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Climatic Constraints for the Development of the Far South of Latin America

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Abstract: The climatic constraints of the southernmost tip of South America (45° S to 57° S) is examined and compared with the corresponding latitudes in the northern hemisphere.

Southern summers are cooler than northern summers by 5.5 to 6°C owing to subantarctic influences and constantly-blowing oceanic winds. Although frost and snowfall are less common than in the northern hemisphere, they can occur well into the summer months. Cold air exports from the antarctic and the location of the antarctic convergence near 60° S explain the steady coolness of ocean and air masses. The constant winds cause tree deformations and inhibit vegetation growth because of the negative influence that winds faster than 4 m/sec have on photosynthesis efficiency. The absence of long-lasting warm summer periods that would stimulate plant growth is due to scarce or weak anticyclonic thrusts and to the permanent west wind drift. To be added to this is a chronic shortage of air humidity on the eastern slopes of the Patagonian Andes and plains which again curtails crop growth. On the western slopes, on the other hand, continuous orographic rains prove also a hindrance to cultivation. Therefore, only north of 42° S do conditions for permanent cultivation become optimal.

The area to be dealt with comprises the Southern Cone from its southernmost tip near 56° S up to about 40° S, which, from a solar-climatical point of view, is regarded as the equatorial boundary of the upper middle latitudes and the poleward margin of the subtropics. The borderline between the two can be drawn – according to H. Louis' (1958) general proposition – between 42° and 45° S. Under undisturbed radiation conditions, insolation at the Strait of Magellan (ca. 53° S) is similar to that of Bremen or Hamburg (Germany) or central British Columbia (Canada), and insolation on the borderline between the subtropics and the upper middle latitudes resembles that of central Oregon or central Italy/N Spain.

An orographic feature of great climatical significance is the Cordillera de los Andes, which, in the extreme south of the continent, averages between 2,000 and 2,500 m of elevation, and between 45° and 40° S ranges from 2,800 to 3,800 m.

From a dynamic-climatological view, and within the general atmospheric circulation, the Far South is characterized by its year-round exposure to the S-hemispheric cyclonic W wind drift.

Endeavors to typefy the regions of this area for the purpose of placing them into a world-wide climate classification lead to highly unsatisfactory results because the natural geographic conditions are completely different from those of the corresponding N-hemisphere landscapes. The decisive limiting characteristics of the S-hemispheric westwind climates depend also from an intricate set of topographic-climatic phenomena.

The Thermal Conditions

The poleward boundary of wheat growing runs on the W flank of the Cordillera at 42° S, through central Chiloë, and on the leeside of the Patagonian Cordillera at 45° S. Further poleward it is possible to grow oats and – in good years – potatoes, but only in well-protected places. Transposing similar climatic conditions to the N hemisphere, the poleward limit for growing wheat would have to be drawn through N Spain or Oregon. Between 46.5° to 48° S and 48.5° to 51.5° S, the Cordillera of Patagonia, at only 2,000 m asl, is covered by two inland icefields that comprise over 17,900 km^2 (Bertone 1960). In the Seno of Ofqui a glacier reaches the ocean at a latitude which, on the W coast of North America, corresponds to that of Seattle/Vancouver and in Europe to the Lake of Geneva, where vineyards can still be cultivated at the foothills of the Alps.

Investigations by Hoinkes (1970) about the factors that influence the glacial budget decisively indicate that the location of the glaciers of South America at low latitudes is due to the heavy snow falls and relatively cool summers with scarce sunshine.

The coolness of the S summers is illustrated by the fact that, at 52° S, a solid snow cover may reach down to 400 m asl, even in summer. As a matter of fact, on February 24, 1956, I myself was caught in such a snow cover, near Puerto Natales at 450 m. Correspondingly in the N hemisphere, one would have to imagine a solid snow cover in the middle highlands of the Sauerland or the Eifel, at the end of August.

Climate tables by A. Miller (1976) for Punta Arenas, at about 53° S, give 0.1 as average value for days with snowfall during the summer months December through February. This means that, even at sea-level, once every ten years a day of snow fall may be expected in the middle of summer. It is also noteworthy that, during 22 years of observations in Punta Arenas, from 1919 to 1940, January was the only month in which the temperature never fell to 0°C (Re 1945). The coolness of summer is revealed not only by these telling extremes, but also by the average thermal conditions: 9°C at night, only 14°C in the early afternoon. Daily averages above 10°C are reached only during three months.

These summer conditions as they apply to Punta Arenas remain practically the same in northeastern Patagonia and in the S Patagonian *tierra firme* (Fig 1). The summer averages in Punta Dungenes (PD), at the Atlantic end of the Magellan Strait, lie between 10.5° and 11.4°C. Toward the equator the temperatures near the coast rise to

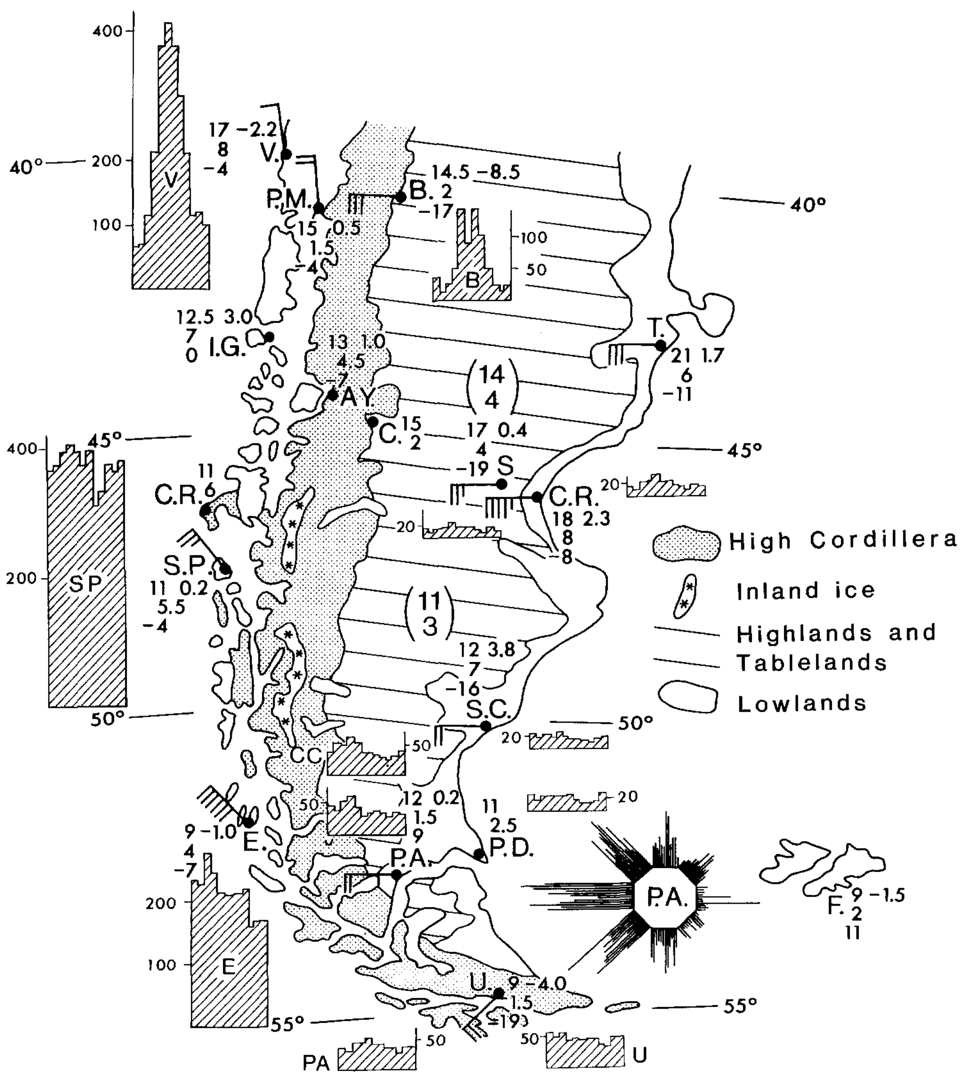


Fig 1 Thermal conditions, precipitation and winds in the Far South of South America. Listed along with the station initials are: average and absolute minimum temperatures of the warmest month; the mean temperature of the coldest month and the lowest temperature ever recorded. The averages of the coldest and warmest months for highlands and tablelands above 500 m were interpolated (in parentheses). Arrows indicate direction and intensity of the winds for the given year. One barb equals 2 m/sec. The wind diagram of Punta Arenas shows the yearly frequency of the eight main wind directions (values for January through December).

13.5°–14.3°C in Puerto Santa Cruz (SC) at 50° S and to 17.3°–18.6°C in Commodoro Rivadavia (CR) near 46° S. On the Atlantic coast there is always the possibility of summer frosts up to Santa Cruz. Comodoro Rivadavia is the first station to be frost free in summer. The cause of this high risk of summer frosts between 50° and 53° S is the advection of cold air from the antarctic.

Not so easy to assess are the thermal summer conditions for the *mesetas* and the hillsites which characterize the larger part of E Patagonia with heights between 600 and 1,200 m. S of 40° S there are only three stations whose data can be utilized: San Carlos de Bariloche (B. 41° S, 836 m asl), Coyhaique (C. 46° S, 140 m asl) and Sarmiento (S. 46° S, 266 m asl). These stations serve as bases from which the thermal conditions of the depopulated highlands can be inferred. Prohaska (1976) claims that a temperature drop of .6°C per 100 m is normal during the summer months. Accordingly, the summer averages in the tablelands and highlands around 500 m, in the central part of E Patagonia, should lie between 13° and 14°C in the N, and between 10° and 11°C in the S part. Above 400 m of elevation, summer frosts can be expected anytime.

The above-mentioned values all lie 5.5° to 6°C below the average in corresponding N-hemispheric latitudes and heights. This thermal reason alone would suffice to explain the absence of cultivation. But there is also the wind as a limiting factor, whose action will be discussed further on.

The thermal summer conditions on the highly oceanic W flank of Patagonia are generally cooler than those on the E side, the difference increasing with declining latitude and increasing with the width of the land masses from about 2°C at the Strait of Magellan, to 5°–6°C between 40° and 45° S. S of 50° S, the average of the warmest month remains below 10°C, due to the decisive influence of the ocean surface temperatures. Therefore, near the coast and without topographic protection, tree growth has become impossible. The definition of this climate as "isothermal tundra climate" (Fuenzalida 1965) seems, however, unjustified, since the extreme colds of winter and the frost phenomena associated with the tundra are totally absent from this area. The climate here is extremely unfavorable for trees, which results from the concurrence of subantarctic coolness and high oceanic wind effects, whose ecological impact will be dealt with in detail later on.

At the W entrance of the Magellan Strait, directly under oceanic influence, winter averages lie around 4° and 5°C, with minimum daily variations. In the channels behind the first coastal ranges, temperatures are lower during the night due to the greater stillness of the air, but even at the southernmost stations, daily averages remain above freezing (2°C) during the coldest month. Closer towards the equator, at the foot of the Patagonian icefields, the coldest month with mean temperatures of 5° to 7°C is as warm as the coldest month on the Channel Islands or on the coast of S England.

Ecologically and biogeographically representative of the winter conditions behind the protective cover of the first coastal ranges is an evergreen forest which grows on the shores of the channels and even on the lateral moraines as they reach the ocean. In the undergrowth of that forest one finds fuchsia and the giant herb *nalca* (*Gunnera chilensis*). These plants are highly susceptible to frost and belong to the "subantarctic laurel- or ouchpaya forest" formation (Oberndorfer 1960), which, in protected areas, reaches the S tip of the continent near 56° S.

In the E foothills of the Cordillera, winter frosts are more frequent due to the stronger continental influences, but only rarely do they last long enough to result in a real cold spell. During normal winters, the monthly average of 2°C in the flat and hilly lands of Tierra del Fuego and in S East-Patagonia remain so far above freezing that a snow cover occurs only episodically and lasts for a short period, similar to conditions in S England, Holland or the coast of Oregon. The scarcity of snow cover allows year-round grazing, the decisive prerequisite for the extensive sheep farming which has developed in that area. If, once in a while, a snow storm strikes, huge flocks of sheep will be completely snowed under. Normally, they will survive for several days – the period of time within which the snow will usually have melted – due to the excellent isolation provided by their wool and the formation of breathing holes in this not overly cold snow. Should a solid snow cover last longer, though, then the farmers face a catastrophe as they will have to undig the sheep and bring in food from afar to be scattered over the area from airplanes. This, of course, happens only rarely, because, owing to the mild winter conditions of the south hemispheric upper-middle latitudes, winter grazing without necessity for food storage is the norm.

The thermal advantages of the Atlantic coast over the Pacific coast are much less pronounced during the winter than during the summer. The mean values are closer and, when nearing the absolute minima, conditions turn around completely, while the temperature extremes increase with declining latitude. This is the consequence of the dynamic-climatological fact that one of the preferred paths of antarctic cold-air outbreaks runs along the eastside of the Patagonian Cordillera.

Wind as a Climatic Element and its Ecological Effects

Seafarers used to call the latitudes between 45° and 50° S "the roaring forties" or "furious fifties". When referring to these latitudes, which roughly correspond to the south of Chiloë, the Chilean writer Fuenzalida (1965) stated that "life is extremely restricted by the west winds that blow with extraordinary force in that part of Chile."

Question is, which mechanisms transform the wind into such a restrictive factor? Biogeographers have not decided yet "whether the location of the southern tree line is determined by the low temperatures of the constantly cool climate or by the effect of the ever-blowing wind" (Schmithüsen 1968).

The effect of the wind on exposed sites is dramatic. In an area of schists which extends in the E foothills of the Cordillera near Cerro Cazador (51° S) I found active dune fields with drifting grains of diameters between 5 and 10 mm. Fortunately, in the lowlands, such dunes are restricted to areas where most of the natural vegetation has been destroyed by overgrazing. Above the tree line where the wind blows freely, the gound is covered by a stone pavement from which all fine particles have been blown away by deflation. Effects of the wind on the natural trees – generally southern beeches – are crown deformations, from "brushing" and "flagging" to "tree carpets", or from "bentshapes" and "flag shapes" to "hedges" (Weischet 1963) or "creeping trees" (Barsch 1963). Similar phenomena and forms are also found in wind-exposed coastal fringes or hill sites in the outer-tropics of the N hemisphere. Comparatively, however, the effects are much stronger in Patagonia. While, for example, near the English or French W coast, tree tops have developed into "flag shapes," in a similar location on the east coast of the Otway Bight (NW of Punta Arenas) there is no tree growth at all near the shore. Only a few hundred meters away, some southern beeches appear in the form of "creeping trees" or as "hedges" which provide protection for other exemplars that grow "crippled" or in "flag shapes" (Weischet 1963). Another significant feature is that, around the Ultima Esperanza Bight, the slopes of the Cordillera between 450 m and the upper limit of the tree line at 700 m are void of almost any vegetation if they are exposed to the west winds. Inversely, on protected E slopes, southern beeches do well at the mentioned elevations.

The question is: how does the wind inhibit vegetational growth? Is it through physical damage of the buds, blossoms and branches, through modification of the ground-level microclimate due to continued advection from cooler maritime air masses or through a reduction of the photosynthesis efficiency by the gusty winds? In order to answer this question properly it would be informative to refer to the situation of an apple orchard planted in front of the administration building of the former Estancia Bories, located in an elongated meridional depression near the town of Puerto Natales (51° 45′ S). At the time of my visit (1956) the trees were fifteen years old, their height, however, did not exceed that of a man's and they evinced clear signs of deformation. Although they flowered, they never bore fruit. The only exception was a six-meter tree of the same age which stood close to the building and behind a tall fence, obviously protected from the wind.

To understand the differences in growth that are caused by climate, two circumstances must be considered: first, the thermal disadvantage of the wind-exposed trees in the sense that, during the summer, they do not benefit from the thermal conditions that guarantee their growth. In protected sites, however, the radiation conditions assure a microclimate which allows vegetational growth into the stage of fruit bearing. In this argumentation, the wind is considered only as a vector of air transport and an agent of heat exchange mechanisms. A second way of looking at this would be to consider the wind as a direct negative influence on the photosynthesis process. In relation to the first alternative, the fact that photosynthesis works optimally between 30° and 35°C is well known. The question that must be asked then is, what is the character of the atmospheric circulation that does not allow cereals to be cultivated and fruit trees to bear fruit under summer radiation conditions of 52° latitude? The second alternative, namely the consideration of the wind itself as a direct inhibitor of biomass production, is seldom mentioned when the problems of climatic ecology are addressed: its implications deserve therefore, closer examination.

Empirical proof has been supplied by Satoo (1955) and Tranquilini (1969) who exposed plants in a climatized wind tunnel to thermal and hygrical conditions which they optimized at various wind speeds, measuring photosynthesis efficiency in the process. From their findings and those of Holmsgaard (1955) about beeches on free sites in Denmark, the conclusion can be drawn that plants of the cool-temperate climates, when exposed to wind speeds of more than 4 m/sec, undergo a remarkable limitation of their net photosynthesis efficiency. This corresponds to the 10 to 30 % shown in Tranquilini's diagram.

These findings justify the consideration of the wind as a climatic limiting factor in all those areas where its velocity lies above 4 m/sec during the period of activated physiological plant functions.

The values of wind velocity for the middle latitudes of South America are shown in Fig 1. According to Prohaska (1976) and also Miller (1976), the annual average on Isla Evangelistas (E), is 12 m/sec, in Comodoro Rivadavia (CR) 9 m/sec, and at the station of Trelew (T), located further inland, 6 m/sec. These values must be considered as exceptionally high for continental places.

The negative climatic conditions for vegetal growth become even more evident when the yearly values are seasonally disaggregated. The anemogram (Fig 1) and the wind-isopleths diagram (Fig 2) for Punta Arenas were drawn from the data presented by Re (1945). They show that, beyond the dominating influence of the cyclonic W wind drift – expressed by the frequency of NW, SW and W winds –, the W winds are most constant, and reach their maximum speed, during the summer months. In the middle latitudes of the N hemisphere, the constancy of the W winds, in summer, is the lowest, and their velocity evinces also a relative low between the spring and autumn peaks (see the wind isopleth of Hamburg in Fig 3). When comparing the absolute values of Hamburg and Punta Arenas, it should be noted that, in the latter, the anemometer was not placed at the prescribed height of 9 m above the highest obstacle, but level with the city roof tops. The average wind intensity should, therefore, be assumed much higher. Jenne et al. (1968) and Van Loon (1974) calculated the mean zonal component at sea level for the sea-dominated latitudes around 50° S to be 10 m/sec during the summer peak, and to be 8 to 9 m/sec for the continental plains of Patagonia.

Special Characteristics of the South-Hemispheric Cyclonic West Wind Drift

With regard to the special characteristics of the cyclonic W wind circulation in the S hemisphere, it is of interest, first, to compare the sequences of daily temperatures and daily minima for the summer months in Punta Arenas and Hamburg, two stations that correspond to each other in the S and N hemispheres from a latitudinal and locational point of view (Fig 4). Along with the different thermal levels there is also a fundamental difference in the periodical array of the temperatures. In the N-hemispheric W wind zone, the warm periods during summer usually last between one to three weeks and end with a cold pause. These long-lasting periods are overlain by short-lived thermal up-and-downs. Inversely, in the S-hemispheric W wind drift zone, there are no long-lasting warm periods during the summer, only a sequence of thermal episodes consisting of 3 to 5 relatively "warm" days interrupted by cold relapses. Correspondingly, the mean temperatures drop below the 6°C which are considered the minimum for plant growth.

At this point the dynamic and climatic foudations for the following decisive differences should be outlined:

(i) The relatively low thermal level of the summers and the relatively mild conditions of the winters;
(ii) The absence of periods with uniform weather conditions and stable thermal levels lasting between one and three weeks;
(iii) The year-long high wind velocity;
(iv) The strengthened wind maxima during the summers.

The determining reason for the comparatively lower thermal level of the S hemisphere is the remote influence of the Antarctic ice sheet. In comparison with the relatively thin ice packs of the Arctic sea, the Antarctic ice mass (4,000 m high in some places, and reaching into the S polar circle itself) constitutes a chronic expender of energy due to the high albedo of ice and snow and the absence of air humidity. Also, no heat is transmitted from the ground to the atmosphere, not even in summer. By reason of the dome-like morphology of the Antarctic, there is a constant flow of katabatic winds from the continent (Schwerdtfeger 1979). This is the reason for the steady radial flow of antarctic cold air as opposed to the pulsating outbreaks of cold air that characterize the N hemisphere. The air masses that emanate from the antarctic's interior are transformed on their transit over the circum-antarctic waters so that they arrive in the middle latitudes always with the characteristics of oceanic polar air masses. Their thermal properties are determined by the ocean conditions in the subantarctic

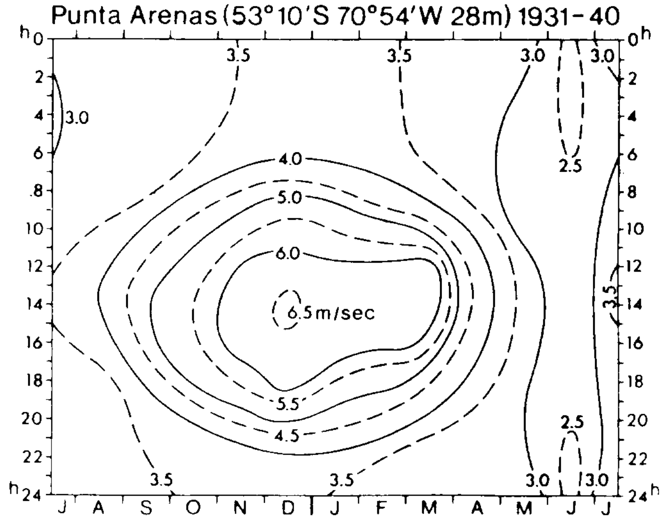
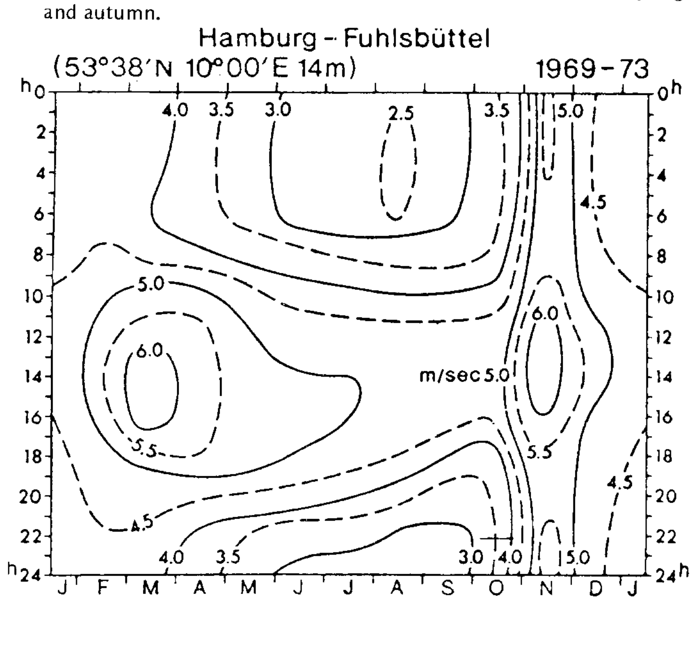


Fig 2 Anemo-Isopleths for Punta Arenas (values taken from Re, 1945). Note the wind maximum during the summer months.

Fig 3 Anemo-Isopleths for the airport of Hamburg-Fuhlsbüttel (values from the German Weather Bureau 1975). In the north hemispheric high-middle latitudes, wind maxima occur in spring and autumn.



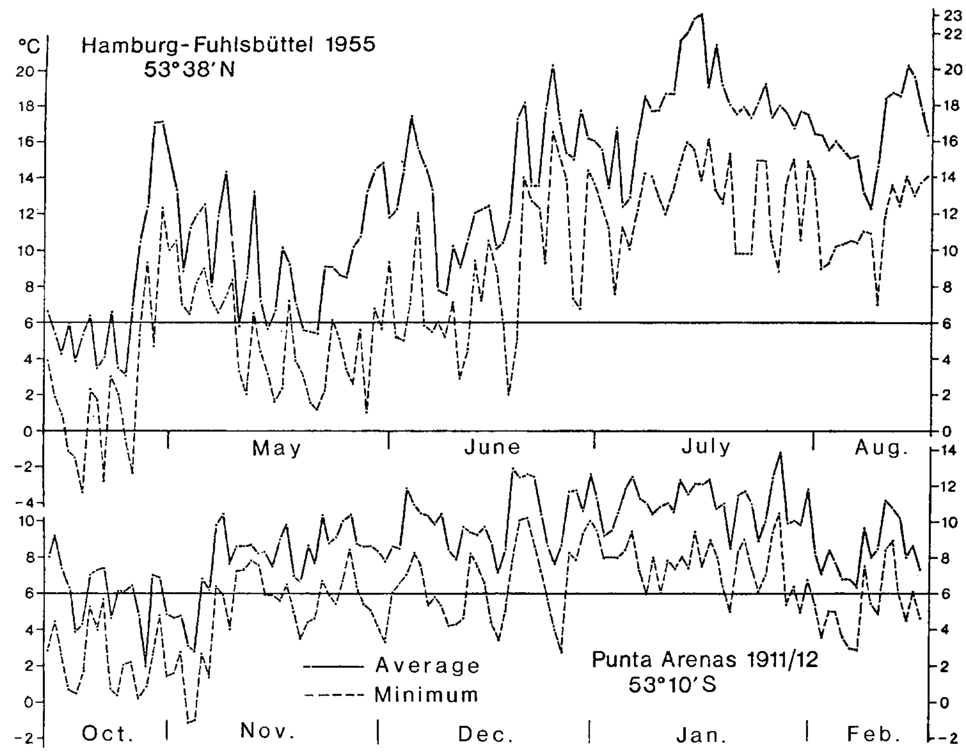


Fig 4 Comparison between the typical curve of the daily mean- and minimal temperatures in corresponding geographical latitudes within the north and south hemispheric west wind drift during the growing period.

and by the path they follow within the atmospheric circulation.

Concerning the nature and effects of ocean conditions, the "Antarctic convergence" plays a leading role. This is a fringe only 200 km wide where the melting waters of the antarctic ice sheet (temperatures between 2,5° to 4°C) dip under the subantarctic water masses. Equatorwards, within approximately 2 degrees of latitude, the surface temperatures rise from 4° to 11 °C (Gordon 1967).

From the margins of the antarctic continent to the antarctic convergence, the sea-surface temperatures vary very little from winter to summer and the Antarctic convergence itself is quite stable in its position. In the Atlantic and Indian quadrant the latter lies between 50° and 55° S, while in the Pacific it is closer to the antarctic continent (near 60° S in Graham Land). As a consequence of the oceanic conditions mentioned above, air temperatures stay below 5°C up to the Antarctic convergence, but then equatorwards they rise rapidly. Upper air observations (Jenne et al. 1968) show in the lower toposphere the formation of a "planetary frontal zone" which, in the Atlantic and Indian quadrant, extends between 55° and 40° S; in the Pacific quadrant between 60° and 45° S (Van Loon 1966, 1974).

The expanse of the meridional temperature gradient within the planetary frontal zone oscillates in the course of the year. While, polewards of the Antarctic convergence zone, the summer temperatures do not differ greatly from those of the winter, equatorwards they are remarkably higher, resulting in a better developed frontal zone in the summer than in the winter. Since steep temperature gradients are coupled with steep barometric gradients, the west wind drift gains energy, its cyclogenesis becoming activated and its winds accelerated. This explains the conspicuous summer maximum of the W winds in the S hemisphere.

At this point of the discussion it has become clear that the low thermal level of the cool temperate zone of the S hemisphere is caused by the antarctic influence and that the maritime effect suppreses frost occurrences and activates the meridional temperature gradients in the summer (Meinardus 1940, Van Loon 1974). Because of the relatively constant location of the polar front, the large temperature gradient is responsible for the high frequency of cyclones (Van Loon and Rogers 1984), their great intensity (Lamb 1959) and rapid translation (Streten and Kellas 1973), and for the summerly maximum wind intensity on both sides of 50° S.

Still to be answered is the question why long-lasting periods of warm weather do not exist in the corresponding zones of the S hemisphere? Such periods are the consequence of the blocking action of the west winds by poleward advances of warm subtropical highs and equatorward shifts of subpolar lows (low-index circulation type). The meteorological conditions within the semipermanent blocking highs are characterized by periods of clear skies and high insolation weather which result in one-to-three week periods of warm summer temperatures: from the coastal zones up into the high mountains, plant growth is stimulated by the calm atmospheric conditions and high insolation.

Vohwinkel (1955), Van Loon and Rogers (1984) have demonstrated that, with respect to the S hemisphere W wind drift, real blocking situations in the summer months are quite rare. In cases of low-index circulation only a diminution of the intensity of the W winds is observed, but no fundamental changes in their flow directions. The occurrence of blocking highs near the surface, at distances of nearly 10° S (about 45° S) from the average location of the subtropical anticyclone, takes place with a frequency of less than 10 % of the summer days and is restricted to the following areas: Australia-West Pacific (centered around 170–180° W); SW Atlantic (around 40–60° W); the Indian Ocean (40–60° E).

Such scarce and weak subtropical anticyclonic advances are an indication that the cyclonic west wind drift of the high middle latitudes stays – practically uninterrupted by blocking actions – almost stationary between 45° and 55° S. The development of calms or locally favorable weather conditions that might contribute to stimulate the period of plant growth are inhibited by the strong circulation mechanisms. Correspondingly, there exist no longlasting warm periods in the thermal regime. Furthermore, even during the few days of anticyclonic good weather, the air temperatures near the ground are kept down by the constant winds, as revealed by the "truncated" thermograph figures of Punta Arenas (Fig 5) published by Re (1945). The mid-day warming of the local air activates the exchange between ground air and upper layers in such a way that cold air from above descends to the ground, depressing, thus, the thermal conditions before an afternoon radiative maximum is reached. Obviously, these processes contribute to the steady lowering of the surface temperatures.

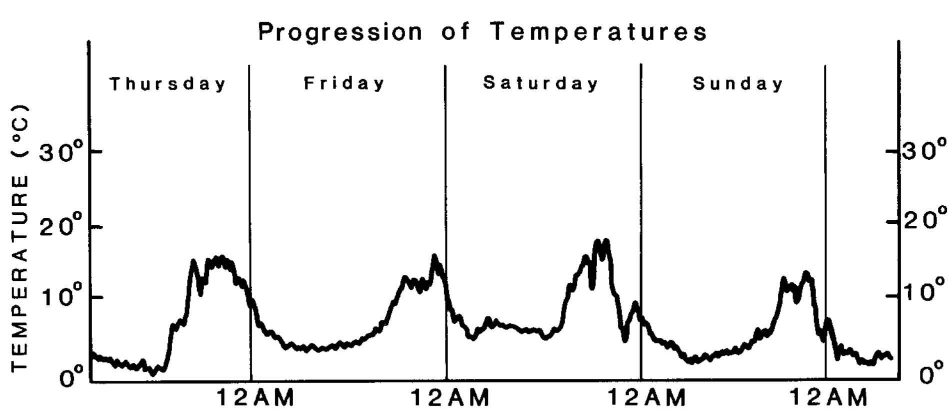
The Hygrical-Climatical Constraints

In the Far South of South America strong differences exist between the wet W flank and the extremely dry side of the continent, so strong, indeed, that Trewartha considered them as unique (Trewartha 1966). On the windward side of the Andes, between 47° and 52° S, it rains from 300 to 320 days, and annual precipitation lies between 2,500 and 7,000 mm. In large parts of the steppes of E Patagonia, by the contrary, the annual precipitation does not even reach 300 mm. The transition from one extreme to the other is specially sharp on the E slopes of the Cordillera. Between 50° and 53° S the amount of precipitation diminishes from 5,000 mm over the glaciated edges of the 3,000 m high mountains to 400 or 500 mm on the W border of the Patagonian tablelands, all this within a distance of less than 60 km. Along the shores of Lago Sarmiento one reaches the *stipa* grasslands of E Patagonia, only 60 km from the E margin of the evergreen forest.

Noteworthy is not only the sharp climatic contrast but also the fact that, with increasing distance from the eastern slopes of the Andes and on approaching the Atlantic coast, there is no increase in precipitation. In fact, at the Atlantic coast the annual precipitation only rarely surpasses 250 mm. Trelew, located in a valley, receives 165 mm, and Comodoro Rivadavia and Santa Cruz, on the Atlantic coast and 250 km E of the Cordillera, only 200 mm. In addition to this anomaly there is a high cloudiness over the steppes of E Patagonia. Just on the lee side of the mountains, in Punta Arenas, the cloudy days per year oscillate between 62 and 81 % and on the E coast, between 55 and 77 %, summer being the worst. Clear skies are not abundant: Santa Cruz and Sarmiento have a mean of 23 and 31 cloud-free days per year, respectively. The S summer months of January and February have only one or two clear days.

As reason for the expansion of the scarcity of rain up to the Atlantic coast, Trewartha (1966) adduces the steadily blowing W winds which, after being adiabatically warmed on the eastern flank of the Cordillera, create a semipermanent meridional high; over the Atlantic Ocean this high is replaced by a low pressure trough. Inside the high pressure cells dynamic warming leads to cloud dissipation and the suppression of rain-producing processes. This hypothesis

Fig 5 The "decapitated" daily temperature curve of Punta Arenas which is due to the high wind velocities during summer weather (From Re 1945).



does not take into account the high cloudiness despite the rain deficit. It seems to me that a more plausible explanation is derived from taking a closer look at the water vapor transport. On the lee side of the mountains the permanent W winds behave like fall winds (foehn effect) and the consequences on the clouds can be observed almost daily. Using mean values of sea-level temperatures from stations at both sides of the Cordillera, it is established that the Pacific air reaches the E foothills with a saturation deficit which, in the summer months, averages between 6 and 8 millibars. Advecting towards the E, the air continues to warm up during those months as confirmed by the rise of the mean temperatures on approaching the Atlantic coast. It necessarily follows that the air masses that blow over the Patagonian steppes suffer a continuous increase of saturation deficit since the steppes themselves supply no moisture. The only sources might be found N or S of the wandering cyclones. To the N, however, the Andes are even higher so that the air advecting from the Pacific is submitted to an even greater loss of humidity. The S is normally dominated by the cold antarctic air which is also low in moisture content. The only possibility to increase humidity would be in connection with a temporary alteration in the general circulation in such a way that moisture would be fed in from the Atlantic Ocean. But, as seen above, due to the strong zonal index of the west winds, that possibility is almost nil.

During the winter months the hygrical conditions tend to be more favorable since, at lower temperatures, the water vapor loss is less intense and the subtle continental warming that takes place in the summer is absent. Moreover, the zonal index is lessened and divergences are common. The fact that stations located in the E foothills of the Andes exhibit, during April and May, a moderate increase in precipitation which – when compared with the summer rains – though, represents a clear maximum, enhances this explanation.

Outside the 50° S latitudinal belt discussed so far, the cyclonic W wind circulation decreases in intensity and constancy as one advances equatorwards. However, the W façade of the Cordillera is affected by it in the form of brisk weather changes resulting from sudden onslaughts of air masses, abrupt temperature changes, high precipitation frequency, constant wind movements at often high velocities, and the absence of periods of calm, so that up to 42° S (middle Chiloë) grain crops will not reach maturity. Inversely, in the rain shadow of the same latitudes, the foehn effects and improved insolation conditions result in a decisive melioration of the regional climate. On that side of the mountains the limitation of biomass production due to the effects of the wind become noticeable only further polewards. Northward of the S limit of wheat cultivation, at 42° S, the action of the W wind circulation is remarkably lessened by the influence of the subtropical high. This is particularly true during the summer semester when the frontal systems are neutralized or weakened by the anticyclonic influence. In the measure as one advances to the N the precipitation regime evolves into one characterized by a winter maximum and a summer minimum, accompanied by a slackening of the W wind circulation. Up to 38° S, the rainfall on the W side of the Cordillera is sufficient, even in summer, to allow classification of the climate as humid.

The definite change to the alternating dry summers and rainy winters typical of subtropical climates occurs N of 38° S (Weischet 1959, Van Husen 1967). South of this latitude, in a fringe of 300–400 km, the interfacing of subtropical radiation conditions, mild oceanic temperatures, absence of frost and evenly distributed rainfall offer optimal conditions for the growth of natural forests as well as commercial forests consisting of N-hemispheric species. The best examples are the lush growth of "Valdivia's rain forest" and the record-high annual growth rates reached by some exotica, like *Pinus radiata*: 25–30 m^3/ha (Weischet 1970).

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