

## MONITORING GLACIER VARIATIONS IN THE SOUTHERN PATAGONIA ICEFIELD UTILIZING IMAGES LANDSAT 7 ETM+

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COMMISSION VIII, WG VIII/10 - Cryosphere

**KEYWORDS:** Cryosphere, Glaciology, Glacier Variation, Landsat 7, Database

### ABSTRACT:

The monitoring of the variation in glacier areas is increasingly important with the apparent trend of global warming. One of the major ice sheets on the planet, the main glaciers of Southern Patagonia Icefield were mapped using a set of images obtained in 1973, 1976, 1979, 1986, 2005 and 2009 by the ETM + sensor onboard the Landsat 7 satellite. The images were calibrated to planetary radiance and reflectance, where the supervised classification of each image sought to obtain the physical limit of the snow with each glacier. Maps were generated with the terminal position of the glacier tongue for the dates analyzed. The results were compared with previous publications and showed peculiar behavior of each glacier, especially from the images of 1986, where there was a pattern of decrease in surface area of glaciers. And the temporal analysis will show the behavior of glaciers to the present day.

### 1. INTRODUCTION

The Patagonian Ice Field is the second largest glacier in the Southern Hemisphere. Located at the southern tip of South America, moves on the border between Argentine and Chilean territories. Composed of two large regions: the Northern Patagonia Icefield (NPI) and the Southern Patagonia Icefield (SPI), with areas of approximately 4.200 km<sup>2</sup> and 13.000km<sup>2</sup> respectively. In the light of an apparent trend of global warming in recent years, it is important the monitoring of the variations of several glaciers on a global scale. With emphasis on temperate glaciers, which tend to respond to climate changes in a relatively short period of time.

With the passing of years the studies about global warming, and the behavior of glacier areas, have been intensified all over the world. With the Patagonian ice field wasn't no

different and several authors have studied its glaciers since 1950.

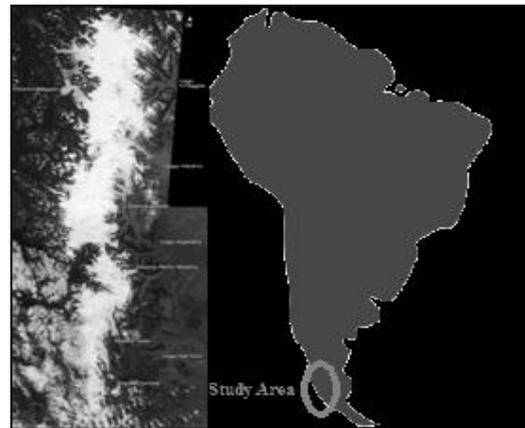


Figure 1. Study area – Mosaic of two digital photographs of Southern Patagonia Icefield.

Currently, most studies are conducted for specific glaciers, for example as the Moreno glacier (ANIYA, 1992(1); ROTT, 1998; STUEFER, 1999), Upsala (ANIYA, 1992 (1); SKVARCA, 1995), Bruggen (IWATA, 1983;

RIVERA, 1999), Tyndall (CASASSA, 1992; RAYMOND, 2005) and O'higgins (KRIMMEL 1988).

Estimates indicate that Southern Patagonia Icefield will reduce of  $38,7 \pm 4,4 \text{ km}^3/\text{year}$  between the years 1975-2000, suggesting an acceleration rate of melting quite high. The Intergovernmental Panel on Climate Changes (2007) showed that the losses accumulated since 1960 in Patagonia are approximately 40m ice thickness, calculated over the glacier (LEMKE *et al.*, 2007). This study aims to calculate the surface area of the main glaciers of Southern Patagonia Icefield through the digitalization of Landsat 7 ETM+ images obtained in the years 1973, 1976, 1979, 1986, 2005 and 2009.

## 2. DATA AND METHODOLOGY

The Southern Patagonia Icefield limited by coordinates to  $74^{\circ}10' - 73^{\circ}30' \text{ W}$  and  $48^{\circ}20' - 51^{\circ}30' \text{ S}$  is approximately 60km wide, 350km in length and a total area of  $13.000 \text{ km}^2$ . The glaciers studied were selected based on size, location and the existence of past studies to compare the results. The digitization and classification was done from a database of 24 images of the ETM + sensor aboard the Landsat 7 satellite, with a spatial resolution of 30m and georeferenced in WGS84 datum obtained in the years 1973, 1976, 1986, 2005 and 2009. The images were acquired in the virtual portals of United States Geological Survey (USGS) and National Institute for Space Research (INPE).

The methodology was developed with help of software ENVI 4.5 © 2008 and CartaLinx 1.2 © 1999 where Landsat images were calibrated to radiance and reflectance for a global standardization method. The calibration procedures employed in this study were used according to Chander and Markham (2003).

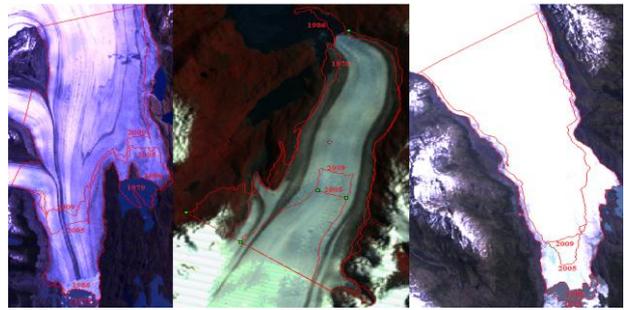


Figure 2. Linhas de variação na posição da língua das Geleiras Upsala, Jorge Montt e Tyndall. Geradas a partir de imagens Landsat 7 ETM+ para os de 1973-1976-1979-1986-2005-2009.

The digitization of each glacier was made in order to obtain the limiting position of the tongue (Figures 2 and 3), where each image was classified individually to avoid overlapping the range of pixels. Areas composed of multiple regions and pixel border between snow and sediment were excluded to avoid overlapping values and false classifications. Been generated lines of advance indicating the ceiling for each glacier for the period analyzed. Researchers such as Warren & Sugden (1993) and Aniya *et al.* (1992, 1996) showed that the main glaciers of Southern Patagonia Icefield presented until the beginning of the decade 90 a general pattern of decline and reduced its volume, with exception of some glaciers showed a profile of frontal accretion and growth.

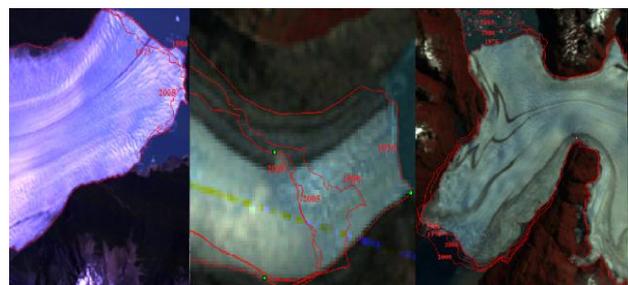


Figure 3. Linhas de variação na posição da língua das Geleiras Moreno, O'Higgins e Bruggen. Geradas a partir de imagens Landsat 7 ETM+ para os de 1976-1979-1986-2005-2009.

Jorge Montt Glacier: Located within a fjord on the northern edge of the Southern Patagonia Icefield has the drainage flow to the north

ending northwest at coordinates 48°18'S and 73°27'W. With an area of 602km<sup>2</sup> in 1976 lost 63km<sup>2</sup> of total ice surface in the period 1976 - 1986 reaching 555km<sup>2</sup>. The data obtained from the Landsat image of 2005 show a dramatic reduction in the volume of the glacier after a decrease of 10.060m reached a surface area of 198km<sup>2</sup>. Image data from 2009 show that an increase of 8km<sup>2</sup> ice surface area increased the total area of the glacier to 206km<sup>2</sup>, due primarily to an advance of the tongue of 1,3km.

**Brüggen Glacier:** It is the only studied glacier on the west side of the Southern Patagonia Icefield and is among the highest volume glaciers. Located at 49°10'S – 75°53'W has its terminal part forked north toward the lake Greve and south to the Eyre fjord. In recent decades, it has shown a very unusual behavior compared to other glaciers in the Southern Patagonia Icefield, opposed the others it has increased its area with a steady growth of the tongue through the years. With an area of approximately 1.604km<sup>2</sup> in 1976 was increased its total area to 1.653km<sup>2</sup> after a breakthrough of 800m in image 1986. The data show that the tongue North increased 21km<sup>2</sup> in the period 1976-1986 while the tongue area south maintained your area stable. The image of 2005 shows a decrease in the glacier total area of 148km<sup>2</sup>, but the tongue north continued to grow about 550m. The pattern of growth recorded by other authors in the images obtained in 2009 the glacier increased its 130km<sup>2</sup> in total area compared to 2005. Adding in the period 1986-2009 a total advance of approximately 18km<sup>2</sup>.

**O'Higgins Glacier:** Located in upper side of the ice field at coordinates 48°54'S and 73°12'W, ends in an arm of Lake O'Higgins, who on the Argentine side is known as Lake St. Martin. This glacier has shown a very large number of recessions between 1945 and 1986, with a

total of 13,4km (327m/year) this value was considered exceptionally large in Patagonia, including the glaciers of the Northern Patagonia Icefield (ANIYA, 1988). With a total area of 440km<sup>2</sup> in 1976 it had its area decreased to 376,9km<sup>2</sup> after a decline to 1.460m and a loss of 63,1km<sup>2</sup> in 1986. With lower indices of decline since the decade of 90 the glacier has reduced its total area to 347km<sup>2</sup> in 2005, reaching 329,2km<sup>2</sup> in 2009.

**Upsala Glacier:** Considered one of the largest glaciers in South America, Upsala is located on the east side of the ice field in the coordinates 49°51'S and 73°16'W. It had retreated constantly until the decade of 60 (ANIYA, 1992), passing at a decline rate of decline of 2.300m (135m/year) during the period from 1969 to 1986, measured near the center of the glacier. Values obtained for the glacier in this study showed a surface area for the year 1979 of 1.596km<sup>2</sup> and 1.447,4km<sup>2</sup> in 1986, declining approximately 2.100m and a lost area of 148,6km<sup>2</sup> area in the period 1979-1986. Between the years 1986 and 2005 the loss was 377km<sup>2</sup> on the surface, to come in 2009 with a total area of 917,4km<sup>2</sup>, reducing approximately 530km<sup>2</sup> in the period 1986-2009.

**Moreno Glacier:** Moreno is located in the lower east side of the Southern Patagonia Icefield in 50°29'S and 73°06'W, has its forked tongue to the north and east flowing toward an arm of Lake Argentino. Among the studied glaciers Moreno was the one with the lowest levels of area variation and tongue movement. Data obtained from Landsat image shows that to the glacier were about 538km<sup>2</sup> area in 1979, with an increase of approximately 480m of the glacier tongue the total area was increased to 557km<sup>2</sup> in 1986. Since the decade of 90 to the glacier began to show a retraction process very expressive, with practically stable behavior in 20 years. The values obtained

for the total area of glacier were 513km<sup>2</sup> in 2005 and 507km<sup>2</sup> in 2009. This type of behavior less intense shows that for understanding the

dynamics of the glacier we need annual data and field studies, in order to know the real evolution of the glacier along time.

Tyndall Glacier: Is the glacier studied more to the south of the Southern Patagonia Icefield with approximately 40km in length, flows into the lake pro-glacial Geikie originated from it. Located in the coordinates 51°12'S - 73°18'W and is adjacent to the famous mountain of Paine. In 1973 the glacier had a total surface area of 507km<sup>2</sup> that after a decline of approximately 750m had its area reduced to 449km<sup>2</sup> in 1986 and since then has suffered intense retreats of the tongue and reduction of the glacier total volume. Data from 2005 show a surface area of 380km<sup>2</sup> in a decrease of approximately approximately 1.300m of tongue in relation to 1986. For the year 2009 images showed a further retraction to 2.650m in relation to 1986 and a nice-covered area of 363km<sup>2</sup>.

### 3. RESULTS AND CONCLUSIONS

Variations in the front area of the glaciers are important not only for the calculation of area, flow and speed, but in order to gain knowledge about the behavior of ice masses. The data in Table 1 show a evident tendency of retreated the glaciers from the first images. The exception Bruggen glacier that during the study period showed a growth profile in the region of discharge and body of the glacier. Upsala and Jorge Montt glaciers obtained the greatest loss of mass, with very accelerated process of retraction from the 90's. Jorge Montt is glacier studied with more troubling levels of retraction and volume loss, reaching approximately 50km<sup>2</sup>/year of ice area lost. The Moreno glacier

showed during the century alternations of frequent advances and retreats, with a behavior considered stable in your area during the years analyzed.

Glacier	Area lost (km <sup>2</sup> )				
	1973-1986	1976-1986	1979-1986	1986-2005	2005-2009
Jorge Montt	X	63km <sup>2</sup>	X	357km <sup>2</sup>	(-) 8km <sup>2</sup>
Bruggen	X	(-) 49km <sup>2</sup>	X	148km <sup>2</sup>	(-) 130km <sup>2</sup>
O'Higgins	X	63,1km <sup>2</sup>	X	29,9km <sup>2</sup>	47,7km <sup>2</sup>
Moreno	X	X	(-) 19km <sup>2</sup>	44km <sup>2</sup>	6km <sup>2</sup>
Upsala	X	X	148,6km <sup>2</sup>	377km <sup>2</sup>	153km <sup>2</sup>
Tyndall	58km <sup>2</sup>	X	X	69km <sup>2</sup>	17km <sup>2</sup>

Table 1. Loss of frontal area of the glaciers due to retreat - 1973-2009.

Studying the conduct of Patagonian ice masses we must consider that obtaining field data and climatology in this region are very difficult, especially because it is a sparsely populated region with a limited number of meteorological stations and terrain complex. The values of retraction of glaciers indicate that the Southern Patagonia Icefield can be responding to climate change so quickly and intensely. Data of the Chilean Meteorological Office show that there was a significant increase in temperature in the region throughout the year, from 1986 until today. According Aniya (1992) the Patagonian glaciers are supposed to respond quickly to climatic changes, because they are characterized by a large mass balance, that is, large amounts of accumulation and ablation, and since the change in air temperature affects the snout area more quickly, it seems that these climatic trends would explain some glaciers' behaviors; however, naturally, not all of them. This work was elaborate from the analysis of surface area of glaciers, so we need more

detailed studies in order to we be able to conclude that these variations in the body of the glaciers are really caused by global warming. However, it appears that the recent rapid recession is a response to the recent world-wide warming trend.

#### 4. ACKNOWLEDGEMENTS

The authors are grateful to United States Geological Survey (USGS) and National Institute for Space Research (INPE) by images.

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