Recent climate-fluctuations in Patagonia

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Abstract. Precipitation and temperature data taken at the Chilean stations were analyzed to show the characteristics and year-to-year fluctuations of the climate of Patagonia. As a result, great-year-to-year fluctuations of monthly mean temperature were revealed in summer (January) and winter (July), although the regular seasonal change was not striking. Precipitation shows less seasonal variation. A Patagonia Precipitation Index (PPI) which shows the fluctuation of precipitation in this region is derived. The PPI was applied to analyze the precipitation in a mountainous region, where topography influences on the distribution of precipitation. The PPI in summer shows a high negative correlation with summer temperature; the correlation coefficient is −0.87. Correlated fluctuations of precipitation and temperature are considered to make the environment suitable for glacier existence. The correlation analysis between PPI and 500 mb geopotential height of the weather chart reveals that high PPI is related to strengthened jet stream over Patagonia (in January and July) and the upper air trough extending from the Antarctic Peninsula (in July) influences the variation of precipitation.

1. Introduction

The characteristics of the climate in the Patagonia Icefield area have been studied as fundamental research to study glacial changes. Due to lack of data in the middle to high latitudes area in the southern hemisphere, only few climatological studies have been done on this area (SCHWERDTFEGER, 1956; MILLER, 1981; FUENZALIDA, 1982).

The climate of this region is affected by the jet stream and the polar atmosphere. Studies in the Patagonia region require knowledge of the climatic characteristics of the westerly zone in the southern part of South America. Patagonia is located in a key position in the middle latitude area. Here, the characteristics of climate in the Patagonia Icefield are described and their relation to the general circulation analyzed.

2. Data set

The results presented in this study have been obtained from three Chilean data sets and supplemented for the upper air by an Australian data set. Specifically, these four data sets are of the Chilean Air Force data set (DS-1), the Chilean Meteorological Service data set (DS-2), the National Electric Company (Chile) data set (DS-3; Precipitaciones Mensuales Respectivas), and the Australian Meteorological Service data set (DS-4; Southern Hemisphere Grid Point Data). One of the Chilean Air Force meteorological stations is located about 3 km north of San Rafael Glacier (see MAP 2 in front page). DS-1 taken at this station was used for daily weather data around San Rafael Glacier. The National Electric

Company has about 20 meteorological stations near the Patagonia Northern Icefield (DS-2). Temperature data taken at a meteorological station in Puerto Aisen about 200 km north of the Northern Icefield were used as long term temperature data in the Northern Icefield region (DS-3). The DS-2 and DS-3 are available for analyzing year-to-year fluctuations of monthly mean temperature and monthly precipitation. The DS-3 gives the preciptation around the Patagonia Icefield. The DS-4 was used for a correlation analysis between the fluctuation of precipitation in Patagonia and the 500 mb geopotential height over Patagonia.

3. Weather around the Northern Icefield

3.1. Precipitation

The climate of the Patagonia Icefield is characterized by high precipitation and relatively warm temperature. Figure 1 shows the daily amount (solid line) and the monthly amount (dashed line) of precipitation in 1983 using the DS-1. The annual precipitation and number of

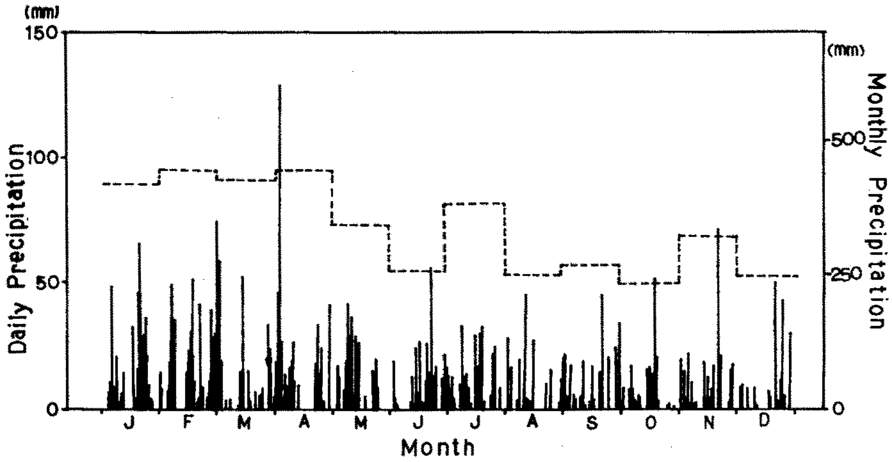


Fig. 1. The daily amount (solid line) and monthly amount (dashed line) of precipitation in 1983 at the Chilean Air Force meteorological station near San Rafael Glacier.

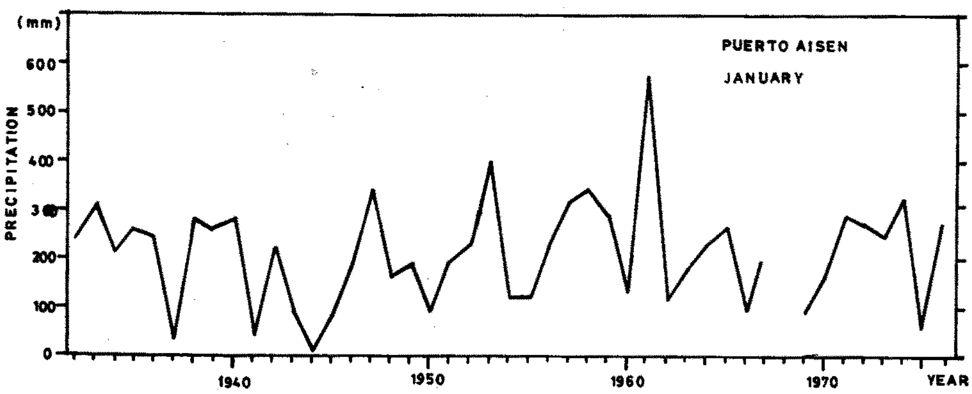


Fig. 2. Year-to-year fluctuation of January precipitation at Puerto Aisen, 1932–1976.

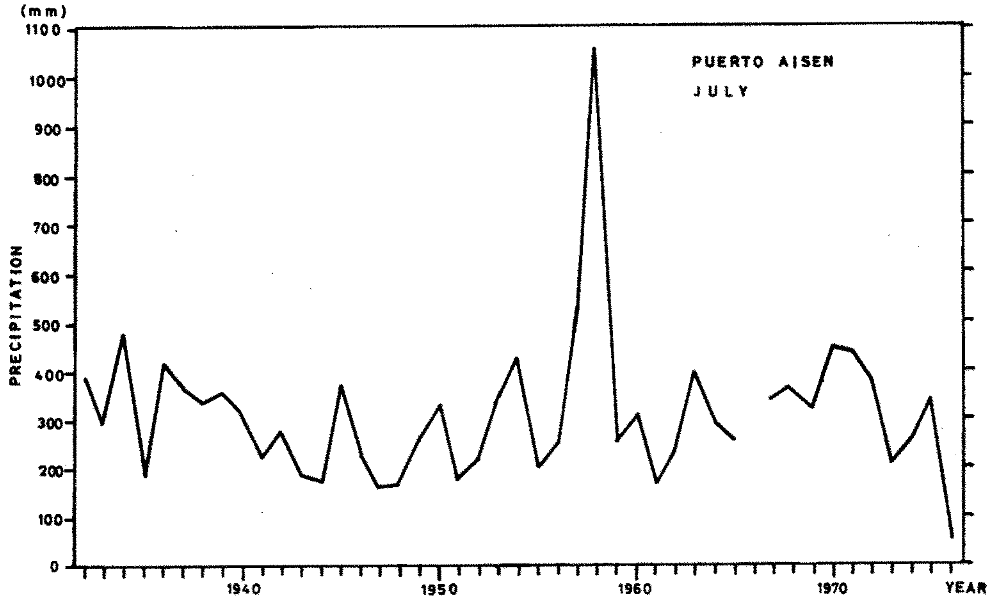


Fig. 3. Year-to-year fluctuation of July precipitation at Puerto Aisen, 1932–1976.

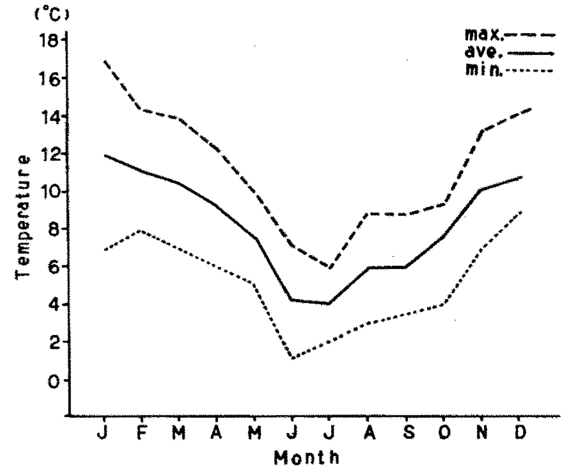


Fig. 4. Monthly mean temperature of 1983 observed at the Chilean Air Force meteorological station near San Rafael Glacier (solid line). The dashed line and dotted line show the monthly mean of daily maximum and daily minimum temperatures, respectively.

days with precipitation in 1983 were 4095.2 mm and 266 days, respectively. Precipitation does not show a regular seasonal change. The year-to-year fluctuations of precipitation in summer (January) and winter (July) at Puerto Aisen are also shown in Figures 2 and 3 using the DS-3.

3.2. Air temperature

Figure 4 shows the monthly mean temperature in 1983 at the Chilean Air Force meteorological station near San Rafael Glacier (DS-1). Figure 5 and 6 show the year-to-year fluctua-

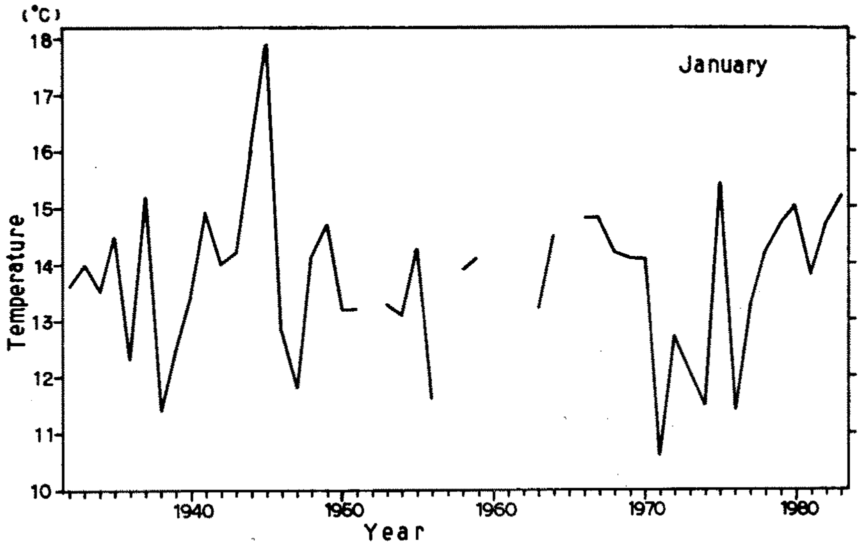


Fig. 5. Year-to-year fluctuation of monthly mean January temperature at Puerto Aisen, 1932–1983.

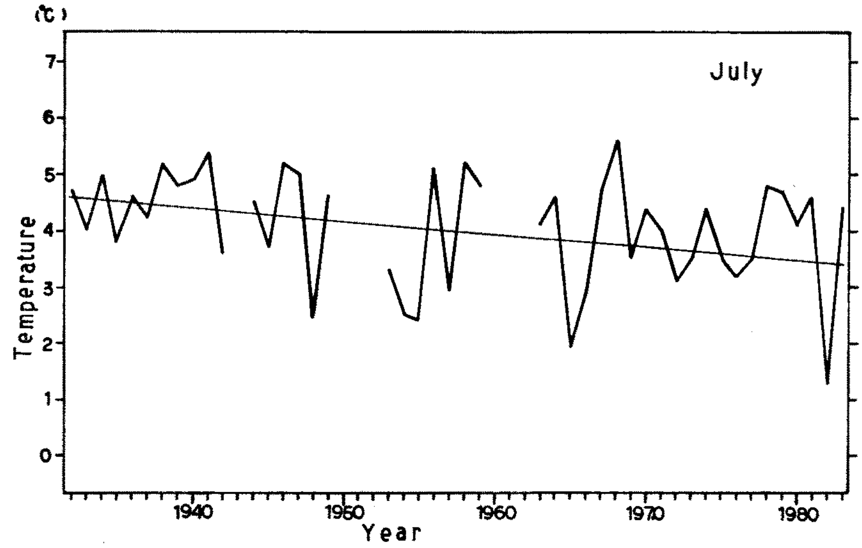


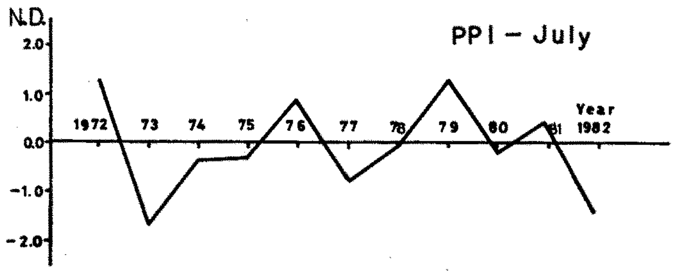
Fig. 6. Year-to-year fluctuation of monthly mean July temperature at Puerto Aisen, 1932–1983.

tions of summer (January) and winter (July) temperatures at Puerto Aisen. Although seasonal temperature variation is small owing to the influence of the sea (Fig. 4), the year-to-year fluctuations of summer (January) and winter (July) air temperatures are large as seen in the Puerto Aisen data (Figs. 5 and 6). A slight decreasing tendency is revealed in winter temperatures (Fig. 6), but summer temperatures do not show any such tendency. Year-to-year fluctuations of summer temperatures in Puerto Aisen and summer precipitations in Patagonia show a high negative correlation.

4. Patagonia Precipitation Index (PPI)

The topography of the region induces the spatial variation of precipitation. Especially in the mountainous region, its influence is remarkable owing to the direction of the mountain slope where the station is situated and by affecting the seasonal change of cloud movement and wind dierection. While the spatial variation of precipitation is caused by the topographical effect, the fluctuation of precipitation is caused by the variation of large-scale atmospheric phenomena. In order to evaluate the fluctuation of precipitation amount in relation to the large scale atmospheric circulation, the topographic effect must be minimized. For this purpose, one index (Patagonia Precipitation Index, PPI) is derived for summer (January) and winter (July), comparing data from 17 stations distributed around the Northern Icefield in the following manner using the DS-3. In the first step, stations having high correlations with each other were selected as groups; as a result, eight stations were selected for summer (January) and seven stations for winter (July). Then the mean value over an 11-year period was calculated at each station, and precipitation anomalies defined as deviations from the mean values which were normalized using the standard deviation were obtained at each station. Finally, the PPI was computed as the average precipitation anomalies of all selected stations. Anomalies of eight stations were averaged for the summer PPI and anomalies of seven stations are averaged for the winter PPI.

The PPI shows the fluctuation of precipitation in the Northern Icefield in recent years (Fig. 7). Although a station in the interior area of the icefield is not included, this PPI fluctuation can probably be applied to the fluctuation of precipitation in the Northern Icefield interior.



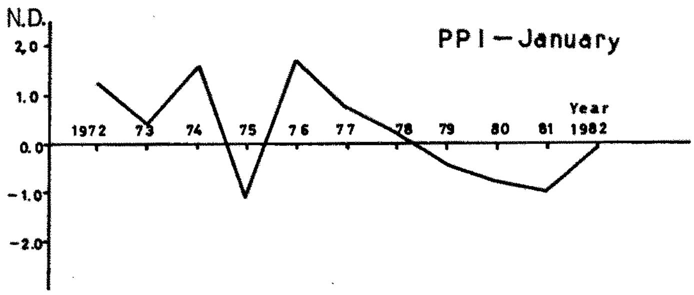


Fig. 7. Year-to-year fluctuations of the Patagonia Precipitation Index (PPI) for 1972–1982. PPI of January were computed from data of 8 selected stations, PPI of July were also computed using the data of 7 selected stations.

5. PPI and atmospheric circulation over Patagonia

The PPI was related to the large scale atmospheric circulation. Then the correlations between the PPI and monthly mean 500 mb geopotential height (DS-4) were derived (Figs. 8 and 9). Monthly mean 500 mb geopotential height is a good indication of the general circulation and of the areas where cyclones originate, strengthen, and weaken. Here, the negative correlation indicates that the 500 mb geopotential height is lower than normal when a large amount of precipitation occurs in the Northern Icefield area.

Figure 8 shows the area with negative correlation extending from the Antarctic Peninsula to Patagonia in winter (July), which corresponds to the upper trough. This pattern indicates that the upper air flow has a meridional component in high latitudes; polar cold air flows into the southern part of South America. This area of negative correlation in higher latitudes contrasts with the area with positive correlation around 40°S. This contrast means that the meridional gradient of the 500 mb geopotential height increases, resulting in a strengthened jet stream in the upper air over Patagonia.

Figure 9 (January) shows that the jet stream shifts southward in summer compared with winter (July) position. A large amount of summer precipitation occurs in the Northern Icefield when the jet stream has also strengthened in higher latitudes in summer.

6. Discussion

The fluctuations of precipitation and temperature in the Patagonia Icefield region is described in this study. Also, a method to study the fluctuation of precipitation is applied in

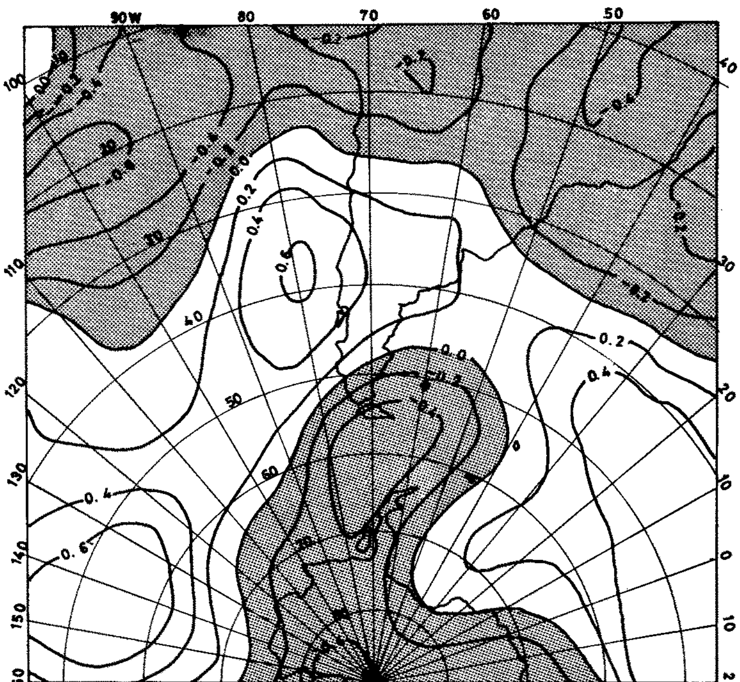


Fig. 8. Distribution of correlation coefficients between the PPI and monthly mean 500 mb pressure height in the South America sector of the southern hemisphere in July.

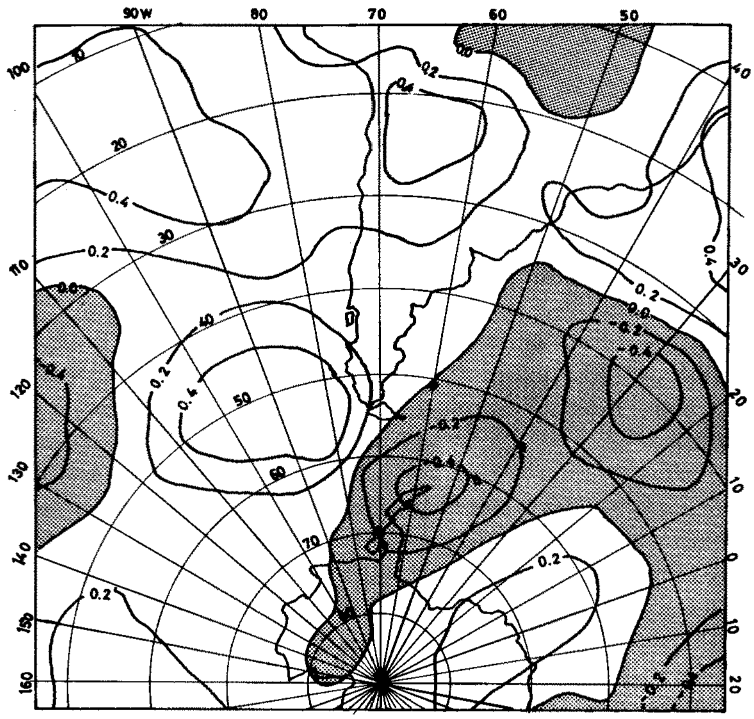


Fig. 9. Distribution of correlation coefficients between the PPI and monthly mean 500 mb pressure height in the South America sector of the southern hemisphere in January.

the Patagonia Icefield where the topography strongly influences it. Here, we will now relate the climatological condition to the mass balance of the glacier.

The precipitation in the Patagonia Icefield is characterized by large amount and low regular seasonal change (Fig. 1). Due to lack of regular seasonal change, it is rather difficult to determine the accumulation season of the glacier in Patagonia.

The year-to-year fluctuations of summer (January) temperature are large (Fig. 5). Since summer temperature predominantly controls ablation of the glacier, its influence on change in the mass balance of the Patagonia Icefield is considered to be great.

Temperature and precipitation are two important elements which control the mass balance of glaciers. As far as Patagonia is concerned, the summer temperature at Puerto Aisen has a high negative correlation with summer precipitation using the PPI. The correlation coefficient is calculated to be −0.87. This high negative correlation means that monthly mean temperature falls as monthly precipitation increases. In case of high monthly precipitation, overcast days increased. This frequent overcast decreases solar radiation resulting in fall of surface temperature. This coupling of precipitation and temperature in summer is considered to have a predominant role in the mass balance of the Patagonia Icefield. In winter (July), the correlation between PPI and temperature is positive but the correlation coefficient is low only 0.40.

At the present, it is difficult to conclude about the relation between glacier mass balance and the climate in Patagonia. However, this relation seems to be regulated by different principles when compared with other glaciated regions, as the climate variation has characteristic features as mentioned above.

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Resumen. Fluctuaciones climáticas recientes en Patagonia

Las características del clima en la zona del Hielo Patagónico se reveló como una investigación fundamental para los cambios glaciales usando datos climatológicos tomados de los alrededores. El clima del Hielo Patagónico se caracteriza por altas precipitaciones con relativament altas temperaturas. Las figuras 1 y 4 muestran la variación diaria de la precipitación y la temperatura media mensual en 1983, respectivamente, en la estación meteorológica de la FACH, situada 3 km al norte del frente del Glaciar San Rafael. La precipitación no muestra una variación estacional regular, sino que está uniformemente distribuída en el año. La variación estacional de temperatura es pequeña sebido a la influencia del mar. Por lo tanto, es mas bien sificil demarcar la estación de acumulación en forma precisa. A pesar que la variación estacional de temperatura es pequeña, año a año las fluctuaciones de precipitaciones y temperaturas de invierno y verano es considerablemente alta, como puede apreciarse en los datos de Puerto Aisén (Figs. 2, 3, 5 and 6). Como la temperatura en verano controla predominantemente la ablación del glaciar, se considera que su influencia en el cambio del balance de masa es importante.

Ciertamente, la topografía de esta región influencia la variación espacial de la precipitación. Para evaluar la fluctuación de la precipitación en esta zona en relación a la circulación atmosférica a gran escala, se deriva el Indice de Precipitación Patagónico (PPI) para Enero y Julio, comparando datos de 17 estaciones distribuídas alrededor del Hielo Patagonico Norte de la siguiente forma. En una primera etapa, se seleccionan en un grupo las estaciones que tienen gran correlación entre sí, y los valores medios en el período de 11 años se calculan en cada estación. Luego se definen las anomalías de precipitación como desviación de los valores medios y son normalizados usando desviaciones estándares en cada estación. Finalmente el PPI se calcula como el promedio de las anomalías de precipitación para todes las estaciones seleccionadas en un grupo. El PPI muestra la fluctuación de la precipitación en la zona del Hielo Norte en años recientes (Fig. 7).

Este índice se relaciona con circulación atmosférica a gran escala. La correlación entre el PPI y la altura de presión atmosférica media mensual de 500 mb ha sido usada para mostar la circulación superior de aire sobre esta zona. Aquí la correlación negativa indica que la altura de 500 mb es inferior a la normal cuando ocurre una precipitación elevada en el Hielo Norte. La figura 8 muestra la zona con correlación negativa, que se extiende desde la Península Antártica a la Patagonia en invierno (Julio), que corresponde al paso superior de frontes. Así, el área con correlación negativa en atlas latitudes contrasta con el area con correlación positiva alrededor de los 40° de latitud sur. Este contraste significa un incremento del gradiente meridional de la altura de 500 mb, que resulta en un jet stream reforzado en las capas superiores de aire sobre Patagonia. La figura 9 revela en verano (Enero), a pesar que la posición del jet stream se mueve hacia el sur con relación al invierno, que occure una precipitación alta en el Hielo Norte cuando el jet stream también ha aumentado.