CAUSES AND PERIODICITY OF LARGE FLOODS IN RIO DE LA PLATA

(FLOOD OF 27 AND 28 JULY 1958)

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INTRODUCTION

The sea coast of Buenos Aires Province and the rio de la Plata are systematically affected by the action of storm waves, which under certain conditions result in catastrophe for the local population.

The Plata is an estuary, which owing to its size and shallow depth, cannot generate tides. Thus any variation in its level is due to action of the ocean influenced by weather disturbances.

Its present length is about 290 km, and its width varies from 40 km in its narrowest part to 220 km at its mouth, which resembles a vast trough open to seawards; the tide waves penetrate through the latter and give the river its ocean-like dynamic character.

The probable original length of the Plata was 640 km, of which 350 km have already been taken by the Parana to form its delta.

Tide waves occur throughout the estuary, and are propagated as far as the inland courses of its traditional affluents. Thus they proceed up the Parana to Rosario under unusual conditions, and normally reach Villa Constitucion if the Parana is falling, and San Pedro if rising. In the Uruguay, the tide wave is normally recorded up to Concepcion, but on unusual occasions as far as Concordia.

The study and prediction of different states of the tide in the Plata and on the Argentine seacoast no longer offer major difficulties, as the Hydrographic Office possesses a modern tide-predicting machine totalizing 42 constituents, including the most important long-period (annual and semi-annual; monthly and semi-monthly) constituents; diurnal, semi-diurnal and third-diurnal constituents; compound tides; and a considerable number of shallow-water constituents, which greatly influence the estuary.

These tidal predictions are published annually for the rio de la Plata and the leading ports on the American coast, including the Argentine Antarctic.

The high floods in the rio de la Plata are due to meteorological influences on adjacent or even remote ocean zones, since local influences, owing to their limited fetch, are restricted in the majority of cases to the production of secondary effects.

Unusual heights for the river may thus occasionally be recorded at Buenos Aires, in the absence of any observation of a local weather disturbance to justify them. This is due to the fact that atmospheric disturbances move at a lower rate of speed than the storm waves they generate, and the latter may appear on the coast 12 to 24 hours beforehand.

This complicates the problem of predicting various states of the river in a specified area, as the weather forecasts available may not always be timely or accurate enough to enable the prediction and evaluation of their effects on the water level.

Hence the populations dwelling on the banks of the Plata so far have invariably been taken unawares by the river's sudden upheavals during its periodic attempts to reoccupy its original bed, which is systematically shrinking owing to the relentless progress of the delta and the ominous rise of its muddy bottom.

SEQUENCE OF FLOODS IN THE PLATA

At the present time (1958) valuable statistics are available for a period of over 54 consecutive years showing variations in the level of the Plata at different places.

In this paper, statistics will only be given for the port of Buenos Aires; based on these, the purpose of the following analytical study is to show the significant sequence of large floods in the rio de la Plata and its coincidence with certain astronomical, meteorological and oceanographic cycles.

The above values of maximum annual heights recorded at Buenos Aires and referred to the datum at Riachuelo have been rearranged in diagram form, to show their pattern in relation to time.

The diagram in figure 1 should not be considered as the development of a tide wave as plotted against time, but as representing the maximum annual effects produced in the river by atmospheric disturbances; their numerical expressions are the ordinates of the diagram.

The resulting diagram cannot therefore be regarded as denoting any known physical action of periodic character. There is no denying, however, that the existence of certain cycles can be derived from its examination, and that these can be likened to the following among others :

8.85-year cycle, corresponding to period of revolution of perigee of lunar orbit.

Harmonic 1/2 of foregoing period.

18.6-year cycle, corresponding to period of revolution of ascending node of moon.

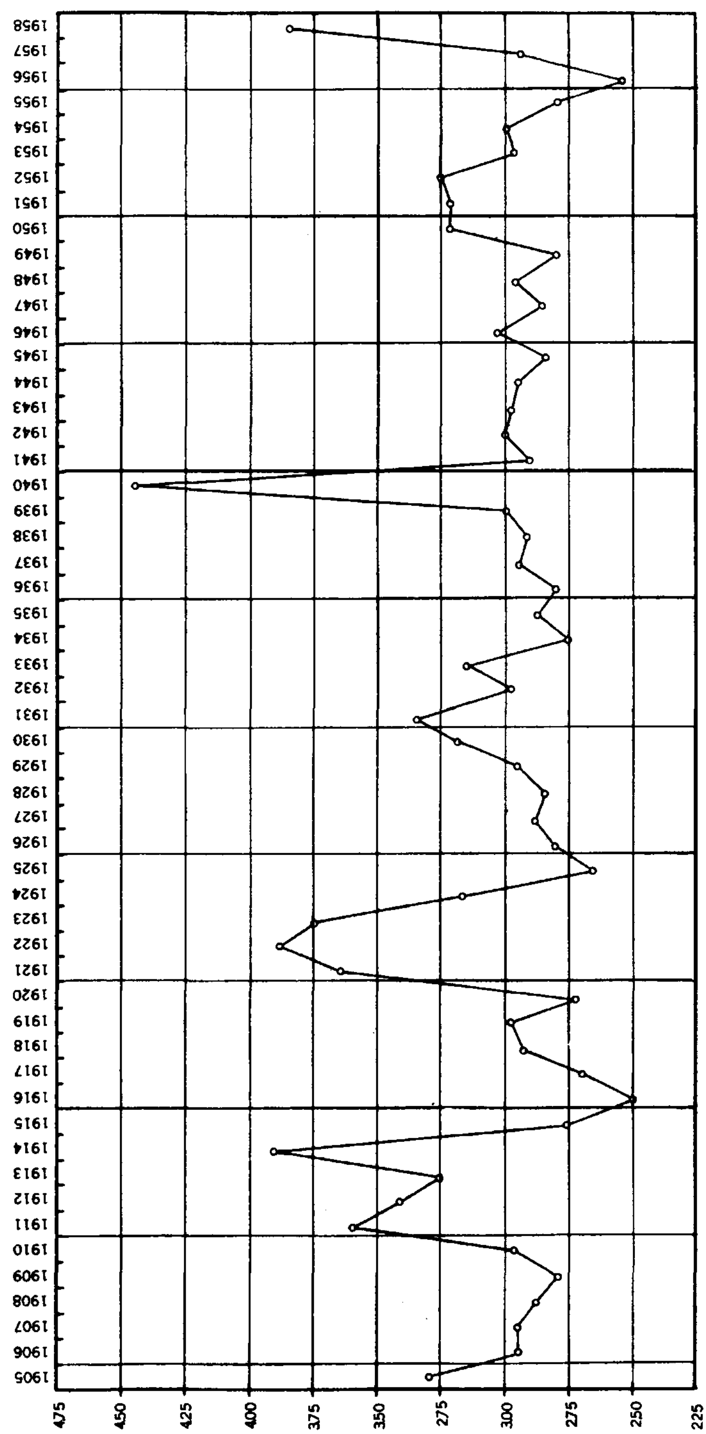
Harmonic 1/4 of foregoing period.

11.1-year cycle, corresponding to period of activity of sun spots.

Harmonic 1/2 of foregoing period.

These facts induced the author in 1942 (*) to study and analyse this problem from a new aspect, on the basis of statistics resulting from a

(*) M. A. Balay : Variaciones anuales del nivel medio del rio de la Plata y su correlacion con las grandes crecidas. *Boletin Centro Naval,* Vol. LXI, No. 556.



Maximum Annual Heights in Rio de la Plata

Port of Buenos Aires

FIGURE 1

TABLE 1

Maximum Annual Heights in Rio de la Plata

Port of Buenos Aires
(Referred to datum of Riachuelo)

Year	Cm	Year	Cm	Year	Cm
1905	330	1923	375	1941	290
1906	296	1924	315	1942	300
1907	296	1925	265	1943	298
1908	288	1926	281	1944	295
1909	280	1927	288	1945	284
1910	297	1928	285	1946	305
1911	360	1929	295	1947	287
1912	343	1930	318	1948	297
1913	325	1931	336	1949	279
1914	390	1932	298	1950	322
1915	277	1933	315	1951	321
1916	250	1934	277	1952	325
1917	270	1935	288	1953	293
1918	293	1936	280	1954	300
1919	298	1937	295	1955	279
1920	273	1938	293	1956	252
1921	364	1939	300	1957	294
1922	389	1940	444	1958	385

37-year series of tidal observations recorded at the port of Buenos Aires (1905-1941).

He moreover established a significant coincidence between the unusual floods of 1905, 1914, 1922, 1923, 1931 and 1940 (now confirmed by that of 1958) and certain values of the mean longitude of the lunar perigee and of the moon's ascending node for these same years.

In table 2, values for P and N have been underlined whenever passing through 180° and 360° respectively. It will be observed that these values precisely occur during the years of largest flooding of the Plata.

It will also be noted that the floods of destructive character coincide with the years during which values of P and N approximate 180°.

On the basis of these coincidences, the author attempted (in the work referred to above) to predict floods in the Plata over a period extending up to 1962, even though the statistics available were somewhat limited (37 years) and he was compelled to resort to various artifices in order to compute the parameters of the constituents, with an inevitable loss of accuracy.

In order to obtain satisfactory separation of the constituents (the astronomical cycles mentioned), more than 100 years of continuous observations would be required, without allowing for the 93-year constituent (five Metonic cycles).

The result obtained in the 1942 investigations are reproduced herewith:

The coincidence of the two curves will be noted (the continuous line represents observed heights, and the dotted line computed heights).

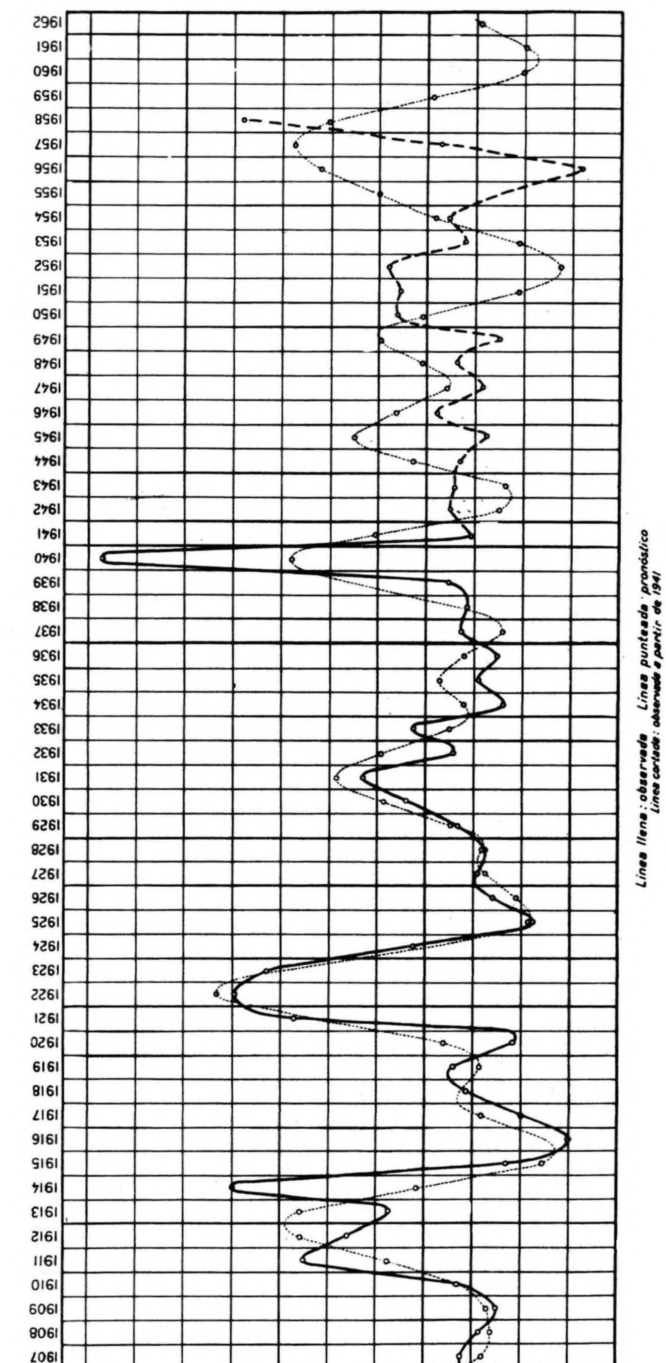
The error in time was established as amounting to about half a year, owing to the limited statistics used in the computations (37 years).

TABLE 2

Mean Longitude of Lunar Perigee and of Moon's Ascending Node on 1 January of Each Year

Year	P	N	Year	P	N	Year	P	N	Year	P	N	Year	P	N
1901	15°	240	1913	143	8	1925	272	136	1937	40	264	1949	168	31
1902	56	220	1914	184	348	1926	312	116	1938	81	244	1950	208	12
1903	96	201	1915	225	329	1927	353	97	1939	121	225	1951	250	353
1904	137	182	1916	265	310	1928	34	78	1940	162	206	1952	290	333
1905	178	162	1917	306	290	1929	74	58	1941	203	186	1953	331	314
1906	218	143	1918	347	271	1930	115	39	1942	243	167	1954	12	295
1907	259	124	1919	27	252	1931	156	20	1943	284	148	1955	52	275
1908	300	104	1920	68	232	1932	196	0	1944	325	128	1956	93	256
1909	341	85	1921	109	213	1933	237	341	1945	5	109	1957	134	237
1910	21	66	1922	150	194	1934	278	322	1946	46	89	1958	174	217
1911	62	46	1923	190	174	1935	318	302	1947	87	70	1959	215	198
1912	103	27	1924	231	155	1936	359	283	1948	127	51	1960	256	179

Revolution of lunar perigee : 8.85 years.
Revolution of moon's node : 18.61 years.



Maximum Annual Heights in Rio de la Plata

Port of Buenos Aires

Continuous line : observations.
Dotted line : predictions.
Dashed line : observations since 1941.

FIGURE 2

The theoretical (dotted) curve nevertheless reproduces with notable accuracy the floods occurring in 1921, 22, 23, 31 and 40, although showing as of 1912 and 1913 floods that actually occurred in 1911 and 1914. But even in these cases the theoretical curve reveals the existence of major disturbances during this period, since it remains above the general average.

The comparison of the other predictions with events occurring after the date of analysis, i.e. from 1942 to 1958, has been effected through use of a dashed line for purposes of differentiation.

From 1941 to 1957, computations indicate no unusual flood, but a period of relative calm borne out for the most part by actual events.

The computed figures showed a period of irregular variation, similar to the 1924-1939 period, for which the most important floods of 1931, 1932 and 1933 may be compared with those of 1950, 1951 and 1952.

The large flood forecast for 1957 actually occurred in July 1958, which does not detract from the quality of the prediction, since the accuracy to be expected was dependent on the 37-year series under analysis.

Coincidence of the curves is moreover significant with regard to the nature of the phenomenon considered.

In calculating the 1942 figures, only the constituents corresponding to the above-mentioned cycles were analysed. Later investigations have revealed the existence of certain meteorological and oceanographic rhythms which likewise affect sea level, such as :

5- to 8-year rhythms of temperature variation

11- to 13-year rhythms in the cycle of sun spot activity

24- to 26-year rhythms caused by double cycles of sun spot activity.

Other as yet ill-defined rhythms, such as the 15- to 16-year rhythm denoted as Wagner's; Easton's 89-year rhythm; and Memery's 100-year rhythm also have a marked influence on sea level.

The latter long-period rhythms refer to variations in winter temperatures, and may respectively extend up to 104 and 112 years.

The existence of these cycles is brought out by the systematic analysis of tidal records, since the sea level faithfully reveals all weather disturbances of whatever periodicity and intensity.

Thus annual variations in the mean level of the Plata show characteristics that are notable for their periodicity, since they correspond with peculiar regularity to the cycles mentioned above.

In tables 3 and 4, values corresponding to annual mean levels and to the 9-year, 18-year and 11-year cycles are shown.

These values have been plotted in diagram form in figure 2a, which will enable analysis of variations of mean level in the rio de la Plata during the periods considered.

The constituent (dot-and-dash line) of which the period is approximately equivalent to four (4) cycles of sun spot activity (44 to 52 years) is thus clearly apparent, with a minimum (1916-1926) and maximum (1938-1948).

Similarly, for the cycles of variation in the mean longitude of the lunar perigee (continuous line), a constituent with a period of approximately six (6) cycles of nine (9) years has been determined, showing a minimum (1914-1922) and maximum (1941-1949).

TABLE 3

Annual Mean Levels in the Plata

Buenos-Ayres

Year	Height mm	Year	Height mm	Year	Height mm
1905	838	1923	789	1941	843
1906	767	24	730	42	854
1907	771	1925	718	43	809
1908	740	26	775	44	771
1909	765	27	757	1945	747
1910	694	28	799	46	843
1911	753	29	765	47	810
1912	806	1930	797	48	771
1913	770	31	792	49	793
1914	847	32	841	1950	804
1915	768	33	765	51	791
1916	678	34	740	52	816
1917	673	1935	821	53	794
1918	700	36	815	54	833
1919	767	37	752	1955	731
1920	775	38	768	56	762
1921	776	39	812	57	787
1922	849	1940	883	58	842

Average for period : 782 mm above Riachuelo datum.

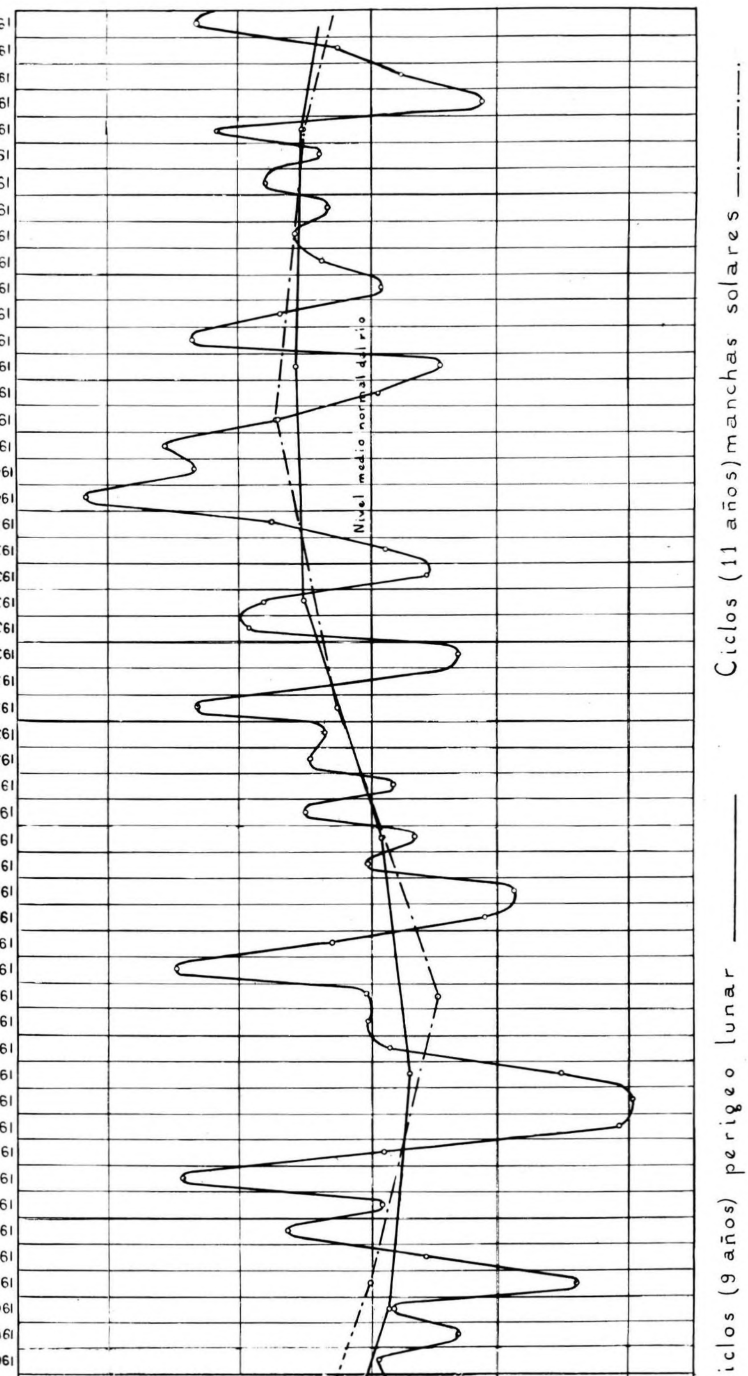
TABLE 4

Mean Levels of Plata

Buenos-Ayres

Period : 9 years		Period : 18 years		Period : 11 years	
Years	Heights	Years	Heights	Years	Heights
1905	...	1905	...	1905	...
1913	767	1922	763	1915	774
1914	...	1923	784	1916	748
1922	759	1940	...	1926	...
1923	...	1941	800	1927	786
1931	769	1958	...	1937	...
1932	...			1938	810
1940	800			1948	...
1941	...			1949	795
1949	805			1959	...
1950	...				
1958	796				

Values in mm above Riachuelo datum.



Annual Mean Levels of Rio de la Plata
Buenos Aires

Lunar perigee cycles (9 years).
Sun spot cycles (11 years).

FIGURE 2*a*

The coincidence of the maximum values of variations in annual mean level and of the years during which major floods in the river occurred is significant.

This situation recurs in all the available statistics. The evident result is the existence of a certain correlation between periodic variations in the mean level of the river and the occurrence of such large floods.

Progress in this field of investigation and prediction is hence dependent on coordinated and continuous action. Precise, consecutive observations should be carried out in as many places as possible, and should then be analysed with great mathematical and statistical care; they should be systematically referred to all physical phenomena occurring simultaneously over the whole planet.

In this type of investigation, scattered observations and those carried out over short or isolated periods are useless. Carefully thought out plans in regard to the geographical location of the stations, methods, instruments, and accuracy desired for the final values are essential.

CAUSES OF STORM WAVES IN THE PLATA

A storm wave is an oscillation in sea level of meteorological origin, which obeys dynamic rather than static effects.

Statically considered, the atmospheric pressure acts on the sea according to the equilibrium ratio between the densities of mercury and water (13/1). The sea behaves as an inverted barometer, i.e. a minimum height corresponds to a maximum pressure and vice versa.

As maximum deviation of atmospheric pressure with respect to its mean value amounts to about 40 mm, the maximum effect of this deviation on sea level would be 52 cm. This value is frequently exceeded, however, even during weather disturbances of minor importance, which shows that the static effect of atmospheric variation on sea level is small and represents only a part of the total variation.

Dynamically considered, a pressure system moving at a specified speed affects the sea level as a tractive force, producing an oscillation whose period and elevation will largely depend on the dimensions of the disturbed area, its depth and shape.

The dynamic action of the shifts in pressure centres over the sea reaches considerable proportions when these shifts occur in shallow waters. As the depth increases, there is a notable decrease in dynamic action until it practically reduces to the static values.

It is assumed that an atmospheric disturbance travelling above the sea surface can originate a variation in level expressed as follows :

$$y = \frac{13(760 - p)}{1 - \dfrac{c^2}{gh}} \tag{1}$$

y = elevation of the sea surface in mm
c = velocity of atmospheric disturbance in m/s
p = atmospheric pressure in mm
h = mean depth of water.

The formula shows that when velocity c of the atmospheric disturbance approximates $\sqrt{gh}$, which is the velocity of propagation of a free oscillation, a phenomenon of resonance occurs; the level of water may then largely exceed the value corresponding to the static effect determined by the equilibrium ratio.

In the outer Plata a free wave is propagated at an approximate speed of 30 miles per hour; in the adjacent ocean zone, it reaches 45 miles, so that any atmospheric disturbance travelling above this area at a speed of 20 to 30 miles per hour can create a considerable oscillation in these waters which will be propagated through the estuary as a free wave, exceeding normal expected values.

Wind action on the sea is manifested through tractive force, which acts on the surface through friction, setting into motion the upper layers approximately in the same direction. The upper particles transmit their motion to those in the lower layers, which travel less rapidly than the former.

If the zone is very extensive and deep, motion is successively transmitted to the separate layers making up the entire mass, reaching down to considerable depths (150 m in the Atlantic, and 300 m in the Pacific). If the zone is of limited extent and shallow, and the wind directed towards the coast, the water mass will be driven against it, and by gravity action, an opposite motion of the lower layers will be generated to restore equilibrium. A hydraulic current seawards is thus created, with an erosive effect.

Owing to the elongated shape of estuaries, winds blowing inland along their axis increase the water level, and in the opposite direction decrease it. The level is generally not affected by crosswinds, or only slightly through the estuary's section.

The tractive force of the wind is partially governed by the relationship between the viscosity of the air and of the water, which determines the friction between the two fluids. This force was determined by Rossby, in accordance with the mechanics of fluids, and is expressed as follows :

$$\tau_0 = 2.6 \times 10^{-3} \rho_a V^2 \quad (2)$$

where :

ρ_a = density of air (1.25×10^{-3})
V = velocity of wind (m/s).

Formula (2) has been considered valid for wind velocities between 10 and 26 m/s.

A wind blowing from the southeast at a speed of 60 km per hour (17 m/s) raises the level of the Plata at certain times by more than 1 m.

The action of wind on the Plata is decisive and immediate, owing to its large surface and shallow depth.

It is a well-known fact that the winds which have a maximum effect on the river are from the north sector at low water, and from the SSE sector at high water. Minimum effect occurs respectively from the SW and ENE sectors. Given an equal wind velocity, effects vary according to direction, since owing to the shape of the estuary, there is no equivalent area of action for all bearings.

Statistical investigations carried out since 1940 show that changes in the level of the river at Buenos Aires (inner Plata) are closely connected with the winds prevailing at the river mouth (outer Plata) (*).

A diagram for the inner Plata has been plotted showing mean veriations in the river's level in cm for each m/s variation in the velocity of winds active at Punta del Este and Montevideo (outer Plata).

Diagram of Mean Variation of River Level for each m/s. Variation in Wind Velocity

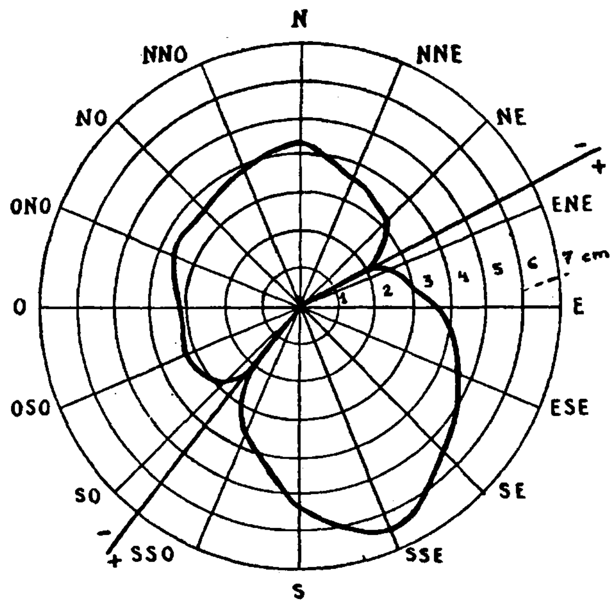


FIGURE 2*b*

It should be emphasized that the diagram represents a « mean effect » only, and for wind velocities between 5 and 24 m/s.

This diagram enables corrections for each m/s of wind velocity (see weather forecasts for outer Plata) to be obtained for tidal heights listed in the tide tables for stations of the inner Plata (Martin Garcia, Palermo, Buenos Aires and Canal de Punta Indio) issued annually by the Argentine Hydrographic Office.

The height of the river at such points may thus be forecast with acceptable accuracy.

Large floods, i.e. those of a destructive character, have always been associated with strong, fairly persistent southeast winds.

But in no case have wind velocities recorded at Buenos Aires reached unusual values.

(*) M. A. BALAY : Ondas de tormenta en el rio de la Plata. Su prevision por el pronostico meteorologico. *Boletin Centro Naval,* Vol. LXXII. No. 619-1954.

Values observed in Buenos Aires are as follows :

Date	Wind	
	Velocity	Direction
19 August 1914	58 km/h	S
30 June 1922	60	SE
10 June 1923	39	S
15 April 1940	41	SSE
27 July 1958	57	SE

Instead, on these dates, hurricane winds were recorded in the outer Plata, which came from the SE sector and in some cases exceeded 130 km per hour (36 m/s) at the highest moment of the flood.

These unusual velocities were recorded at the weather stations of Punta del Este and Montevideo.

It is therefore evident that in order to determine the causes of large floods in the Plata river, we must analyse the atmospheric circulation in general, and that of prevailing winds in particular over the whole maritime area affecting the estuary.

It will be useful to review, even briefly, the formation and displacement in this area of depressions and anticyclones, which are the determining elements of atmospheric disturbances.

Over Central Patagonia is commonly formed the polar Pacific front, consisting of large masses of subtropical air from the great Pacific anticyclone and of masses of polar air from the Antarctic regions (fig. 6).

The depressions which frequently cross Patagonia largely originate from this front. Of the frontal cyclones of this type, only 5 to 8 per year reach relatively large intensities, and they occur more frequently in winter than in summer.

These fronts and their associated cyclones as they travel over the Argentine Sea give rise to short-period waves (seiches), which usually occur on the southeast coast of Buenos Aires, and create heavy disturbances in the harbours of Mar del Plata and Quequén.

Anticyclonic cells moreover become detached from the semi-permanent Pacific anticyclone, which are of varying intensity and extent, and whose pressure is felt over wide areas.

If the centre of the anticyclone passes far to the south ($\varphi = 45°$), the polar thrust comes from the SE sector into the rio and eventually over the entire coast of Buenos Aires, giving rise to southeast winds. The duration and intensity of such winds depend on the path of the anticyclone (fig. 7).

If the anticyclone is directed northwards, it is of short duration and the polar thrust comes from the southwest, with effects similar to those of the pampero (*). But if the anticyclone continues towards ENE, the winds will rotate from SE to NE, and may last from 2 to 4 days.

(*) A wind of gale force blowing from the southwest across the pampas of Argentina and Uruguay (Ed. note).

Southeast winds of this type considerably increase the level of the river, but not always to the extent of creating a flood.

The production of a flood of unusual size by a southeast wind requires among other factors the occurrence of a depression on the front between the polar air from the southeast and the warm air of the north sector, centred at the level of the shore, or north of Buenos Aires, as on 15 April 1940 and lastly on 27 July 1958 (fig. 8).

CHARACTERISTICS OF FLOOD OF 27 AND 28 JULY 1958

This most unusual flood in the rio de la Plata is certainly the one that has caused the most damage to the country. A considerable number of victims are to be deplored; more than 100 000 people were made homeless, and it is estimated that approximately 500 000 suffered in some way or other from the impact of the tragedy.

Yet this flood is not the highest on record : its maximum rise occurred at 16 00 hours on 27 July, when the semaphore of Buenos Aires harbour marked 3.85 m above the Riachuelo datum. This figure was exceeded by floods recorded at Buenos Aires in April 1940 (4.75 m); in June 1922 (3.89 m); and in August 1914 (3.90 m). The June 1923 flood (3.75 m) was only 10 cm under the 1958 flood.

But none of these floods caused as much damage as this latest flood; although the one occurring in 1940 killed 25 people.

Most of the damage resulting from the 1958 flood occurred in localities between Punta Lara and El Tigre.

In the areas of the Parana delta, the swelling of the river covered all the islands and resulted in countless losses. The water rose to 4 m at the confluence of rios San Antonio and Capitán.

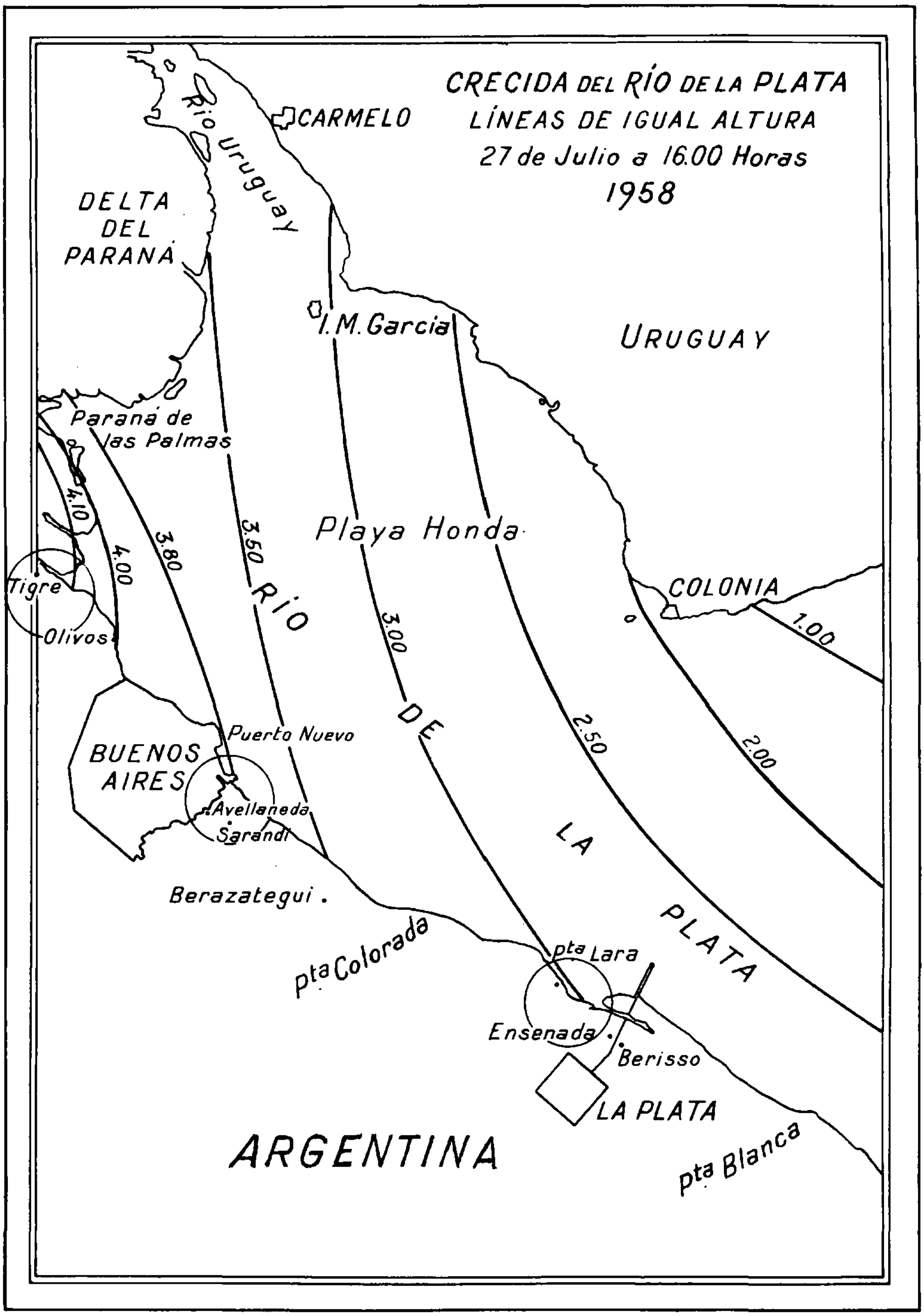
As a reference, it may be reported that only the head of the concrete bull emerged above the waters at the spot marking the junction of the rios Capitán and Toro.

The flood covered all of the thickly populated shore area of Buenos Aires, consisting mainly of flimsy buildings in a rapidly developed section of the city. Here the loss was almost total, as the river tore up everything that stood in its way.

The areas most heavily damaged were in the north, between the Tigre and Nunez, where the flood was highest and piling up of the waters was facilitated by the river's narrowness and the elevation of the river bed. An additional contributing factor was the Coriolis force, which is of course known to increase the storm wave's left-hand path in the direction of propagation.

The lower sections of the capital and of Greater Buenos Aires were very badly damaged, as the major part of the population and greatest number of industrial establishments and warehouses are concentrated there.

The Boca, Barraca, Belgrano and Nunez sections were partially flooded. Maciel island remained under water, as well as a large part of the Boca section, where the streets in the old quarter were under 2.70 m of water at 16 00 hours on the 27th. At Pedro de Mendoza and Palos, the water



Flood of Rio de la Plata. Contour lines on 27 July 1958 at 1600 hours

FIGURE 3

left its mark at a height above 2 m, and at the corner of Almirante Brown and Pedro de Mendoza, it was more than 1.50 m above the sidewalk.

In the south, along the shore areas of Avellaneda, Sarandi, Wilde, Bernal, Quilmes and especially between Punta Lara and Berisso, the flood took on dramatic proportions, although the water did not attain the levels observed farther north.

Here the waves beat violently against the buildings lining the shore; the water rapidly covered extensive low-lying areas, and flooded entire sections over 2 km away from the shore.

The circles in figure 3 indicate the areas most seriously affected by the flood. Contour lines above the Riachuelo datum, showing heights reached at 16 00 hours on 27 July in the inner Plata, have also been plotted.

It will be noted that the water piled up against the Buenos Aires shore, and especially the area adjacent to San Fernando, where it reached maximum height (4.10 m). This is largely due to the effect of the Coriolis force, which was particularly intense when the storm wave arrived at that spot.

It is important to note that the flood was not greatly evident on the Uruguayan shore, or in the rio Uruguay. But its effects were felt in the rio Parana, where in the channel opposite Rosario, the water rose 2.17 m above normal on 28 July.

The Coriolis force is systematically felt in the rio de la Plata, and the ocean tide wave is thus twice as strong on the Argentine shore as on the Uruguayan shore.

The water which accumulated over more than 100 km along the Buenos Aires shore, reaching heights varying between 3 and 4 m, and which progressively decreased in the direction of the Uruguayan shore, represented a mass on the order of 10 000 million cubic metres transported by natural forces.

Figure 4 shows the development of the flood plotted against time as recorded in Buenos Aires harbour (continuous line) in conjunction with the tide wave active during the same period.

It will be observed that the flood commenced on the 26th at 00 00 hour (time zone III), that a steep increase began at 20 00 hours, maximum height being reached at 16 00 hours on the 27th. Its gradual decrease then began, ending on the 29th at 16 00, when the water regained its normal level.

The river left its bed, i.e. overflowed abnormally, upon reaching a height in excess of 2.90 m above the Riachuelo datum at 00 00 hour on 27 July. It remained above this level until 06 00 on the 28th, when the waters began to subside appreciably, but with fluctuations due to the tide wave which persisted during the entire flood and alternately raised or lowered its level.

As a result, the populated shore areas were submerged and subjected to the water's destructive action during 30 consecutive hours.

Figure 4a shows the flood's development at various places on the rio de la Plata. Variations in time and height may be noted as the waters were propagated up the river. They reached maximum height at San Fernando (4.10 m above datum), then decreased upon arrival in the branches of the delta.

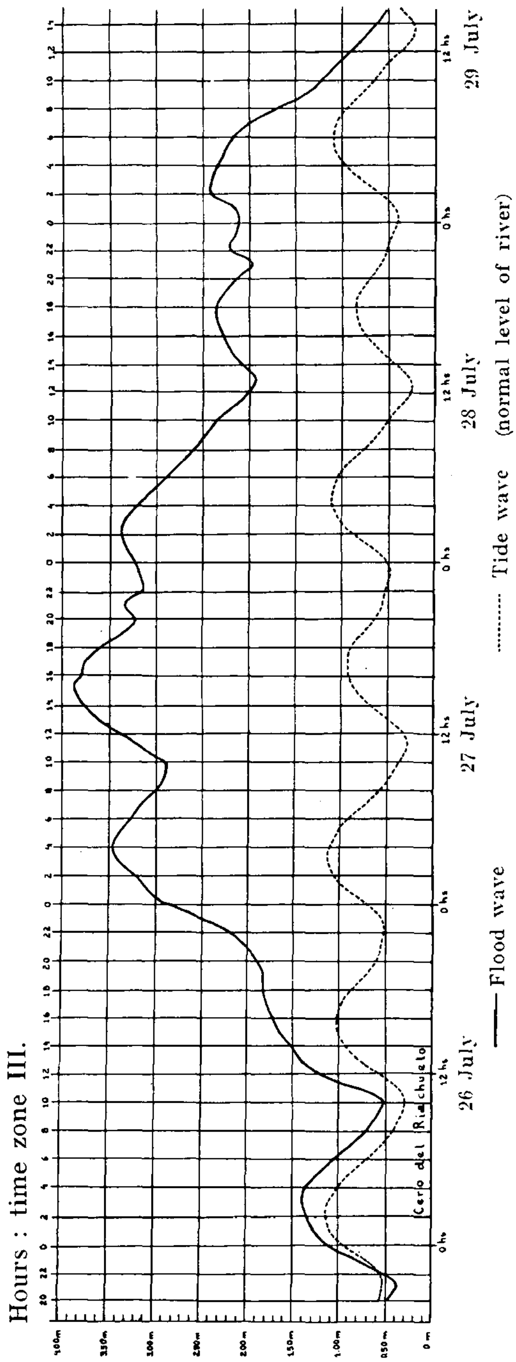


Diagram of Flood in Port of Buenos Aires

FIGURE 4

Rio de la Plata. Diagram of Flood at Various Places

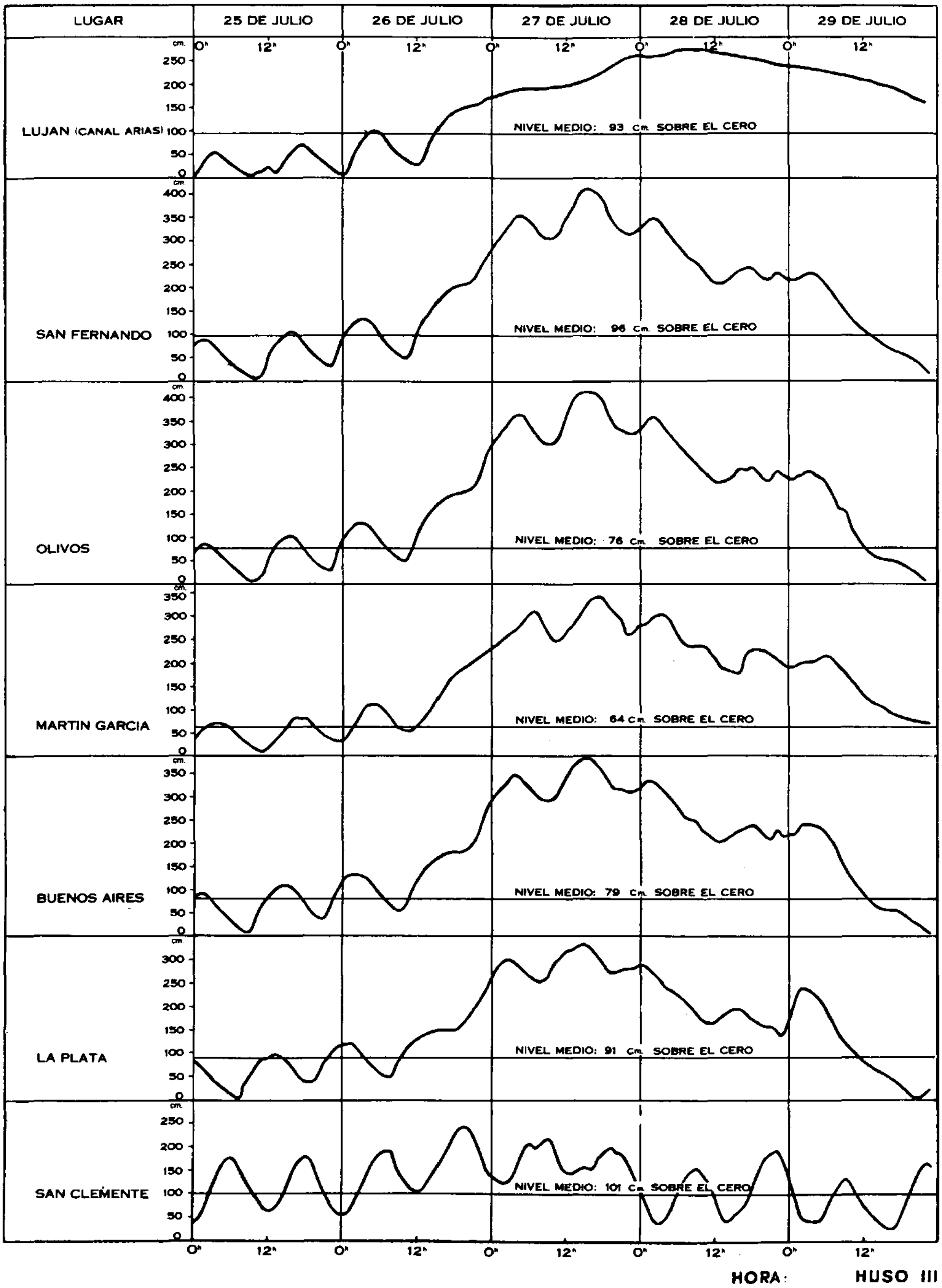


FIGURE 4*a*

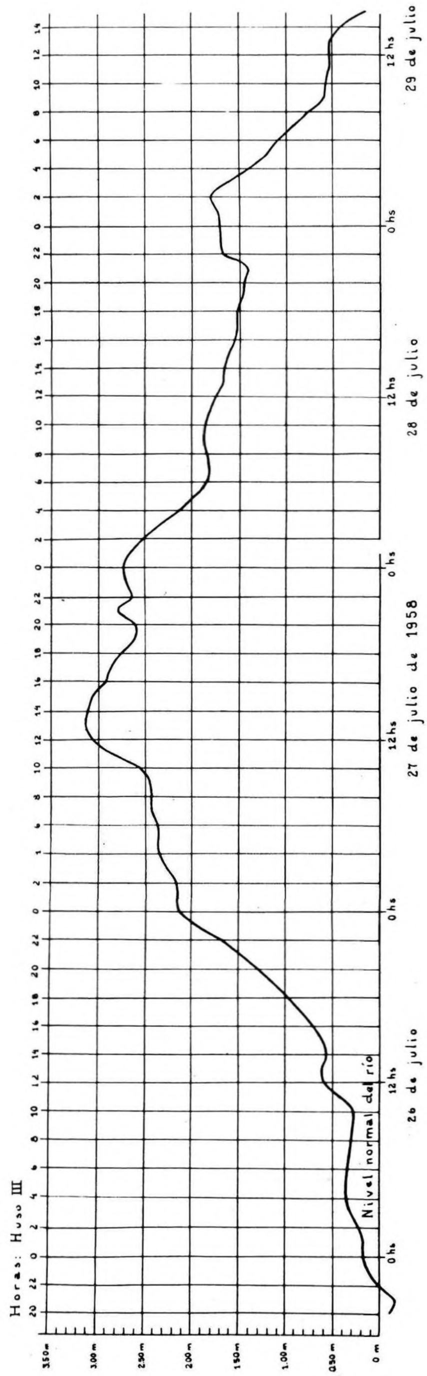


Diagram of Storm Wave in Port of Buenos Aires

FIGURE 5

Figure 5 shows the development of the storm wave causing the flood. This wave has been plotted after subtraction of the tide wave from the total flood wave.

The storm wave basically represents the effect of weather factors, increased in part, as previously stated, by the Coriolis force, and by the topography of the river and shore area, which facilitate propagation.

The storm wave alone raised the normal level of the river by 3.10 m at the time of maximum intensity, i.e. at 13 00 hours on 27 July.

It occurred suddenly at 16 00 on the 26th, practically eliminating the 22 00-hour low tide on that date. Its height rapidly (30 cm per hour) increased until 13 00 on the 27th, when maximum was reached (3.10 m). It remained stationary until 01 00 on the 28th, when it began to decrease with fluctuations which, although slight, sufficed to maintain disquiet among the population.

The storm wave completed its fateful career at 16 00 on 29 July.

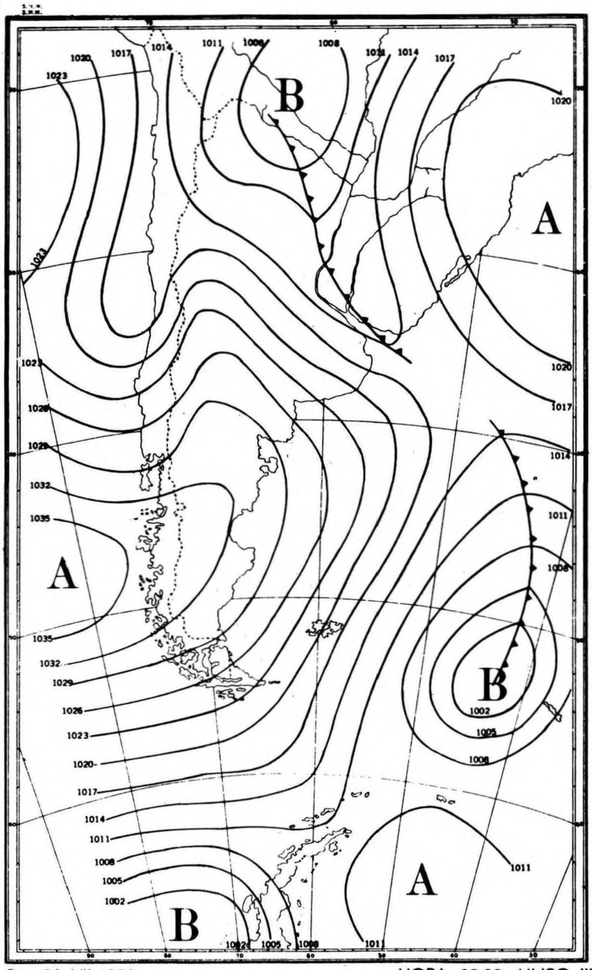


FIGURE 6
Day : 26-VII-1958. Hour : 09 00
Time zone III

WEATHER CONDITIONS DURING THE FLOOD

The weather situation at the time of the flood may be summarized by the statement that the pressure gradient between the anticyclone in the south and the depression centre north of the Plata was 40 mb (30 mm) during the major part of the period.

The corresponding atmospheric pattern appears on the weather charts for these days (figs. 6 to 11). These conditions may be analysed as follows :

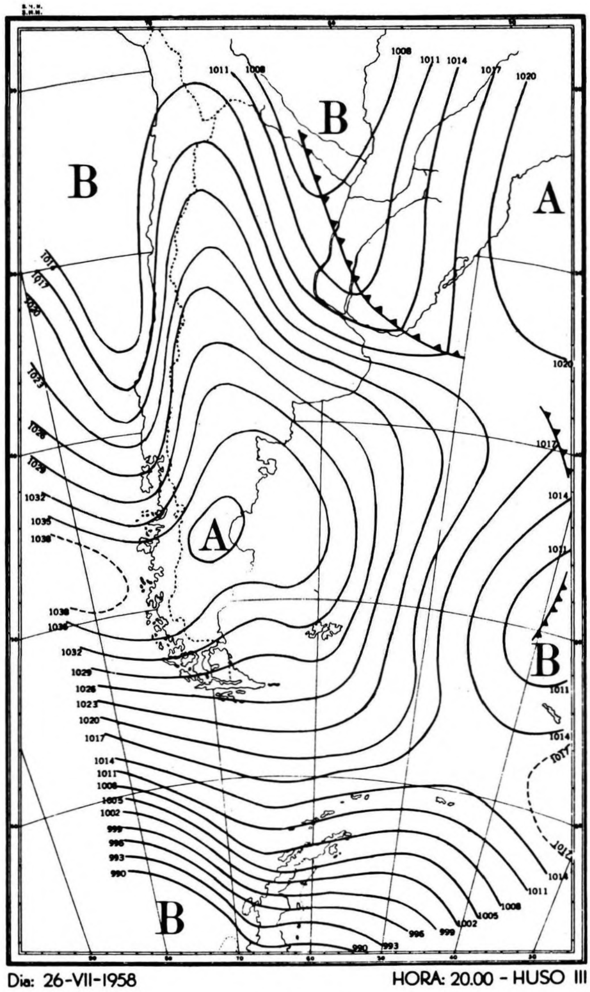


FIGURE 7
Day : 26-VII-1958. Hour : 20 00
Time zone III

26 July, 0900 (fig. 6) : Pacific anticyclone, centred at 45° S, extending over Central Patagonia, with a northward wedge covering the centre and NW of the country. Southern circulation advancing over the mainland SE of Buenos Aires, bringing in large amounts of sea air.

Thermal depression centred at 21.5° S by 62.5° W, extending a trough to the SE, with the addition of tropical continental air, forming over the coast a frontal zone which passed over Montevideo and the centre of Entre Rios.

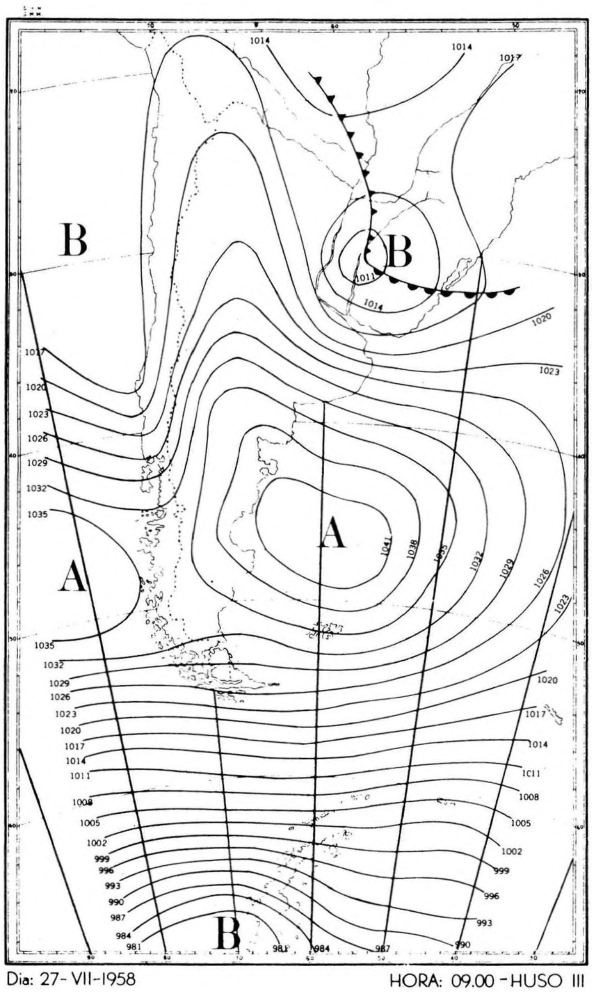


FIGURE 8
Day : 27-VII-1958. Hour : 09 00
Time zone III

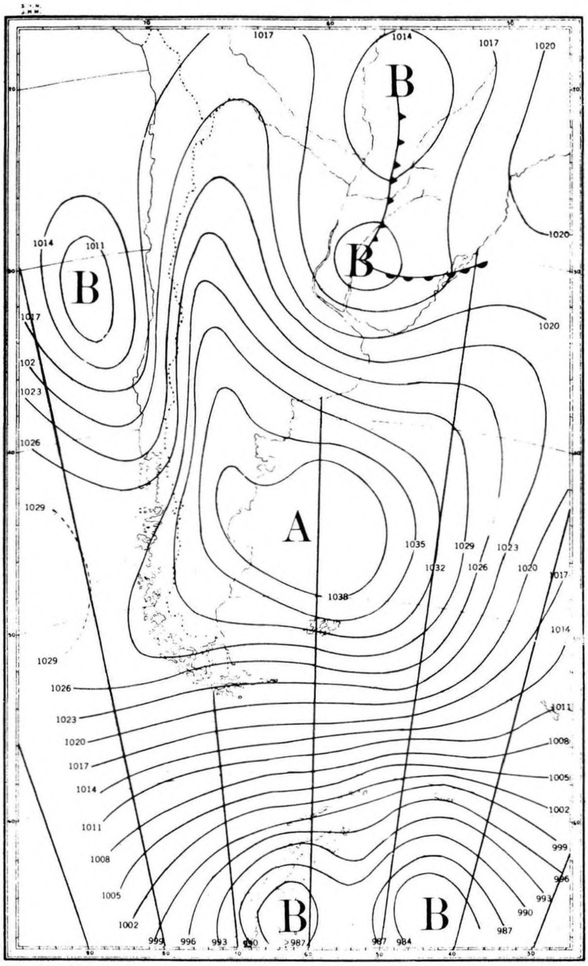
26 July, 1500 : From the Pacific anticyclone centred at 49° S, an anticyclonic cell (1 035 mb) has become detached over Central Patagonia. The southern circulation continues with maritime air penetrating over the mainland SE of Buenos Aires. The moderate SE winds have been added to the regular winds in the same sector.

The thermal depression centred at 24° lat. S by 65.5° long. W, limited by an isobar of 1 002 mb, extended a trough to the SE; tropical continental air continued to be added. Frontal zone stationary since 0900.

26 July, 2000 (fig. 7) : The anticyclonic cell formed at 1500 has increased in intensity, limited by an isobar of 1 038 mb over the Comodoro

Rivadavia area. Continued southern circulation with addition of maritime air over provinces of Buenos Aires, Córdoba, San Luis, Mendoza and San Juan, as well as over Tucumán.

The thermal depression was then located at 22° S by 60° W with



Dia: 27- VII-1958 HORA: 20.00 - HUSO III

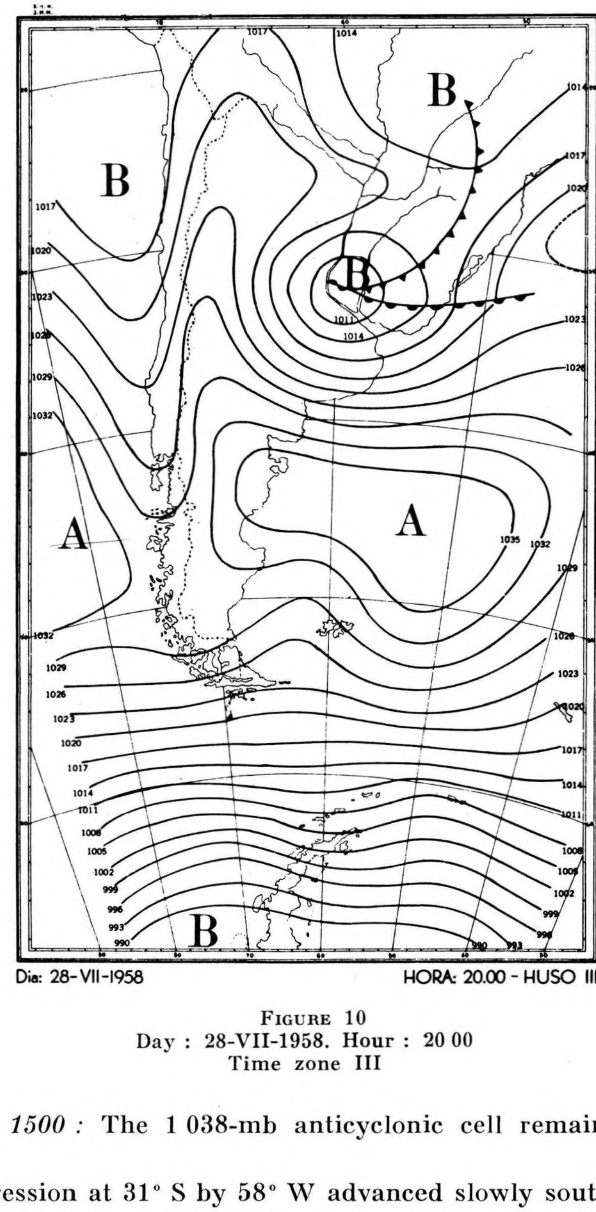
FIGURE 9
Day : 27-VII-1958. Hour : 20 00
Time zone III

a trough extending to the SE. The stationary front began moving NE, with a cold frontal zone. The SE winds, as compared with the 1500 hour situation, have increased from regular to strong, with a tendency to strengthen in the E sector.

27 July, 0900 (fig. 8) : The anticyclonic cell has split into two units of 1 041 mb, one centred at 44° S by 68° W, and the other at 47° by 62°, the northward wedge reaching Salta province.

The NW depression has moved SE, centred at 30° S and 58° W. enclosed by an isobar of 1 014 mb; and has increased the pressure gradient over rio de la Plata, with cyclonic circulation in the E and SE sectors

and winds increasing from very strong to stormy. The depression was accompanied by a cold frontal zone in the NW which covered Corrientes province and the centre of Formosa from south to north, and by a warm frontal zone passing north of Entre Rios and south of Brazil.



Dia: 28-VII-1958 HORA: 20.00 - HUSO III

FIGURE 10
Day : 28-VII-1958. Hour : 20 00
Time zone III

27 July, 1500 : The 1 038-mb anticyclonic cell remained practically stationary.

The depression at 31° S by 58° W advanced slowly south, maintaining circulation of the E sector, with strong winds. The frontal systems remained approximately in the same situation as at 0900.

27 July, 2000 (fig. 9) : The anticyclonic cell remained stationary, centred at 40° S by 59° W, with a wedge extending NW in Tucumán province.

The depression on the coast remained almost stationary, centred at

31° S by 57° W; the winds of the E sector increased from strong to very strong.

28 July, 0900 (fig. 10) : The coastal depression retired as compared with its position on 27 July at 2000, due to blocking by the anticyclone (1 038 mb) centred at 46° S by 47° W.

The position of the depression at 31° S by 58° W has extended the cold frontal zone over Posadas and spread northwards; the warm frontal zone extended east of Entre Rios and north of Uruguay. Winds continued to come from the E sector with the same strength as the previous day.

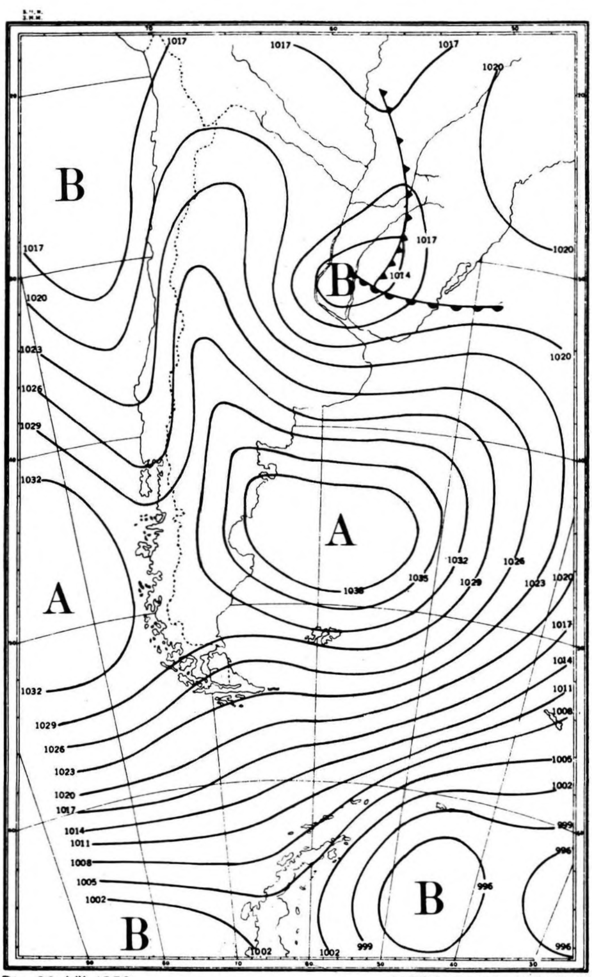


FIGURE 11
Day : 28-VII-1958. Hour : 09 00
Time zone III

28 July, 1500 : The anticyclone centred at 46° S and 56° W continued to block the coastal depression. Winds for the rio de la Plata area continued strong, with violent gusts in the E sector, showing a slight rotation to ENE.

28 July, 2000 (fig. 11) : The coastal depression at 33° S by 59° W continued to advance slowly southwards, closing the frontal systems, and giving rise to very strong winds with stormy gusts in the E and NE sectors, especially over río de la Plata.

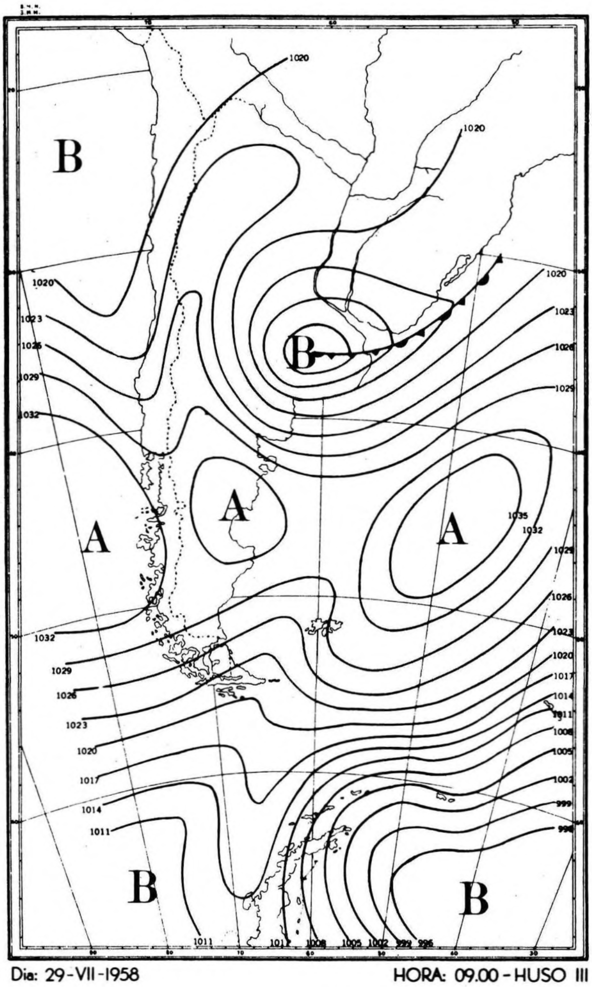


FIGURE 12
Day : 28-VII-1958. Hour : 09 00
Time zone III

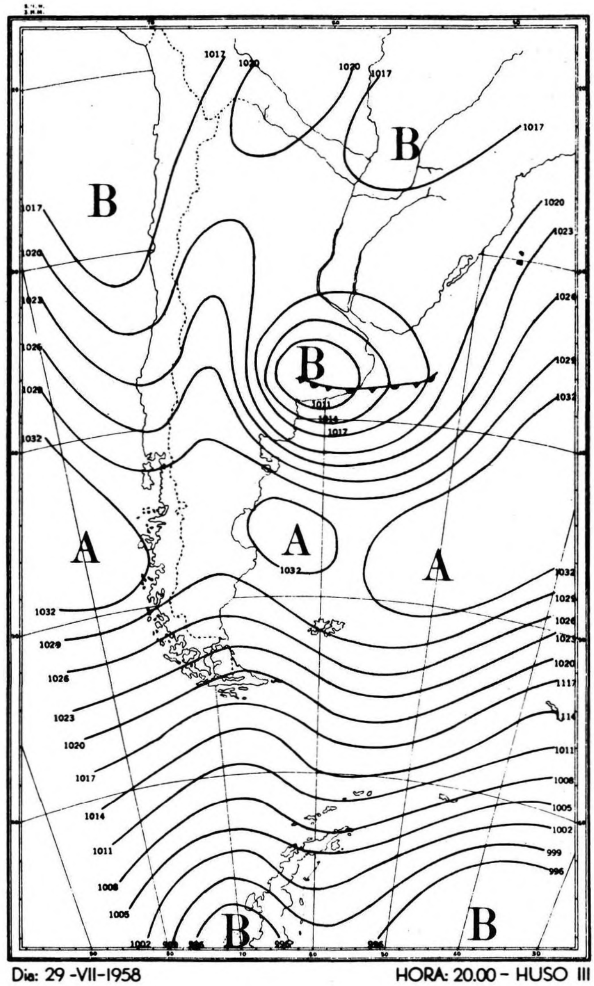


FIGURE 13
Day : 28-VII-1958. Hour : 20 00
Time zone III

The anticyclone at 45° S by 54° W continued to block the coastal depression.

From 27 July at 0900 to 28 July at 2000, the bar values were as follows : anticyclone : 1 038 mb; depression : 1 002 mb (average values).

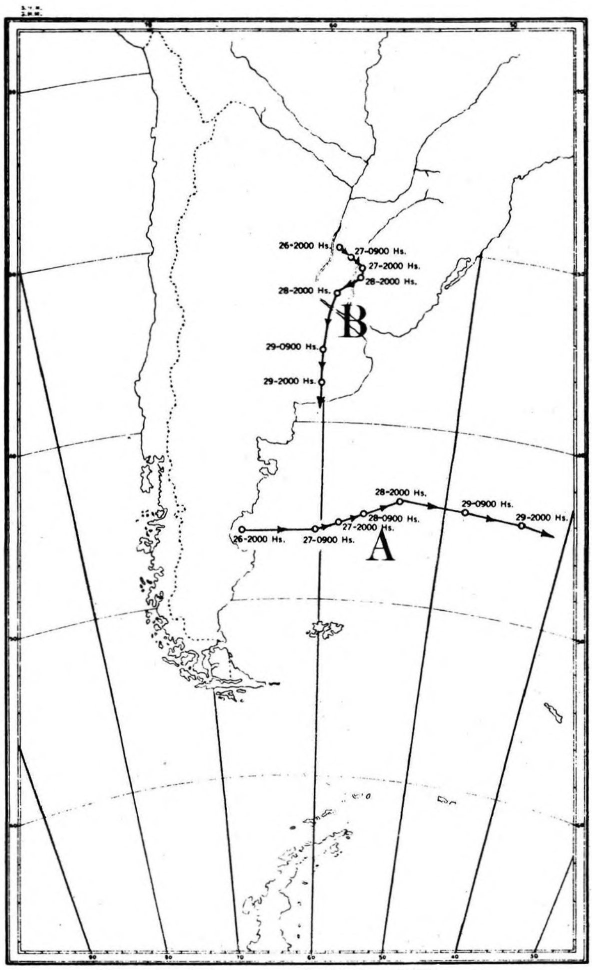
29 July (figs. 12 and 13) : Continuation of southward advance of depression, centring in the Rincón area of Bahia Blanca, and extending an occluded cold front passing over Mar del Plata.

The anticyclone east of Central Patagonia released a cell of 1 032 mb NE of the Falkland Islands.

Paths of pressure centres : Figure 14 shows the daily shifting of the high and low pressure centres during the days of the Plata flood.

The southward path of the depression towards Bahia Blanca is abnormal, and with the ENE path of the anticyclone, gave its character to the southeast wind producing the intense flooding of the river.

Paths of High and Low Pressure Centres from 26 to 29 July 1958



Trayectoria de los centros de BAJA y ALTA presión
Del 26 al 29 de Julio de 1958

FIGURE 14

These shifts, combined with the intensity of the pressure gradients between both centres, explain the magnitude of the phenomenon.

It may in consequence be stated that the atmospheric distribution which determines large floods in the Plata is defined by the weather chart corresponding to 0900 hours on 27 July 1958 (fig. 8).

CONCLUSIONS

Unquestionably, large floods in the rio de la Plata are controlled by more or less persistent southeast winds (2 to 4 days). Their standard atmospheric distribution corresponds to that recorded on 27 July at 0900 (fig. 8).

But this type of atmospheric distribution is observed several times a year, without causing in every instance such differences in the level of the river.

An explanation that might be offered is that the pressure centres and associated winds do not always reach the same intensities and degrees of persistence.

It cannot, however, be assumed that this standard atmospheric distribution (fig. 8) accidentally occurs, with equivalent intensity and persistence every few years, so as to cause an abnormal rise in the Plata as revealed by the statistics (fig. 1).

The facts must therefore be analysed with due regard to their sequence and relationship with specific astronomical, meteorological and oceanographic cycles.

It cannot *a priori* be assumed that the periodicity deriving from observation of the diagram (fig. 1) is accidental; still less can this assumption be made with regard to the systematic coincidence of large floods with certain cycles of variation of characteristic points in the lunar orbit with respect to the ecliptic (table 2), or with the cycles of sun spot activity, which are acknowledged to influence certain of the earth's physical manifestations.

All these factors are simultaneously and reciprocally operative in time and space, and their resultant is the determinant of large floods.

This has been the pattern of events up to the present time, as far as can be ascertained from the available statistics, which although not extensive, should not be underestimated.

Nothing is fortuitous in nature; all physical phenomena are governed by immutable laws which may only be revealed by continuous observation and scientific analysis.

The systematic investigation of the atmospheric distribution causing disturbances in the estuary will show its sequence and potential characteristics in each case. Its action combined with that of the waters of the river and adjacent seas can be recorded by means of an adequate network of tidal stations.

It is consequently believed that daily disturbances and large floods in the rio de la Plata are respectively amenable to short- and long-term predictions by means of an exhaustive study of the phenomenon and a general coverage of related meteorological and geophysical cycles.

ACKNOWLEDGEMENT

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