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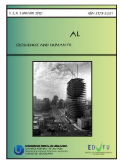

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Climate change and Patagonian ice fields in Chile: a review

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ABSTRACT

Nowadays, understanding of climate change effect in the reduction of the ice cover is a relevant issue**.** Resolving this question is a challenge because ice bodies can respond in different ways to climate change. The reduction of the ice cap region is strong in Patagonia. Consequently, this paper is focused on the review of data in order to document glacier alterations in the Chilean Patagonian during the 20th century and beginning of the 21th century. There are some authors who have documented the influence of climate change in Patagonian ice fields (MASIOKAS et al., 2009; VEBLEN et al., 2011). Much data shows a generalized thinning and retreat trend of glaciers in the Northern Patagonia Icefield (NPI) and the Southern Patagonia Icefield (SPI). Furthermore, the contribution that Patagonian glacier retreat makes to sea level rise (SLR) is one of the important issues of the interaction between glaciers and climate change. An original analysis of glaciers HPN2 and HPN3 conducted for this paper provides additional support for the general recession of glaciers Patagonia.
A typology of these towns and cities is also proposed based on these resources and industries.

PALAVRAS-CHAVE:
Mudanças Climáticas
Norte da Patagônia campos de gelo (CHPN)
Sul da Patagônia Campo de Gelo (CHPS)
Elevação do nível do mar

RESUMO A MUDANÇA CLIMÁTICA E OS CAMPOS DE GELO DA PATAGÔNIA, NO CHILE: UMA REVISÃO. Hoje, há um grande interesse em compreender os efeitos das alterações climáticas para reduzir as camadas de gelo ao redor do mundo. No entanto, a análise desse fenômeno é um desafio porque os corpos de gelo têm reagido de formas diferentes às mudanças climáticas. Na Patagônia a redução de gelo tem sido forte em comparação com outras regiões. Consequentemente, este trabalho centrou-se na análise de dados para documentar as mudanças nas geleiras da Patagônia chilena durante o século XX e o início do século XXI. Alguns autores têm documentado a influência das alterações climáticas nos campos de gelo da Patagônia (MASIOKAS et al., 2009, Veblen et al., 2011). Muitos dados mostram uma tendência geral de adelgaçamento e recuo das geleiras do Campo de Gelo Norte e Campo de Gelo Patagônico Sul. Além disso, a contribuição do recuo dos glaciares da Patagónia na elevação do nível do mar é um dos mais importante na interação entre as geleiras e as mudanças climáticas. Análise das geleiras e HPN3 HPN2, por este estudo, forneceu informações adicionais para entender o declínio geral nas geleiras da Patagônia.

Palabras-clave:
Cambio climático
Campo de Hielo Patagónico Norte (CHPN)
Campo de Hielo Patagónico Sur (CHPS)
Aumento del nivel del mar

RESUMEN El cambio climático y los campos de hielo patagonicos en Chile: una revisión. Hoy en día, hay un gran interés en la comprensión de los efectos del cambio climático en la reducción de las capas de hielo alrededor del mundo. Sin embargo, el análisis de este fenómeno presenta un desafío porque los cuerpos de hielo han respondido de diferentes maneras al cambio climático. En la Patagonia la reducción de las capas de hielo ha sido fuerte comparado con otras regiones. En consecuencia, este documento se centró en la revisión de datos con el fin de documentar las alteraciones en los glaciares de la Patagonia chilena en relación durante el siglo XX y principios del siglo XXI. Hay algunos autores que han documentado la influencia del cambio climático en los campos de hielo patagónicos (MASIOKAS et al., 2009; VEBLEN et al., 2011). Muchos datos muestran una generalizada tendencia al adelgazamiento y al retroceso de los glaciares en el Campo de Hielo Patagónico Norte y Campo de Hielo Patagónico Sur. Por otra parte, la contribución del retroceso de los glaciares Patagónicos en el aumento del nivel del mar es uno de los aspectos más importantes en la interacción entre los glaciares y el cambio climático. El análisis de los glaciares HPN2 y HPN3, realizado por este estudio, proporcionó información adicional para entender la recesión generalizada de los glaciares de la Patagonia.

1 Introduction

The part of the Earth that is dominated by glaciers, ice sheets, ice fields, and sea ice is about 10 percent of the land surface, but the current distribution of the cryosphere becomes increasingly exaggerated towards the poles. Thus, one important issue is whether the alteration of the climate system by fossil fuel combustion is going to be so severe that the enhanced greenhouse effect will lead to the reduction of ice cover (HAMBREY; ALEAN, 2004). Resolving this question is a relevant challenge because ice masses can respond in different ways to climate change. It causes variations in temperature and snowfall, altering mass balance that is the difference between the quantity of snow and ice accumulation on the glacier and the amount of snow and ice melting and ice sublimation lost from the glacier (PELTO, 2011).

In mountainous areas, glaciers are an important source of water for hydroelectric power plants, agriculture and tourism. However, one of the major consequences of the global climate change during the last decades is glacier mass balance alteration in mountainous regions by melting and/or evaporation. The kinds of glaciers located in these regions are called ice fields or ice caps that cover an area of less than 50,000 square kilometers with a smooth surface. They tend to develop on high plateaus where ice spills over the plateau edge (HAMBREY; ALEAN, 2004). Ice caps normally can have smaller or larger glaciers which flow onto lower terrain and into the sea (OERLEMANS, 2001).

The biggest ice fields in temperate regions are Vatnajökull in Iceland and the Patagonian ice caps in the Andes Mountains (HAMBREY; ALEAN, 2004). Thus, the largest glaciated area in the Southern Hemisphere, outside Antarctica, is located in the extra tropical Andes of Chile and Argentina where glaciers can be found not only at elevations of over 6,000 meters in the high arid Andes, but also at sea level in the humid southwestern region of Patagonia and Tierra del Fuego (MASIOKAS et al., 2009). In the southern part of the Chilean-Argentinean border, the reduction of the ice cap region is strong in the two larger ice bodies called the Northern Patagonian Ice field (NPI) and the South Patagonian Ice field (SPI), and their response to climate change has been investigated by many researchers showing that the glaciers have retreated during the last six decades (ANIYA et al., 1997; RIVERA et al., 2007).

This paper is focused on the review of scientific data in order to document glacier mass balance and glacier recession in the Patagonian Andes of Chile in relation to climate change during the 20th century. Thus, it is possible to improve not only the understanding of the causes and consequences of ice field alterations, but also the disturbance in the surrounding environment of Patagonian glaciers. This study provides some background information on the connection between climate change and glacier mass balance. Then, the paper presents examples from Chilean Patagonia through photographs documenting the glaciers in order to explore that relationship.

2. Area of Study

In this review, the geographic setting is the Patagonian region on the Chilean Andes Mountains. This area extends approximately from latitude 35° S to 55° S, with a vast glaciated region and a rich variety of glaciers (Fig.1). The geographic features of Chilean Patagonia are determined by the interaction between factors such as the North–South orientation of the Andes Mountains and the westerly winds. Thus, due to the particular geographic location of this mountain range in relation to ice fields, Patagonia has the potential to provide insights regarding the nature and mechanisms of past and present glacier variations and their connections with atmospheric processes in different spatial scales (MASIOKAS et al., 2009).

For this study, the South Patagonian Andes is the most interesting region because it supports the two biggest ice fields so-called the Northern Patagonia Icefield (NPI) and the Southern Patagonia Icefield (SPI). The NPI, located in Chile and covering 4,200 square kilometers and it lies astride the southern Andes Mountains between latitude 46° S and 47° S. Its outlet glaciers extend to lower latitudes than any other ice mass on the Earth (GLASSER; HAMBREY; ANIYA, 2002; RIGNOT; RIVERA; CASASSA, 2003; BARCAZA et al., 2009). The SPI, shared between Chile and Argentina, is the largest temperate ice body in the Southern Hemisphere with a total area of 13,000 square kilometers, extending North-South along 350 kilometers between 48° S and 51° S on the western margin of the continent (RIGNOT; RIVERA; CASASSA, 2003; RIVERA, 2004).

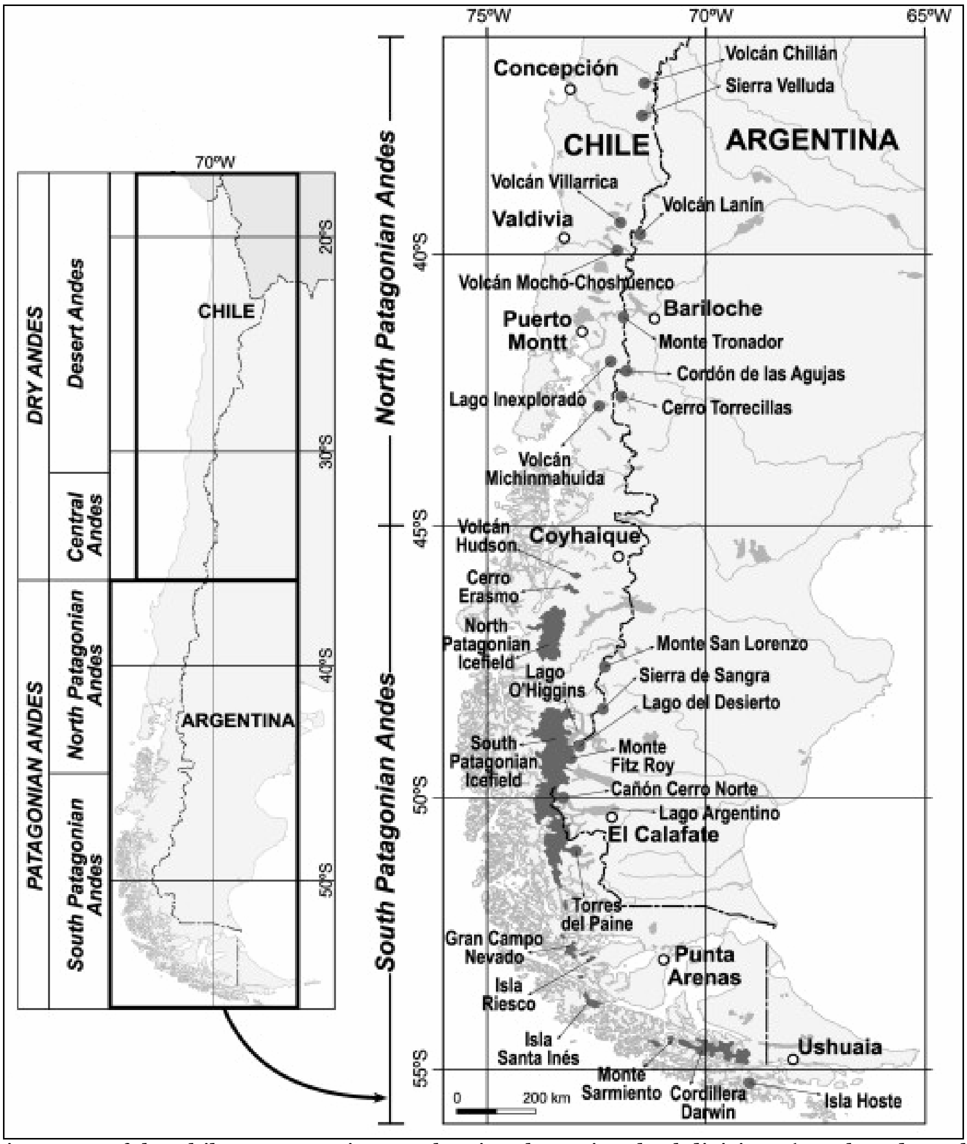

Fig 1. Map of the Chilean Patagonia area showing the regional subdivisions (North and South Patagonian Andes) and the location of some glacier sites. The limits for the subdivisions are based on Lliboutry (1998), from MASIOKAS et al. (2009).

3. Background

Climate observations for the Patagonian Region of Chile

There are many authors who have documented the influence of climate change on the Patagonian ice fields. In this context, MASIOKAS et al. (2009) argued that over the 1912–2002 interval, the linear trends in regionally-averaged annual and seasonal temperature and precipitation records show significant warming and decreasing precipitation in Patagonian Andes. This author developed a climatic index based on winter precipitation and summer temperature records that mimics glacier mass balance relationships. The climatic index shows a negative trend, corroborated with glacier recession shown by photographic comparisons. Furthermore, the regional runoff record shows a negative trend, remarkable similarities with the climatic index, and highly positive correlations with the regional precipitation series.

According to VEBLEN et al. (2011), there are many climate records that have documented a strong warming trend in the Patagonian-Andean region during the last century. Gridded climate records interpolated from numerous dispersed climate stations show strong late 20th century warming trends and modest decreases in precipitation during the season between October-March, for both the North Patagonia Andes and South Patagonian Andes. In addition, the general trend for temperature shows an increase in the season between October-March in Patagonia due to an increase in the number of positive anomalies for that period (Fig.2).

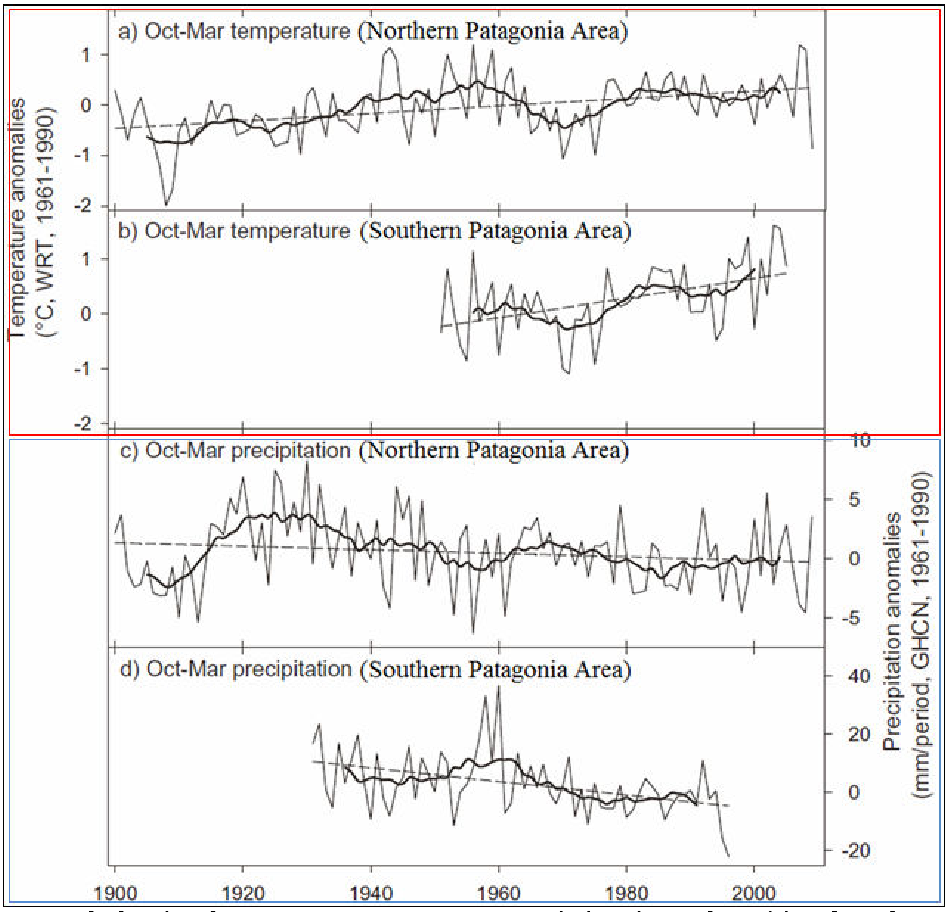

Fig 2. Graph showing the warm season temperature variations in northern (a) and southern (b) Patagonian areas expressed as mean anomalies (°C) with respect to the 1961–1990 reference period, and dry season precipitation variations in northern (c) and southern (d) Patagonian areas expressed as total anomalies (mm) with respect to the 1961–1990 reference period, from VEBLEN et al. (2011).

Through record data from the KONINKLIJK NEDERLANDS METEOROLOGISCH INSTITUUT (2011), it is possible to see there is a trend of increasing temperatures in the Patagonian ice fields. For example, the seasonal mean temperature variations during the time series of 1900-2011 in the southern section of the NPI shows decreasing in negatives anomalies from 1900's to 1940's, which means a general rising temperature for that period. Since the 1970's, there has been a constant growth of positives anomalies in summer seasons, which means a warming during the ablation time in glaciers. In fact, the highest anomalies recorded occurred after 2000 (Fig.3).

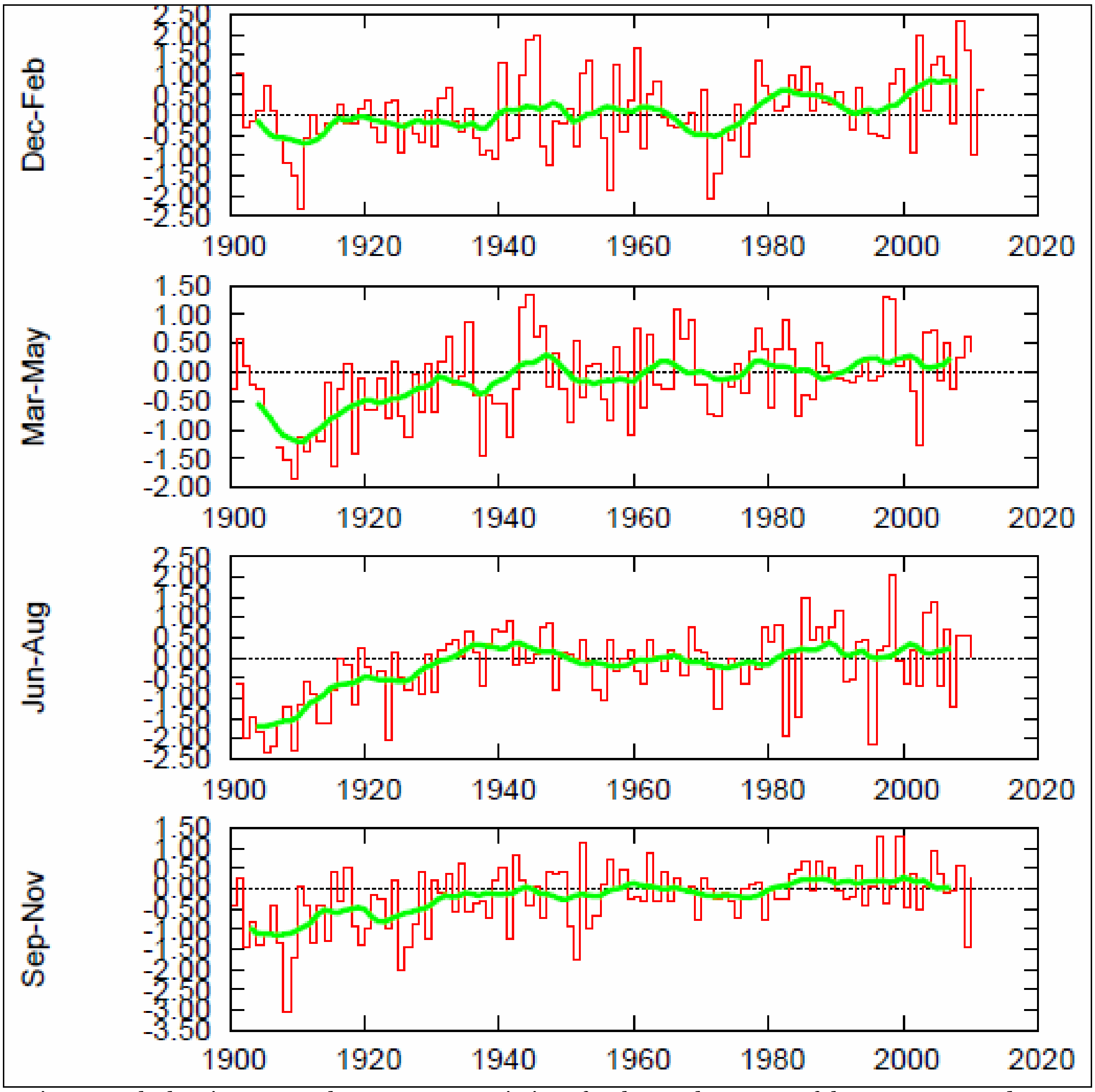

Fig 3. Graph showing seasonal temperature variations for the southern area of the NPI, expressed as mean anomalies (°C) in relation to the period of 1900-2011. Data from the KONINKLIJK NEDERLANDS METEOROLOGISCH INSTITUUT (2011).

Thinning and retreat of ice fields of Chilean Patagonia

FERNANDEZ; ARAOS; MARIN (2010) argued that in the last decades, much research has been performed to determine the current behavior of glaciers in the Chilean Patagonian, especially in relation to the volumetric changes in the outlets of the NPI and SPI ice fields. Measurements taken by MASIOKAS et al. (2009) have shown a generalized thinning and retreat of Patagonian glaciers (Fig.4).

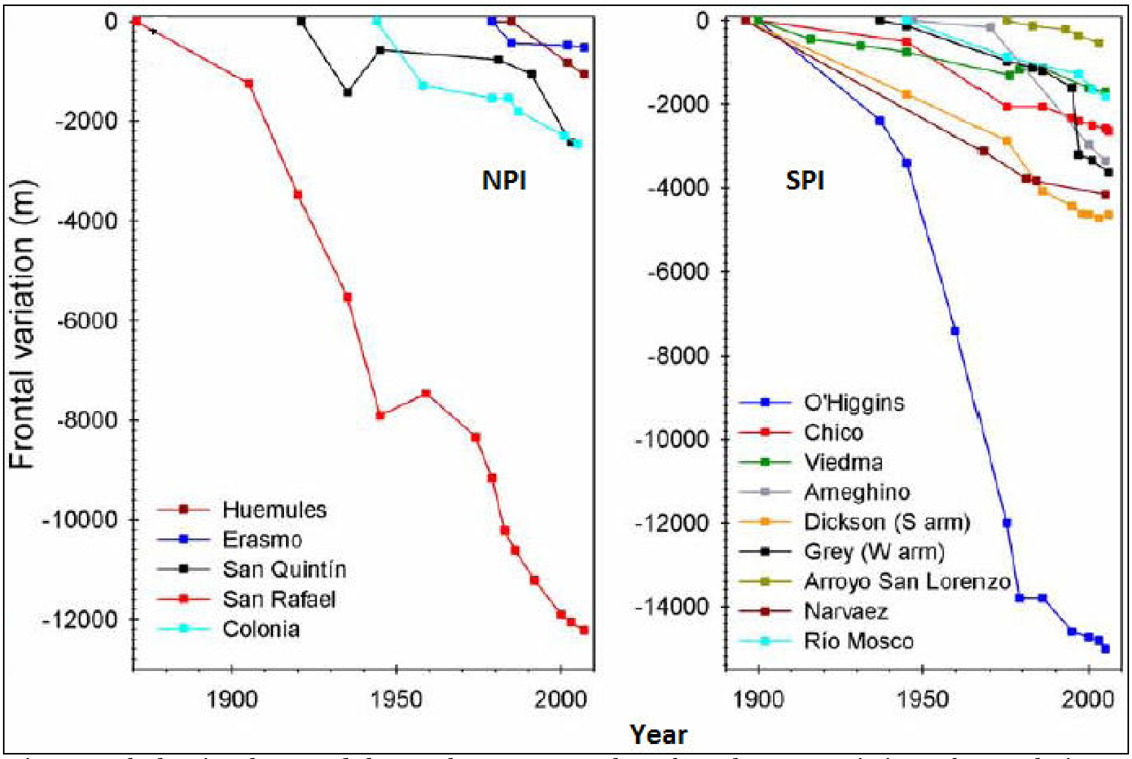

Fig 4. Graph showing the records longer than 100 years about frontal retreat variations of some glaciers of the NPI and SPI ice fields, where the largest glacier retreat in these areas are Glacier San Rafael (NPI) and Glacier O'Higgins (SPI), from MASIOKAS et al. (2009).

ANIYA (2007) reported a general retreating trend in the NPI between 1944-1945 and 2004-2005. The total front area lost at 21 major outlet glaciers in six decades is about 101.36 square kilometers, of which the two largest outlet glaciers account for 41.44 square kilometers. They are San Quintín with 28.8 square kilometers (Fig.5) and San Rafael with 12.64 square kilometers (Fig.6). The large retreat undergone by the NPI after 1975 indicates that melting trends have been accelerating, especially in the two largest outlet glaciers.

Other examples could be the current general retreat in the smaller glaciers located in the southern area of the NPI, which is another indicator of the warming in the Chilean Patagonian Andes. Thus, the glaciers called HPN2 and HPN3 have a general retreating trend between 1987 and 2011 with a front area lost of 2.1 and 3.2 square kilometers respectively. One interesting thing about the melting process is that it is possible to see in these cases the expansion and/or first appearance of terminus lakes beside the ice bodies (Fig.7).

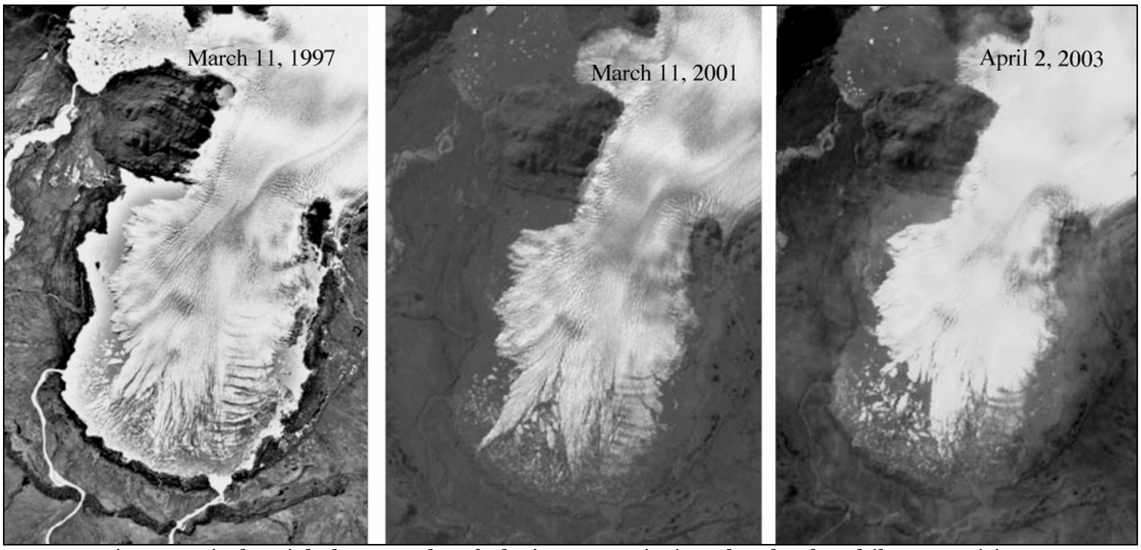

Fig 5. Vertical aerial photographs of Glacier San Quintín, taken by the Chilean Servício Aerofotogramétrico (SAF), shows the features of splaying crevasses near the west, where disintegration appears to be imminent since 1997, from ANIYA (2007).

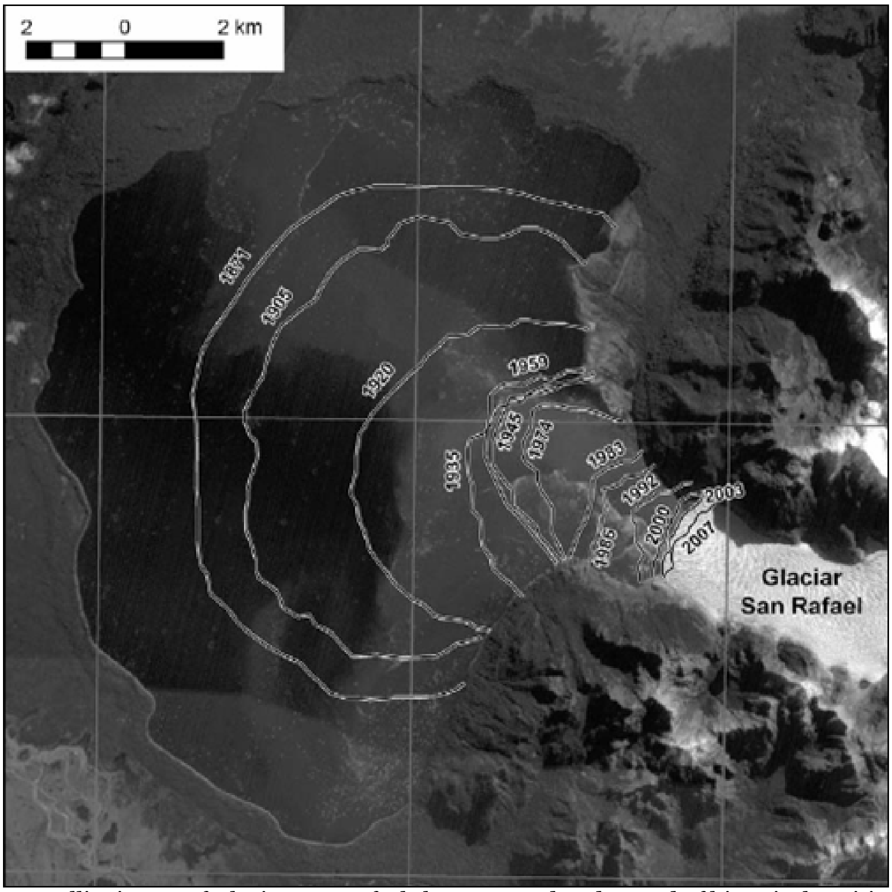

Fig 6. The Satellite image of Glacier San Rafael shows an updated record of historical positions of the front part of the glacier, from MASIOKAS et al., 2009.

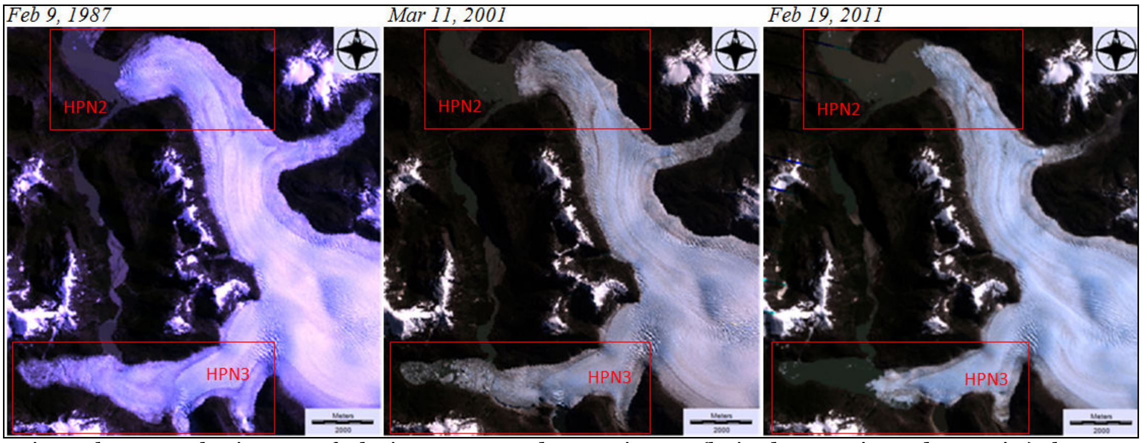

Fig 7. The true color images of Glaciers HPN2 and HPN3 in NPI (latitude 47° 13' S and 47° 19' S) show an updated record of the historical positions of the front part of the glaciers in summer for three different years (1987, 2001, and 2011), elaborated from Landsat TM imagery by the author of this research. It is possible to register the retreat of both glaciers over the last twenty four years.

In relation to SPI, ANIYA et al. (1997) calculated the area variations of 48 outlet glaciers of that ice field for a period between 1945-1986 utilizing different remotely sensed data. He indicated that most glaciers retreated, while during the same time period four glaciers were in equilibrium and two advanced. According to his results, the largest rate area for loss was 1.21 square kilometers per year at the Glacier O'Higgins, which is the largest loss in Patagonia. In addition, CASASSA et al. (1997) and RIVERA (2004) in MASIOKAS et al. (2009) argued that the frontal recession of Glacier O'Higgins is one of the most impressive recent recessions of all outlet glaciers in the SPI because that process continued until the 21th century.

RAYMOND et al. (2005) reported measurements of ice surface elevation, ice thickness and area for Glacier Tyndall that were made between1999-2002. These observations showed acceleration over the last decades of the rates of thinning and retreat of the main calving front. That acceleration appears to be the result of a combination of some climate and feedback processes associated with mass balance. Thus, positive feedback mechanisms, such as freezing air and highest Earth's albedo, produce that ice and snow fields grow until competition with negative feedback forces which increases the melting process on the glacier surface. However, the feedback effect is smaller than the climate driving of the glacier retreat. The melting potential in the terminus lake is limited because of their small size relative to the total area of the glacier. But, a bed well below the lake spillway level for > 14 kilometers up-glacier from the 2000 year front indicated the potential for a retreat.

Sea level rise from ice fields of Chilean Patagonia

The potential contribution that glacier retreat makes to sea level rise (SLR) is one of the relevant aspects of interaction between glaciers and climate change. However, uncertainty is an important aspect in SLR understanding because tide-gauge measurements are unevenly spread over the Earth (OERLEMANS, 2001). Some researchers have reported surface elevation variations by means of data from different sources such as topographic maps, fieldwork, and remote sensing (LOPEZ; CASASSA, 2009). One of them was CHEN et al. (2007) who, using released reprocessed gravity solutions from the Gravity Recovery and Climate Experiment (GRACE), estimates that the contribution of the Patagonia ice field (NPI and SPI) for the period April 2002-December 2006 to global SLR was 0.078 ± 0.031 mm year. In addition, he estimates the ice loss rate for the Patagonia ice field in 27.9 ± 11 cubic kilometers per year equivalent to an average loss of 1.6 meter per year in ice thickness change.

RIGNOT; RIVERA; CASASSA (2003) argue that during the second part of the last century NPI and SPI have had a large influenced on the proportion of melt water that is produced worldwide SLR, estimating that NPI and SPI during 1995–2000 have contributed to SLR by 0.105 ± 0.011 mm year, which is more than double the amount calculated for the 1975-2000 period, which was calculated 0.042 ± 0.011 mm year. It is the result of thinning and changes experienced by their glaciers. The main cause of the thinning of Patagonia glaciers must be attributed to a negative mass balance by climate change. In the last decade, changes in temperature suggest a 0.4° to 1.48° C increase south of 48° S, which explains the higher thinning rates of SPI than NPI.

4. Conclusions

In the Chilean Patagonia, the warming trend during the last century is presumably the main factor behind the general glacier variations, but precipitation could be playing a relevant role because glacier mass balance is correlated to precipitation anomalies in the NPI and SPI. In this context, the thinning and retreat of ice fields caused by the complex interaction among ice bodies, temperature, and precipitation, could be corroborated with some documented examples that show the volumetric and spatial alterations of Patagonian glaciers. However, the melting and retreat of the Patagonian-Andean ice field not only have local effects, but also worldwide impacts due to the fact that changes in glaciers have a correlation with the worldwide SLR.

References

ANIYA, M.; SATO, H.; NARUSE, R.; SKVARCA, P.; CASASSA, G. Recent glacier variations in the Southern Patagonia icefield, South America. **Arctic and Alpine Research**, v. 29, n. 1, p. 1-12, 1997.

ANIYA, M. Glacier variations of Hielo Patagónico Norte, Chile, for 1944/45-2004/05. **Bulletin of Glaciological Research**, v. 24, p. 59-70, 2007.

BARCAZA, G.; ANIYA, M.; MATSUMOTO, T.; AOKI, T. Satellite-derived equilibrium lines in Northern Patagonia Icefield, Chile, and their implications to glacier variations. **Arctic, Antarctic, and Alpine Research**, v. 41, n. 2, p. 174-182, 2009.

CHEN, J.L.; WILSON, C. R.; TAPLEY, B.D.; BLANKENSHIP, D.D.; IVINSI, E.R. Patagonia icefield melting observed by Gravity Recovery and Climate Experiment (GRACE). **Geophysical Research Letters**, v. 34, p. 1-6, 2007.

FERNANDEZ, A.; ARAOS, J.; MARIN, J. Inventory and geometrical changes in small glaciers covering three Northern Patagonian summits using remote sensing and GIS techniques. **Journal of Mountain Science**, v. 7, n. 1, p. 26-35, 2010.

GLASSER, N.F.; HAMBREY, M.J.; ANIYA, M. An advance of Soler Glacier, North Patagonian icefield, at *c*. AD 1222-1342. **The Holocene**, v. 12, n. 1, p. 113-120, 2002.

HAMBREY, M.; ALEAN, J. **Glaciers**. Cambridge, New York, Melbourne, Cambridge: University Press, 2004.

LOPEZ, P.; CASASSA, G. Analysis of long-term hydro-meteorological data of Baker River Basin and the mass balance of NEF glacier, Patagonia. **IOP Conf. Series: Earth and Environmental Science**, v. 6, 2009.

MASIOKAS, M.H.; RIVERA, A.; ESPIZUA, L.E.; VILLALBA, R.; DELGADO, S.; ARAVENA, J. C. Glacier fluctuations in extratropical South America during the past 1000 years. **Palaeogeography, Palaeoclimatology, Palaeoecology**, v. 281, p. 242-268, 2009.

OERLEMANS, J. **Glaciers and climate change**. Exton, Pennsylvania: A.A. Balkema Publishers, 2001.

PELTO, M.S. Glacier mass balance. Retrieved March 26, 2011, from http://www.nichols.edu/departments/glacier/mb.htm

RAYMOND, C.; NEUMANN, T. A.; RIGNOT, E.; ECHELMEYERE, K.; RIVERA, A; CASASSA, G. Retreat of Glaciar Tyndall, Patagonia, over the last half-century. **Journal of Glaciology**, v. 51, n. 173, p. 239-247, 2005.

RIGNOT, E.; RIVERA, A.; CASASSA, G. Contribution of the Patagonia icefields of South America to sea level rise. **Science**, v. 302, p. 434-437, 2003.

RIVERA, A. Mass balance investigations at Glacier Chico, Southern Patagonia icefield, Chile. 2004. Doctoral thesis, School of Geographical Sciences, University of Bristol.

RIVERA, A.; BENHAM, T.; CASASSA, G.; BAMBER, J.; DOWDESWELL, J. A. Ice elevation and areal changes of glaciers from the Northern Patagonia Icefield, Chile. **Global and Planetary Change**, v. 59, p. 126-137, 2007.

KONINKLIJK NEDERLANDS METEOROLOGISCH INSTITUUT (KNMI). KNMI climate explorer. Retrieved March 26, 2011, from http://climexp.knmi.nl

VEBLEN, T.T.; HOLZ, A.; PARITSIS, J.; RAFFAELE, E.; KITZBERGER, T.; BLACKHALL, M. Adapting to global environmental change in Patagonia: What role for disturbance ecology? **Austral Ecology**, 2011. This article is provisionally accepted.