# Recent variations of some outlet glaciers of the Southern Patagonia Icefield, South America, using ALOS and Landsat data

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***Abstract***

Applying 2006-2007 ALOS PRISM data to some major glaciers of the Hielo Patagónico Sur (Southern Patagonia Icefield), recent glacier variations were elucidated by comparing with 2001 Landsat 5 TM data. Seven major glaciers (Jorge Montt, O'Higgins, Pío XI, Viedma, Upsala, Perito Moreno, and Tyndall-all calving) were studied. Included are two exceptional glaciers of the Patagonia Icefield, Pío XI and Perito Moreno, which have been advancing and stagnant, respectively since 1945. We found out that the variation trend of the each glacier in the past continued for 2001-2007. Glaciar Pío XI gained area by advance, and Glaciar Perito Moreno also gained area; but the amount is within the range of the past fluctuation, thus stagnant. The rest retreated more or less, but the retreat rate considerably diminished at Jorge Montt, O'Higgins, Viedma and Tyndall. Glaciar Upsala continued to retreat fast, but its rate also has slowed down compared with those during the 1980s and 1990s. Slowing down of the retreat rate may be attributed to the snout position nearing the end of the lake, at some glaciers.

## 1. INTRODUCTION

The Patagonia Icefield (Hielo Patagónico) is located at the southern end of South America, between 46˚30' and 51˚30'S along 73˚30'W (Fig. 1). It stretches about 350 km N-S, with a total area of 17,200 km$^2$ and widths ranging from some 8 km to 50 km. It comprises Hielo Patagónico Norte (HPN, or Northern Patagonia Icefield) and Hielo Patagónico Sur (HPS, or Southern Patagonia Icefield). The HPN has 28 outlet glaciers with a total area of 4200 km$^2$ [1], and the HPS has some 48 outlet glaciers with a total area of 13,000 km$^2$ [2].

Aniya has been conducting fieldwork in Patagonia many times since 1983. His works include a glacier inventory of the HPN [1] and the HPS [2], and glacier variations since 1945 using aerial photographs, Landsat MSS and TM, SPOT, JERS-1 (SAR), RADARSAT and aerial surveys [3], [4], [5], [6].

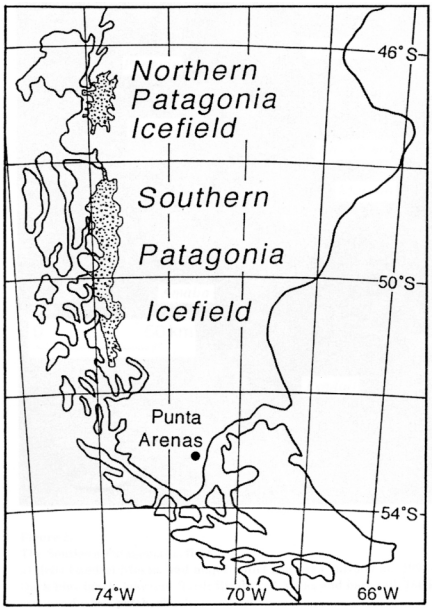


*Fig. 1. Location of Patagonia Icefield, South America*

Based on these experiences and scientific results, we initially proposed the following objectives using ALOS data; (1) to study glacier mass balance and dynamics using DEMs generated with PRISM data; (2) to elucidate variations of major outlet glaciers using AVNIR-2 and PALSAR data; and (3) to detect the glacier surface conditions by PALSAR data.

Among these objectives, the current study was aimed to elucidate recent variations of some major outlet glaciers of the HPS (Fig. 2), based upon the ALOS data available for Patagonian glaciers. These glaciers include Jorge Montt, O'Higgins, Pío XI, Viedma, Upsala, Perito Moreno and Tyndall glaciers, all of which except for Pío XI are calving in freshwater.

## 2. DATA AND METHOD

Because PRISM data were available mainly for some outlet glaciers of the HPS, we concentrated on the glacier variation study using PRISM taken in 2006 or 2007 and Landsat 5 TM of March 2001 data. Thus the time span of the variation in this study is seven years, more or less.

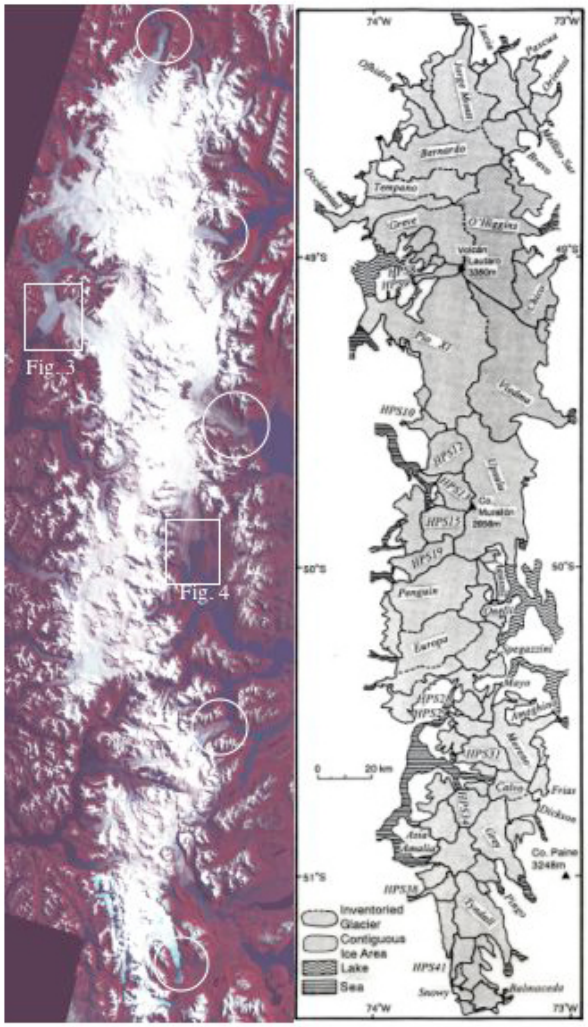


*Fig. 2. Landsat 5 TM 2001 (March 12) Mosaic of HPS and Inventory map [2]. Studied glaciers are indicated by circles and rectangles.*

The nadir image of PRISM was geometrically corrected with image to image registration to the 1986 Landsat data within the accuracy of one pixel, which has been corrected using 1:250,000 maps published by Chilean Instituto Geográfico Militar, and resampled for 30-m pixels. Then, we superimposed it with the 2001 Landsat 5 TM that was also corrected using 1986 Landsat data. We delineated the difference at the snout area by hand with visual interpretations, because automated delineation of the snout of calving glaciers tends to be problematic in Patagonia due to extensive calving and consequent icebergs. Although the pixel size of the PRIMS data is 2.5 m, we could not take advantage of such fine resolution because of the fuzzy nature of the front delineations, as well as superimposing with the 30-m Landsat image. We discussed the results in conjunction with previous studies in order to elucidate the long-term trend, which is very important for discussing the effect of global warming.

## 3. RESULTS AND DISCUSSION

### 3.1 Glaciar Jorge Montt

This is located at the northernmost end of the HPS, with an area of 464 km$^2$ [2]. The variation between 2001 and 2006 was about 940 m retreat with a loss of 1.6 km$^2$. Since 1945, the notable change at this glacier was the loss of large area at the left side [7], which amounted to 4.2 km$^2$ by 1986 [3]. After that the glacier body is confined in a fjord. Calving appears very active and often the fjord is choked with a dense pack of icebergs, which makes automated delineation of the snout very difficult. The glacier retreated at an average rate of 53 m/yr between 1945 and 1986. Then a fast retreat commenced with 296 m/yr for 1986-1998, and 333 m/y for 1998-2001 [8]. Therefore the ALOS data revealed that the fast retreat stopped for the moment.

### 3.2 Glaciar Pío XI

This is the largest glacier in South America with an area of 1265 km$^2$ [2]. Among more than 70 outlet glaciers in Patagonia, this glacier is only one that has shown strong advances since the1940s, when all other glaciers except for Glaciar Perito Moreno have shown a retreat [7]. For example, between 1945 and 1976, it advanced about 9 km (290 m/yr), thereby blocking a fjord and splitting the snout into two, north and south snouts.


*Fig. 3. Glaciar Pío XI, the largest glacier in South America. North snout retreated, while south snout advanced.*

After splitting, the behaviors of the two snouts between 1976 and 1986 were different, i.e. the north snout advanced 1200 m (120 m/yr), while the south snout retreated a maximum of 600 m (60 m). From

1986 to 1997, the north snout advanced about 950 m, gaining an area of 3.68 $km^2$ [4]. The south snout retreated a maximum of 650 m at the center part; however, it gained an area of 0.70 $km^2$ in net due to advances of the glacier margins. Superimposition of 2001 Landsat data and PRISM data revealed that the north snout retreated by 0.73 $km^2$, while the south snout advanced greatly, thereby gaining an area of 2.55 $km^2$ (Fig. 3).

### 3.3 Glaciar O'Higgins

This is the fourth largest glacier in South America with an area of 810 $km^2$ [2]. Between 2001 and 2007, it lost an area of about 0.44 $km^2$, which is very small compared to the previous variation. From 1945 to 1986, it retreated about 14 km (484 m/yr), by far the largest in Patagonia, with an area loss of 50 $km^2$ (1.21 $km^2$/yr) [7]. Then, it stagnated between 1986 and 1995 [9]. This was quite a contrast to Glaciar Pío XI that is located near the same latitude but on the opposite side of the icefield (see Fig. 2) and has shown strong advances during the same period. We do know the reason for this contrast. The slow retreat since 1995 may be attributed to the fact that the snout has come near the end of the lake.

### 3.4 Glaciar Viedma

This is the second largest in South America with an area of 945 $km^2$ and the longest with a length of 71 km [2]. It retreated very little between 2001 and 2007 with an area loss of about 0.1 $km^2$. The earliest remote sensing data for this glacier is 1968 and until 1981 it retreated very little. Between 1981 and 1991, it retreated about 400 m (40 m/yr) [3]. Since 1993, the position of snout has not changed much [4], probably because the snout is located near the end of the lake. Therefore, the variation between 2001 and 2007 may be just apparent, which was caused by the image acquisition time of Landsat TM data.

### 3.5 Glacier Upsala

This is the third largest glacier in South America with an area of about 902 $km^2$ [2]. The variation between 2001 and 2007 of the main snout is a retreat with 1.1 km, losing an area of 1.4 $km^2$ (Fig. 4). It has a general trend of retreat since 1945, although it advanced about 400 m during the 1970s [10]. A very rapid retreat has commenced in the 1980s when a large-scale calving occurred due to snout disintegration, thereby retreating 1-2 km in one season, and it has been occurring every two or three years to date [11]. Between 1990 and 1993, the surface elevation near the snout then (now ice was gone) was lowered by 40 m, which was by far the largest in the world [12]. Between 1986 and 1997, it lost an area of 6.48 $km^2$ with an average yearly retreat of 250 m. A large collapse was captured with Radarsat data between January and April 1997, revealing a maximum retreat of 2 km with an area loss of 2.71 $km^2$ in just four months ([4]. So the recent rapid recession due to extensive calving has slackened a little. The deepest part of the lake is over 600 m [11].

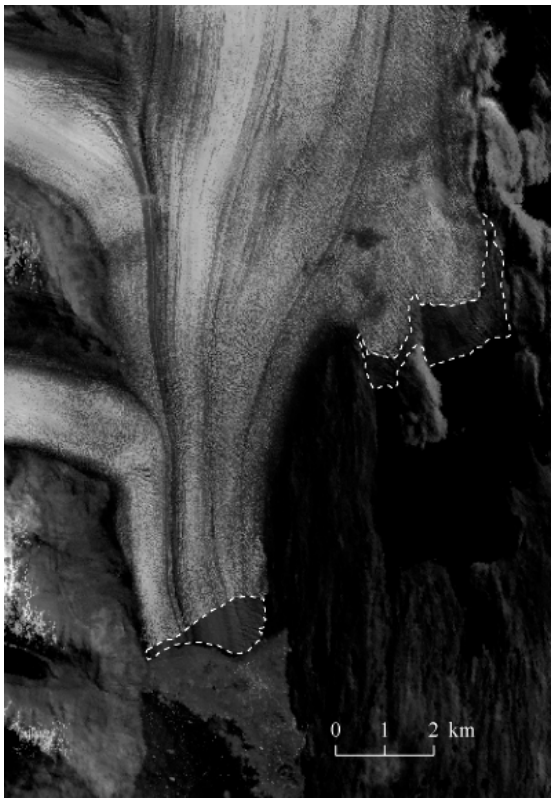


*Fig. 4. Glaciar Upsala: retreats. In 2001 image a pack of icebergs is recognized.*

### 3.6 Glaciar Perito Moreno

With the area of 257 $km^2$, this is one of the two exceptional glaciers in Patagonia, along with Glacier Pío XI, because it has stagnated during the 20$^{th}$ century after it advanced to the present position around 1917 [13]. Since then the glacier has been more or less stable, especially after 1945 [10]. This glacier is also noted for repeated damming-up of the lake to the south (Brazo Rico) and subsequent rapture by advancing and reaching the opposite bank [13]. The most recent damming-up and rapture occurred in March 2004 [14]. So although the ALOS data showed that the southern part of the glacier advanced, thereby gaining an area of 0.4 $km^2$ since 2001, this amount of the change is within the range of the past fluctuations [10].

### 3.7 Glaciar Tyndall

This is located near the southern end of the HPS. Between 2001 and 2007, it retreated 530 m with an

area loss of about 2 km$^2$. The glacier narrowed considerably at the right margin due to surface lowering. Its area is 333 km$^2$ [2]. This glacier has been fairly steadily retreating since 1945 until 1986, with an average of 83 m/yr [3]. After 1986, the left side of the glacier started retreating fast, thereby losing an area of 3.44 km$^2$, compared to 1.03 km$^2$ of the center part, to 1997 [4].

## 4. SUMMARY

Seven major calving glaciers of the HPS that were studied for the 2001-2007 variations were found to have continued the variation trend of the past 10-20 years, as you can see in Fig. 5 that shows the variation since 1945 [4]. Pío XI advanced in net (gain of area) and Perito Moreno was stable, while the rest, Jorge Montt, O'Higgins, Viedma, Upsala and Tyndall retreated. At Glaciar Pío XI, although the net area change was gain, north snout was a slight retreat, while the south made a strong advance. In general, the retreat rates were slowed down, one of the causes of which may be the snout position getting near the end of the lake, at some glaciers.

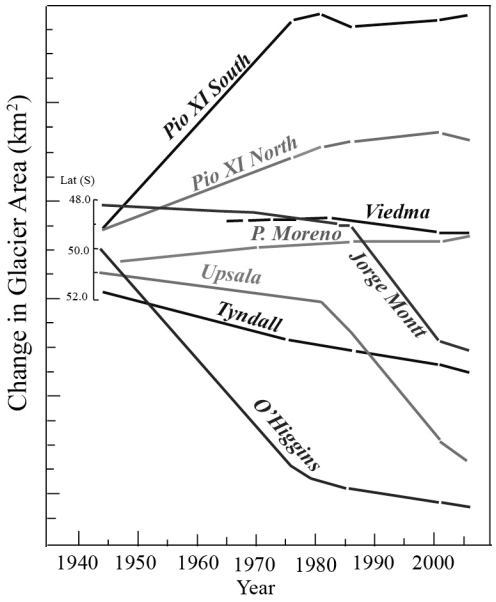


*Fig. 5. The summary of variations since 1945. The results of the present study were added to the previous study [4].*

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