Chapter 3
Geographical Singularities of the Patagonian Climate

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Abstract Patagonia (36°–56° S) is fully located in the belt of the southern hemisphere west winds, and because no other continental landmass stands in the way of the westerlies at these latitudes, the constancy and strength of these winds become decisive climatic factors. The westerly flow is fairly perpendicular to the Andean Range so as to create very sharp differences between both sides, mainly in precipitation. Thus, windward (Pacific side) mountainous wet Patagonia contrasts abruptly with leeward (Atlantic side) dry plateaus. This contrast is smoother northward, beyond the Patagonian limits, as the westerly flux slowly gives way to the subtropical anticyclonic prevalence. Because of this, both flanks of the Andes are equally dry north of parallel 32° S. Central Chile shows a clear Mediterranean climate, but the dry season shrinks dramatically south of 36° S until it disappears south of 40° S. Further south, on the Chilean flank of the Andes, the Patagonia climate clearly becomes an example of a cool temperate windward coastal area in midlatitudes. On the opposite side of the mountains, and because of their very presence, the climate of east Patagonia fits poorly in global classifications. Elsewhere on Earth, the eastern side of a continent at equivalent latitude would present a cool temperate climate, with a noted degree of continental and moderate rainfall. Instead, a windy rain-shadowed semidesert, strongly conditioned by the narrowness of the continent (<700 km) and the influence of the sub-Antarctic Ocean, spreads over extra-Andean Patagonia. The uniqueness of Patagonian current climate stems from large-scaled geographic factors that will be analyzed in this chapter.

Keywords Wind-conditioned climate · Westerlies · Southern midlatitudes · Rain shadow

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3.1 Study Area

The borders of Patagonia have always been very controversial. The very concept of Patagonia varies according to the disciplines. On the east the coasts of the Atlantic and those of the Pacific on the west do not pose any difficulty to delimit the region. To the south, there is an ambiguity with the Strait of Magellan, which separates Patagonia from Tierra del Fuego. Should this island be considered as the southernmost part of Patagonia, which would then culminate not in the Strait but in Cape Horn? However, it is in the north that the real difficulties to define the boundary arise.

Traditionally the Argentine geography considered a border as arbitrary as practical for all: the Colorado River, which crosses the Argentine territory entirely from the Chilean border to the Atlantic. This physical division has the great advantage of not breaking any of the five Argentine provinces located south of the river (Neuquén, Río Negro, Chubut, Santa Cruz, and Tierra del Fuego) and that are considered Patagonian. The small portion of the Province of Buenos Aires situated south of the Colorado is an individual administrative unit that does not lend itself to confusion insofar as it bears the name of Patagones.

However widespread or practiced, the frontier of the Colorado River could not sustain a more detailed, geographical, or ethnographical analysis. Indeed, from the point of view of physical geography there is a progressive transition between the plains of the Pampa and those of northern Patagonia. All that huge area is characterized by an extensive shrubland dominated by *Larrea* spp., interspersed with open forest of *Prosopis* spp., and belongs to the Monte phytogeographical region. In fact, the Monte biome is much more extensive spreading from the Chubut River (43° S) to Salta (25° S) (Abraham et al. 2009). Not only the Monte biome marks the continuity of Patagonian biophysical characteristics far beyond the Colorado River but also the Patagonian phytogeographical province itself, a colder biome that stretches over the plateaus and Andean foothills as north as 35° S in Mendoza.

On the other hand, west of the Andes, in Chile, it could be said that the northern border of Patagonia is even less defined than in Argentina. This is so perhaps because the very concept of Patagonia was born on the Atlantic coast in 1520, at the beginning to define the landscape of the arid plateaus along the shoreline. Thus, if all Chilean geographers agree that the arid plains along the Strait of Magellan are undoubtedly part of Patagonia, the conceptual disagreement begins as soon as one moves away from the interoceanic passage and the landscape becomes less flat and less arid. For some, the Chilean Patagonia does not go further north of the Taitao peninsula (47° S), which constituted a barrier for the circulation of the aboriginal coastal nomads; others take it to Reloncaví Sound (42° S), which carries the waters of the Pacific very close to the Argentine border. The extension of the concept of Patagonia to the north is a phenomenon that continues nowadays and that may stem on tourism marketing, nothing to do with biophysical or ethnographic features.

All in all, and in spite of the title of this chapter, the area to be analyzed from a climatological point of view exceeds the surface of Patagonia even in its widest acceptance. In order to meet the herpetology scope, this chapter will cover a broader area, well beyond Patagonian boundaries toward the north so as to include a great extent of Mendoza and La Pampa rangelands, in Argentina, and, very especially, an important area of central-southern Chile, perhaps the most favored of that country climatically speaking.

3.2 General Features

> In few parts of the world is the climate of the region and its life so determined by a single meteorological element, as is the climate of Patagonia by the constancy and strength of the wind (Prohaska 1976).

Patagonia, the southernmost region of the Americas, extends approximately from 36° S to 56° S; i.e., it is fully located in the belt of the west winds. Because of the triangular shape of the region, the continent is about 1500 km wide at the latitudes of north Patagonia and gradually narrows southward until it disappears in Cape Horn. Less than 1000 km separate it from the northernmost tip of the Antarctic Peninsula, but the Drake Passage is wide enough to sensibly warm the Antarctic air masses that may reach South America. In such a way, Patagonian winters are much milder than those at equivalent latitudes in North America. Although they are more frequent during the winter, maritime polar air masses can reach Patagonia throughout the year and they are one principal cause for the relatively low temperature in southern Patagonia (Weischet 1985).

In the South American quadrant the westerlies are put in motion by the interplay between the permanent subtropical anticyclones on the south Atlantic and southeast Pacific (both centered about on 30° S) and the subpolar low at 60° S (Prohaska 1976; Paruelo et al. 1998). The strong pressure gradient between the two belts generates the strong upper air westerly jet (Hobbs et al. 1998; Lenaerts et al. 2014); besides the seasonal N–S shift of the high cells is quite noticeably while the sub-Antarctic low belt hardly changes its position, thus in summer when the anticyclones move southward, the pressure gradient increases and consequently does wind speed too.

Since the main geographical feature of Patagonia, i.e., the Andean Range, intersects the dominant westerly flux perpendicularly, there is a very clear rain shadow effect eastward. This creates an abrupt contrast between windward, well-watered, and forested western Patagonia and leeward, namely, dry steppes covering plateaus and peneplains until the Atlantic shores. Even though the Andes south of 40° S seldom exceed 3000 m height, they generate abundant orographic precipitations over the Pacific flank. On the western side rainfall amounts may be up to 20 times greater than on the eastern flank, where in addition subsidence leads to arid and highly evaporative conditions downwind (Garreaud et al. 2013). This marked climatic contrast entails one of the sharper vegetation gradients in the world (Endlichter and Santana 1988; Warren and Sugden 1993).

In South America owing to the poleward movement of both subtropical anticyclones during the summer, anticyclonic influence is quite clear roughly until 40° S; thus, that season is usually sunnier and drier in the northern half of Patagonia (i.e., north 46° S). Because of this the climate of northwestern Patagonia could be considered as a type of an arid-degraded Mediterranean (Le Hoérou 2004). This area may be considered as a marginal area of the truly Mediterranean climate that predominates over central Chile. There, the weakening of the westerlies with decreasing latitude is reflected in the steady lengthening of the dry season, from none month at 40 °C up to all year round at 30 °C.

The Andean range between the latitudes 30–35° S is particularly high, with several summits over 6500 m. This explains that both sides of the mountains, although they share an insufficient rainfall amount, present different precipitation regimes. Whereas winter cyclonic rains prevail on the west flank foothills and the border of highest peaks, convective summer rains are the rule eastward over the Argentine plains. An incipient core of continentality develops on these rangelands east the Andes, and though annual temperature range is quite modest (17 °C), it is the greatest figure in the whole South America. This area is void of Pacific-originated moisture and, instead, the source of moisture is the distant Atlantic Ocean, at least 1000 km eastward. After gradually discharging its moisture on the pampas, the easterly winds reach the eastern foothills of the Andes with little water content and therefore the annual rainfall does not exceed 200 mm.

The only sporadic irruptions of Pacific air north of 35° S are the foehn events, locally known as "zonda," which—accordingly to the strengthening of the westerlies—are more frequent during the winter.

The border between the air masses of the Pacific and those of the Atlantic roughly follows an oblique NW–SE line stretching from 35° S on the mountains to 41° S on the Atlantic coast. Southward, despite the fact that westerlies become dominant all the year round, some counteracting anticyclonic influence can be felt during the summer as already stated. Further east, on the Atlantic coast north of 46° S, summer drought may be slightly attenuated because of episodic ingressions of oceanic air masses from the Atlantic and consequent rainfall.

On the contrary, on both sides of the Andes south of 46° S the strong westerly flux is not counteracted at any season and thus rainfall is more evenly distributed throughout the year. Lesser seasonal variation of precipitation is not related to the total amount, which—as already said—decreases abruptly eastward the Andes.

Further south, beyond the 50° S parallel, cloudiness and precipitation are greater in summer according to the proximity of the subpolar regime, which in the southern hemisphere reaches much lower latitudes than in the north.

3.3 Wind Patterns

The average position of the front dividing South Pacific air masses from the SW and south Atlantic air masses from the NE depicts a NW–SE boundary, reaching the Atlantic coast at 41° S and fairly coincident with the Colorado River, i.e., the

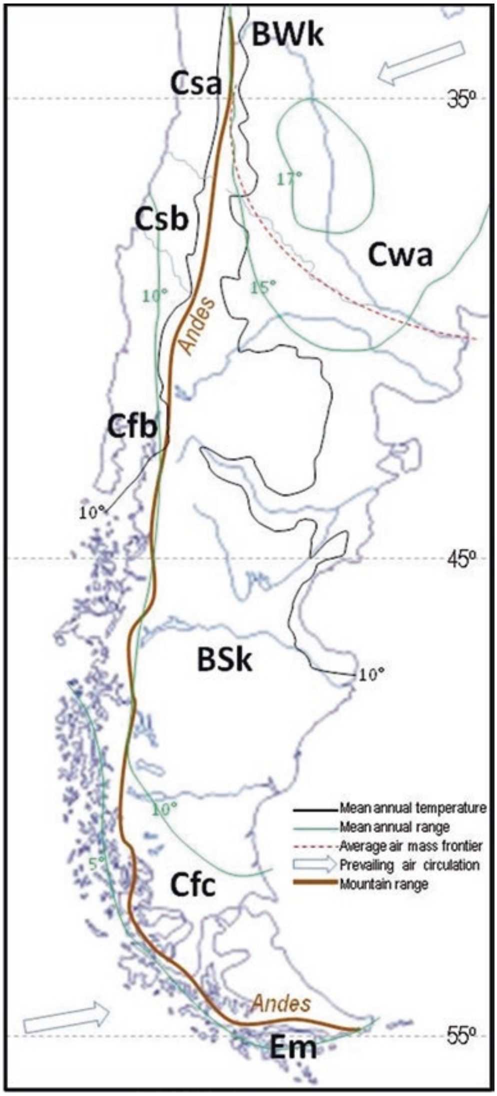

Fig. 3.1 Main features of Patagonian climates linked to Köppen climate classification system: *BWk* arid cool, *BSk* semiarid cool, *Csa* Mediterranean hot summer, *Csb* Mediterranean warm summer, *Cwa* dry-winter humid temperate, *Cfb* temperate oceanic, *Cfc* subpolar oceanic, *Em* subpolar oceanic no summer (Geiger 1954)

northern political border of Argentine Patagonia. South of this front, circulation from the west prevails, entailing the consequent strong W–E gradient of precipitation that characterizes the Patagonian climate. The prevalence of the westerlies provides a good criterion for the delimitation of Patagonia as a uniform climatic region (Fig. 3.1).

In all Patagonian stations west winds (i.e., SW + W + NW) count for 50–70% of all observations. Along the year some variations appear because of small seasonal displacements of the predominant pressure systems. In winter, due to the land mass cooling, a ridge over the continent connects the south Pacific and the south Atlantic anticyclones, located approximately at the same latitude and with similar intensities, and so isobars run parallel to latitudes resulting in a clear W–E component. On the contrary, in summer the two high-pressure cells are separated over the continent by a low-pressure trough, entailing a stronger (although never dominant) N–S component.

West of the Andes, in central Chile, prevailing wind is SW but strong local variations stem on the topography of the area, mainly on the barrier effect of the coastal range enhanced by quite compact mountain ranges between 35–37° S and 40–41° S. Thus, climate of the central valley flanked by the coastal range and the Andes is somehow more continental in those sectors, i.e., slightly drier, less windy, and warmer summers (31 °C, mean maximum January temperature in Talca, 35.43° S; the hottest summer in Chile).

Seasonal changes in high- and low-pressure centers not only affect wind direction but also control wind speed. This is especially true further south, in Patagonia, where the narrowness of the continent and the absence of another continental mass south of 40° S determine that general circulation patterns are simpler and more persistent than at equivalent latitudes in the Northern Hemisphere.

During the setting of summer, the subtropical south Pacific and south Atlantic anticyclones move a few degrees of latitude southward; on the other hand, the subpolar low-pressure belt has almost no displacement owing to the stability of underlying oceanic conditions. As result of this unequal displacement of the pressure belts, the barometric gradient between them strengthens as spring progresses (Lamb 1972). It stems on thermal differences between subtropical South America, which becomes warmer earlier, and the Antarctic sea ice, which persists still for 3 or 4 months more at 60° S (Burgos 1985). For this reason, although in Patagonia the average wind speed is quite high throughout the year, in most of the region it reaches the maximum in spring.

Strong winds play an important bioclimatic role because of the cooling effect and the systematic reduction of the temperature felt. Since—as said above—average wind speed is higher in the warm season, wind cooling effect is greater in this season too. This entails an apparent shrinking in the annual range of temperature and so climate is perceived as being cooler and more maritime than it actually is (Coronato 1993).

The effect of wind in reducing the boundary layer determines that the homeothermic animals must increase their energy investment to compensate for the additional heat loss. Ectothermic animals, and plants, also have a diminished ability to accumulate radiation and their temperature tends to equal that of air (Oke 1978). Weischet (1985) highlights the extent of this phenomenon in Patagonia, especially pernicious during the spring, supposed to be the blooming and reproductive season for most species.

3.4 Temperature Regime

Mean annual temperatures vary from 15 °C (7 °C in winter and 23 °C in summer) in north Patagonia to 5 °C (i.e., 0 °C in winter and 10 °C in summer) in Tierra del Fuego and southern Andes. Such differences are not surprising since, as already mentioned, Patagonia spans over 20° in latitude, i.e., about 2200 km in a N–S direction. In Europe, it would be the distance between Malta and Copenhagen (an equivalence not merely geometric but also environmental). Such latitudinal extension entails noticeable differences in the incoming solar radiation, which changes from little above 180 W/m^2 (annual average) in the northernmost stations, such as Neuquén or Curicó, to only 100 W/m^2 in Tierra del Fuego (Paruelo et al. 1998) or even less in the outermost islands of the Magellanic archipelago.

Due to the augmenting latitude the ratio summer/winter solar radiation increases progressively as well, from 4:1 at Neuquén (39° S) to 13:1 at Ushuaia (55° S). Nevertheless, the temperature regime follows an opposite pattern because of the narrowing of the continental mass southward; the mean annual temperature range varies from 16 °C in the north to 9 °C in the south or even down to 5 °C in the southern archipelagos that have been considered as having a "hyper-oceanic" climate (Tuhkanen 1992). In contrast, the northern value anticipates the already mentioned South American continentality core, centered around 35° S/66° W east to the Andes, while on the contiguous Chilean regions, because of the influence of the Pacific, annual temperature range does not exceed 12 °C (Fig. 3.1).

The extreme temperatures follow the same pattern, with maxima over 42 °C in north Patagonia and 38 °C as south as 46° S in eastern Patagonia; in turn, in Tierra del Fuego they do not surpass 30 °C and not even 20 °C in the hyper-oceanic islands. Further north, beyond the limits of Patagonia, extreme temperatures are very similar on both sides of the Andes; 45 °C was the highest temperature ever recorded in Mendoza city, in Argentina, as well as in Talca (Chile), previously mentioned as the warmest section of the Central Valley (35–37° S).

Excluding the high Andes, minima temperatures of −30 °C are recorded in the central tablelands as north as 41° S. Along the windward Pacific coast the absolute minima never go below −10 °C (Zamora and Santana 1979). Since maritime influence from the Atlantic does not penetrate much inland due to offshore circulation, temperatures below −10 °C are not rare in eastern Patagonia peneplains near the coast, though the shore itself is usually free of such values.

Besides the dramatic rainfall contrast produced by the Andean range, it is evident that the mountains restrict also the inland extent of maritime influences carried by the westerlies coming from the Pacific. However, it cannot be said that leeward Patagonia has a definite continental climate since annual temperature range is rather low (12 °C in average in eastern Patagonia). Indeed, authors disagree about qualifying the climate of the area within a continentality-oceanity continuum; whereas for Walter and Box (1983) it is "definitely maritime," for Mensching and Akhtar (1995) "it has distinct continental features." In fact, it is as if the continental characteristics generated eastward by the barrier of the Andes were attenuated by narrowness of the continent at these latitudes (Miller 1946), which obviously hinders the formation of continental air masses (Taljaard 1969).

3.4.1 Trends

Year to year variations of temperature are not in phase in the whole Patagonia; instead two main isofluctuative areas (N and S) were detected. These areas appear to be more dependent of latitude rather than affected by the Andean barrier, which in this matter behaves as a second-order differentiation factor. The meteorological stations that better correlated to each main area are Trelew and Río Gallegos, both located on the Atlantic coast at 43° S and 51° S, respectively (Coronato and Bisigato 1998).

Regarding long-term changes, a clear warming is noticeable in most of Patagonia since 1950 (Villalba et al. 2003; Vincent et al. 2005). On average, annual mean temperature increased 0.4 °C in the whole region; also a decline in the number of cold days and an augmentation of warm days since 1960 was reported (Rusticucci and Barrucand 2004).

3.4.2 Wind Chill

Treating wind and temperature separately as done above fails in reflecting accurately the climatological weight these factors have when acting simultaneously as always happens in real conditions. We briefly mentioned this topic when referred to the effect of wind in reducing the boundary layer; yet in Patagonia the wind cooling effect deserves further attention since it is a major bioclimatological issue. The first permanent European settlers in the mid-nineteenth century soon became aware of this climatic constraint: "certainly it is not a very low temperature compared to those of Canada, but when these low temperatures are coupled with a strong wind, as it occurs often in Chubut, cold is almost insupportable" (Hughes 1927).

Since in Patagonia east of the Andes wind speed is higher in summer (as it can be seen in Table 3.1), the wind cooling effect is also greater in this season (4.7 °C versus 3.6 °C) (Coronato 1993). Thus, the climate of the plains is perceived not only as being cooler than it is but also more maritime because of the diminished annual thermal range of equivalent temperatures (eT). The opposite occurs west of the Andes, especially on the Pacific shoreline openly exposed to the west winds; as their speed increases during the winter, they therefore determine an overcooling in that season. However, being that the actual temperatures are not too low (once again because of the maritime influence), eT remain higher than the ones experienced east of the mountain range.

The eT pattern of two contrasting locations of eastern Patagonia, Puerto Madryn (42.7° S, 65° W) and Punta Arenas (53.1° S, 71° W), is shown by means of the

Table 3.1 Seasonal and geographical wind speed variation

Mean wind speed (m/s) at 1.5 m above ground level				
Average of nine east coast, seven inland, and three west coast sites (series 1978–1985)				
Area	Summer	Winter	Year	Variation (%)
East coast	4.6	4.1	4.3	12
Inland	4.1	2.8	3.5	46
West coast	4.3	4.0	4.2	8
Whole region	4.3	3.6	4.0	20

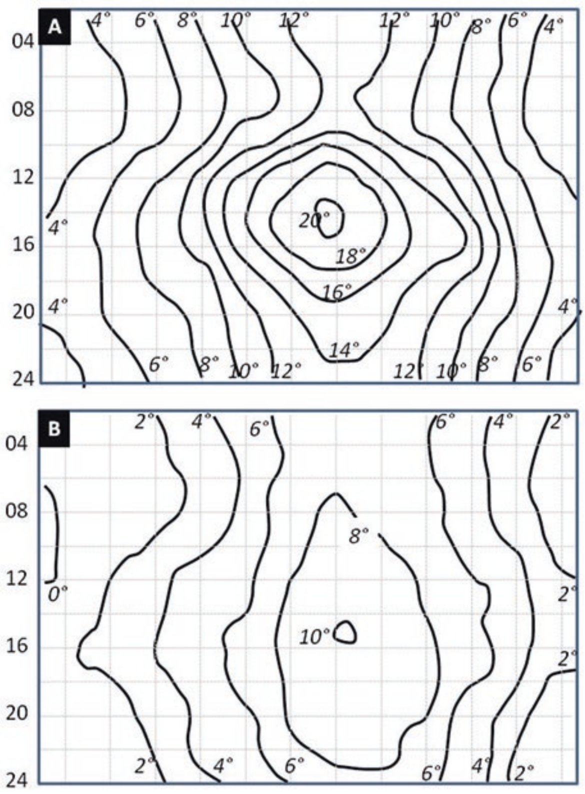

Fig. 3.2 Diurnal × monthly equivalent temperatures; (**a**) Puerto Madryn, (**b**) Punta Arenas (hours of the day on *y*-axis; months of the year on *x*-axis)

diurnal × monthly isopleth diagrams of average hourly eT (Fig. 3.2). They allow to compare the result of wind cooling on the thermal regime along the year. Both stations are quite separated in latitude so as to include most of Patagonia between them; both are at the sea level and mean annual temperatures are 14 °C and 7 °C, respectively, while mean annual wind speed are 2.4 m/s and 3.7 m/s.[1] Those figures

[1] Taken from Coronato (1995) and Endlichter and Santana (1988), respectively.

determine an annual average eT of 10 °C in Puerto Madryn and 3 °C in Punta Arenas, corresponding roughly to a heat loss (HL) of 590 W/m² to the former and 780 W/m² to the latter.

In the isopleth diagrams of Fig. 3.2, the number of intersections of the contour lines with an imposed 12 × 12 grid is a measure of the trends of eT fluctuations according to S (seasonality; horizontal gridlines, i.e., variation along the year) or D (diurnality; vertical gridlines, i.e., variation along the day). It can be seen that both parameters are greater in Puerto Madryn according to the higher continentality in the north; also, in agreement with midlatitudes it is clear that S > D in both locations. Wind cooling effect is evidenced by the flattening of the eT daily curve when compared to actual temperature. Whereas in midsummer (January) the daily range of temperature is 14 °C in Puerto Madryn and 8 °C in Punta Arenas, the range of eT lessens to 6 °C and 4 °C (Fig. 3.2a, b, respectively).

Figure 3.3 shows 31 Patagonian weather stations ordered by mean annual temperature and wind speed; thus, more severe eT conditions are in the bottom right corner whereas less severe are in the upper left corner. It can be seen that most of Patagonia falls within the eT range of the two analyzed locations (n°23 and 26), materialized by the oblique dashed lines. Several inland localities situated well above sea level, in which mean actual temperature may be lower because of elevation, do not experience eT values lower than coastal stations since wind speed in lower inland (see Table 3.1) and thus wind cooling effect is less marked. This turns out in more even equivalent temperatures between coast and inland.

In short, the bioclimatic effect of wind cooling could be summarized by marking the fact that wind smoothes thermic differences between coastal and interior regions, as well as along the day or along the year.

3.5 Precipitation and Moisture Budget

The barrier to the westerly winds that form the Andes has already been mentioned as the main geographic factor affecting the climate of South America south of 35° S. The rain shadow effect increases as the prevalence of the westerlies and the rainfall they bring increase as well. North of parallel 32° S both flanks of the Andes are equally dry but noticeable differences appear southward and become marked south of 35° S. From that latitude on, differences in precipitation at both sides of the barrier reaching a 10:1 ratio within a distance of 150 km are far from uncommon and may even reach 20:1. The sharpest rainfall gradients are coincident with the highest sectors of the mountain range (48°–51° S) that enhance the contrast between uplift-induced hyper humid conditions on the west side and stronger leeward subsidence evaporative conditions (Garreaud et al. 2013). Annual precipitation in such windward areas may surpass 6000 mm (Miller 1946) yet an average rainfall amount throughout the west flank of the Andes may be figured around 2000 mm. Only north of parallel 37° S, where westerlies begin to weaken, yearly rainfall goes down 1000 mm on the Chilean side. The transition between wet southern Chile and the

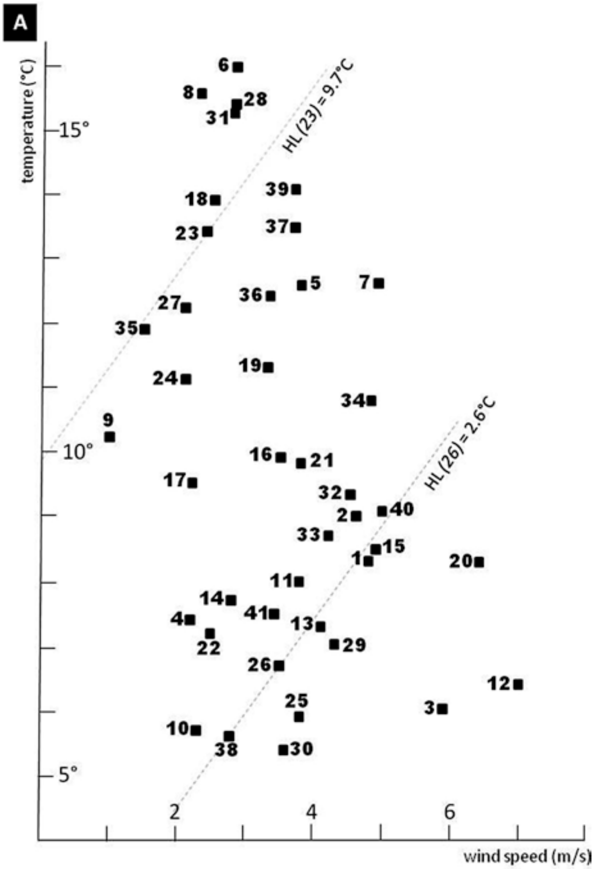

Fig. 3.3 Patagonian stations ordered by average annual temperature and wind speed Weather stations whose temperature and wind mean annual values are graphed: (*1*) Bariloche, (*2*) Cabo Raper, (*3*) Cabo Vírgenes, (*4*) Calafate, (*5*) Camarones, (*6*) Choele Choel, (*7*) Comodoro Rivadavia, (*8*) Conesa, (*9*) El Bolsón, (*10*) El Turbio, (*11*) Esquel, (*12*) Evangelistas, (*13*) Fitz Roy, (*14*) Gobernador Costa, (*15*) Gobernador Gregores, (*16*) Las Heras, (*17*) Maquinchao, (*18*) Neuquén, (*19*) Paso de Indios, (*20*) Perito Moreno, (*21*) Puerto Deseado, (*22*) Puerto Edén, (*23*) Puerto Madryn, (*24*) Puerto Montt, (*25*) Puerto Stanley, (*26*) Punta Arenas, (*27*) Punta Delgada, (*28*) Río Colorado, (*29*) Río Gallegos, (*30*) Río Grande, (*31*) San Antonio, (*32*) San Julián, (*33*) Santa Cruz, (*34*) Sarmiento, (*35*) Sierra Colorada, (*36*) Temuco, (*37*) Trelew, (*38*) Ushuaia, (*39*) Viedma, (*40*) Zapala, (*41*) Coihaique

desert covering the northern third of the country is very clearly evidenced by the number of dry months, i.e., those in which the precipitation (in mm) is less than twice the temperature (in °C). There is just one dry month at 39° S, 3 months at 37° S, 5 months at 35° S, 7 months in Santiago at 33° S, and all the year round beyond La Serena at 30° S.

Everywhere on the Patagonian plateaus in the Argentinean side, average yearly rainfall is about 200 mm, and even some spots with less than 150 mm are recorded as near as 150 km from the Pacific shores (Smith and Evans 2007). The result is a very marked vegetation gradient that starts on the Pacific coast with a wet temperate forest, turns into Alpine forests and grasslands, and changes again into moderate continental forests to merge finally into arid rangelands stretching over hundreds of kilometers until the Atlantic (Bailey 1989). It is possible to seize this vegetation gradient in the glacial lakes of the Argentinean side while standing at the distal eastern end, in pebbled wide beaches on morainic hills, surrounded by xerophytes and active sand dunes, looking west toward the Andean section of the lake, where long sounds deeply penetrate between snow-capped mountains, covered by a humid and cool forest.

If precipitation amounts change sharply at both sides of the Andes south of 35° S parallel, rainfall seasonality, cloudiness, and temperature regime do not or much less marked. The mountain range does not affect the cloudiness and temperature regimes as it affects precipitation. The annual isonephs of sky cover show a roughly latitudinal pattern ranging from 50% in north Patagonia to 70% in the south, with a noticeable inward depression (Prohaska 1976). Although percentages of sky cover are quite similar at both sides of the mountains, the type of cloudiness is not the same. Very often, mid and high cloudiness in eastern Patagonia (as far as the Atlantic coast) is merely residual cloudiness generated by the orographic uplift of the wet Pacific air over the Andes.

In the whole Patagonia north of the 50° S parallel most of precipitation falls from May to October (46% during the 3 winter months, i.e., June to August) (Labraga and Villalba 2009; Jobbágy et al. 1995). This seasonality stems on the equatorward shift of the westerlies, which increment the frequency of front activity coming from the Pacific (Garreaud and Aceituno 2007). Even if rainfall amount is low, the fact that the winter is the rainy season in north Patagonia east of the Andes, it is a Mediterranean-like feature that this region shares with the Mediterranean core of central Chile. Eastward, where some influence of Atlantic air masses becomes noticeable especially in summer, precipitations are more evenly distributed throughout the year (Jobbágy et al. 1995). In fact, in eastern Chubut there is not a defined rainy season and toward the northern portions of the region (east of Río Negro), the rising of summer rainfall anticipates the subtropical continental pattern of central and northern Argentina and it affects most of the Monte biome. South of 50° S, and on the Pacific coast south of 47° S, a summer rainfall pattern is recorded; it is a subpolar maritime pattern conditioned by the sea temperature, located in latitudes as low as nowhere else in the world.

3.5.1 Trends

Unlike what happens with temperature, precipitation did not show significant changes in the last 50 years in most of Patagonia; besides, year-to-year variability overrides long-term changes throughout the region. Nevertheless, different models agree in forecasting 10% less rainfall within the near future scenarios, mainly in northern Patagonian Andes (Masiokas et al. 2008). In agreement to this and in the conterminous central Chile, a decrease greater than 20% was recorded during the last century (González et al. 2011) and further decreasing up to 40% of summer rainfall is foreseen along the present century (CONAMA 2006).

As the major rivers of Eastern Patagonia have their headwaters in the Andes, north of 45° S (i.e., Colorado, Neuquén, Limay, Chubut, Senguerr), and that most of Patagonian population depends exclusively on water carried by these streams, any reduction of rainfall is not to be neglected, above all because it is linked to foreseen higher temperatures, i.e., greater atmospheric demand.

3.5.2 Water Balance

It was already seen how wind alters the bioclimatic role of temperature in Patagonia. Indeed, wind also alters the water balance by dramatically increasing evaporation. Whether the ratio between monthly evaporation rates and monthly mean temperatures is about 5–7 in wetter and less windy climates of Argentina, it reaches 10–15 in eastern Patagonia because of higher wind speed (Walter and Box 1983). Moreover, once the onshore westerlies dropped their humidity on the windward flank of the Andes and cross the mountains downward, their evaporative power is enhanced because of the adiabatic heating, making that atmospheric demand be as high as 1200–1400 mm/year in central Patagonia. The strong negative water balance affects the whole extra-Andean region; only on the west side of the mountain range the water balance becomes positive.

Notwithstanding, due to the increasing of precipitation during the winter, water balance in some eastern areas may be positive during the rainy season. Obviously, the length of the positive balance situation diminishes eastward, ranging from 5 months on the Andean foothills (Bariloche, May–September) to none on the Atlantic shore of Chubut or northern Santa Cruz.

The aridity index (IA) defined as the ratio between mean annual precipitation and potential evapotranspiration (Le Hoérou 2004)[2] is very clear in defining driest areas of Patagonia (Fig. 3.4). It can be seen that Patagonia is split in two contrasting areas from a hygric point of view and it is worthy to note that transitional areas (SA and SH) are confined to two narrow fringes over the east Andes foothills and only expand toward the south, in the Magellan area.

3.6 Climatic Classification

From everything explained up to this point it emerges that eastern Patagonia fits badly in a global climatic classification. There is nowhere else in the world an arid region on the eastern side of a continent in midlatitudes. Elsewhere, a region so

[2] HA = HyperArid (IA < 0.05); A = Arid (0.05 < IA < 0.2); SA = SemiArid (0.2 < IA < 0.5); SH=SubHumid (0.5 < IA < 0.75); H=Humid (IA > 0.75).

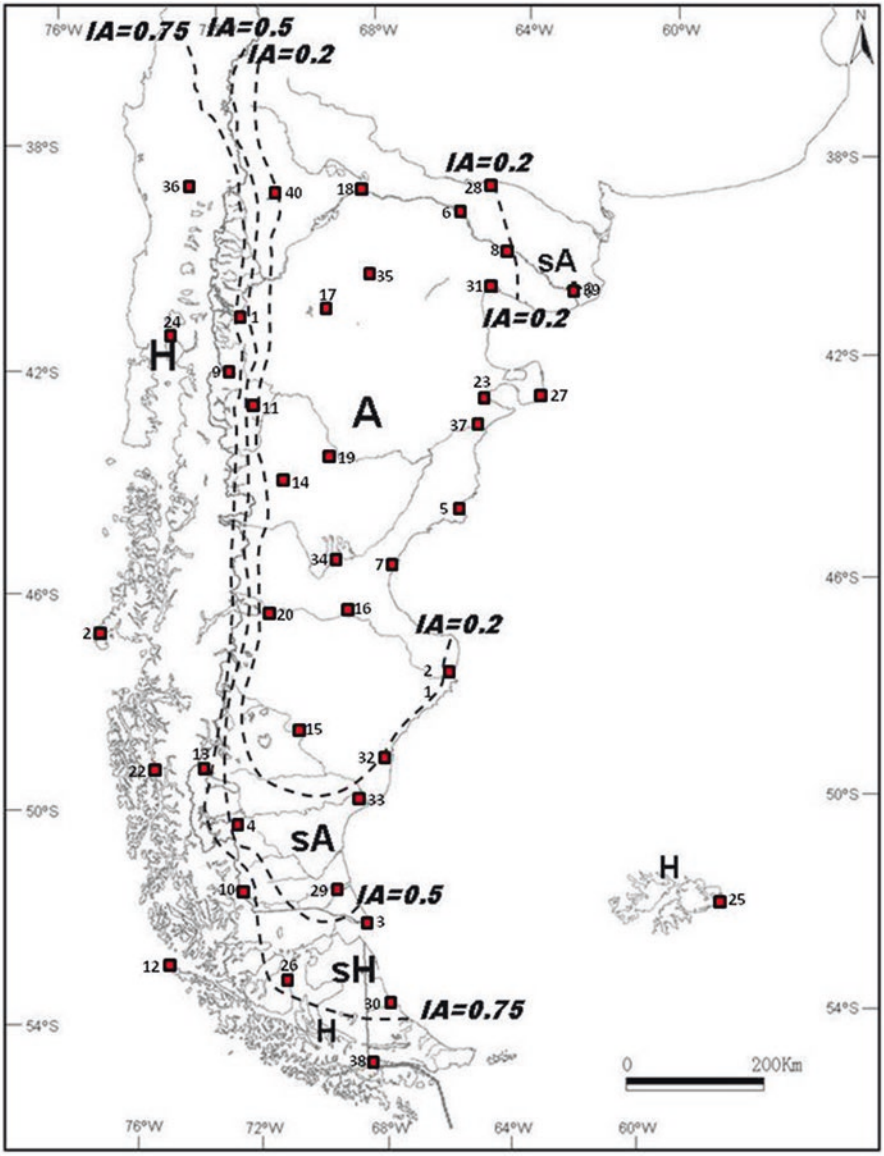

Fig. 3.4 Aridity index in Patagonia (see footnote 1)

located would present a cold temperate climate, rather continental and with a moderate annual rainfall amount (a Cfb or Dfb climate in Köppen's classification). Instead, eastern Patagonia exhibits a temperate dry climate with moderate annual temperature range; that is, a BSk climate or even a BWk in drier areas. The same arid climates span beyond the northern border of Patagonia, on the plains of

Mendoza and eastern Andean foothills, and cover—or indeed define—the Monte Desert biome, stretching up to 25° S and connecting to the South American Arid Diagonal, of which—in fact—Patagonian steppe is the southernmost link.

The uniqueness of rain-shadowed east Patagonian climate is reinforced by the sharp contrast with western Patagonia, which displays an oceanic climate (Cfc) a little colder than its counterparts elsewhere in the world, especially because of the lack of real summer heat (Weischet 1985). North of the 37° S parallel, where a dry period begins to appear during summertime, the Cf climate gives way to Cs climate, Csb first and Csa further north as summer becomes hotter. This is the core of the Mediterranean climate of central Chile (Fig. 3.1).

North of the 51° S parallel the Cfc climate is restricted to the Pacific coast and the west flank of the Andes but further south it stretches all across the continent until the Atlantic coast so as to include the Falkland Islands as well. The southernmost areas of Tierra del Fuego, where summer mean temperature does not surpass 10 °C, have thus an Em climate clearly marked by the lack of heat.

On the opposite end, as it can be seen on Fig. 3.3 north of 40° S, where westerlies fail, a less arid area appears eastward owing to the last regular rainfalls originated in the Atlantic Ocean. In this semiarid area, as rainfall increases northward the BSk climate tends toward a subhumid Cwa climate with some continental features. According to the flat topography, climatic transition is extremely gradual, so the northern border of Patagonia is really ill-defined on earth as in sky.

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