

# The Climate of Península Valdés Within a Regional Frame

Fernando Coronato, Natalia Pessacg and María del Pilar Alvarez

**Abstract** Peninsula Valdés shares with the whole of Eastern Patagonia the main features of the regional climate, i.e. scarce rainfall, strong winds and cool-temperate temperatures. Not with standing it has an ill-defined climate because of its geographical location not far from the transitional area, where Pacific and Atlantic air masses merge. Also, because of its latitude ( $42^{\circ}$ – $43^{\circ}$  S), the southward migration of the subtropical anticyclones is still noticeable over the area in summer. This chapter aims to explain the interplay between large scaled factors as the above-mentioned, and local ones as the almost insularity of the study area. A concise description of the climate is presented through the usual basic elements, temperature, precipitation, and wind. The maritime influence upon these variables is evaluated. It is shown that although mostly commanded by the rain-shadowed westerlies as the entire Patagonia, the climate of Peninsula Valdés has singularities that make it a less arid, more even, and milder climate which presents some Mediterranean features. Historic trends of rainfall and temperature are discussed and appear to be in agreement with global warming projections, according to which future scenarios would be drier and warmer in the Península Valdés region.

**Keywords** Climatic gradient · Temperature · Precipitation · Wind · Oceanity

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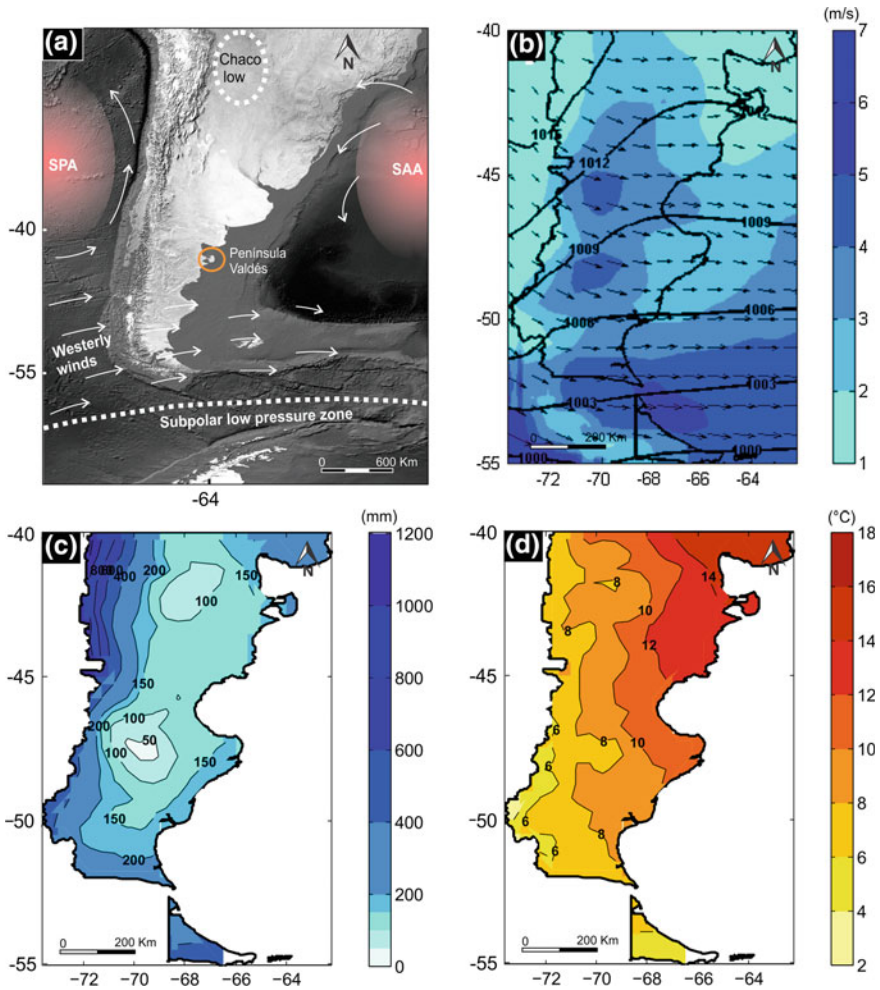
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# 1 The Climate of Patagonia

Patagonia, the southern tip of South America, extends from 40° S—where the continent is 1000 km width—and gradually narrows until disappear in Cape Horn at 56° S. This region is the only continental mass in the Southern Hemisphere that intersect the mid-latitude *westerlies* (Fig. 1a, b), which strongly influences the atmospheric circulation at lower and upper levels and consequently the climate of the region (Zhu et al. 2014).



**Fig. 1** a Major climate features of southern South America; b wind direction (*arrows*), intensity (m/s, shaded), and mean sea level pressure (hPa, *black line*) from ERA-Interim reanalysis (European Centre for Medium-Range Weather Forecast—ECMWF-), average 1980–2009; c precipitation (mm/a) d temperature (°C) at 2 m from CRU dataset (Climate Research Unit, University of East Anglia), average 1980–2009

Patagonia is also located north of the subpolar low pressure trough and between two semi-permanent anticyclones systems at 30° S approximately. One is located over the South West Pacific and the other over the South Atlantic Ocean (Prohaska 1976; Paruelo et al. 1998; Fig. 1a). The strong pressure gradient between both belts generates the strong upper-air westerly jet (Hobbs et al. 1998; Lenaerts et al. 2014).

The climate of regions located at mid-high latitudes is primarily influenced by the physical features of the surface such as the topography, distribution of land and sea, and the extent and concentration of sea ice. In Patagonia, the Andes Mountains strongly affect the regional climate by blocking the disturbances embedded in the westerly flow (see Chapter “Climatic, Tectonic, Eustatic and Volcanic Controls on the Stratigraphic Record of Península Valdés”), producing the precipitation over this area and influencing wind patterns and precipitation in the whole region (Insel et al. 2010). South of 40° S the Andes rarely exceed 3 km height and consequently the Pacific air masses are dominant in the region (Labraga and Villalba 2009). Uplift on the west side of the Andes leads to hyper humid conditions, while downslope subsidence dries the eastern plains leading to arid and highly evaporative conditions (Garreaud et al. 2013). At the same latitude of the Peninsula Valdés but in western Patagonia, there is a very strong precipitation gradient, ranging from 6000 mm/a on the Chilean coast to less than 300 mm/a in Argentina, just a few tens of kilometres leeward the Andes (Smith and Evans 2007). Thus, in Argentine Patagonia the maximum precipitation is located close to the Andes, between 40 and 45° S, and the west-east gradient in this region is from 1500 mm/a close to the mountain range to 150 mm/a the Atlantic coast (Fig. 1c). As in most arid and semiarid mid-latitudes regions of the world, precipitation is related to *frontal activity* (Jobbágy et al. 1995; Bell 1981). Yet, since the forcing of frontal rainfall is dynamical, the annual cycle of precipitation in Patagonia is not as pronounced as at lower latitudes, with thermodynamic forcing (Garreaud and Aceituno 2007).

In Patagonia as a whole, precipitation is concentrated from May to October and, on average, 46% of it falls during the three winter months, i.e. June–August (Labraga and Villalba 2009; Jobbágy et al. 1995). Such concentration is related to the intensification and equatorward shift of the *stormtrack* (preferred path of *synoptic-scale disturbances*) and the subtropical anticyclones during this season, which increment the frequency of Pacific synoptic perturbations (Garreaud and Aceituno 2007). There is a clear relationship between winds and precipitation, since stronger westerlies increase the local precipitation in western Patagonia whereas decrease local precipitation east of the Andes (Garreaud et al. 2013).

In northeastern Patagonia, where some influence of Atlantic air masses is noticeable, precipitations are more evenly distributed throughout the year (Jobbágy et al. 1995). The South Atlantic Ocean may also be an additional source of moisture during intense precipitation events over this region (Agosta et al. 2015).

In regard to surface temperature, the spatial pattern of this variable is characterized by a gradient northeast-southwest (Fig. 1d), related to both latitude and altitude effects. Mean annual values range from 15 °C in the northern sector to 4.5 °C in Tierra del Fuego and southern Andes. East to the Andes, the north-south temperature

gradient is stronger in summer due to the stronger continental warming in the north, leading to a north-south pattern of temperature variability (Berman 2012). On the contrary, in winter, the high-pressure systems which expand to the east of the Andes lead to intense southerly advections of cold air over most of east Patagonia and thus the temperature variability east of the Andes is less marked during this season (Müller et al. 2005; Berman 2012).

In much of Patagonia temperature pattern is correlated to wind. Persistent and strong westerlies throughout the year will result in a decrease of the amplitude of the local air temperature annual cycle. Besides, the strong winds reduce the perceived temperature (i.e. wind chill), and because of higher wind speed in summer the wind-chill effect is more pronounced during this season driving to cool felt summers (Coronato 1993).

The cloud coverage in Patagonia is almost permanently high, particularly over the southern part of the region during summer due to the intensification of the westerlies. The southward shift of the subtropical anticyclone leads to a decrease of cloud coverage over northern Patagonia during summer (Castañeda and González 2008).

## ***1.1 Influence of Large-Scale Variability Modes***

Understanding the climate variability in Patagonia is relevant on one hand due to effect in the mechanisms that govern the circulation of the extratropical Southern Hemisphere, and on the other hand because of the impact of such variability in the *cryosphere*, biosphere and society (Garreaud et al. 2013). In particular, the variability of rainfall in dry areas of Patagonia induces changes in different processes as desertification, water erosion and soil compaction, which influence the human activities and increase the climate vulnerability of the region (Berman et al. 2013).

The *Southern Annular Mode* (SAM) is the leading pattern of year-to-year circulation variability at high latitudes in the Southern Hemisphere. The SAM describes the north-south movement of the westerly wind belt surrounding Antarctica (negative and positive phase of the SAM, respectively) (Kidson 1988; Karoly 1990). The changes in the position of the westerly wind belt influences the strength and position of cold fronts which in turn influences the seasonal and annual mean temperatures in the east of Patagonia (Gillett et al. 2006; Garreaud et al. 2008; Silvestri and Vera 2009). The positive phase of the SAM is related to anomalously warm and dry conditions in southern Argentina south of 40° S, related with the southward shift of the stormtrack (Gillett et al. 2006). Garreaud et al. (2013) found a correlation between the SAM and the circumpolar anomalies of zonal flow at mid-and high latitudes which in turn lead to precipitation anomalies in Patagonia during summer. In contrast, during winter there is a low correlation between SAM and precipitation anomalies.

The other two leading patterns of circulation variability in the Southern Hemisphere are the Pacific South American modes PSA1 and PSA2, respectively

(Kidson 1988). Both models are wave trains extending from tropical Pacific to the extratropical regions of the Southern Hemisphere. These modes of variability show a large correlation with *El Niño-Southern Oscillation* (ENSO). In fact, some authors described that the dynamics of the tropical signal ENSO is transported to the higher latitudes via the PSAs modes (Turner 2004).

Different studies have found that the interannual variability of temperature in Patagonia is related to the ENSO phases. The El Niño events are negatively correlated with the temperature in Patagonia during spring (Garreaud 2009). This is in good agreement with the results of Rusticucci and Vargas (2002), which showed a persistence of cold air masses over Patagonia during these events.

On the other hand, González and Vera (2010) and González et al. (2010) found an influence of the Pacific sea surface temperature in the interannual variability of winter precipitation over northwest of Patagonia. Besides, Garreaud (2009) found a positive correlation between precipitation in Patagonia and El Niño events for the period March–November. This is in line with a simultaneous and positive correlation between the streamflow and El Niño events for the rivers of north of Patagonia (Campagnucci and Araneo 2007). The variability of precipitation over the Andes of Patagonia during ENSO events is in part explained by changes in westerlies during these periods (Schneider and Gies 2004).

Berman et al. (2013) found that the precipitation in central-north Patagonia is positively correlated with precipitation over the surrounding Atlantic and southeast of South America. The increase of rainfall over the central-north Patagonia is related to the weakened westerly flow over the region and the consequent increasing of Atlantic air flow.

Temperature in Patagonia also exhibits variability on intraseasonal scales (1–3 months). Jacques-Coper et al. (2015a) found that the intraseasonal variability modulates the strong and persistent warm conditions in the east of Patagonia. Besides that, Jacques-Coper et al. (2015b) analyzed the relationship between the intraseasonal air temperature variability in eastern Patagonia and the Madden–Julian Oscillation (Madden and Julian 1971)—main mode of intraseasonal variability of the coupling between atmospheric circulation and tropical convection. The authors showed evidence that the amplitude of the intraseasonal component of temperature in eastern Patagonia is modulated in 1.5 °C approximately for the Madden–Julian Oscillation. Besides that, the authors found that one of the eight phases of this oscillation induces warm conditions and favour heat waves in eastern Patagonia.

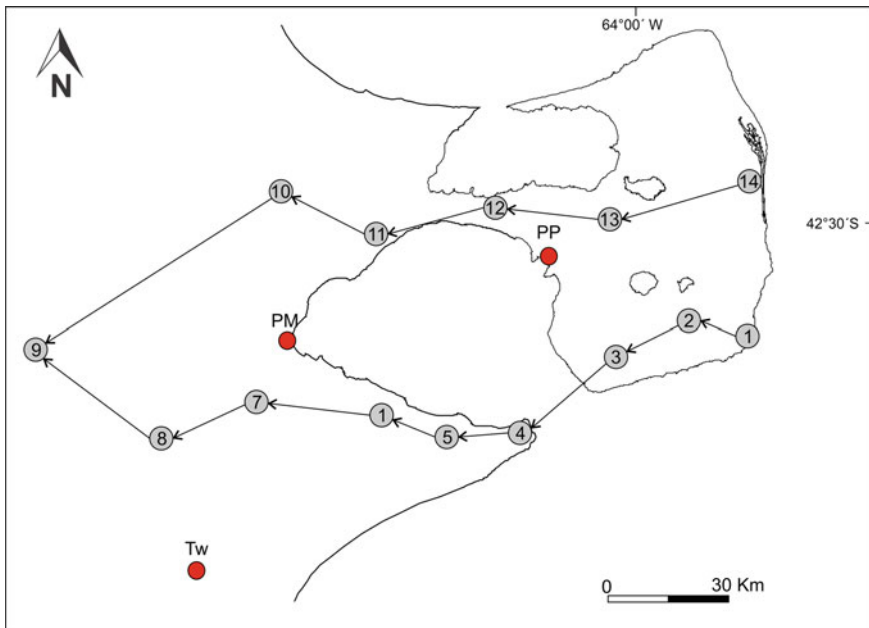
## 1.2 *Climate Change in Patagonia*

Many studies in the last years have addressed the analysis of the climate global change observed during the twentieth century and projected for the twenty-first century, mainly as a consequence of the anthropogenic activity. These activities result in a constant increase in the greenhouse gases concentration in the

atmosphere, which in turn drive to rising global annual mean surface temperature (IPCC 2013).

In most of the Patagonia there is a clear warming since 1950 (Rosenblüth et al. 1997; Boninsegna et al. 2009; Villalba et al. 2003; Vincent et al. 2005). This warming would have been higher than in the rest of Argentina (Barros et al. 2014). In average, the mean annual temperature increased 0.4 °C in the last 50 years, being the rising up to 1 °C in some areas, whereas minima and maxima temperatures increased, respectively, 0.4–0.8 °C and 0.5 and 1 °C depending on the area. However, in the northeast, where the Peninsula Valdés is located, Rusticucci and Barrucand (2004) and Barros et al. (2014), observed a negative linear trend for the minimum temperature and a positive one for the maximum temperature. Coronato and Bisigato (1998) showed that the weather station of Trelew, at 150 km approximately of the study area (Fig. 2) is the one that better depicts the year-to-year trend of temperature in the entire Patagonia. Also, clear regional trends in extreme temperatures were found, evidenced by a decrease in the number of cold days and nights and an increase of warm days and nights since 1960 (Rusticucci and Barrucand 2004).

With reference to precipitations, not significant changes were observed in the last 50 years in most of Patagonia and throughout the region interannual variability overrides changes in long term. However two exceptions appear: decreasing of precipitation over the northern Andes and increasing rainfall in the northeast of the



**Fig. 2** Location map of two east-west transects of the interpolated points (grey dots) listed in Table 2. Red dots correspond to: PP Puerto Pirámides; PM Puerto Madryn; Tw Trelew

region including the Península Valdés (Castañeda and González 2008; Masiokas et al. 2008).

The projections performed with different models (General Circulation Models and Regional Climate Models) and for different scenarios, estimate for Patagonia a warming between 0.5 and 1 °C for the near future (2015–2039) and a warming between 2.5 and 3 °C for the far future (2075–2099) (Barros et al. 2014). The greatest warming is projected for February while the smallest is for April (Nuñez et al. 2009).

Regarding the precipitation, the different scenarios and models project less precipitation over Patagonia for both near and far future in the order of 0–10 and 10–20%, respectively. Diminishing is important in the Andes over the climatological rainfall maximum, and it is related to the shift of the Pacific Ocean stormtrack (Blázquez et al. 2012). Moreover, less rainfall in the Andes is important in terms of hydrological ecosystem services since the major river basins of Patagonia have their headwaters in that mountain range.

In the last decades, a few studies analyze the climate change in Patagonia through fossil records. Among them, Villalba et al. (2012) performed reconstructions of SAM indices from tree rings in the Southern Hemisphere extratropics. These authors found that the SAM pattern has a high frequency of positive phases since the 1950s that is exceptional in the past 600 years and is connected with a south shift of the westerlies. This change in the winds pattern impacts in the temperature and precipitations pattern. Besides, the tree growth is related not only to the increase of greenhouse gases but also to the ozone depletion in the stratosphere at high latitudes and the internal variability of the atmosphere (Ablaster and Meehl 2006; Deser et al. 2012; Gonzalez et al. 2014).

## 2 Climate of Península Valdés

### 2.1 Climatic Singularities of Península Valdés

Not many geographical features in the world meet so accurately the etymology of the word “peninsula” such as Valdés does. Indeed, since Península Valdés is “almost an island” it is not surprising that its climate displays insular characteristics that differ from the adjacent mainland. According to its latitudinal location, the Península Valdés (42–43° S) falls within the southern westerlies belt that spread Pacific influence all over Patagonia. However, latitude is not high enough so as to avoid a quite evident subtropical anticyclonic influence during the summer, noticeable up to 45° S (Fig. 1a). Because of sunnier and dryer summers some authors consider that northeastern Patagonia has a marginal Mediterranean climate (Le Houerou 2005). Yet, owing to the eastern location within the Patagonian context, stronger anticyclonic (Atlantic) influence means increasing flux of NE winds on the area, which may carry episodic heavy rains, penetrating little inland. So, on one hand there is the Mediterranean-like dry summer affecting northern

**Table 1** Maritime influence as reflected by temperatures (°C)

Location	Mean temperature	Annual temperature range	Days of frost	Absolute minimum
Punta Delgada	12.5	10.4	6.4	-4.9
Puerto Madryn	14.0	14.0	43	-11.6

Patagonia from coast to coast, while on the other hand, the most eastern locations (i.e. the Península Valdés) may benefit of sporadic rainfalls of Atlantic origin.

As result of the twofold origin of rainfall in the area, the intra-annual rainfall is more evenly distributed than in westwards locations, even if (as elsewhere in central Patagonia) the autumn peak is still noticeable.

Rather than the rainfall distribution along the year, it is the thermal regime that better reflects the influence of the Atlantic Ocean on the climate of the Península Valdés. Every temperature-based index shows clearly a strong gradient between the more exposed eastern locations and the inner ones. A cursory comparison between basic temperature data (series 1959–1968) from Punta Delgada and Puerto Madryn (Fig. 2) is enough to grasp the climatic differences at both ends of a 110 km-long transect (Table 1).

More detailed transects can be drawn from De Fina et al. (1968; Table 2, Fig. 2). These authors worked with carefully interpolated data checked with local and official records (SMN, Servicio Meteorológico Nacional) from the period 1951–1960. Both east-west transects show increasing continentality towards the west as well as decreasing yearly rainfall amount. It can be noted that no point within the Peninsula Valdés is located above 100 ma.s.l. (no climatic data from central depression [-40 mb.s.l.] are available; Table 2). Owing to the flat or gently undulating relief, no marked topoclimatic influence exists and observed differences stem on larger scale factors, mainly distance to the sea. Only further inland, westwards of the Peninsula Valdés, the gradually increasing altitude may become a noticeable topoclimatic factor, yet partially counteracted by the plateau-like relief (Coronato 1994). This could be seen in the change in the trend to higher summer temperature observable in the west end of the transects presented on Table 2.

Trend towards less maritime conditions westwards are observed not only in temperature patterns but also in less evenly distributed and less abundant rainfall (Table 2).

The maritime influence all over the Peninsula Valdés and its swift decreasing further inland are clearly evidenced by the diverse isolines mapped in Fig. 3. This is noticeable not only in the plain annual temperature range (Fig. 3a) but also in the more subtle asymmetry and phase lag in the temperature curve, usually assessed by simple difference between April and October mean temperatures (Fig. 3b), as well as in more elaborated calculations as Daget Continuity index (Fig. 3c) and even in no temperature-related parameters, as absolute humidity (Fig. 3d). The Daget Continuity Index (CI) (Daget 1968) is defined as follows:



**Table 2** Calculated figures based on Punta Delgada and Puerto Madryn data. Ea: Estancia (farm, inhabited spot)

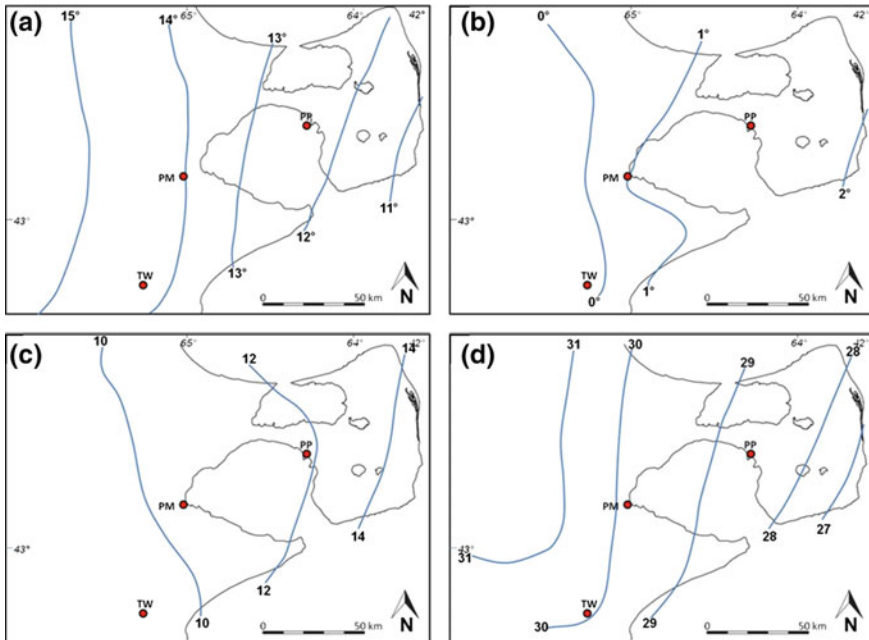
	Location		Mean January temperature (°C)	Mean July temperature (°C)	Elevation (m.a.s.l.)	Annual rainfall (mm)	Winter months rainfall (mm)
South transect	1	Punta Delgada	17.4	6.8	54	236	64
	2	Ea. La Pastosa	17.8	6.9	40	230	62
	3	Ea. La Cantábrica	18.3	6.7	30	220	60
	4	Ea. El Pedral	19.0	6.7	18	206	57
	5	Ea. Muzio	19.1	6.3	78	196	52
	6	Ea. Urtazun	19.5	6.3	83	182	46
	7	Km 11	20.0	6.0	113	169	40
	8	Ea. El Confort	19.9	5.3	160	160	33
	9	Sierra Chata	20.3	5.2	187	149	33
North transect	10	Ea. Valdés Creek	18.3	7.0	30	251	64
	11	Ea. La Ernestina	18.6	6.8	53	203	53
	12	Ea. Iriarte	19.6	7.0	10	168	44
	13	El Desempeño	19.7	6.5	87	163	41
	14	Ea. Dos Naciones	20.5	6.3	95	158	38
	9	Sierra Chata	20.3	5.2	187	149	33

Data from De Fina et al. (1968)

$$CI = [1.7 A / \sin(\varphi + 10 + 9 h)] - 14$$

where  $A$  = annual temperature range;  $\varphi$  = latitude;  $h$  = absolute altitude in km.

The values of every one of the parameters above over the Peninsula Valdés are among the highest figures along the Patagonian Atlantic coast north of 48° S according to the maps presented by Coronato (1994). Sensible maritime influence coupled to mild temperatures make climatic risk much lower than in the rest of Patagonia to the greatest advantage of sheep farming in the area.



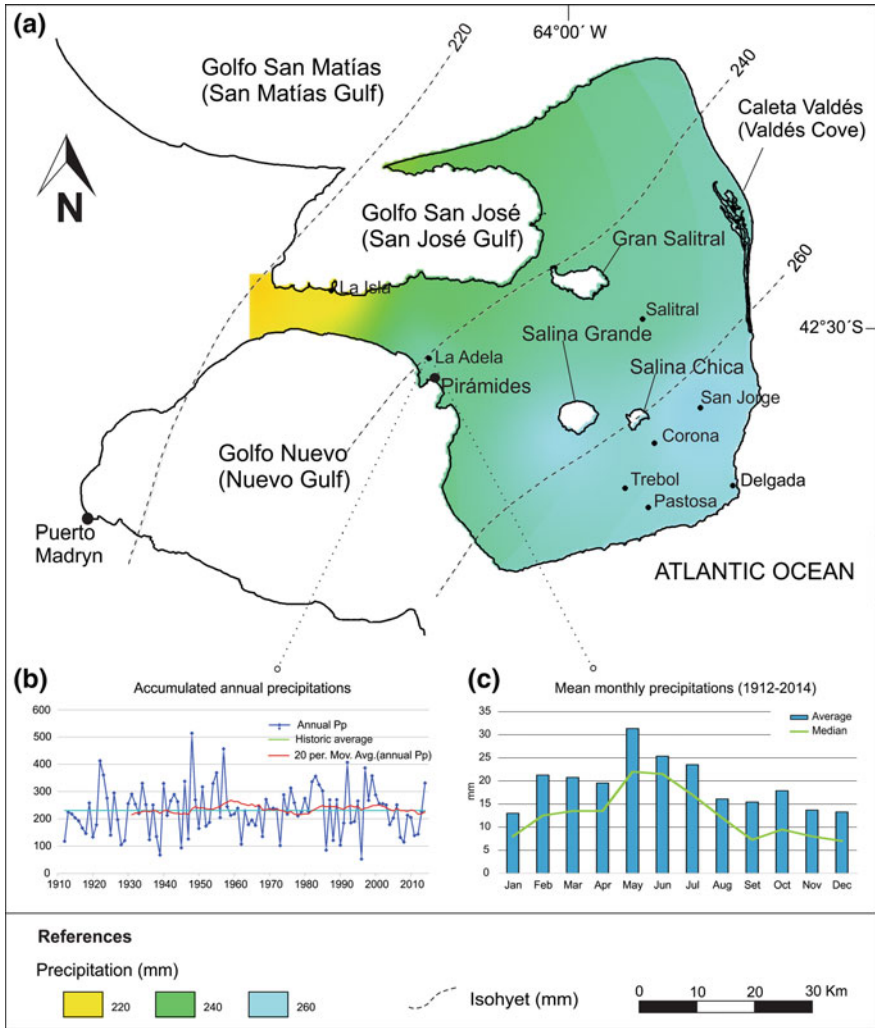
**Fig. 3** Maritime influence on Peninsula Valdés climate. **a** Annual temperature range; **b** Autumn-Spring thermal difference; **c** Mean vapor pressure (Jan, hPa); **d** Daget's Continentality Index (from Coronato 1994); *PP* Puerto Pirámides; *PM* Puerto Madryn, *TW* Trelew

## 2.2 Characterization of Península Valdés Climate

### 2.2.1 Precipitation

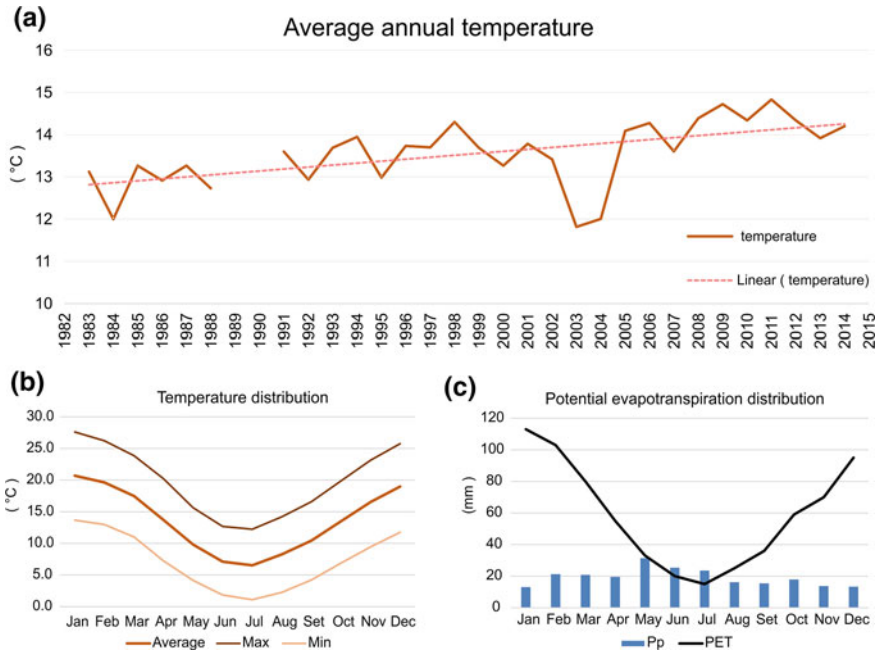
Spatial distribution (1979–1992) of rainfall over the Península Valdés presents a west-east gradient since precipitation increases towards the Atlantic shore; annual average is 218 mm at the isthmus (Ea. Iriarte) and from there gradually increases eastwards beyond 260 mm on the external shore (Fig. 4). It should be noted that the meteorological station located in Puerto Madryn, has always recorded accumulated rainfall averages lower than those of the stations in the Península Valdés regardless of the selected period. This increase towards the Atlantic has been interpreted as due to the influence that adjacent water bodies (Atlantic Ocean, Nuevo Gulf and San José Gulf), generated on the rainfall amount (Barros et al. 1979). The prevailing S and SW winds running through the gulfs and the ocean are moisture loaded and thus generate some increase of rainfall amount, respect to the values registered in the stations westwards in the study area.

The longest rainfall record of the region (Ea. La Adela, 1912–2014) shows a mean annual precipitation of 230.8 mm and a pattern that highlights the high interannual variability (Fig. 4). Although most of the mean annual precipitation



**Fig. 4** a Isohyetal map of the Península Valdés region, b precipitation trend in Ea. La Adela, c Mean monthly precipitations in Ea. La Adela. The climatological records gathered by Instituto Nacional de Tecnología Agropecuaria (INTA), Servicio Meteorológico Nacional (SMN), Centro Nacional Patagónico (CENPAT) and from the mapped farms in the area

values are within the 100–300 mm/a range, there are some years of very low precipitation (about 50 mm) and other with exceptionally high values (>500 mm; Fig. 4). As an example, an extreme case of variability occurred in 1947/1948, when the variation from 1 year to the next was 388 mm (126 and 514 mm, respectively). This versatility in the rainfall amount is typical of the arid climates, in which storm effect can markedly alter the expected annual value.



**Fig. 5** a Temperature historic trend of Península Valdés region, b Mean monthly temperatures, c Mean monthly Potential Evapotranspiration (PET). Data from the Centro Nacional Patagónico (CENPAT) station

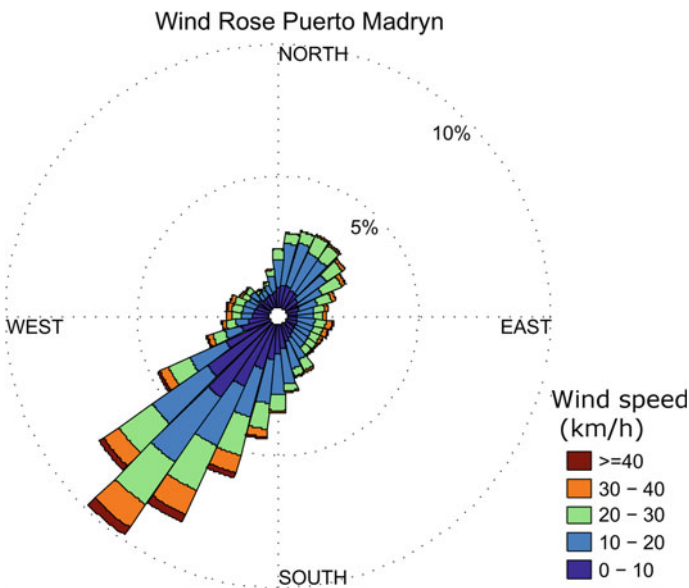
A 20-year moving average line was included in the graph (Fig. 5) to smooth out short-term fluctuations and highlight longer term trends. It can be observed that there is not a uniform tendency for the whole period, but the alternation of humid and dry periods can be recognized all along the record.

The annual distribution of the mean monthly precipitations shows a wettest period in May–July and a drier one in November–January, even if from September the values are already low. The existence of a high variability in the records for the same month within the analyzed period, makes the distribution of the mean monthly precipitations being affected by extraordinary storms. A strong single precipitation event could generate great space and time variations of the mean values distributions. To avoid this, the analysis of median values allows to smooth the variations and confirms the existence of a wetter period between the autumn–winter seasons. Similar monthly precipitation patterns are recorded in other farms of Península Valdés, showing in some cases that the rainy period is slightly displaced to March and April.

### 2.2.2 Temperature

Temperature records are much scarcer than the rainfall ones and only the Puerto Madryn station has a record long enough to be representative (more than 20 years); the official meteorological station located in within the Península Valdés itself (i.e. Ea. Punta Delgada) has a 10-year long record but stopped in 1968. According to Puerto Madryn records, the average annual value (1983–2014) is 13.6 °C, and the mean annual temperatures show a clear upward trend, since values were between 12 and 13 °C in the beginning of the period but reached 14 and 15 °C by the end of the period (Fig. 6a), which is in agreement with the Patagonian warming mentioned above. As for the annual distribution of mean monthly temperatures, the coldest month correspond to July, with an historical average of 6.4 °C, while the warmest correspond to January, with a historical average of 20.4 °C. As can be seen in the thermogram (Fig. 5b), the average values of the maximum and minimum monthly temperatures accompany the annual average temperature cycle. July has the low minimum temperature: 1 °C, and January the high maximum temperature: 27.5 °C. Absolute minimum temperatures at both ends of the study area were shown in Table 1. With respect to the average temperature range, it is lower in the winter months, with values of 10.8 and 11.1 °C for June and July, respectively, and reaches the maximum values in summer, with values of 14.0 and 13.9 °C for December and January.

Regarding the temperature records of the stations located within the Península Valdés (Punta Delgada excepted), although they are very restricted in terms of



**Fig. 6** Puerto Madryn wind rose (Data from CENPAT station: 1982–2010)

length, the annual distribution of the figures is the same as for Puerto Madryn (Alvarez 2010). This is due to the fact that the latter is located at the same latitude and that the temperature variable is much more homogeneous than the precipitation. The only discernible differences stem on the influence of the sea, as seen in Sect. 2.1.

### 2.2.3 Wind

As mentioned above, the prevalent atmosphere circulation in the region is strongly influenced by the presence of two large high-pressure systems or quasi-stationary anticyclones located on both sides of the continent, and a belt of low pressure, located at about 60° S (see Fig. 1a). The persistence of these pressure systems throughout the year determines an overwhelming proportion of westerly winds (NW-W-SW), although the frequent change of position of the migratory cyclones produce fluctuations in wind direction and intensity (Labraga and Davies 2014).

Although there are no records long enough in the Península Valdés, the wind trend of Puerto Madryn (CENPAT station records) shows the effect of these pressure systems (Fig. 6). The southwestern winds dominate throughout the year, even though it is possible to observe the incidence of the Atlantic anticyclone by the presence of NE winds (Fig. 6). With respect to the velocities, the annual average is 16.2 km/h with a maximum in December of 19.4 km/h and a minimum in May 11.4 km/h (Labraga and Davies 2014).

A study of the migration of the dunes of the southern sector of the peninsula (Del Valle et al. 2008), based on the analysis of its geomorphology, together with the interpretation of wave trains from ERS 1–2 imagery, allowed to define the existence of a bi-directional pattern in which the high prevalence of N wind is not found elsewhere in Patagonia. The orientation of the dune fields in the Valdes Peninsula (WNW–ESE) responds to intermediate conditions in wind direction, between the west wind prevailing towards the west and the north wind prevailing towards the east. In agreement with its easternmost location, Punta Delgada records (1959–1968) show 37% of N and NE winds.

### 2.2.4 Evapotranspiration

In the Península Valdés the annual *potential evapotranspiration* (PET) estimated by Thornthwaite-Mather method (1957) is 704 mm/a. Its intra-annual distribution is in direct proportion to the march of the monthly average temperatures, thus the highest values correspond to the summer months, and the lowest to the winter months (Fig. 5b, c).

When the goal is the estimation of the aquifer recharge, instead of the climate characterization, the real evapotranspiration should be calculated differently (see Chapter “Groundwater Resources of Península Valdés”). In that case, as the storm events have a high influence in the recharge phenomena, a soil-water balance in

daily step should be carried on to estimate the daily real evapotranspiration (Carrica 2009). Otherwise from the monthly balance could erroneously be conclude that there is no water recharge given that there are no excesses in any month of the year because the PET is always higher than the precipitations (Alvarez et al. 2013).

### 2.3 Climate Classification

Patagonia fits especially bad in general climatic classifications mainly due to the uniqueness of being a definitely arid region located on the eastern (lee) coast of a continent at mid-latitudes (Coronato et al. 2008). This arrangement of factors, not repeated anywhere else in the world, can certainly be attributed to the rain-shadow effect (see Chapter “Climatic, Tectonic, Eustatic and Volcanic Controls on the Stratigraphic Record of Península Valdés”) created by the Andean Range and extending to the Atlantic shores.

The other major geographic factor affecting Patagonian climate is the Drake Passage that significantly warms the Antarctic air masses that reach South America, which, for this reason, has much milder winters than homologous east-located areas in North America at the same latitudes.

As already seen, the Península Valdés exhibits an original set of climatic parameters within the already original Patagonian climate. The persistent westerly flux, the scarcity of rainfall and the quite marked range of temperature that are common throughout the Patagonian foreland, are noticeably attenuated because of the maritime (Atlantic) influence resulting from the indented coastline.

In most of Eastern Patagonia, there is no doubt that—according to Köppen-Geiger-Pohl (Geiger and Pohl 1953) Köppen’s classification—climate is *B* (arid) in first term and *k* (cool) in the third term. Referring to the second term, it is certainly *W* (desert) in drier areas but becomes *S* (steppe) in the sub-Andean fringe, and towards the Magellan Straits (when eventually first term becomes *C* since climate turns to *Cfc* (i.e. temperate well-watered climate with cool summers). In the Península Valdés, all the climatic parameters related to moisture (Fig. 3) reflect less arid conditions compared to the adjacent mainland. Because of this decrease in aridity some maps of the Köppen-Geiger climatic classification consider the Península Valdés as *Bsk* while the adjacent mainland falls within the *BWk* class. Beyond the transitional climatic position of the Península Valdés, Viedma (<150 km towards northeast) is definitely considered *Bsk* in every map and/or classification.

Climate differences between the Península Valdés region and the adjacent mainland are also observed by analyzing the values of aridity index ( $AI = p/ETP$ ; where  $p$  = precipitation and  $ETP$  = potential evapotranspiration). Comparison of the aridity index in Punta Delgada and Puerto Madryn (0.26 and 0.19 respectively) reflects that both points fall in different ranks, considering that the upper limit of arid conditions is  $AI = 0.20$  (MAB 7 1977). However, other authors place the arid/semi-arid limit at  $AI = 0.3$  (Le Houerou 2005), and therefore range differences

disappear. All in all, the lack of climatic definition showed by the two examples above, allows confirming the transitional characteristic of the Península Valdés climate, which, in fact, may vary from year-to-year from arid to semi-arid and vice versa. These transitional features, not only in rainfall amount but also in seasonal distribution, may explain the Península Valdés ill-defined belonging to one or another phytogeographical district, namely Monte or Patagonia (León et al. 1998).

As stated before, because of the prevalent trend of winter rains manifested throughout Patagonia north of 47° S, the regional climate may be considered like a (cooler, drier and more windy) Mediterranean bioclimate. According to the “Mediterraneity Index” (MI) defined as the ratio between winter trimester rainfall and summer trimester rainfall<sup>1</sup> (Le Houérou 2004), Punta Delgada has a sub-Mediterranean climate (MI = 1.9) while Puerto Madryn and Trelew have an attenuated Mediterranean climate (MI 1.1 and 1.4, respectively). Needless to say, higher figures (MI > 2) are found towards west and south, where rains from the Atlantic Ocean become negligible.

### 3 Perspectives and Future Work

The transitional climate of Península Valdés, not far from the boundary between Atlantic and Pacific circulation realms, makes the area an interesting spot to monitoring global climate change and regional vegetation shift. Thus, the major concern should be to overcome the current lack of long-term systematic observations in the area. Doubtless, continuity and consistence in meteorological records are paramount in any future work on climatic or ecological research in Península Valdés.

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### Glossary

Cryosphere	Are those portions of Earth’s surface, where water is in solid form, i.e. water bodies ice, snow cover, glaciers, ice sheets and frozen ground. It plays a significant role in the global climate
ENSO	(El Niño–Southern Oscillation) Is an irregularly periodical variation in winds and sea surface temperatures over the tropical eastern Pacific Ocean, affecting much of the tropics and subtropics

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<sup>1</sup>Ranges of “Mediterraneity” are: MI > 2 Mediterranean climate; 2 > MI > 1.5 sub-Mediterranean; 1.5 > MI > 1 attenuated Mediterranean; MI < 1 non-Mediterranean.



Frontal activity	Sharp discontinuities of temperature, moisture and wind properties caused by the displacement of boundaries between air mass (fronts), set in motion by low pressure cells and often entailing storms and rainfall
PET	(Potential Evapotranspiration) Maximum quantity of water capable of being evaporated in a given climate from a continuous stretch of vegetation covering the whole ground and well supplied with water
Storm Tracks	Relatively narrow zones in oceans where cyclone-generated storms travel driven by the prevailing winds. Cyclones from the circumpolar storm track in the Antarctic Ocean may derive northward and affect Patagonia
Synoptic-scale disturbances	Are those fit in a horizontal length scale of the order of 1000 km or more. This corresponds to a horizontal scale typical of mid-latitude depressions
Westerlies	Prevailing flux from the west in the mid-latitudes emanating from the polarward sides of the subtropical high-pressure cells. Those of the southern hemisphere are stronger and more constant

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