23 THE PROBABLE IMPACT OF GLOBAL CHANGE ON THE WATER RESOURCES OF PATAGONIA, ARGENTINA

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Abstract

Very little work has been undertaken on the hydrological impact of global warming in South America. In this study, some initial estimates are made using IPCC and Hadley Centre scenarios, supported by an analysis of long-term trends in rainfall patterns. Under the global warming scenarios, we expect a drying trend in the north of Argentina and a wetter climate in the south, accompanied by a reduced meridional temperature gradient. Snowlines are likely to rise, although the overall response of glaciers needs detailed investigation. However, analyses of rainfall records suggest that rainfall has been increasing in the north, contrary to the expected global warming pattern.

23.1. Introduction

Little detailed work has been undertaken on the potential effects of global warming in South America. However, there is natural concern over the likely physical and socio-economic impacts.

The work described in this chapter uses the report of the Intergovernmental Panel on Climate Change (IPCC, 1990) together with the paper by Mitchell and Gregory (1992) as the main bases for prediction. Mitchell and Gregory (1992) developed four scenarios for future emissions of greenhouse gases, which were used to estimate the resulting rate and magnitude of climate change.

Figure 23.1 shows the simulated changes in global mean temperature with 'high', 'best estimate' and 'low climate sensitivities' (4.5, 2.5 and 1.5°C) and in Figure 23.2 we can observe changes of mean global temperature assuming a 'best estimate' climate sensitivity of 2.5°C for the respective 1990 and 1992 scenarios. Using the 'best estimate' climate sensitivity, these scenarios give a range of warming from 1.5°C to 3.5°C for the year 2100 (mean = 2.8°C) and 1.5°C for the year 2050 (IPCC, 1992). The increase in sea level will be 0.20 m and 0.65 m in 2030 and 2100 respectively.

Although these values are the 'official' ones, many authors have given different values for global temperature change. There is even greater difficulty in deriving these values for a regional analysis (Waggoner, 1990).

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With reference to the Southern Hemisphere, several authors (Pittock *et al.*, 1988; Nuñez, 1990; Burgos *et al.*, 1991) applied global circulations models (GCMs), such as GISS, NCAR and others, and have obtained different results. Burgos *et al.* (1991) and Nuñez (1990) found a transition zone about 40°S. The former authors concluded that for the year 2010, to the North the temperature will be increased, the humidity of the air will be lower and the radiation increased because of diminished cloudiness, whereas to the South of this transition zone the air humidity will be greater, the surficial temperature will not change, but the tropospheric temperature will be increased by the heat exchange. For the year 2050, the process will be more intense, but with the same characteristics. Nuñez (1990) predicted very high ΔT values, but then reduced them in line with other researchers.

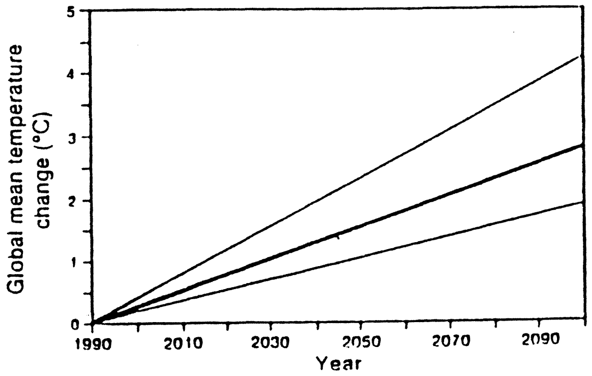


Figure 23.1. Simulated changes in global mean temperature after 1990 due to doubling CO_2 concentrations, assuming high (4.5°C), 'best-estimate' (2.5°C) and low (1.5°C) climate sensivities (IPCC, 1992).

On the other hand, Russian researchers have developed analogue techniques based on the analysis of paleoclimates (Budyko *et al.*, 1994). These results shall be discussed in a later part of this analysis.

Novelli *et al.* (1995) have referred to recent changes in CO_2 concentrations and their implications on global changes. The impact on the climate of the recent changes in CO_2, CH_4 and CO is difficult to predict. The latest measurements of atmospheric concentrations by NOAA/LCDC show that they have begun to increase markedly.

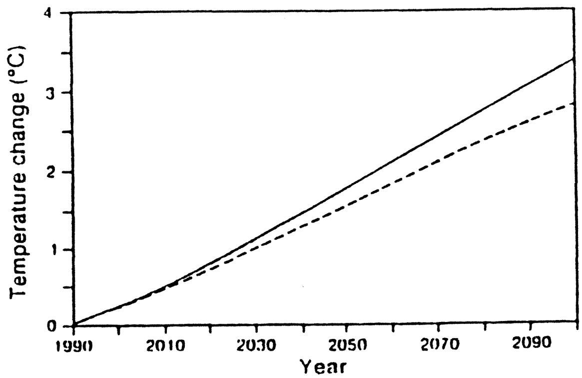


Figure 23.2. Changes of mean global temperature after 1990 assuming a 'best estimate' climate sensitivity of 2.5°C (estimates from IPCC (1992) = dashed curve; from IPCC (1990) = solid curve).

23.2. Present Hydrological and Climatic Characteristics of Patagonia

Patagonia is an arid to semiarid region. It grades westwards into a narrow and wetter climatic region dominated by forests and lakes (Figure 23.3), which is the source area for many of its more important rivers.

It extends approximately between 38°S and 55°S to the south of the Colorado River, and it covers an area of 700 000 km^2. The principal soils, according to the Soil Taxonomy (USDA, 1975) are: aridisols (50-60%), entisols (18%), molisols (10-20%), and alfisols, histosols and inceptisols in smaller percentages (INTA, 1990) (Figure 23.4).

Patagonia's water resources are contained in important rivers that flow from west to east through the Patagonian plateau, and in numerous lakes, glaciers and a huge mass of ice in the South Andes piedmont. Some of these drain to the Atlantic Ocean and others into the Pacific Ocean (Table 23.1) (Ferrari Bono, 1990). The river regimes are characterized by two annual peaks, one caused by snow and rainfall in winter, and the other produced by the snowmelt from the Andes mountain chain in spring, as shown on the Limay River illustrated in Figure 23.5. The most important characteristics of some rivers that we must mention are:

1) the Neuquen and Limay Rivers that form the Negro River, which has the largest discharge (1000 m^3 s^{-1} of mean flow). These two tributaries have the greatest potential for hydroelectric power. They provide almost 1/4 of the total energy installed in Argentina (26 400 GWh/year)

2) the Futaleufu dam provides energy (448 MW) to the Aluar aluminium factory near the shores of the Atlantic Ocean, and the Ameghino dam on the Chubut River feeds 22 000 ha of irrigation area.

3) south of the Andes, the Patagonian Continental Icefield, which is a huge mass of ice extending 280 km long between 47°30'S and 50°50'S.

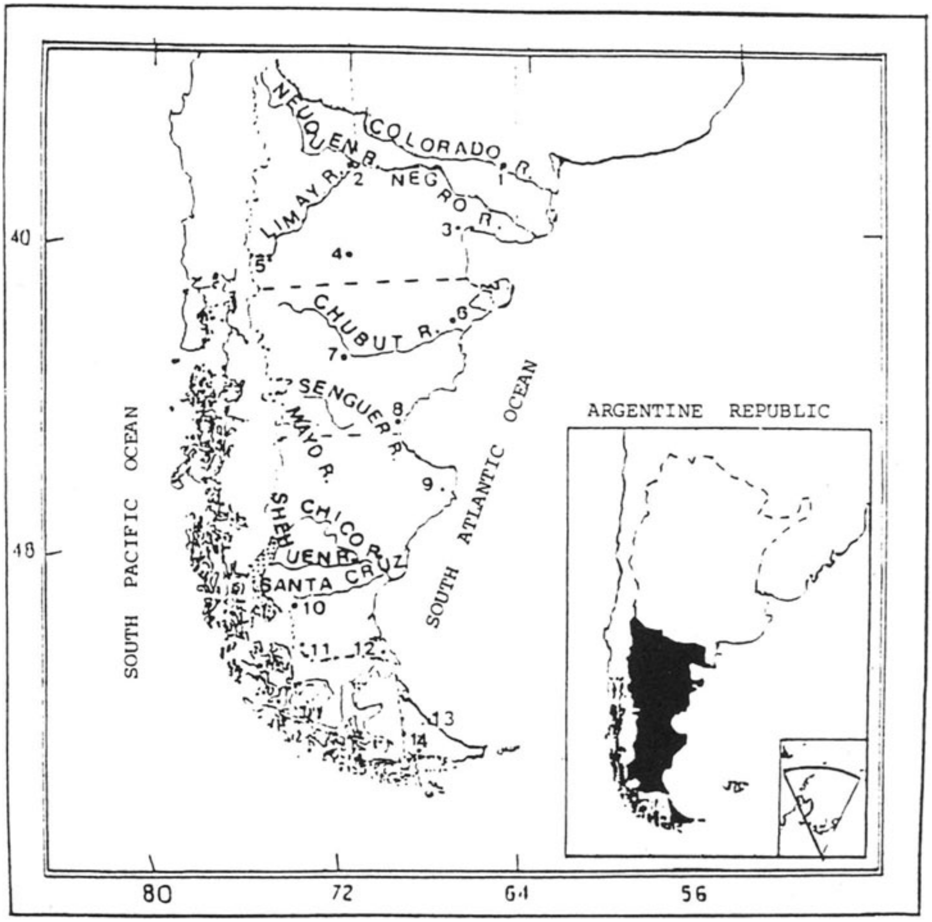


Figure 23.3. Map of Patagonia, with the most important rivers and pluviometric stations.

KEY:

::: Patagonian Continental Icefield

1. Río Colorado
2. Neuquén
3. San Antonio Oeste
4. Maquinchao
5. San Carlos de Bariloche
6. Trelew
7. Paso de los Indios
8. Comodoro Rivadavia
9. Puerto Deseado
10. Lago Argentino
11. Río Turbio
12. Río Gallegos
13. Río Grande
14. Ushuaia

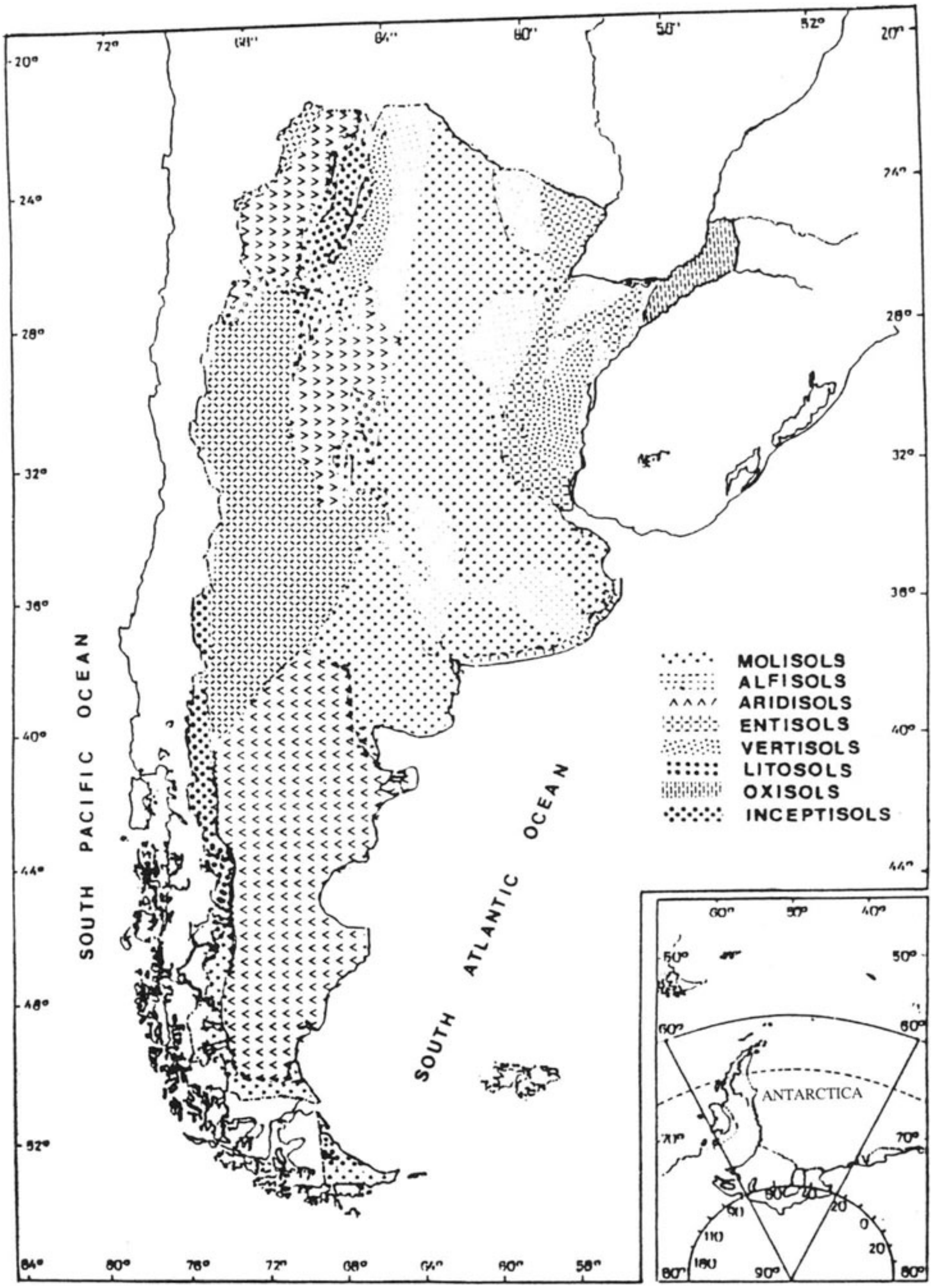


Figure 23.4. Argentine soils taxonomy.

TABLE 23.1. Characteristics of the principal rivers.
(From Ferrari Bono, 1990.)

Rivers	Basin area (km^2)	Mean flow ($m^3\ s^{-1}$)	Length (km)	Generating potential (GWh/year)	Natural lakes	
					Number	km^2
a) Basins with Atlantic drainage						
Colorado	69 000	133	977	3700	3	37
Neuquén	32 450	316	541	5000	15	205
Limay	56 185	733	804	18 600	29	1113
Negro	95 800	1014	635	5666	--	--
Senguer	28 025	50	360	1540	--	--
Chubut	29 400	49	867	1000	--	--
Deseado	14 450	5	615	--	9	48
Sheuen-Chico	16 800	30	2	--	2	74
Santa Cruz	24 510	750	382	6576	13	2632
Coyle	14 600	5	350	--	2	14
Gallegos	5200	15	360	--	22	39
Chico	800	2	75	--	--	--
Mayer	6500	235	250	2600	14	764
b) Basins with Pacific drainage						
They are eleven rivers. One of the principal rivers is:						
Manso	2810	132	70	2500	16	115

The rivers which drain into Atlantic Ocean have a total discharge of 1920 $m^3\ s^{-1}$ and those that flow into Pacific 1240 $m^3\ s^{-1}$; together they represent approximately 3000 $m^3\ s^{-1}$ of surficial resources. Many basins have a water resources potential that are not totally used (Table 23.1). Figure 23.6 shows the principal dams built and projected in the hydroelectric complex of the Neuquen and Limay Rivers (installed power: 2700 MW).

The climate is dominated by position of the Subtropical anticyclones in the Atlantic and Pacific oceans. Figures 23.7a and b show atmospheric pressure at sea level for summer and winter in South America (Schwerdtfeger, 1976). We can deduce that in the summer the thermo-orographic low pressure is intensified over the higher regions in the west of Patagonia (Lichtenstein, 1990) and the South Pacific high pressure centre is situated at 32°S 90°W. In winter, the isobars shift toward a north-south direction; the

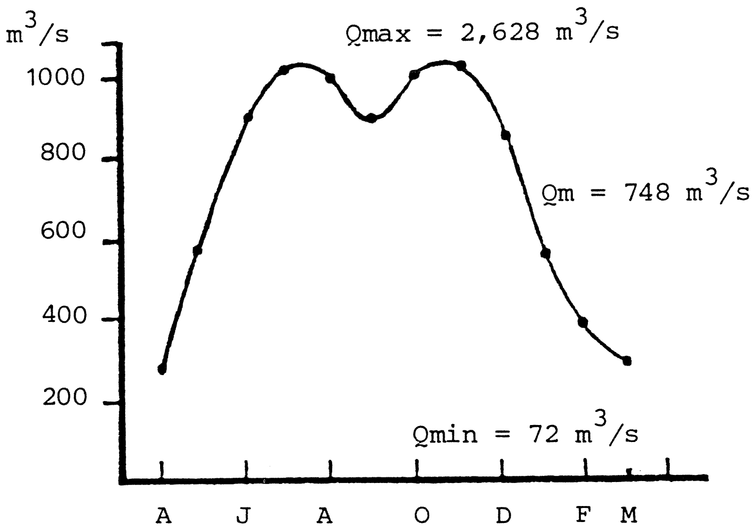


Figure 23.5. Mean annual discharge of the Limay River (1903-1980).

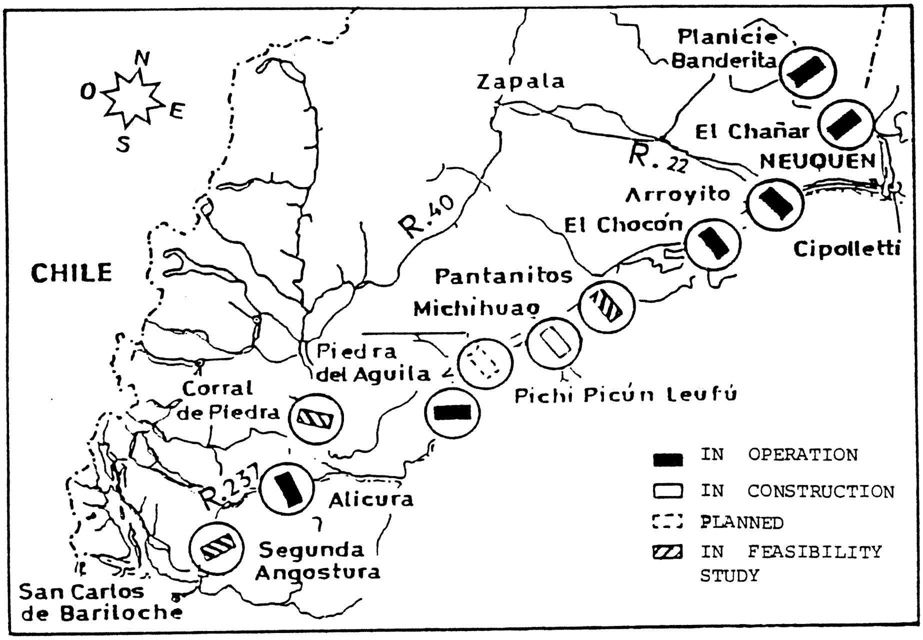


Figure 23.6. Principal dams functioning and planned in the Negro River basin.

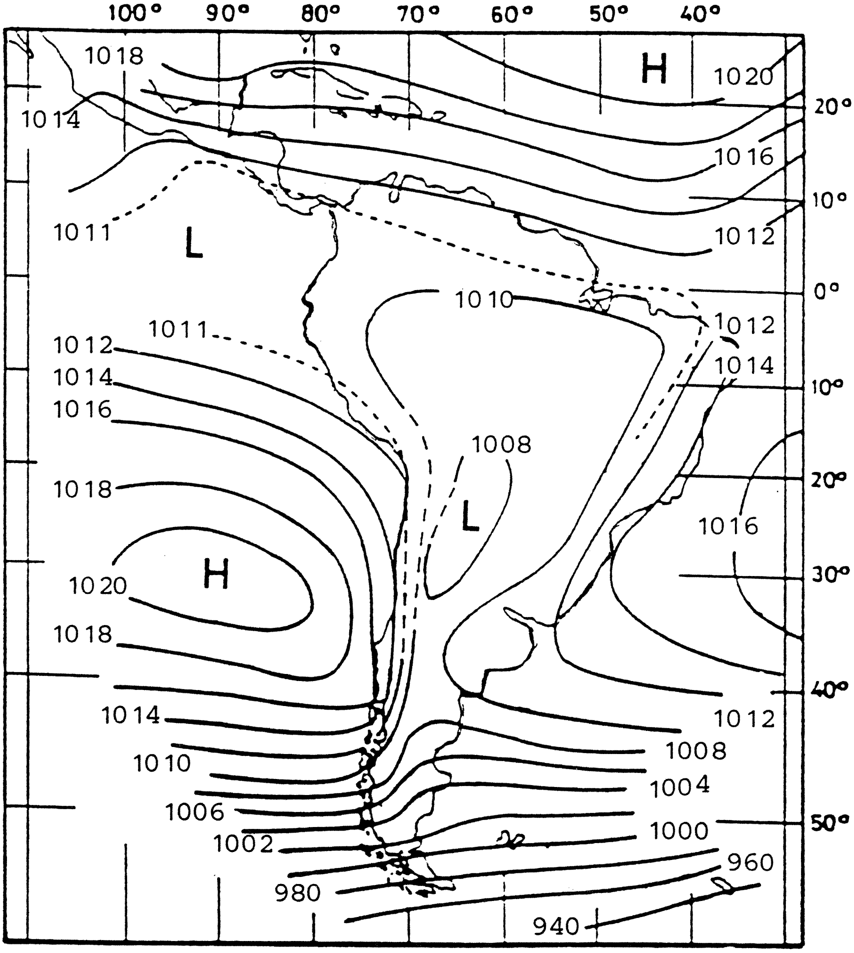


Figure 23.7A. Atmospheric pressure at sea level in South America during the summer.

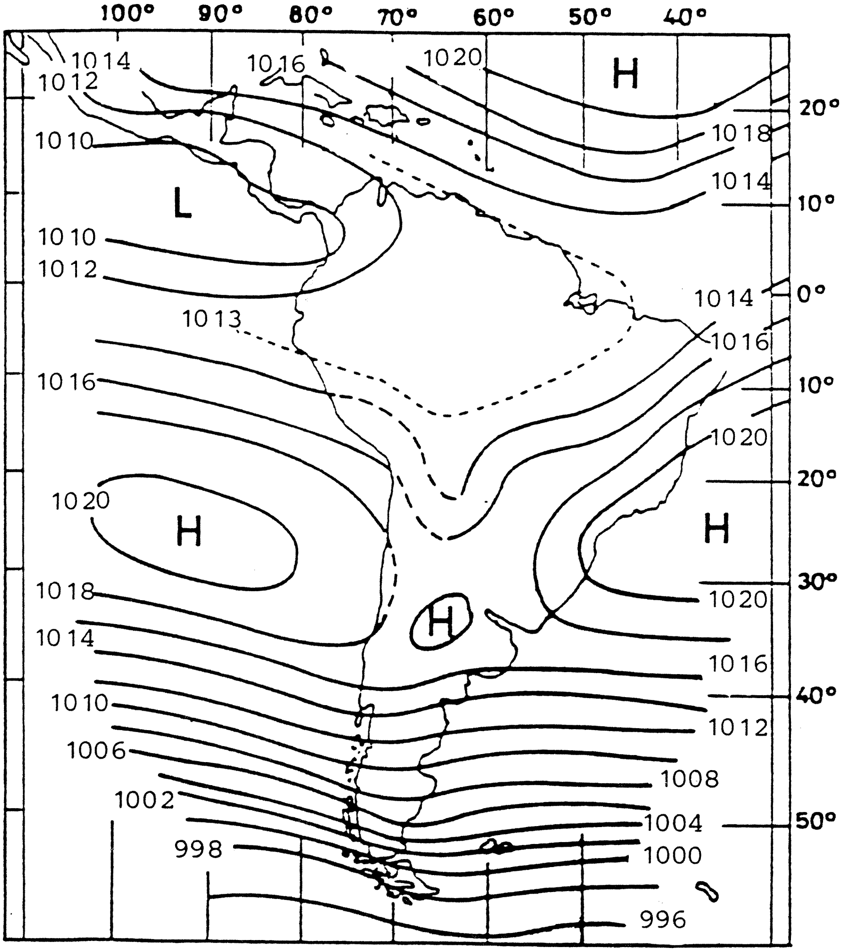


Figure 23.7B. Atmospheric pressure at sea level in South America during the winter.

notorious westerlies are situated along 40°S and in the region immediately polewards, and the two semi-permanent anticyclones are in a similar position.

The north-south orientation of the mountain chain, the wind circulation from west to east and the rising of humid air masses from the Pacific Ocean cause more abundant precipitation in west Patagonia than in east Patagonia. The heavy rainfall supports forests, peat-bogs and tundra, on organic, wet and acid soils in the piedmont zone. On the other hand, in the central plateau and in the Atlantic riparian plain, a xerophytic steppe has been formed on mineralized soils (Burgos, 1985; Endeicher and Santana, 1988). To the west, over the Andes mountain chain, the rainfall are more than 4000 mm.

The water balance calculated by the methods of Budyko (1948) or Thornthwaite and Mather (1955), shows a very high water deficit. El Turbio, (51°40'S 72°02'W) has an annual deficit of 87 mm and Rio Gallegos (51°35'S 69°00'W) has a deficit of 314 mm (Burgos, 1995). The most important climatological values for some Patagonian stations are given in Table 23.2.

Hoffmann (1990) has studied the trends in air temperature, comparing the periods 1941-50 and 1981-90, with the following results: Rio Gallegos, +1.2°C; Lago Argentino, +0.4°C; San Julian, +0.7°C (49°19'S 67°42'W); Comodoro Rivadavia, +0.2°C and Trelew, +0.1°C. It is observed that the decadal changes increase from north to south, coinciding with the results of the GCM models for global warming.

23.3. Possible Changes in Patagonian Water Resources Induced by Global Warming

Two global atmospheric circulation models (GCM) were chosen, CSIRO9 from the Division of Atmospheric Research, Commonwealth Scientific and Industrial Research Organization, Australia, and UKHI from the United Kingdom Meteorological Office, following the results obtained by Boer (1992) and Labraga (in press).

A comprehensive assessment of GCM performance over the Southern Hemisphere as a whole is still pending and would be very valuable. The procedure used to evaluate the capability of models to simulate the contemporary earth climate was as follows. Selected sets of climate features in the observed MSL pressure, surface temperature and precipitation fields, relevant to the present climate, were highlighted. Qualitative evaluation was then undertaken of the model's capability to simulate each of these selected climate characteristics, and statistical measures of global performance were computed.

Double CO_2 equilibrium experiments were compared, and some consistent patterns of climate trends were detected in the selected surface variables. Attention was focussed on surface data only, because any significant change in this variables could seriously affect the evolution of natural ecosystems and the output of many essential human activities.

The resolution of the transform grids used for calculating the model physics and number of vertical levels of each model are indicated in Table 23.3.

TABLE 23.2. Climatic characteristics of selected stations, 1981-90. (Servicio Meteorológico Nacional Estadísticas climatológicas.)

		S. C. de Bariloche	Catedral 2000	Paso de los Indios	Rio Gallegos	Ushuaia
Location		41°09' S	41°15' S	43°49' S	51°37' S	54°48' S
and		71°10' W	71°37' W	68°53' W	69°17' W	68°19' W
Altitude		840 m	1955 m	460 m	19 m	14 m
Mean	S*	15.0	8.1	19.1	14.1	10.3
Temperature	W	2.1	-2.5	3.4	1.2	1.6
(°C)	A	8.4	--	11.3	8.0	--
Mean Min.	S	6.7	4.1	9.6	8.1	5.7
Temperature	W	-1.5	-4.7	-2.6	-1.9	-1.4
(°C)	A	2.3	-0.8	3.8	3.3	--
Mean Max.	S	22.2	14.5	27.1	20.1	15.0
Temperature	W	6.6	0.5	8.7	4.6	4.5
(°C)	A	14.6	6.9	18.0	13.3	--
Precipitation	S	16.4	--	9.1	34.6	30.7
(mm)	W	105.7	152.0	20.0	19.3	46.2
	A	714.5	--	200.0	274.0	--
Main Wind	S	W	W	W	W	W
Direction	W	W	W	W	W	W
	A	W	W	W	W	--
Wind velocity	S	26.9	33.1	16.6	32.9	16.9
(km h^{-1})	W	17.8	41.1	10.9	23.3	10.8
	A	22.6	--	15.3	29.2	--

* S - January (Summer); W - July (Winter); A - Annual.

TABLE 23.3. GCM horizontal and vertical resolution.

	CSIRO9	UKHI
Horizontal resolution (Lat. x Long.)	3.2°x5.6°	2.5°x3.75°
Number of grid points	3584	6912
Number of vertical levels	9	11

Latitudinal pressure gradients in the southern tip of the continent calculated by these GCMs are shown in Table 23.4. There is general agreement among the model results about a possible southward shift and intensification of the summer continental low pressure system in the 2 x CO_2 equilibrium climate.

TABLE 23.4. Latitudinal pressure gradient between 45° and 55° S, at 70°W (hPa / ° Lat.).

Season	Observed	CSIRO9 prediction	UKHI prediction
Summer	1.4	1.4	1.2
Winter	1.2	1.7	1.8

The computed RMS errors between observed and model MSL pressure, surface temperature and precipitation rate are presented in Table 23.5. This provides an objective measure of model performance. Calculations were carried out after interpolating model output onto a mesh equal to the observed data (3.18°Latitude x 5.63°Longitude). A weighting function was used to take into account the latitudinal variation of the area represented by grid points.

TABLE 23.5. Annual and seasonal pattern correlation and RMS error (in brackets) of the MSL pressure, surface temperature and precipitation fields.

	Annual	DJF	MAM	JJA	SON
Pressure (hPa)					
CSIRO9	0.96 (2.5)	0.92 (3.7)	0.96 (2.5)	0.96 (2.8)	0.96 (3.1)
UKHI	0.95 (3.0)	0.89 (4.8)	0.95 (2.9)	0.95 (2.9)	0.95 (3.3)
Temperature (°C)					
CSIRO9	0.88 (2.8)	0.76 (2.9)	0.88 (2.7)	0.93 (3.1)	0.87 (3.3)
UKHI	0.95 (2.4)	0.91 (2.3)	0.96 (2.2)	0.96 (3.2)	0.93 (3.5)
Precipitation (mm)					
CSIRO9	0.68 (1.7)	0.66 (2.5)	0.65 (2.5)	0.61 (2.5)	0.73 (2.1)
UKHI	0.67 (2.0)	0.75 (2.6)	0.67 (2.8)	0.71 (2.6)	0.66 (2.2)

MSL pressure difference fields between the 2 x CO_2 and 1 x CO_2 numerical experiments were analysed. No consistent change can be discerned in the latitudinal pressure gradient at the southern end of the continent, between 45° and 55°S. Both CSIRO9 and UKHI have predicted for Patagonia an increase of summer surface temperature of about 4-5°C and for winter, 3-5°C. The mean precipitation differences between the 2 x CO_2 and 1 x CO_2 are not significant.

Budyko *et al.* (1994), working with analogous models and paleoclimates, arrived at a forecast for temperature change in South America of 1°C by the year 2000, 2-3°C for 2025 and 3-4°C about the middle of the 21st century. Furthermore, they calculated the latitudinal differences of the mean air temperature for the different latitudinal belts in both hemispheres and their results for Patagonia are summarised in Table 23.6. Mean annual rainfall in the centre-oceanic region will decrease by 50 mm by the year 2000; by the year 2025 they calculate an increase of 100 mm for the northern zone and a 50 mm decrease for the extreme south and Tierra del Fuego. By the year 2050, increases of 100 and 50 mm in the centre-north and in the centre-south respectively are indicated.

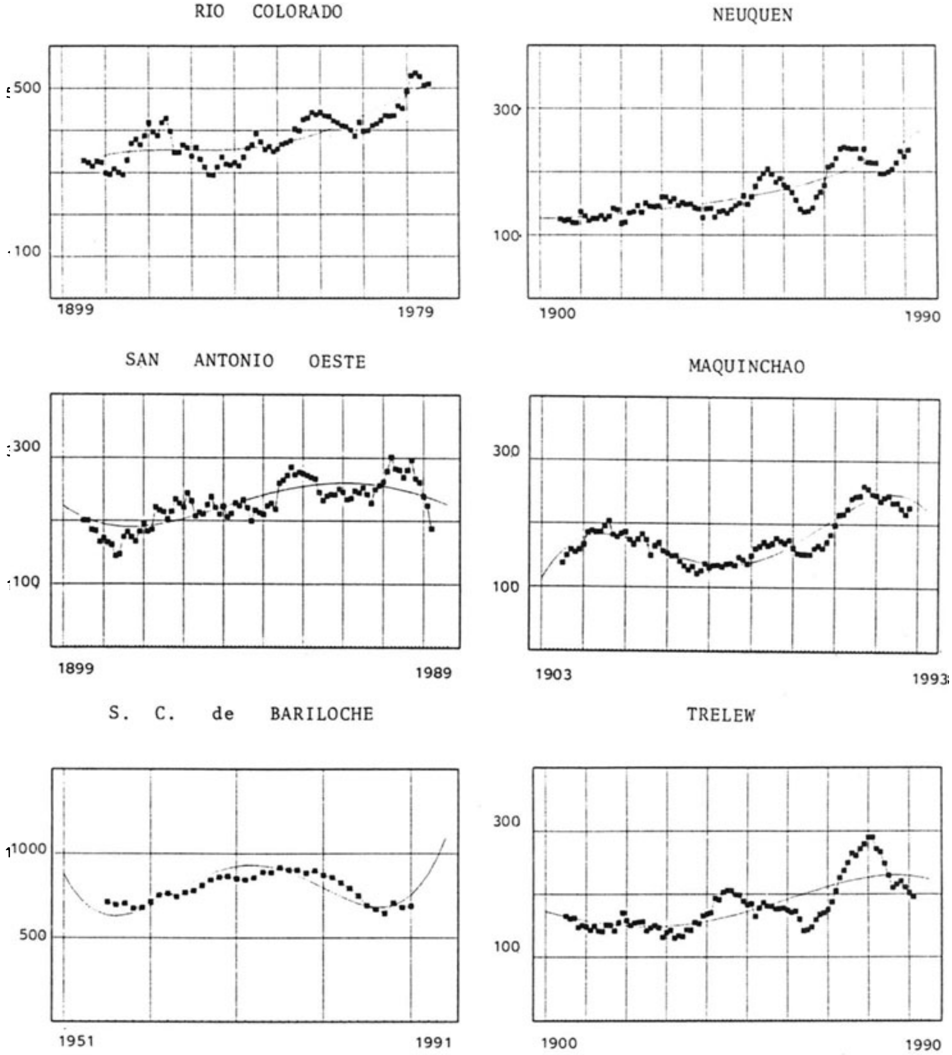
TABLE 23.6. Latitudinal differences for mean air temperature (°C).
(From: Budyko *et al.*, 1994.)

Latitude (South)	Year 2000		Year 2020		Year 2050	
	Winter	Summer	Winter	Summer	Winter	Summer
40-50°	1.4	1.6	2.5	2.6	3.2	4.0
50-60°	1.7	2.6	3.0	3.2	5.1	6.2

Comparison of the regional changes in temperature determined by the two climate models with those derived from the paleoclimatic data permits a forecast for the winter air temperature anomalies, especially in middle and high latitudes. The numerical climate models and the paleoclimatic reconstruction all provide similar values on the temperature changes,with correlation coefficients among them of between $r = 0.8$ to 0.9. It is more difficult to predict the anomalies for summer temperature, because these changes are of smaller magnitude (Budyko *et al.*, 1992).

Changes have already been observed in precipitation. Ten-year moving averages and rainfall trends with a fourth degree equation, have been calculated for Patagonian stations and are shown in Figure 23.8. A positive trend is observed in the two stations near to the Andes piedmont, i.e., Bariloche and Esquel (42°54'S 71°22'W) (Quintela *et al.*, 1993; Scarpati and Faggi, in press).

Most Patagonian water resources are held in its rivers, lakes and snow mass, located in the piedmont region and high mountain chain. Patagonia's surficial water resources have experienced a disminution during the last three decades, in contrast with what has



RIO COLORADO

NEUQUEN

SAN ANTONIO OESTE

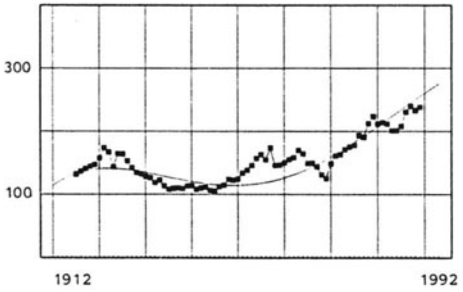
MAQUINCHAO

S. C. de BARILOCHE

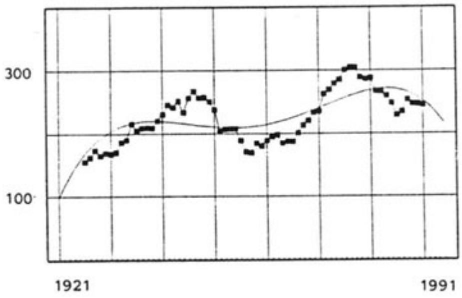
TRELEW

Figure 23.8. Moving averages (■) and trends (—) for mean annual precipitation. Y axis is annual precipitation in millimetres. See Figure 23.3 for locations.

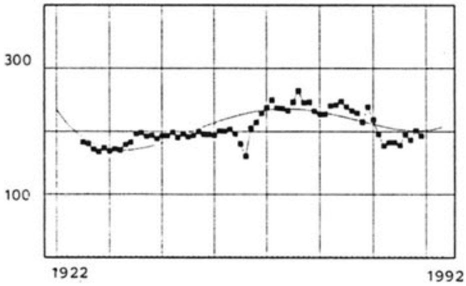
PASO de los INDIOS



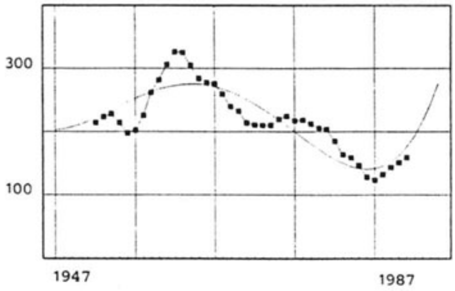
COMODORO RIVADAVIA



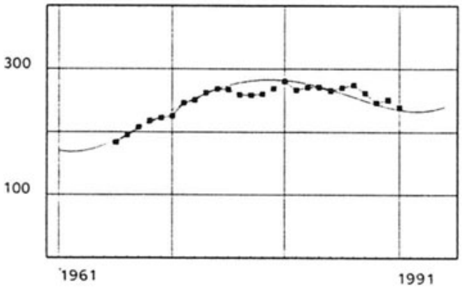
PUERTO DESEADO



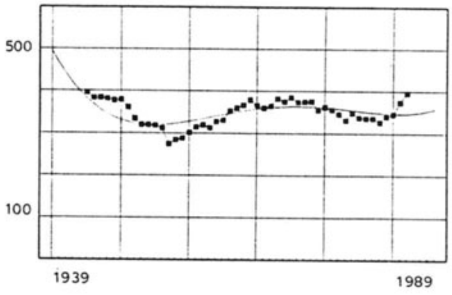
LAGO ARGENTINO



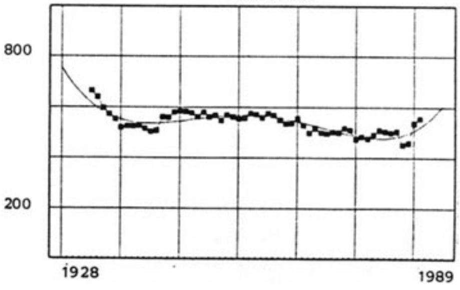
RIO GALLEGOS



RIO GRANDE



USHUAIA



occurred in the pampean region, where there has been a water excess (Quintela *et al.*, 1989; Quintela and Scarpati, in press).

In Patagonia, the Andes mountain chain introduces a very important morphologic element. It can be conjectured that an increase of 20-50% in rainfall would produce an improvement in water resources in the Andes piedmont subzone (Quintela *et al.*, 1993; Scarpati and Faggi, in press). A large part of Patagonia has been suffering a growing deterioration from eolian and water erosion, due to mismanagement of the soils and over-grazing; 40% of soils has suffered serious deterioration (Prego, 1988). Soriano and Movia (1988) noted that the Patagonian semidesert and neighboring steppes are areas where the advancement of dunes, covering fields and settlements, the formation of active gullies and ravines, the cutting of roads, the filling up of river channels and the formation of wide rocky pavements, have been occurring with increasing intensity.

The main change below an altitude of 2000 m is likely to be the temperature increase. According to the soil characteristics of the different Patagonian regions (Figure 23.4), it would be expected the variations produced on them.

The temperature increase would act as a severe limiting factor for the snowline level. According to Australian researchers, it would be raised by 100 m for each °C of warming. The glaciers would also suffer a disquieting impact. In Bolivia, icemelt is already occurring on the high summits, for example the Chacaltaya glacier (5343 m) near La Paz, where B. Francou has recently reported measurements confirming losses of 6 m height of ice thickness in one year. Kellog (1993) reports similar situations occurring in other places of the world related to the greenhouse effect. According to Shepard, the mountains of this nation and of Peru show a rise in the snowline.

Finally, we must consider an important physico-chemical phenomenon, the disminution in the ozone layer in Antarctica. This has decreased the temperature in the south of Argentina during recent decades. Models confirm that the loss of stratospheric ozone is capable of reducing temperatures by up to 0.3-0.4°C per decade, according to Bojkov (1995). The great sensitivity of stratospheric temperatures to ozone radiation shows the necessity to analyze the climatic implications. The same applies to CO and CH_4.

23.5. Conclusions

The preceding analyses suggest that global warming will have the following effects on Patagonian water resources.

1) The temperature differences between the north and south of the region will be reduced. Temperatures will rise most in the south and during the winter. This will be associated with a southward shift in the average location of the Subtropical anticyclones in both the Atlantic and Pacific Oceans.

2) The altitude of the snowline will rise with increased temperatures, which will eventually produce a decrease in snowmelt resources feeding the headwater rivers. Rivers that currently receive major contributions from snowmelt, like the Senguer and Mayo will be most affected. Those that are fed by large lakes or from ice fields, like the

Santa Cruz, will be least affected.

3) The response of the Patagonian Continental Icefield is more difficult to predict and should be the subject of a special study. It could gradually increase the levels of the Argentino and Viedma lakes and eventually enhance the relatively small discharges of the Rivers Coyle and Sheuen.

4) A positive rainfall trend is observed in the region near the Andes piedmont and, if continued, this would produce an improvement in the land resources in this zone, depending on the prevailing soil type.

5) It remains very difficult to predict the response of Patagonian water resources to global warming with certainty. Some zones could benefit, like the rivers of Santa Cruz province. Others may experience reduced resources, like the Negro River basin. However, we see no reason to share the despair of Lauria (1995):'A realistic global model exceeds the actual computation and data communication capacities', and we expect a sustained improvement in the reliability of regional predictions from the new generation of GCMs.

Acknowledgements

We thank *in memoriam* the important climatological contribution given by Ing. R.J. Broqua, before his death. We also thank P. Fernández, M.A. Soria Nóbile and A. Quintela for their technical assistance.

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