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MONTHLY MEAN PRESSURE MODEL FOR CHILE

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ABSTRACT

A simple empirical model to describe the latitudinal distributions of monthly mean surface pressure along the Chilean coast is proposed. Model hypotheses, such as regions into which latitude distributions are to be divided and latitude dependencies of pressure within these regions to be assumed, are discussed with reference to a climatic scenario that has been found of value in developing simple empirical climatic models for coastal stations in Chile. Equations are derived giving pressure at any latitude as a function of the latitude of the location of maximum monthly mean pressure in Chile (LMP) and of pressure at that location. It is concluded that the proposed model describes adequately the observed latitudinal distributions. Moreover, it is found that the coupling between the Pacific Anticyclone and the continent is particularly simple for locations north of the LMP's latitude, leading to a unified quantitative description of climate for those latitudes. Furthermore, the model allows qualitative inferences to be made regarding the interaction mechanisms between the main meteorological centres of action on a regional scale, which may prove of value to identify trends of regional climatic change.

KEY WORDS Pressure Model Chile

1. INTRODUCTION

The climate of a given region may be described by the annual change of the monthly mean values of meteorological variables usually measured at synoptic stations, computed for many years. If local effects, which could be important and even dominant, are not considered, these values could be interpreted as resulting from the monthly mean interaction of main meteorological centres of action for that region.

In the Chilean case these centres are: (i) Pacific Anticyclone (PA); (ii) synoptic frontal wave cyclones denoted here as polar lows (PL); (iii) coastal low (CL), which relates to differential heating of continent and ocean; and (iv) what will be denoted as the enhancement of coastal low (ECL). The latter is a nucleation of the CL that is observed frequently during summer in Central Chile. Figures 1 and 2 show two synoptic charts that can be considered as being representative of predominant meteorological conditions in Chile, corresponding to two consecutive days in February 1979. The typical surface isobar pattern shows a 'high wedge' on the continent whose location and maximum pressure vary considerably from day to day. The CL and/or ECL (Figure 2) are found north of the wedge and the PL south of it. Although on occasions isobar patterns differ significantly from the norm, they are not important when computing monthly mean values of meteorological variables in order to describe climate because they are very rare.

Weather forecasting in Chile dictates that 'good weather' is to be found in the domain of the CL. This can be regarded as a result of coupling between the PA and the continental boundary. Consequently, the region may be considered as one in which the PA dominates, i.e. winds blow from the south, and clear skys and lack of rainfall are prevalent. The ECL occurs only sporadically (usually twice a month during summer). As a shallow and localized warm-nucleus low, it produces wind direction changes in nearby locations only, it is accompanied by cloudiness only rarely and very occasionally yields some drizzle. On the other hand, 'bad weather' is related to the PL domain, which is associated with the polar front. In this case winds blow from the north, skys are cloudy and the probability of heavy rainfall is very high.

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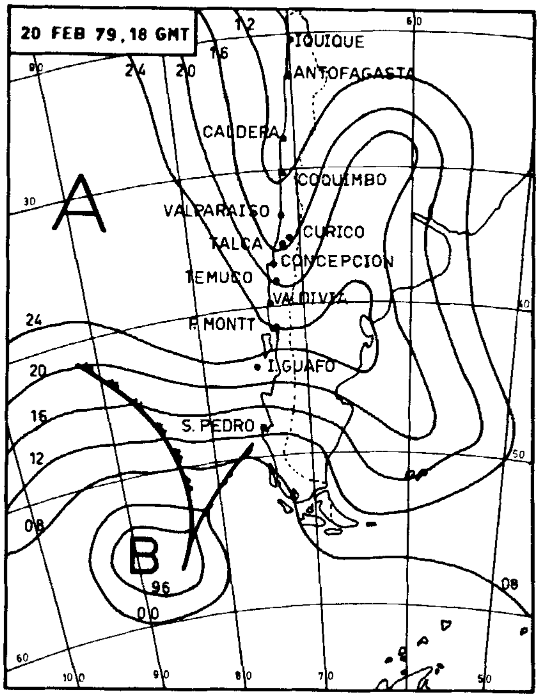

Figure 1. Synoptic chart, 20 February 1979, 1800 GMT. A = High; B = Low

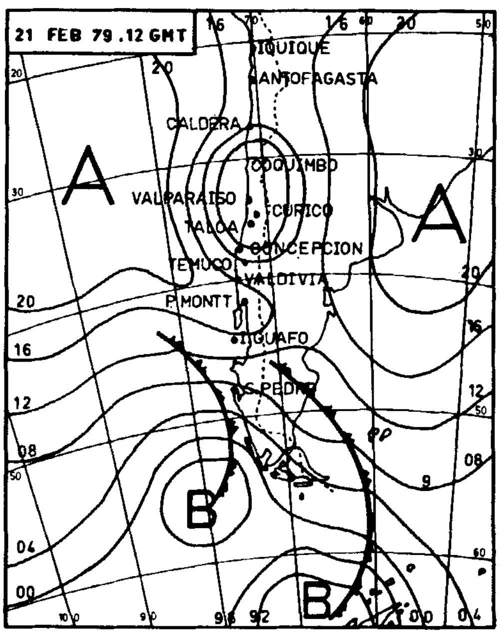

Figure 2. Synoptic chart, 21 February 1979, 1200 GMT. A = High; B = Low

Assuming that a climatic scenario could be envisaged maintaining the same features of the meteorological scenario outlined above, then the location of the maximum monthly mean pressure in Chile (LMP) can be used as a pointer that divides the country into two regions. The climatic properties of these regions correspond to the meteorological properties already mentioned. Moreover, the LMP can be considered then as an index of the monthly mean spatial interaction of the meteorological centres. The monthly mean distribution of surface pressure for locations along the Chilean coast corresponding to January is shown in Figure 3. This best indicates the elements of the climatic scenario because it corresponds to the month in which the ECL is fully developed.

The LMP's role as a climatic indicator has been shown by Saavedra (1980). Pittock (1971, 1980) finds significant correlations between a similar indicator, defined as the mean latitude of the subtropical high-pressure belt along the Chilean coast, and rainfall amount and temperature in Argentina and Chile. Other indicators associated with the Pacific and Atlantic anticyclones have been used by Minetti *et al.* (1982) and Minetti and Vargas (1983a, b) to describe rainfall in Chile and the central Andes, and rainfall anomalies in north-east Brazil. Before them Prohaska (1952) already had suggested that parameters of latitudinal distributions of mean sea-level pressure along the Chilean coast could have significance as climatic indicators.

The LMP changes from month to month, defining in this way the changing limits of the different domains. Figure 4 presents the annual latitude displacement of LMP, which totals about 7° of latitude. It is evident that the LMP moves faster from the south to its northernmost position, where it is almost stationary during winter, than from there southwards. The fastest movement occurs between April and May. The climate of locations encompased by the extreme positions of the LMP changes most as a result of the interaction of the four meteorological centres. For these locations winter conditions arrive more rapidly than the summer ones. North of the northernmost position of the LMP, climate is increasingly a result of the coupling between the PA and the continent boundary. South of LMP's southernmost position, climate depends more markedly on the evolution of the PL alone. Figure 4 also shows the annual evolution of pressure at the LMP. By contrast, pressure changes slowly from summer to winter, reaching a maximum in August, from which it decreases faster until January. Details of the LMP's capacity as a climatic descriptor for Concepción (36°48′S, 73°02′W) are given in Saavedra (1985a, 1986).

The purpose of this paper is to show how the knowledge of only the LMP's latitude and pressure at the LMP permits a simple model to be developed giving latitudinal distributions of pressure along the northern Chilean coast (northward from the LMP's latitude). The goodness of fit of this model to measured values confirms that the main properties of Pacific Anticyclone coupling to the continental border are well expressed by the LMP's most significant features, leading to a unified quantitative description of climate for that coast, thus enhancing the LMP's value as a climatic descriptor. Moreover, the model allows qualitative inferences to be made regarding the interaction mechanisms between main meteorological centres of action on a regional scale. These inferences should prove of value when addressing the problem of identifying trends of regional

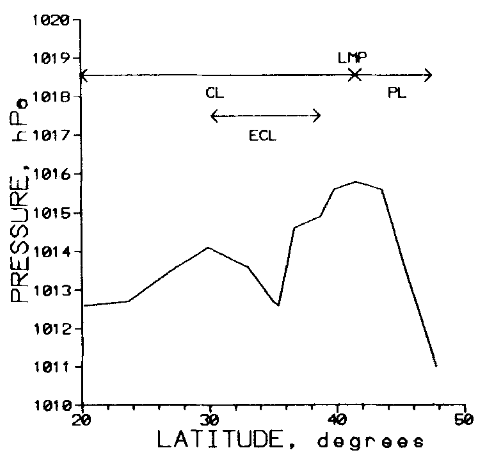

Figure 3. Monthly mean latitude distribution of surface pressure along the Chilean coast for January corresponding to the 1911–1940 period (adapted from Wittaker, 1943). Latitude regimes for coastal low (CL), polar lows (PL), the enhancement of the coastal low (ECL), and the latitude of the location of maximum monthly mean pressure in Chile (LMP) are indicated

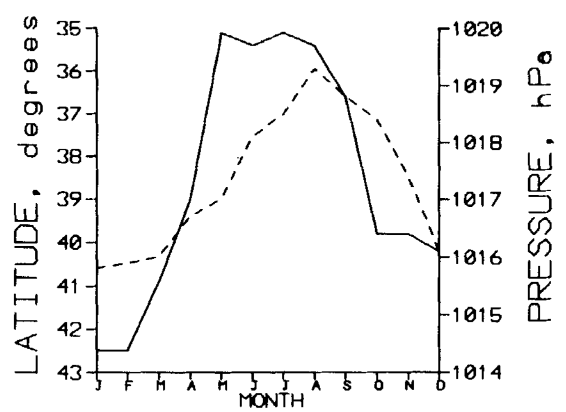

Figure 4. Latitude of location (———) of maximum monthly mean surface pressure along the Chilean coast (LMP) and pressure (- - - -) at the LMP corresponding to the 1911–1940 period (reproduced from Saavedra, 1980)

climatic change. In section 2, measured climatic latitudinal distributions of surface pressure are presented, and the proposed model for the northern part of these is described in section 3. Finally, in section 4 the validity of the model is discussed with relation to the data for two stations located in two different latitudinal regimes.

2. OBSERVED LATITUDINAL DISTRIBUTIONS

Pressure values used here have been derived from latitudinal distribution plots of surface pressure published by Whittaker (1943), covering most of the Chilean coast, and relating to the 1911–1940 period. Only these results were considered because monthly mean values corresponding to a 30-year period are believed to be representative of climatic conditions. Moreover, comparison of these distributions with annual evolutions of

Table I. Stations for which pressure values have been read from published plots and stations-months used to determine the slope and intercepts of model linear latitudinal distributions of pressure. Stations-months marked by an *X* were used to determine the slope. These and those marked by a *Y* were used to determine the intercepts

Station	South (latitude)	West (longitude)	Month J	F	M	A	M	J	J	A	S	O	N	D
Iquique	20°12′	70°11′	Y	Y	Y	X	X	X	X	X	X	Y	Y	Y
Antofagasta	23°39′	70°25′	Y	Y	Y	X	X	X	X	X	X	Y	Y	Y
Caldera	27°03′	70°33′	Y	Y	Y	X	X	X	X	X	X	Y	Y	Y
Coquimbo	29°55′	71°22′	Y	Y	Y	X	X	X	X	X	X	Y	Y	Y
Valparaiso	33°01′	71°38′				X	X	X	X	X	X	Y		
Curicó	34°59′	71°14′				X	X	X	X	X	X			
Talca	35°26′	71°40′				Y					Y			
Concepción	36°40′	73°03′				Y						Y	Y	Y
Temuco	38°45′	72°33′			Y	Y						Y	Y	Y
Valdivia	39°48′	73°14′	Y	Y	Y									Y
Puerto Montt	41°28′	72°57′	Y											
Isla Guafo	43°34′	74°75′												
San Pedro	47°43′	74°55′												

monthly mean pressure for several coastal stations, corresponding to different periods (e.g. Concepción 1968–1977 period; Saavedra, 1980), confirm their stability. Consistency with the main features of Pittock's indicator, relating to the 1941–1960 period is a further indication of stability. Table I gives stations for which pressure values have been read from the published plots, and Figures 5 and 6 show monthly mean latitudinal distributions produced using these values. Figure 5 corresponds to winter months, while Figure 6 relates to summer months.

The main feature of winter distributions is a nearly linear decrease of pressure for latitudes equatorwards from the LMP (i.e. the CL domain), with almost the same gradient for all months. For summer months this linear decrease is altered by a superposed depression (i.e. the ECL) centred almost at the same latitude for all months, increasing in depth from October to January and decreasing afterwards, being negligible by April. A detailed study of these distributions has been published by Saavedra (1985b).

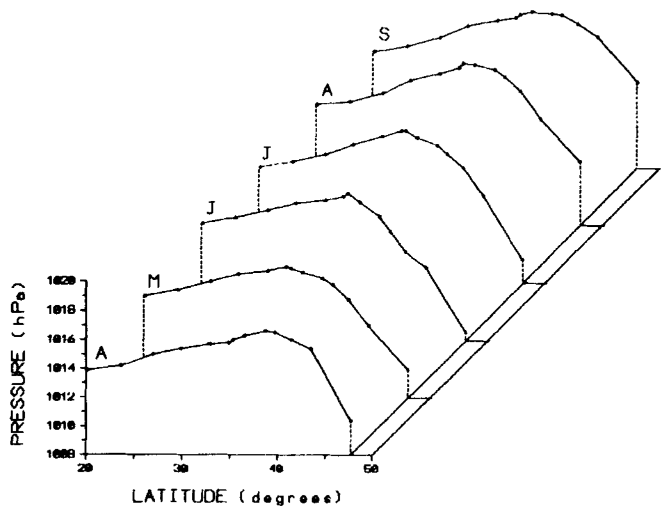

Figure 5. Monthly mean latitudinal distributions of surface pressure along the Chilean coast for winter months corresponding to the 1911–1940 period (adapted from Wittaker, 1943)

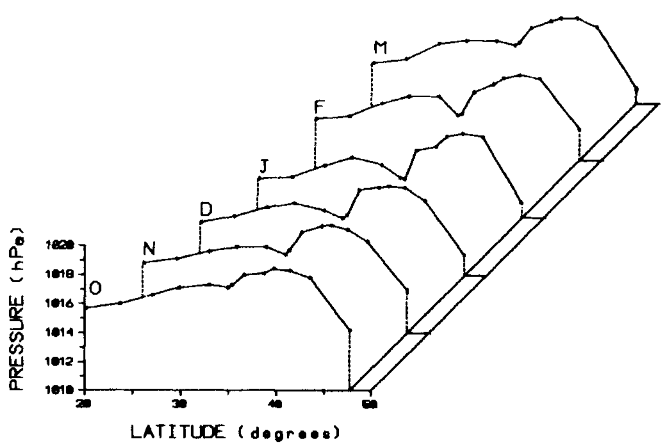

Figure 6. Monthly mean latitudinal distributions of surface pressure along the Chilean coast for summer months corresponding to the 1911–1940 period (adapted from Wittaker, 1943)

3. PROPOSED MODEL

Model hypotheses

A simple analysis of Figures 5 and 6 suggests that the following assumptions could be regarded as a reasonable basis for an empirical model of the latitudinal distributions of surface pressure.

(i) The LMP divides the latitudinal distribution into two regions only: the northern region is the CL domain, which includes the ECL, and the southern region is that of the PL. Only the northern region is amenable to being parameterized in terms of the LMP's latitude and pressure at the LMP alone, owing to the regularity of the annual evolution of its latitudinal distribution of pressure, which strongly depends on the PA. In the southern region, latitudinal distributions of pressure are shaped predominantly by the PL's whose tracks, depths, and pressure gradients cannot be linked obviously in a simple manner to the PA, because of lack of experimental data with the required spatial resolution, although such a link may well exist, as suggested by preliminary evidence.

(ii) If the ECL is not taken into account, which may be convenient for some applications, pressure at any latitude for a given month is a linear function of latitude up to the LMP's latitude, the latitudinal gradient being the same for all months, and pressure at the LMP changing from month to month.

(iii) When the ECL is to be considered, pressure is assumed to be determined from two terms. For the first term the same assumptions given in (ii) apply. For the second term it is assumed that pressure changes with latitude for a given month following a Gaussian distribution, the latitude of maximum pressure and distribution width being the same for all months, and the maximum pressure changing from month to month as a linear function of both the LMP's latitude and pressure at the LMP. The properties of this term are associated to the monthly mean temperature fields for central Chile, which exhibit a latitude elongated region (less than 2°) around Talca, with maximum temperatures from September to May, with highest temperatures during January (IREN, 1979; see also Prohaska (1976) for temperature fields corresponding to January and July only). Figure 7 sketches both terms. Note that the second term is negative.

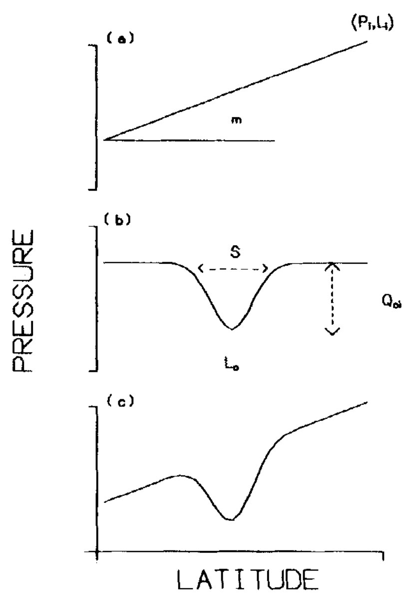

Figure 7. Sketch of proposed model of the latitudinal distribution of surface pressure for conditions when the ECL effects are significant (see text). (a) linear term, (b) Gaussian distribution term, and (c) sum of both terms

Model without ECL

To derive the slope and intercept of the straight lines giving pressure as a function of latitude for each month, mean values of monthly mean pressure at Iquique, Antofagasta, Caldera, Coquimbo, Valparaíso, and Curicó, corresponding to April through to September were first determined, i.e. for winter months at stations located north of the northernmost latitude reached by the LMP, for which conditions the ECL can be regarded as negligible. The slope of a best-fit line through these six pairs of values was taken to apply to all 12 straight lines. The intercept of each of these lines was determined afterwards by a best-fit procedure using corresponding monthly mean values for all stations north of the LMP, which are not affected significantly by the ECL (see Table I and Figures 5 and 6 to assess selection criteria).

Model pressure P at any latitude L for a given month i can be written as

$$P = mL + n_i$$

where m is the slope, same for all months, and n_i is the intercept corresponding to month i. Moreover, since this expression also holds for each month at the LMP's latitude L_i, for which pressure is P_i, then it is seen that

$$P = m(L - L_i) + P_i$$

(see Figure 7). It should be noted that either P_i or L_i values to be used in model computations are then slightly different from the observed ones because fitted straight lines do not necessarily include the observed points (P_i, L_i). Here, keeping observed L_i values in model computations has been considered to be more meaningful, because it is the LMP's latitude the climate descriptor used, thus corrected values for P_i have been produced. Table II gives values of m, L_i, and corrected P_i for every month (note that observed values of P_i are given in Figure 4).

Observed and model pressure latitude distributions for June, corresponding to all stations north of the LMP, are compared in Figure 8, while annual evolutions for Antofagasta are shown in Figure 9. These have been chosen because June is considered representative of winter conditions when the CL regime is not altered

Table II. Values[a] of parameters[b] used in the proposed model

Month	L_i	Corrected P_i
January	42·5	1015·9
February	42·5	1016·2
March	40·9	1016·0
April	39·0	1016·6
May	35·1	1017·2
June	35·4	1018·1
July	35·1	1018·3
August	35.4	1018·8
September	36·6	1018·7
October	39·8	1018·5
November	39·8	1017·6
December	40·2	1016·4

[a] $m = 0{\cdot}159$, $L_0 = 34{\cdot}98$, $S = 1{\cdot}34$, $a = 0{\cdot}219$, $b = -0{\cdot}249$, and $c = 245{\cdot}5$.

[b] m, slope of fitted linear latitudinal distributions; L_i, latitude of location of maximum monthly mean pressure in Chile; P_i, pressure at L_i corrected to be consistent with fitted linear latitude distributions; L_0, latitude of centre of enhancement of coastal low; S, measure of width of enhancement of coastal low; a, b, and c, multivariate regression analysis constants.

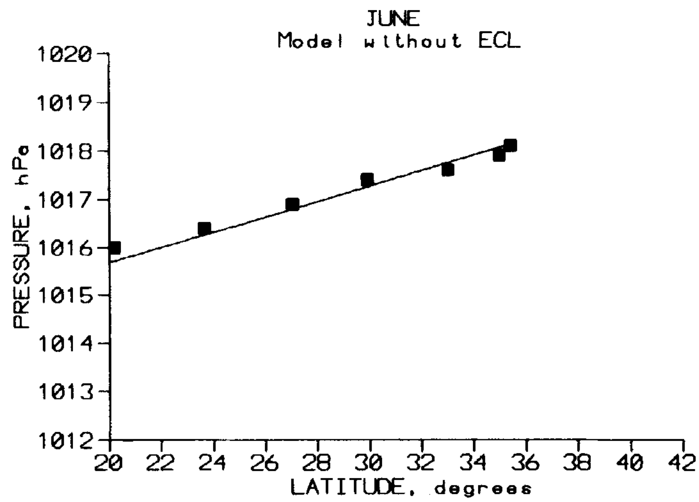

Figure 8. Observed (squares) and model (line) monthly mean latitude distributions of surface pressure for June

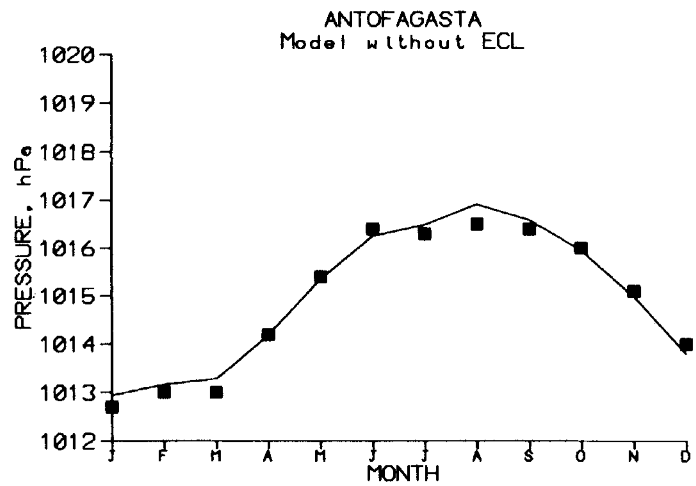

Figure 9. Annual evolutions of observed (squares) and model (line) monthly mean pressure for Antofagasta (23°39′S; 70°11′W)

by the ECL, and because Antofagasta is a typical station of latitudes north of the ECL even for summer conditions.

Model with ECL

When the ECL needs to be accounted for, expressions for only the second term mentioned above have to be derived. This has been done assuming that for a given month i, pressure Q_i changes with latitudes L as:

$$Q_i = Q_{0i} \exp[-(L-L_0)^2/2S^2]$$

where Q_{0i} is maximum pressure for that month, which occurs at latitude L_0, and where S accounts for the width of the distribution (see Figure 7). Both L_0 and S are taken as the same value for all months. Values for Q_{0i} were determined as the difference between pressure values given by the straight lines of the model without

ECL and pressure observed at Curicó, located at the centre of the ECL. Multivariate regression analysis was then used to derive a single linear dependence between Q_{0i} and the latitude of the LMP and the pressure at the LMP, which can be written as

$$Q_{0i} = aL_{i+1} + bP_i + c$$

where a, b, and c are constants. Values of L_0, S, a, b, and c also are given in Table II. Note that this dependence includes a lag between Q_{0i} and the latitude of the LMP (for December, $i = 12$, L_{13} is taken as equal to L_1). Although the lag resulted from numerical considerations, it seems to warrant further study as suggested in the following section.

The complete expression for pressure P at any latitude L is then

$$P = m(L - L_i) + P_i - Q_i$$

Observed and model pressure latitude distributions for January, a month for which the ECL is deepest, are

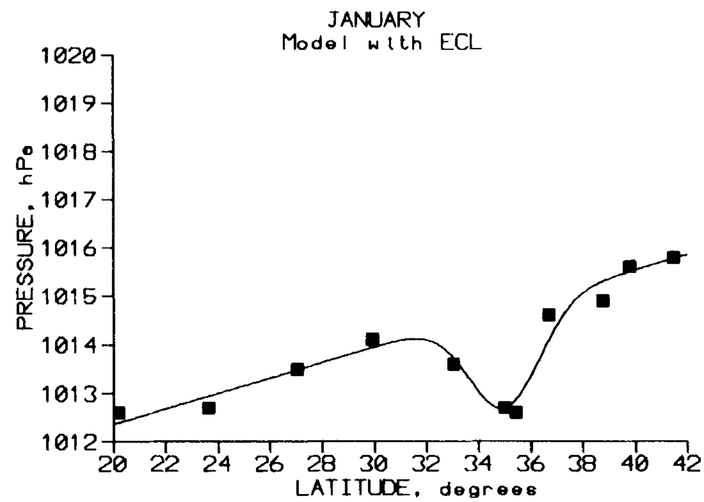

Figure 10. Observed (squares) and model (line) monthly mean latitude distributions of surface pressure for January

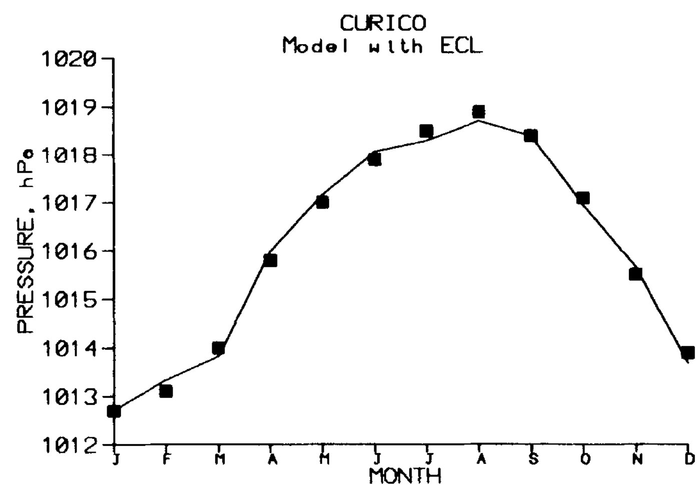

Figure 11. Annual evolutions of observed (squares) and model (line) monthly mean pressure for Curicó (34°59′S; 71°14′W)

compared in Figure 10, while annual evolutions of pressure for Curicó, located where the ECL is most significant, are shown in Figure 11.

4. DISCUSSION

In order to assess the accuracy of the proposed complete model, differences between observed and model values were determined for all stations located north of the LMP for each month. Approximately 87 per cent of these differences are less than 0·3 hPa and over 98 per cent of them are less than 0·5 hPa. When pressure ranges for latitude distributions are considered (a mean range of about 2·7 hPa), a difference of 0·3 hPa corresponds to only about 11 per cent. These differences correspond to less than two-thirds of that percentage when compared with the annual evolution of pressure for all stations for which the model holds. Figures 8 and 10 illustrate overall fitting of the model for two months for which latitude pressure ranges are near the smaller and the largest, respectively. On the other hand, Figures 9 and 11 relate to stations with corresponding annual pressure ranges.

The proposed model allows a significant interpretation of climatic conditions for a region in Chile known as Norte Grande, which encompases latitudes north of Coquimbo. This region, where the ECL effects even during summer are negligible, could be considered as a region particularly suited to test coupling mechanisms between a regional oceanic anticyclone and a continental border. At a given latitude for this region, changes of pressure from one month to the next can be regarded as resulting from the combined corresponding changes of the LMP's latitude and pressure at the LMP. This can be seen recalling model expressions that do not include the ECL. Since the intercept of a straight line giving latitudinal distribution of pressure for month i is

$$n_i = -mL_i + P_i$$

and because the slope m is the same for all months, then

$$n_{i+1} - n_i = -m(L_{i+1} - L_i) + (P_{i+1} - P_i)$$

Values of these two terms are shown in Figure 12, where January has been chosen as a reference for which both terms are zero. Thus, while the annual evolutions of pressure for all stations within the Norte Grande exhibit the same pattern, the contribution of the two terms changes significantly from month to month. Furthermore, during winter and early summer the contribution related to changes in pressure at the LMP is twice as large the one associated with the LMP's latitudinal changes.

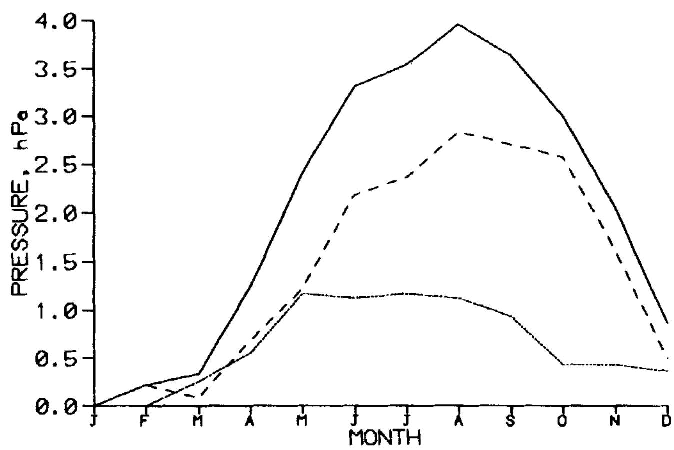

Figure 12. Pressure changes for any station within the Norte Grande relative to values for January at the station. Total change (———), change associated with LMP latitude variation (- - - - -), and change associated with pressure variation at the LMP (– – – –)

Since the observed pressure values for Norte Grande stations are well reproduced by this model, which depends only on two terms directly related to the LMP, it is considered here that the property of the LMP associated with the largest term would be the one responsible for main features of the annual evolution of pressure of the region, i.e. changes of pressure at the LMP, which are related directly to the PA interaction with the continent along the coast via the CL.

The same reasoning can be extended to all latitudes north of the LMP provided the ECL is considered as a perturbation of the CL occurring only in summer. Thus, the amplitude of a normalized CL relative to the pressure at the LMP can be regarded as a constant (decreasing pressure north of the LMP at a constant latitude rate for all months). This implies a very steady coupling between the PA and the continental border, which is confirmed by the prevalent south-component winds observed away from the ECL when this has developed. By contrast, conditions south of the LMP are completely different. Another feature of the annual evolution of pressure for stations north of the LMP that also can be interpreted is a slight kink in the pressure march observed between June and August (see Figure 12 in relation to Figures 9 and 11). Although the mechanisms is unclear, the kink could be associated with pressure changes at the LMP, but not to those related to changes in the LMP's latitude.

The simple interpretation given for conditions in the Norte Grande does not apply for latitudes where the ECL effects during summer are noticeable. The ECL develops centred at the same latitude (Curicó), and its depth is much smaller compared with the PL, even when deepest (January). As noted already, it is associated with a region where monthly mean temperatures are highest in central Chile, suggesting a thermic origin and a mechanism linked with a certain lag to heating sources. The LMP starts its southwards movement in August, leaving latitudes where the LMP remains almost stationary during winter. As a result, clear skys are more frequent, global radiation increases and, probably with some thermic inertia, conditions slowly arise allowing the ECL to be formed. This suggested mechanism is consistent with the expression found for Q_{0i}, which gives Q_{0i} as being proportional to L_{i+1}, i.e. a 1-month lag.

It should be noted that although the ECL clearly marks the latitude distributions of pressure for summer months for latitudes north of the LMP, it does not alter significantly either the 'good weather' concept or the LMP's role as a climatic descriptor. This is because, as mentioned already, in most cases it is associated only to surface wind direction changes and low thin strata cloudiness. Rainfall is very rare, and falls larger than 1 mm are extremly scarce.

5. CONCLUSIONS

The proposed model describes adequately the observed latitudinal distributions of monthly mean surface pressure along the Chilean coast for latitudes north of the location of maximum monthly mean pressure in Chile (LMP). It is significant that the model relies only on the LMP properties. This enhances the scope of the LMP as a climatic descriptor.

The steady coupling found between the Pacific Anticyclone and the continental border is particularly simple for locations along the Chilean coast north of the LMP's latitude, leading to a unified qualitative description of climatic variables for those latitudes.

The model allows qualitative inferences to be made regarding interaction mechanisms between the main meteorological centres of action on a regional scale, which may prove of value for identifying trends of climatic change.

The model's term describing the enhancement of the coastal low allows an estimation of the time-scale of mechanisms linking heating sources and circulation effects.

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