



HAL
open science

Multi Hazard scenarios in the Mendoza/San Juan provinces, Cuyo Region Argentina

Dominique Daudon, Stella Moreiras, Elise Beck

► **To cite this version:**

Dominique Daudon, Stella Moreiras, Elise Beck. Multi Hazard scenarios in the Mendoza/San Juan provinces, Cuyo Region Argentina. 4th International Conference on Building Resilience, Sep 2011, Salford Quays, United Kingdom. pp.560 - 567, 10.1016/S2212-5671(14)00976-9 . hal-01101801

HAL Id: hal-01101801

<https://hal.science/hal-01101801>

Submitted on 12 Jan 2015

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial - NoDerivatives 4.0 International License



4th International Conference on Building Resilience, 8-11 September 2014,
Salford Quays, United Kingdom

Multi Hazard scenarios in the Mendoza/San Juan provinces, Cuyo Region Argentina

Dominique Daudon^{a*}, Stella Maris Moreiras^b, Elise Beck^c

^aUniv. Grenoble Alpes, 3SR, F-38000 Grenoble, France, dominique.daudon@3sr-grenoble.fr,

^bIANIGLA – CCT-CONICET- Parque San Martin, CP 5500, Mendoza Capital, Argentine, moreiras@mendoza-conicet.gob.ar

^cUniv. Grenoble Alpes, PACTE, F-38000 Grenoble, France, elise.beck@ujf-grenoble.fr

Abstract

This paper exposes major natural hazards inventory encountered in the two San Juan and Mendoza provinces, such as climatic, seismic, gravitational, and social/anthropic ones. The contrast between the high altitude of the region and low one is addressed in order to manage the inhomogeneity of prevention plans. The international road to Chile is greatly affected by gravitational hazards that proceed in out of run period and commercial traffic interruption, and large economic waste more than people vulnerability, as the urban areas are more affected by seismicity scenarios. But as gravitational hazard is affected by the seismicity it is proposed to analyze some co-hazard effect in a multi-scenarios approach from geology geography and mechanical modelling of events to explore the co-effects on the scenarios. Moreover, some similarities with the Rhone-Alpes region of France are evocated and may be of interest.

© 2014 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/3.0/>).

Selection and/or peer-reviewed under responsibility of the Centre for Disaster Resilience, School of the Built Environment, University of Salford.

Keywords: hazard inventory; Cuyo Region Argentina; multi scenarios; interdisciplinarity

1. Introduction

The provinces of Mendoza and San Juan, in the Cuyo region (Argentina) are situated at the foot of the highest part of the Central Andes. This semi-arid region characterised by large concentrated urban areas such as Mendoza and

* Dominique Daudon. Tel.: +33-4-7682-7044; fax: +33-4-7682-7043.

E-mail address: Dominique.daudon@3sr-grenoble.fr.

San Juan capital cities (800000 and 120000 inhabitants respectively). They were founded in the 16th century (Correa 2008) being affected by various destructive seismic events. This part of the world, near Chile, is one of the most seismic regions and it is also greatly susceptible to climate hazard in highest altitude areas. Aconcagua Mount reaches 6958 masl, while permafrost stays over 3,800 masl. Region climate is affected by both Atlantic and Pacific Anticyclones leading to perturbations with contrasted precipitations. The region has great economic reliability through tourism, agriculture and wine production. Economical exchanges with Chile exist through the international road to Santiago de Chile that also connects with Buenos Aires and Brazil, reason why this road is known as Bioceanic corridor. Today, the infrastructure uses a tunnel at 3,200m (Las Cuevas), but for a long time a 3,850 m frontier pass was the only crossing point. In fact, around 80% of the terrestrial heavy trucks traffic for commercial exchanges cross the Andean mountains by this road. A large project of a second bi-oceanic corridor is through the 4,700 m Agua Negra Pass at east of San Juan city is of actuality and will need quite the same civil engineering infrastructures as road 7 one's (tunnels, bridges, protections, dams). As the areas are affected by large storms, windy and snowy conditions, the highways may be out of run several days due to large gravitational flows, rocks falls, and snow avalanches. In period of developing hazard plan and resilience considering, this context raises some potential investigations and methods that should be done in order to understand and quantify the phenomena and the specific related questions from a scientific point of view, and evaluate the variability of the scenarios. The aim of this paper is to generate an inventory of multi natural hazards as suggested by Wick (2010) for the ruta 7, in order to suggest preventive measures on this key infrastructure. The Rhone Alpes region and Grenoble city is one the most active seismic zone of France, and some similarities in the geography may allow comparison of interest and rich in an interdisciplinary and inter regionally companion work. Indeed, the region has several large urban areas, high mountains and cross-border infrastructures well used such as Lautaret/Mongenevre itinerary to Italy, Mont-Blanc/Modane tunnels. The paper presents first some natural hazards of the Mendoza province, then the evidence of multi-hazard scenario is deduced and mitigation measures are proposed. A parallel with the Rhone-Alpes region is presented. As conclusion, some prior possibilities of works are proposed in an engineering point of view.

2. Natural Hazard Inventory of Mendoza Province

2.1. Seismic hazard

The Cuyo region is the most seismic zone of Argentina, still reported events start in the 16em century (INPRES 1985). Large catastrophic events occurred in the last century leading to the destruction/reconstruction of the cities of San Juan and Mendoza. Events with magnitudes between 4 and 5 regularly occur: in 2013, 58 events were reported in San Juan (weekly frequency), whereas a monthly frequency is observed in Mendoza (Figure 1).

The seismicity in the region is due to both active local faults and to Chilean subduction like the last Iquique event in April 2014. In the Mendoza piedmont region, active faults cross the urban areas of the capital, (Moreiras and Páez, 2014). The same situation exists in San Juan city (see faults map fig 1d). These active faults generate most of the seismicity of the two provinces. Even further Chilean subduction earthquakes are generally registered. Due to this high hazard, the seismic studies institutes of Argentina (INPRES-created after the destruction of San Juan in 1944, IDIA, IMERIS, CEREDETEC, CCT-CONICET) involved in the risk evaluation are localized in this region, managing and reporting accelerometers net measurements. For building codes design, INPRES defined the Argentina zoning with 4 levels, giving the highest values (4) to all the Mendoza and San Juan province's territories, without considering any local amplification factor except in some particular zones where the ground accelerations were defined more precisely (Tonnelo 2010).

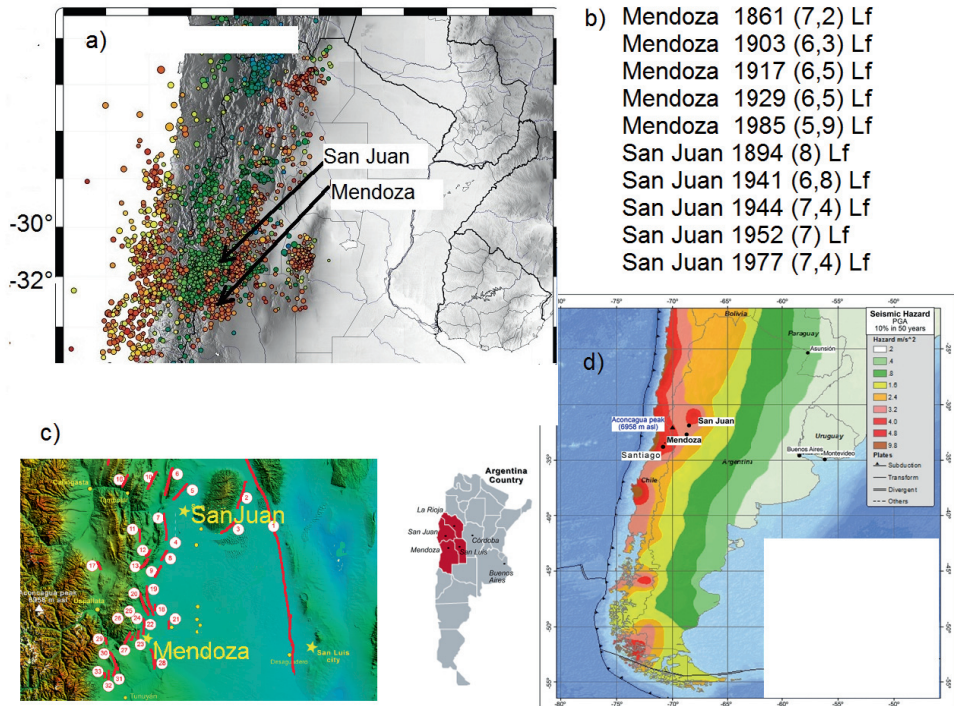


Fig 1: (a)-seismicity map of Cuyo region (INPRES) and (b)-catastrophic historical events with liquefaction (Lf) (Moreiras 2004) (c) active faults at the piedmont of the central Argentinian Andes (Moreira 2014). (d) Potential ground motion for Argentinean local and subduction Chilean earthquakes in Moreiras (2014 from USGS)

2.2. Geological considerations

The liquefaction phenomena is a well-known behavior of saturated soils especially under dynamic loading and part of the damage in urban areas as it is a triggering factor of soil failure (Youd 1978). The dynamic over-pressure on the liquid phase of the saturated soil leads to a liquid like behavior instead of solid one. The liquefaction soils susceptibility may be measured by cone penetration test and is generally common in the sandy and Limon soils (Robertson 1992). The alluvial terrains of great part of the Mendoza/San Juan provinces is constituted of silty and sandy soils that are the soils type with a high susceptibility of liquefaction. The evidence of liquefaction effects in the region for the historical earthquakes has been documented (Perucca and Moreiras, 2006, Moreiras and Páez, 2014) especially in Holocene sediments with upper phreatic levels. Some areas demonstrate to be prone to liquefaction when adequate geotechnical tests are done. These areas were identified, as demonstrating seismic liquefaction “secondary effect” hazard precursors and a micro-zoning was defined, in coincidence with the all urban sites of Gran Mendoza and San Juan (INPRES 82).

2.3. Climatic hazards

Various contrasted climatic effects affect the Cuyo region as it considers semi-arid latitudes (29°S to 34°S) with large altitude range (500 m to nearly 7000m). Topography forces precipitation being less than 100mm/year in the lowlands to more than 500mm/year in the highlands. Region is affected by both Pacific and Atlantic oceans perturbations. The influence of latter are limited to the western Cordón del Plata range, 1200 km from Atlantic coast. Whereas the Pacific influence could not really cross the highest cordilleran summits being associated to snow precipitations in high altitude during winter season; while the Atlantic Anticyclone leads heavy summer

earthquake in February 2010 (Ms 8.2) with epicenter 300 km far from the area generated many rockfalls in Aconcagua Park (Wick et al, 2010). As demonstrated by Burjanek J.(2011) less value has been recorded presenting that ground motion (taking into account the local amplification effect) is a more pertinent parameter and that amplification factor may be used if necessary.

Gravitational events have great influence on the economic development as (, when occurring, the road may be cut for several days and international traffic stopped up to the complete restoration of the infrastructures. The economic wastes are directly related to the duration of the out of run.

2.5. Social components

The Cuyo region is characterized by contrasted areas: densely populated zones around the cities of Mendoza and San Juan and empty mountainous areas. In the urbanized areas, both San Juan and Mendoza cities were completely destroyed by historical great seismic events. As demonstrated in flood risk perception by (Viggilione 2014) , the collective memory may largely be involved in the perception and preparation of the population to catastrophic events.. In the investigated area, the return period of major earthquakes is quite long as the Cauçete event (Magnitude 7.4) occurred in 1977. The complete generation of adults (up to 35 years) does not have any experience of strong earthquake, even if training exercises are done at school, at work... and even if the 2010 Chilean event was felt in both provinces. An ongoing perception survey in Mendoza ciudad (collaboration between Univ. of Grenoble and Univ. of Cuyo, Mendoza) may help considering if the knowledge of safety measures as well as seismic risk perception and preparedness strategies are different for several social groups defined by age, gender, study level, earthquake experience, etc. This may also help emphasizing resilience factors of the population facing several natural hazards.

If the Mendoza and San Juan gather 2,420,000 inhabitants (INDEC, Censo 2010), the population is concentrated in urban areas, where human, economic and physical vulnerabilities are greater due to the concentration of buildings, population and activities. In mountainous context, vulnerabilities are different: the probability of deaths is lower due to low densities. The vulnerabilities are more related to networks. First, the economic activities that depend on these roads are most vulnerable. The traffic interruption could generate millions of dollars loss. Secondly, mountainous populations may be isolated during several days: because they do have to face the same threat, their resilience factors are certainly different from urban populations. Special attention could also be given to tourists who are numerous in the studied area region (wine tourism, andinism...). They are a priori less familiar to hazards they are exposed to, what increase their vulnerability (Kelman et al., 2008). The exposure is also different between urban and mountainous populations, due to distinct hazards they have to face (see paragraphs above).

3. Evidence of co-seismic co-rainfall co-social scenarios

Here we have to point out that cities are located out of the mountain environment, then collapse or gravitational processes will affect communication systems (like international road to Chile). However, cities could be affected by other secondary seismic events like liquefaction or local ground acceleration due to soil material (measured by UTN). San Juan airport is situated on soils prone to liquefaction and the high seismic province deals with the same hazard inventories as geographically similar. Climate hazards could affect both mountain environment and lowland cities. The analysis of natural hazards of the Cuyo province is quite complex as for vulnerability and risk management, the contrast between urban and non-urban areas constitutes a difficulty to homogenize the scenarios and methodology. In fact, not only the human vulnerability should be studied but the economic and social ones. Depending on epicenter distance the minimum magnitude to trigger rock falls may start between and 4 and 5 (Keefer 1984, 1988, 2002, Moreira 2006), and amplification factors due to topography, geology is necessary to be known especially in the possible fracturing of recurrent seismicity without apparent damage as co-seismic triggering in critical spots is possible.. The inventory of past gravitational events gives a good mapping of potential event localization, but may not be exclusively relevant of future events. Occurrence conditions are not well known due to lack of observation and observers. Some numerical simulation of return analysis may help (Taboada 2007, Cuervos 2013) to explore the potential threshold parameters the consequence of variability (Baroth 2012). As experimental studies is hard work (Manzella 2013) and but had permitted calibration and validation of the numerical modelling of

rock avalanches (Richefeu 2012) Relevant numerical results run out, flow velocities, “Fachboschung angle” may be compared with classical ones and proposed to evaluate the vulnerability of peoples, infrastructures the increase of expertise on a typical case is of interest, and the effect the initial mechanical energy, given by the dynamic seismic ground loading is not actually considered in the deposit run-out on co-seismic event, nor the fracturing effect of initial volume due to M4-5 ground motions. Moreover Moreiras depicted that largely high fractured/degraded zone combined with co-rainfall seems to generate debris flows as .Those rapid events have greater technical and economic impact and generate more vulnerability than slow one (Mora 2010). Smaller solicitation effects such as wind and heavy traffic waves could be also computed if some sites topographic amplification effects are evident.

Seismicity is also of importance for urban areas as the destruction of the city’s infrastructure is a key factor in the risk management, and it has been demonstrated that large zone are in liquefaction potential areas (Moreiras 2007). The post seismic analysis of Christchurch (New Zealand) damaged areas conduced to abandon some large areas due to liquefaction susceptibility (Cubrinovski 2012) that is of importance in the urbanization future plans managing of every cities. Analyzing the multi hazard scenario Wasowski (2011) suggested studying co-rainfall and co-seismic hazard as dynamic loading generate liquefaction phenomena initiating some gravitational events.

The climate change may modify the frozen zones altitude, in higher it and displacing the pacific-oceanic influence border himself as well as the snow/rainfall limit. The hazard in the mountains area will change by increasing numbers of events and decrease the return frequency. This will modify the actual zoning as small return frequency with better reliability due to collective memory and generally less intensity that allows possible efficient protections.

Conclusion

Mendoza and San Juan Provinces are territories of contrast due to high and low altitude, semi- arid climate, permafrost melting, isolated and urban areas...Regarding the checklist of the potential hazard, it is observe that many of them could interact and a multiscenarios should be proposed. Hard constraints of the zone lead to sometimes contradictory and/or additional and/or successive problematic for the urban and non-urban areas that complexify hazard managing due to inhomogeneity. It may be possible to propose methodology to divide in homogenous zone. Moreover developing hazard plans and trying to evocate resilience, the discussion raises some investigations potential subjects and methods that should be done in order to understand and quantify the phenomena and the specific related questions from a scientific point of view, and evaluate the variability of the scenarios. As both territories may be in altitude disparities, a comparison with the Rhone Alpes region may done keeping in mind an evident scale factor especially in altitude characteristics. The same contrasted constraints are facts for this similarity: few inhabited Alpes mountains and large urban lowlands and cities, economic reliability in outdoor tourism, agriculture zone, and heavy traffic infrastructure with exposed critical point between Italy and France And several process such as the debris flows, avalanche, rockfalls, and as recently, the 7 April 2014 seismic events of M5.

It also necessary to identify probable chain reactions against which authorities may be destitute, as these reactions are rarely taken into account in emergency plans.

Acknowledgements

The authors would acknowledge the Mendoza organisms (CEREDETEC-UTM, UNCu, IANIGLA, CCT-Conicet, and Grenoble University) and their personals who have provided adequate facilities to allow the friendly work sabbatical stays of the French authors.

References

- Banff, BC.Di Toro G., Mitterpergher S., Ferri F., Mitchell T.M., Pennacchioni G., The contribution of structural geology, experimental rock deformation and numerical modelling to an improved understanding of the seismic cycle: Preface to the Special Volume “Physico-chemical processes in seismic faults”, *Journal of Structural Geology*, Volume 38, May 2012, Pages 3-10, ISSN 0191-8141, <http://dx.doi.org/10.1016/j.jsg.2012.01.025>.
- Baroth J. (2013) *Construction Reliability : Safety, Variability and Sustainability* ; editorsEditor(s): Julien Baroth, Franck Schoefs, Denys Breyse Wiley edition DOI: 10.1002/9781118601099

- Burjánec J. (2011), Moore, J. R. Gassner-Stamm G., Fäh D. Seismic response of unstable mountain rock slopes: Topographic site effect. 4th IASPEI / IAEE International Symposium: Effects of Surface Geology on Seismic Motion, August 23–26, 2011, University of California Santa Barbara central western Argentina Geological Society, London, Special Publications, first published February 19, 2014; doi 10.1144/SP399.6
- CCT-Conicet Centro Científico Tecnológico (CCT) CONICET Mendoza <http://www.mendoza-conicet.gov.ar/portal>
 CEREDETEC <http://www1.frm.utn.edu.ar/ceredetec/> Centro Regional para el Desarrollo Tecnológico de la Construcción, Sismología e Ingeniería Antisísmica [CeReDeTeC]
- Chang K.J., Taboada A. (2009) Discrete element simulation of the Jiufengershan rock-and-soil avalanche triggered by the 1999 Chi-Chi earthquake, *Taiwan Journal of Geophysical Research: Earth Surface* Volume 114, Issue F3, September 2009.
- Correa E., Ruiz M.A., Canton A., Lesino G., (2012) Thermal comfort in forested urban canyons of low building density. An assessment for the city of Mendoza, Argentina, *Building and Environment*, Volume 58, December 2012, Pages 219-230, ISSN 0360-1323, <http://dx.doi.org/10.1016/j.buildenv.2012.06.007>.
- Cubrinovski M, Henderson D., Brandley B. (2012) Liquefaction impacts in residential areas in the 2010-2011 Christchurch earthquakes. *Proceedings of the International Symposium on Engineering Lessons Learned from the 2011 Great East Japan Earthquake*, March 1-4, 2012, Tokyo, Japan
- Cuervo S. (2014), Daudon D., Richefeu V., Villard P. and Lorentz J. Discrete element modeling of a rockfall in the south of the “Massif Central”, France ; IAEG XII Congress - Torino, September 15-19, 2014.
- Cuervos S., J Lorentz, P Villard, V Richefeu, D Daudon 2013 : Utilisation d'un modèle numérique discret pour l'analyse de la propagation d'un éboulement rocheux dans le Massif Central, France, *Journées aléas gravitaires*, Septembre 2013, University J. Fourier, Grenoble, France.
- Diario Los Andes 2014 Viernes 11 of abril 2014 proyectan pupitres que sirvan de refugio ante terremotos
- Hunaidi O. (2000) Traffic Vibrations in building, *Construction technology update* n°39, June 2000, National research council of Canada
- IDIA Instituto de Investigaciones Antisísmicas <http://www.idia.unsj.edu.ar/>
- IMERIS Instituto de Mecánica Estructural y Riesgo Sísmico <https://fing.uncu.edu.ar/Investigacion/institutos/imeris/imeris>
- INPRES : Instituto Nacional de Prevención Sísmica. <http://www.inpres.gov.ar/>
- Keefer, D. K. (1984). Landslides caused by earthquakes, *Geol. Soc. Am. Bull.* 95, 406-421.
- Kelman I, Spence R., Palmer J., (2009) Tourists and disasters: lessons from the 26 December 2004 tsunamis, *Journal of Coastal Conservation*, 2009, Volume 12, Number 3, p. 105-113
- Manzella, I., & Labiouse, V. (2013). Empirical and analytical analyses of laboratory granular flows to investigate rock avalanche propagation. *Landslides*, 10(1), 23-36.
- Marzorati S., Luzi L, De Amicis M. (2002) Rock falls induced by earthquakes: a statistical approach, *Soil Dynamics and Earthquake Engineering*, Volume 22, Issue 7, September 2002, Pages 565-577, ISSN 0267-7261, [http://dx.doi.org/10.1016/S0267-7261\(02\)00036-2](http://dx.doi.org/10.1016/S0267-7261(02)00036-2).
- Mollon, G. (2012), V. Richefeu, P. Villard, and D. Daudon (2012), Numerical simulation of rock avalanches: Influence of a local dissipative contact model on the collective behavior of granular flows, *J. Geophys. Res.*, doi:10.1029/2011JF002202.
- Moore, J.R., Gischig V., Burjánec J., Amann F., and Hunziker M. (2012). Earthquake-Triggered Rock Slope Failures: Damage and Site Effects, *Proceedings 11th International & 2nd North American Symposium on Landslides*.
- Mora S, Roumagnac A, Asté J.P., Calais E, Haase J., Saborio J., Marcello M., Milcá J.E., Zahibo N. (2010) Analysis of Multiple Natural Hazards in Haiti, report of the government of Haiti, Port-au-Prince, Haiti March 26, 2010
- Moreiras S.M. (2005). Landslide Susceptibility Zonation in the Rio Mendoza Valley, Argentina. *Revista Geomorphology* Vol 66/1-4: 345-357.
- Moreiras S.M. (2006) / Frequency of debris flows and rockfall along the Mendoza river valley (Central Andes), Argentina: Associated risk and future scenario *Quaternary International* 158 (2006) 110–121.
- Moreiras S.M. (2009). Análisis de las variables que condicionan la inestabilidad de las laderas en los valles de los ríos Las Cuevas y Mendoza. *Revista de la Asociación Geológica Argentina*, 65(4): 780–790.
- Moreiras SM and Páez MS (2014) Historical damage and earthquake environmental effects related to shallow intraplate seismicity of Moreiras, S.M., 2003. Remoción en masa en el valle del valle del Río Mendoza, Mendoza, Argentina. *Utar Ciencia* 2 (1), 2–10.
- Moreiras, S.M., 2004a. Landslide incidence zonation in the Rio Mendoza valley, Mendoza province, Argentina. *Earth Surface Processes and Landforms* 29, 255–266.
- Moreiras, S.M., 2004b. Zonificación de peligrosidad y riesgo de procesos de remoción en masa en el valle del Río Mendoza. Unpublished Ph.D. Dissertation, Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de San Juan, San Juan, Argentina.
- Moreiras, S.M., 2004c. Zonificación de peligrosidad y riesgo de procesos de remoción en masa en el valle del Río Mendoza. In: Gonzalez, M., Bejerman, N.J. (Eds.), *Peligrosidad geológica en Argentina*. Publicación Especial No. 4. Asociación Argentina de Geología Aplicada a la Ingeniería, Capital Federal, Argentina.
- Moreiras, S.M., 2005a. Landslide Susceptibility Zonation in the Rio Mendoza Valley, Argentina. *Geomorphology* 66, 345–357.
- Moreiras, S.M., 2005b. Climatic effect of ENSO associated with landslide occurrence in the Central Andes, Mendoza province, Argentina. *Landslides* 2 (1), 53–59.
- Moreiras, S.M., M. G. Lenzano Y N. Riveros, (2008) Landslide Inventory in the Aconcagua Park, Mendoza Provincia – Argentina *Muldequina* 17: 129- 146, 2008
- Moreiras S.M. and Sepúlveda Sergio A. Megalandslides in the Andes of central Chile and Argentina (32°–34°S) and potential hazards *Geological Society, London, Special Publications*, 399, first published on May 13, 2014, doi:10.1144/SP399.18
- Perucca L., Moreiras SM 2006 Liquefaction phenomena associated with historical earthquakes in San Juan and Mendoza Provinces, Argentina *Quaternary International* 158 (2006) 96–109

- Norte F.A. Ulke A.G. Simonelli S.C. Viale M.(2008) The severe zonda wind event of 11 July 2006 east of the Andes Cordillera (Argentina): a case study using the BRAMS model *Meteorol Atmos Phys* (2008) 102:1–14 DOI 10.1007/s00703-008-0011-6
- Pirulli, M., Mangeney A. 2008 Results of Back-Analysis of the Propagation of Rock Avalanches as a Function of the Assumed Rheology Rock Mechanics and Rock Engineering February 2008, Volume 41, Issue 1, pp 59-84.
- Richefeu V (2012), G Mollon, D Daudon, P Villard Dissipative contacts and realistic block shapes for modeling rock avalanches ; *Engineering Geology* 149, 78-92
- Robertson P.K. , D. J. Woeller, W. D. L. Finn (1992) Seismic cone penetration test for evaluating liquefaction potential under cyclic loading *Revue canadienne de géotechnique*, 1992, 29(4): 686-695, 10.1139/t92-075
- Sepúlveda, S.A., Padilla, C., 2008. Rain-induced debris and mud flow triggering factors assessment in the Santiago Cordilleran foothills, Central Chile. *Natural Hazards*, 47, 201-215.
- Sepúlveda, S.A., Rebolledo, S., Vargas, G., 2006. Recent catastrophic debris flows in Chile: geological hazard, climatic relationships and human response. *Quaternary International*, 158, 83-95.
- Silberschmidt V.V.. Dynamics and Scaling Characteristics of Shear Crack Propagation *Pure appl. geophys.* 157 (2000) 523–538.
- Raveland and Philip Deline (2008) The West Face of Les Drus (Mont-Blanc massif): slope instability in a high-Alpine steep rock wall since the end of the Little Ice Age. *Géomorphologie paraglacière : renouveau conceptuel et méthodologique* . 4/2008
- Taboada, A., and N. Estrada (2009), Rock-and-soil avalanches: Theory and simulation, *J. Geophys. Res.*, 114, F03004, doi:10.1029/2008JF001072.
- Tornello M.E. , Frau C.D. Experiencias sobre aislamiento sísmico argentina diseño, modelación, y construcción en mendoza, *Revista internacional de Ingeniería de Estructuras* Vol. 15, 1, 1-47 (2010).
- Viale, M, Garreaud R., 2014: Summer Precipitation Events over the Western Slope of the Subtropical Andes. *Mon. Wea. Rev.*, 142, 1074–1092.
- Viglione A., Di Baldassarre G., Brandimarte L., Kuil L., Carré G., Salinas J.L., Scolobig A., Blöschl G, Insights from socio-hydrology modelling on dealing with flood risk – Roles of collective memory, risk-taking attitude and trust *Journal of Hydrology* Available online 22 January 2014, <http://dx.doi.org/10.1016/j.jhydrol.2014.01.018>
- Vuille M., Ammann C. (1997) Regional Snowfall Patterns in the High, Arid Andes Climatic Change at High Elevation Sites 1997, pp 181-191 doi: 10.1007/978-94-015-8905-5_10
- Welkner D. (2010) Eberhardt, E. Hermanns R.L. , Hazard investigation of the Portillo Rock Avalanche site, central Andes, Chile, using an integrated field mapping and numerical modelling approach, *Engineering Geology* 114 (2010) 278–297
- Wasowski J, Keefer D.K., Chyi-Tyi Lee Toward (2011) the next generation of research on earthquake-induced landslides: Current issues and future challenges *Engineering Geology* 122 (2011) 1–8
- Wick, E., Baumann, V. and Jaboyedoff, M. 2011. Report on the impact of the 27 February 2010 earthquake (Chile, Mw 8.8) on rockfalls in the Las Cuevas valley, Argentina. Brief communication. *Nat. Hazards Earth Syst. Sci.*, 10, 1989–1993.
- Wick, E., Baumann, V., Michoud, C., Derron, M.-H., Jaboyedoff, M., Lauknes, T. R., Marengo, H., and Rosas, M.: Multirisk analysis along the Road 7, Mendoza Province, Argentina, EGU General Assembly Vienna, Austria, 2–7 May 2010, Vol. 12, EGU2010-4747-1, 2010.
- Youd, T. L., and Perkins, D. M. (1978). “Mapping of liquefaction-induced ground failure potential.” *J. Geotech. Engrg. Div., ASCE*, 104(4), 433–446.