metallic roof and masonry walls without reinforcement; (3) **Shanty houses**: non-engineered shelters made with wood, cardboard and iron sheets. Then, features of prototypes for every category were defined, including typical damage according to the wind speed. The value of each kind of house and repairing costs were estimated and the relationship repairing cost/value of the property was plotted against the wind speeds in Fig. 4. Typically, for gust speeds between 44 to 55 m/s, social housing experienced unroofing, self-built houses suffered unroofing and damage to walls, while shanty houses were demolished.

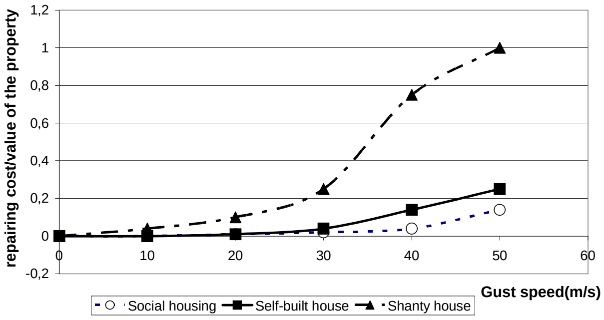

Fig. 4 Plot of the relationship between the repairing cost/total value rate and gust speeds for three typical kinds of houses in Neuquén.

4. Conclusions

Tornados showed to have a pattern of damage clearly different than other kinds of meteorological phenomena. Besides, they are more destructive and constitute a threat to human lives. The likelihood that a tornado will go through an urban centre in the North-East of Argentina is low, but it is not negligible. To be prepared for tornado events is possible and desirable. Simple issues that should be addressed are reinforcement of masonry walls with concrete and awareness of the population on what to do during a tornado event. Although the issues are simple, it is acknowledged that the implementation of remediation policies could be not unproblematic in a region struck by poverty. On the other hand, is unlikely that urban centres of Neuquén experience a tornado. But it must be noted that the severity of damage caused by gusts above 45 m/s might be similar and wind speeds of this intensity are not rare in the area.

Regarding the other meteorological phenomena, they cause most of the wind-induced damage to both public and private property. Topics that must be addressed to reduce the vulnerability in both regions are the connection between roof and walls in self-built houses, large non-engineered canopy roofs and warehouses, electricity lines, streets signs and a better implementation of early warnings to the people.

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