Environment Canada Imaging Cover Page

Report N.: *TEC-429*

SKP Box Number: 672572426

CIR-3747
TEC-429
1 Nov. 62

THE EFFECT OF METEOROLOGICAL CONDITIONS ON SEA LEVEL

by

John B. Armstrong

This study was undertaken during the summer of 1962 while the author was employed as a Summer Assistant at the Vancouver Meteorological Office. Mr. Armstrong is an undergraduate student at the University of British Columbia.

UDC: 551.509.39:

551.461.2
551.556.8

CONTENTS

Illustrations.

CIR-3747
TEC-429
1 Nov. 62

ABSTRACT

A formula making it possible to determine the deviation in the monthly mean sea level at Vancouver and other B.C. coastal stations on the basis of mean pressure and prevailing wind is derived. A formula of similar form is then applied to the errors in individual tidal predictions, and its limitations discussed. A summary of the characteristics of a number of storm surges and the associated "lows" is also included.

CIR-3747
TEC-429
1 Nov. 62

THE EFFECT OF METEOROLOGICAL CONDITIONS ON SEA LEVEL

by

John B. Armstrong

1. INTRODUCTION

Inundation of low lying coastal areas during severe storms is a fairly frequent occurrence in certain parts of the world. Most people are familiar with the disastrous flooding which has occurred in recent years in such widely separated areas as the Gulf Coast of the U.S.A. and the "low countries" bordering the North Sea in Europe. This study is an attempt to evaluate the contribution of Pacific storms to tides recorded along the British Columbia coast.

In the absence of meteorological disturbances, the tides are dependent only on the relative motion of the sun, moon and earth. The heights and times of high and low water may therefore be predicted with considerable accuracy. Variations of up to a foot from the predictions occur frequently in the winter months due to extreme variations in the prevailing meteorological conditions, but storm surges of greater magnitude than two or three feet occur only rarely. For this reason there has been little interest in the storm surges occurring on the western coast of North America, since a surge of a foot or more, even occurring simultaneously with a spring tide, would cause relatively little damage compared with that experienced in the "low countries" of Europe. Nevertheless it was felt that it would be of interest to know something about storm surges on the British Columbia coast, and also the long-term effect of meteorological phenomena on the level of the sea. The investigation was therefore divided into two parts. The first sought to determine a relationship between the monthly mean sea level, atmospheric pressure, and prevailing wind. The second tried to relate the magnitude of various storm surges with meteorological parameters which were felt to be significant.

2. The Long-Term Effect of Meteorological Phenomena on Sea Level

The level of the sea varies from month to month as the positions of the sun and moon change in relation to the earth. However, from year to year the level is reasonably constant for any given month and for the year as a whole. Yet the variations about the average for a particular month are greater than would be expected from observational error alone, and it would be of interest to know the reason for this variation.

2.1. The Determination of Mean Sea Level

Although the heights of individual high and low tides above a fixed datum line are predicted, there is no prediction of the monthly mean sea level. As mentioned above, this value changes seasonally and no one height may be used. It is therefore necessary to determine the mean sea level from the actual records at stations with recording tide gauges. The standard tide gauge consists of an enclosed float attached by a pulley system to a pen which records on a revolving drum. The actual height at the beginning of each hour is abstracted from the continuous record and the monthly sea level is taken as the mean of these values. These records were available for the seventeen-year period 1945 to 1961 at the following major tidal reference ports:

Clayoquot Sound (Tofino)
Prince Rupert
Vancouver Harbour
Victoria Harbour
Alert Bay (1949 to 1961 only)

For each month at each station the average value was determined (fig. 1; table 1). The difference between the mean sea level for an individual month and the 17-year average for that month will be referred to as the sea level deviation. These values should reflect the changes in meteorological conditions in an individual month from one year to the next.

2.2. Meteorological Forces

In the simplest steady state model the sea would be expected to act as an inverted barometer with respect to atmospheric pressure. If no other forces are considered, the hydrostatic effect would be a change of 0.335 feet in the sea level for a change of 10 mb. in the pressure (1). However, in any particular area, the response of the sea surface to changing atmospheric pressure sets up currents which cause accumulation or depletion of water in the area. It is therefore not unreasonable to expect the adjustment of the level of the sea surface to lag behind the change in atmospheric pressure. The effect of this atmospheric change should therefore be delayed or damped, probably in a complex fashion, since the transports generated most likely depend on the areal extent of the pressure disturbance as well as on the local intensity. In an analysis such as this, where areal factors are very difficult to assess, the most that can be derived is an empirical relationship between atmospheric pressure and sea level. Individual cases may be expected to deviate considerably from the norm, and most probably these departures may be ascribed to the limitations mentioned above.

Pressure is not the only meteorological phenomenon influencing sea level. It is well known that currents are caused by wind stress and are proportional to the square of the wind velocity. In the open ocean the total transport by the wind is directed normal to the wind (4) due to the coriolis force, and therefore a piling up of water would occur on the western coast of North America with the wind blowing up the coast. However, the amount of piling up depends on the local topography, and in particular is inversely proportional to the depth of the water (1) so that a theoretical amount cannot be readily determined.

It is possible that other factors such as sea temperature and salinity which are certainly related to meteorological phenomena, affect the sea level slightly. The density of sea water varies about 1% on the B.C. coast and this effect extends downward to about 100 meters (5), but this change is mostly seasonal and no definite relationship to sea level could be detected by the methods of this analysis.

2.3. Relating Pressure to Sea Level

The average atmospheric pressure is not the same for every month in the year. This variation would be reflected in the average monthly sea level, the latter being relatively higher in those months when the average pressure is fairly low. However, as mentioned above, the average monthly sea level is also affected by the relative positions of the sun and moon. Because the two effects cannot be separated, it was found necessary to determine the average sea level and pressure for each month, rather than the year as a whole. The pressure deviation of each month from its average was calculated in the same manner as the sea level deviation and was based on the figures contained in the Monthly Record issued by the Meteorological Branch of the Department of Transport, for the five weather stations:

Vancouver Airport (VR)	1945 to 1961
Victoria City (VI)	" " "
Prince Rupert (PR)	" " "
Estevan Point (EP)	" " "
Alert Bay (LT)	1949 to 1961.

Estevan Point was chosen to go with the tidal records at Clayoquot Sound (Tofino), as the weather records from the latter are incomplete.

The pressure deviation was plotted on a scatter diagram against the corresponding sea level deviation, for a total of 964 pairs of observations. A density diagram for the distribution is shown in figure 2, the numbers being points per unit square (1 mb x 0.05 feet). The method of simple correlation outlined by Brooks and Carruthers (2) was used to determine the significance of the distribution. The correlation coefficient, v, was found to be -0.739, the negative sign reflecting the inverse relationship. For 100 pairs of values, 0.324 should occur only once in a thousand times from a random distribution. This threshold value decreases with increasing N, so that for the N = 964, the odds against two unrelated variables producing a value of v as high as 0.739 are extremely high.

The regression line giving the most probable sea level for any given pressure has an equation of the form E (y) = v x, y and x being the standard deviations in the sea level and pressure observations respectively. Therefore E (y) = 0.0566x (fig. 2) and a deviation in the pressure of 10 mb would most likely cause a deviation in the sea level of 0.566 feet, or almost 7 inches. The standard "error of prediction" of the sea level from the pressure is given by the formula , and is equal to 0.154 feet. Assuming the error distribution to be normal, 68% of the actual sea level deviations would fall within ± 0.154 feet of the regression prediction. The 99% limits are ± 0.396 feet. For purposes of comparison, 9.65% of the monthly mean sea level deviations exceed ± 0.396 feet.

2.4. Relating Wind to Sea Level

Because the influence of the pressure on the sea level appeared to be greater than that expected hydrostatically, it was suspected that there was probably a related wind effect. When monthly mean pressures are low in British Columbia, travelling cyclones pass through the area with above normal frequency. Characteristically many of these leave a decaying centre in the Gulf of Alaska as the main pressure surge moves inland, and inspection of mean charts shows that low average coastal pressure is usually associated with a "low" centre off shore. With such a low situated just off the coast, the winds tend to bank the water toward the shore; the wind circulation around a high would have the opposite effect.

As local topography would tend to influence the wind effect more than the pressure effect, it was decided to test this hypothesis for only one station. Vancouver was chosen on the basis that it is the only station where data were readily available for all seventeen years. The theoretical wind stress in the Vancouver area is shown in figure 3. The tide gauge is not located in the most favourable position, but it was felt that any build-up of water along the north shore of Burrard Inlet would be transmitted, at least in part, to the harbour.

It was initially assumed that the pressure deviation exerted its full hydrostatic effect of 0.335 feet per 10 m.b. on the sea level, and therefore the sea level deviation was corrected for the corresponding pressure deviation on this basis. The wind was summarized in the following somewhat arbitrary way. The total number of miles of wind for each month from the west, north-west, and north quadrants was subtracted from the miles from the east, south-east, and south. The other two quadrants were not considered. The difference was divided by the total number of hours in the month and then squared, negative signs being retained. The average monthly values for the 17-year period were then determined, as was the deviation of each month from the average. This final value, to be known as the wind index, was plotted against the "corrected" sea level deviation. (figure 4)

The correlation coefficient, v, for the 204 observations was 0.349, significant, but considerably less pronounced than the straight pressure relationship. The regression equation of corrected sea level on wind is $E(y) = 0.00552\ x$, y being the corrected sea level deviation in feet, x the wind index in units of mph^2.

It is now possible to write a formula for determining sea level, X, for a given month. If $\overline{X}$ is the 17-year average of the sea level for that month, the sea level deviation is $(X - \overline{X})$. Similarly $\overline{P}$ is the mean pressure for the month, and $\overline{\overline{P}}$ the 17-year average. It has been assumed that a sea level deviation of 0.335 feet is always caused by a pressure deviation of 10 mb., and that the wind accounts for any additional effect in the amount given by the regression equation above. The formula is therefore:

$$(X - \overline{X}) = 0.00552W - 0.0335\ (P - \overline{P})$$

where W is the wind index in units of mph^2.
X and $\overline{X}$ are in units of feet
P and $\overline{P}$ are in units of millibars.

The standard error of prediction of sea level using this formula is 0.140 ft.; the 99% limits are reduced to ± 0.360 feet.

If the wind index is correlated to uncorrected sea level, the correlation coefficient becomes 0.447, and the formula reduces to simply:

$$(X - \overline{X}) = 0.0101\ W$$

The standard error of prediction increases, however, to 0.171 feet. Comparable results for the slightly less reliable tide gauge at Caulfield, based on the same wind data, yield a coefficient of 0.507, or a 13% increase. The formula becomes:

$$(X - \overline{X}) = 0.0112W$$

and the standard error of prediction is now 0.159 feet. These results would appear to verify the assumption that most of the wind effect is transmitted directly to the harbour, and that any effect of stress in the harbour is small in comparison.

2.5. The Combined Effect of Wind and Pressure

In order to clarify the effect of wind and pressure on the sea level, an isoanomaly graph was drawn (fig. 5). In this graph each sea level deviation was plotted against its corresponding pressure deviation and wind index, and lines of constant sea level deviation were then drawn. These lines of constant sea level deviation, or isoanomaly lines, would be expected to cross the zero wind index line at the pressure which would produce that sea level deviation hydrostatically. However, this is not borne out.

A partial correlation of sea level deviation to both pressure deviation and wind index was then carried out. Partial correlation supposedly eliminates from the correlation of sea level and pressure the effect which is due to the relationship between wind and pressure, and vice versa. The formula determined by this method is:

$$(X - \overline{X}) = 0.00191\ W - 0.0608\ (P - \overline{P})$$

This does not mean that the entire pressure effect is hydrostatic, but simply that statistically the best results are obtained, if a linear relationship is assumed, by using this formula. It is probable that a different method of analysing the wind would produce different results, but there is no guarantee that there would be any improvement.

The standard error of prediction is not given by a formula in this case, but determined from the basic data it is 0.125 feet. This gives the following results:

LIMITS	% ENCLOSED (Normal Error Distribution)	ACTUAL % ENCLOSED
± 0.0842 ft.	50%	59.5%
± 0.205 ft.	90%	91.1%
± 0.322 ft.	99%	97%

The total range of sea level deviation at Vancouver for the period was 17 1/2 inches. Using this formula a second isoanomaly graph was drawn (fig. 6b). This is essentially a graphical representation of the above formula. If this is considered to be a predicted chart and figure 5 an observed chart, the major area of error in the prediction may be shown (dotted lines). Most of these errors may simply arise from the assumption, inherent in the partial correlation, that the relationships between the variables are linear. The displacement of sea level is supposedly dependent on the square of the wind velocity, and the wind index was calculated on this basis. Yet there is no reason to believe that the pressure is linearly related to the wind index.

It may be concluded from these results that while it is possible to determine a reasonably accurate empirical relationship between sea level and meteorological phenomena, a simple model cannot be used to explain these relationships. A detailed analysis based on more complete meteorological data might yield better results, but the value of such an analysis would be limited.

3. The Effect of Meteorological Phenomena on Tide Predictions:

The actual heights of the high and low tides are usually different from those predicted. A test group of data from the tide gauge in Victoria's Inner Harbour, consisting of three winter months, had a standard deviation of 0.556 feet from the predicted value. This is roughly 2 1/2 times the size of the standard deviation in the monthly means, 0.229 feet. Except for those surges, known as tsunamis, which are caused by occasional violent upheavals in the ocean floor, these errors are directly attributable to meteorological conditions. It was the object of this analysis to determine the nature of those conditions existing when extreme storm surges occurred, and if possible, parameters for predicting the error in any specific tide.

3.1. Application of the Long-Term Formula

The most obvious initial test was to apply the monthly mean formula based on winds and pressures at Vancouver to individual cases. A test group of 64 high and low tides was chosen from data available at Vancouver during October, 1956 and January, 1959. These were selected so that all fell within 15 minutes after the hour. The pressure deviation, p, was taken as the difference between the pressure at the beginning of the hour and the average pressure for that month. The wind index, w, was taken as the difference between the square of the southeast component of the wind at the particular hour, and the average for that month as calculated for the monthly wind index. Any forecast value admittedly depends on the accurate determination of pressure and wind in advance.

For simplicity in the explanation it is desirable to use symbols for the various quantities involved. The actual recorded height of the tide will be referred to as "a"; the predicted value given in the tide tables as "b". The error in the tide prediction is therefore (a - b). The meteorological correction, m, to be applied to b is defined by the formula:

$$m = 0.00191\,w - 0.0608\,p$$

and is based on that of section 2.5. The m- corrected prediction of the tide will then be b + m = c. Ideally c would equal a in all cases, which would mean that m equals (a - b). The error in the m - corrected prediction is (a - c), and the meteorological correction can only be considered worthwhile if, on the average, (a - c) is significantly less than (a - b). It will be noted that (a - c) is equivalent to (a - b) - m. For the 64 cases considered, the mean of (a - b) was 0.24 feet, with a standard deviation of 0.64 feet. The mean of (a - c) was -0.02 feet, with a standard deviation of 0.50 feet (fig. 7). From this analysis it would appear that the errors, (a - c), in the m- corrected prediction are at least more normally distributed around zero, even if their range has not been greatly reduced.

When those values of (a - c) that correspond to a given value of (a - b) were averaged it was apparent that in extreme cases (a - c) was smaller in magnitude than (a - b); consequently the meteorological correction would lead to an improved prediction in these instances. However, even with the meteorological correction, there was a residual error in c for all values of (a - b), which was reasonably constant and averaged 0.27 feet. Unfortunately this means that if the error in b is small, the addition of the meteorological correction is likely to make it worse. The meteorological correction may be divided into groups as follows:

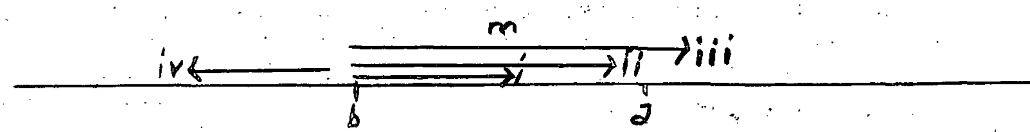
(i) 24 cases in which it was too small in magnitude

(ii) 6 cases in which it was exactly correct

(iii) 15 cases in which it was too large, resulting in c falling on the other side of a.

(iv) 12 cases in which it was in the wrong direction

(v) 6 cases in which b was already correct, and m introduced an error.



It is of interest that the wind index was large enough to have an effect only on 22 of the 64 occasions. Eleven times it made c worse than it would have been if only the pressure part of the formula were considered, in spite of the fact that a data check showed the average sea level to be about 0.6 feet higher when the wind was blowing from the southeast than when it was blowing from the northwest. However, at the same time the pressure was found to average 10 mb. less when the wind was from the southeast.

Predictions based on pressure alone, 0.0566 feet per mb. showed a similar trend of slight improvement at all stations. Consideration of only those cases on which the sea was raised a foot or more at Tofino, which can justifiably be called storm surges, shows that there is a similar trend (fig. 7). The straight line is m, the points (a - b). The horizontal distance between the two represents (a - c).

3.2. Characteristics of Storms:

Although the use of the monthly mean formula makes it possible to determine a meteorological correction, m, which is a not too unreasonable estimate of the height of a storm surge (a - c), it was felt that there was still considerable room for improvement. However, as pointed out by Reynolds (3), "when the pressure system is in rapid motion its effect on water level is very complex, often involving resonance, and little is known quantitatively of its effect in practice."

For this reason it would appear to be difficult to obtain a simple formula or graph for predicting accurately the error in every high or low tide height. Nevertheless, it would be desirable to know the general characteristics of an approaching storm likely to cause a surge of more than a foot, and then, if possible, to forecast the estimated length and maximum height of the surge. Unfortunately comparisons between the predicted tide and the actual tide have only been made in a limited number of cases, and it was impractical to go through hourly records to find more surges. The best data was available from Victoria and Clayoquot for the latter part of 1952 and all of 1954. Some additional data was available from 1956 and 1959.

The original eight surges chosen, with the apparent maximum height and time at Tofino were:

December 6, 1952	1.8 ft.	21:56 PST	low water
December 30, 1952	3.3 ft.	5:35	" "
February 12, 1954	1.5 ft.	21:36	high water
February 17, 1954	1.7 ft.	12:14	" "

March 9, 1954	1.5 ft.	9:46 PST	low water
November 15, 1954	1.1 ft.	22:32	" "
November 19, 1954	1.9 ft.	01:26	" "
December 23, 1954	1.2 ft.	10:50	high water

The path of the low centre with the pressure of the lowest isobar was noted, as were the extreme limits of the paths. It was observed that all approached from the west.

Four additional surges were then chosen from 1956 and 1959. These were:

January 15, 1956	1.5 ft.	20:11 PST	low water
(16)	(1.5 ft.)	(2:32)	(high water)
March 2, 1956	1.4 ft.	22:08	low water
January 12, 1959	1.5 ft.	2:40	high water
March 29, 1959	1.1 ft.	22:07	low water

The first observation was that the paths of these lows fell within the same range as the previous eight. This path was plotted on a chart (fig. 8) and the extreme range of the low centre position at the time of the maximum surge was also noted. A line representing the average position of the low centre at the time of the surge, 6, 12, 18 and 24 hours before was added, and the average pressure of the lowest plotted isobar when the low crossed that line (irrespective of whether it was on time or not) was calculated. The average surge height was 1.63 feet at Tofino; 1.47 if the extreme surge of 3.3 feet is not included.

From this chart and the individual records it may be concluded that storm surges are generally caused by intense low pressure disturbances approaching the lower B.C. coast from the west to southwest at an average speed of 25 to 30 kt. The systems tend to deepen slightly until they cause a maximum surge at Tofino, and then fill over Vancouver Island or move north to the Queen Charlottes. It is to be noted that the extreme limits are not intended to include the system after the time of the surge maximum or before it reaches the 24 hour line.

3.3. Other Lows

It was realized that these lows would probably not be the only ones to appear within the outlined area. Therefore the records for the entire year of 1954 were studied to determine when these other cases occurred and why they did not cause appreciable surges. A total of 35 individual cases were examined in addition to those dealt with above.

In seven cases the low entered the area from the west but moved north to the Gulf of Alaska in the vicinity of the 18 line. Two more headed south after reaching the 18 line. Two got as far as the 12 line before heading north. One of these was associated with a minor surge of 1.1 ft. (high water only) at Tofino. It should be noted that the surge of November 19, 1954, followed a somewhat similar path, not quite reaching the 6 line before heading north.

Ten lows moved in from the west and gradually faded out as they approached the coast. Most varied in pressure from 996 to 1020 mb. Three deeper ones of the ten had only a brief existence in as far as about the 18 line and appeared to be associated with more intense disturbances farther out to sea.

In 6 cases, one of 14 days in extent, weak and indistinct lows were present in the vicinity of Vancouver Island.

Five lows, averaging about 996 mb., came in along the path expected to cause a surge, but there was no rise of as high as one foot, at least at a high or low tide. Four came in during the summer at about the correct speed; the other occurred in October and took 3 days to come in from the 24 hour line.

The remaining three could have been classed as surges. They were, February 19, 1.1 feet; October 19, 1.4 feet; and December 6, 1.5 feet. The duration of these surges was short, however, and not particularly large at other stations.

3.4. <u>Surge Characteristics</u>

In those major cases considered, the level of the sea was raised noticeably above the predicted level for a period of at least two or three high and low tides. In the majority of the cases the maximum reached Vancouver 4 to 6 hours after Tofino and was half a foot or more higher. (fig. 9).

The magnitude of the surge appears to be related to the depth of the low. Statistically the relationship is closer to 0.0566 feet per mb. than the static 0.0355 feet per mb.; as mentioned above.

The time the low spends near the coast and its approach speed seem to have more of an effect on the duration than on the magnitude of the surge at Tofino.

A check on the wind records from Estevan Point, Pachena Point, and Spring Island reveals qualitatively that the height of surges caused by lows of similar pressure is dependent on the wind velocity. It is more probable that the surge is related to areal than local wind stress, but an analysis based on gradient or geostrophic wind is unreliable because of lack of data from the Pacific Ocean.

3.5. Determination of Surge Height

It had originally been hoped that an estimate of the height of the surge, at least at Tofino, could be determined from meteorological parameters other than those of the monthly mean formula. This proved to be completely unsatisfactory. The major attempt involved the setting up of a grid and determining the surface pressure at the various points, on the chart the reference time of which lay between 3 and 6 hours before the surge maximum. No single pressure or pressure difference showed a significant correlation to the height of the surge, though most showed varying degrees of bias.

There are several possible reasons for the failure of this aspect of the investigation. The surge would not necessarily occur simultaneously with a high or low tide. Therefore both its time and height of occurrence would be out. Data were obtained within a range of time before the apparent maximum, rather than at a fixed time. Furthermore data are sparse in most regions of the Pacific Ocean. Most important, a disturbance of the complexity of such an interaction between the atmosphere and the sea may be too complex to be simply forecast with complete accuracy.

APPROVED,

P. D. McTaggart-Cowan,
Director.

REFERENCES

1. Bowden, K.F., March 1953: Storm surges in the North Sea. Weather, London, Royal Meteorological Society. pp. 82-83.

2. Brooks, C.E.P., and Carruthers, N., 1953: Handbook of Statistical Methods in Meteorology. London, Her Majesty's Stationery Office. 412 p.

3. Reynolds, G., April 1953: Storm surge research. Weather, London, Royal Meteorological Society. pp. 101-107.

4. Sverdrup, H.U., 1942: Oceanography for Meteorologists. New York, Prentice-Hall Inc. 235 p.

5. Tabata, S., 1961: Temporal changes of salinity, temperature, and dissolved oxygen content of the water at station "P" in the northeast Pacific Ocean, and some of their determining factors. J. Fish. Res. Bd. Canada, 18(6).

AVERAGE OF 1945-1961 MONTHLY SEA LEVELS.

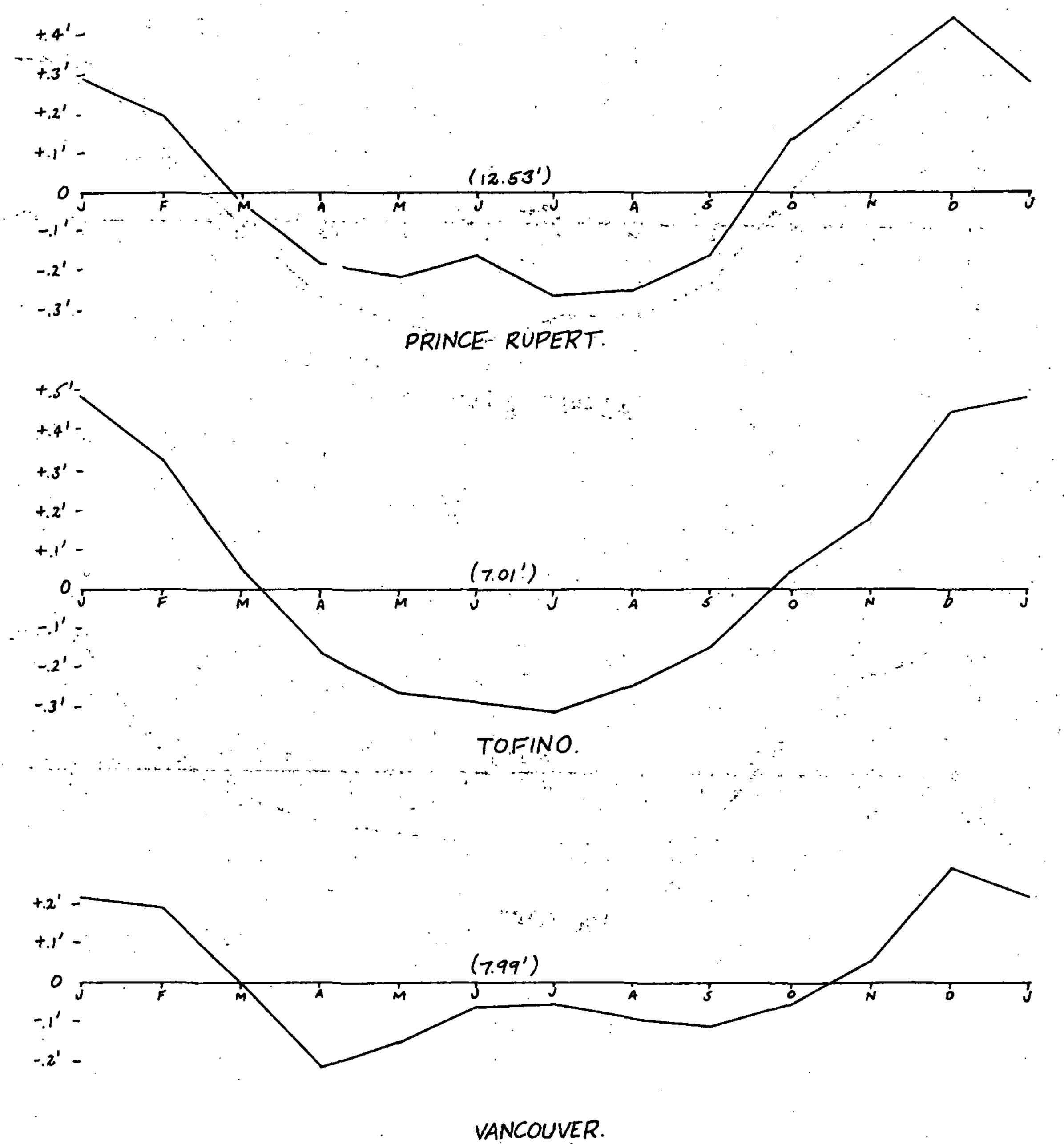
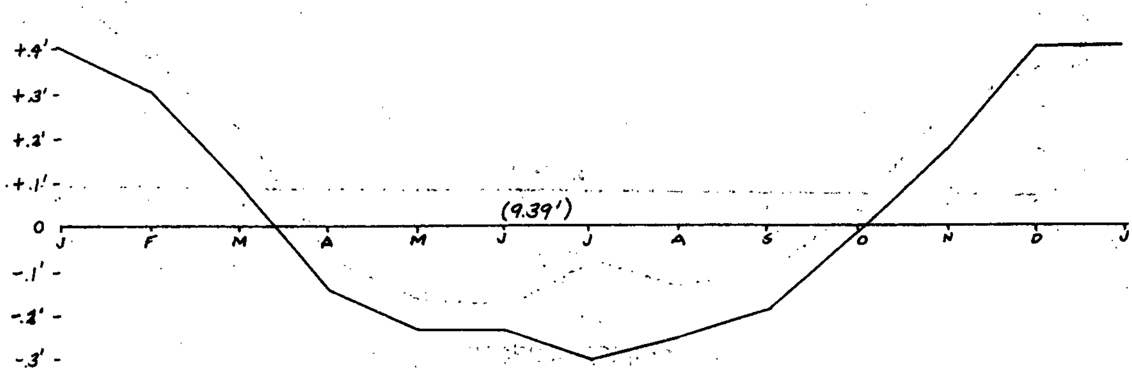
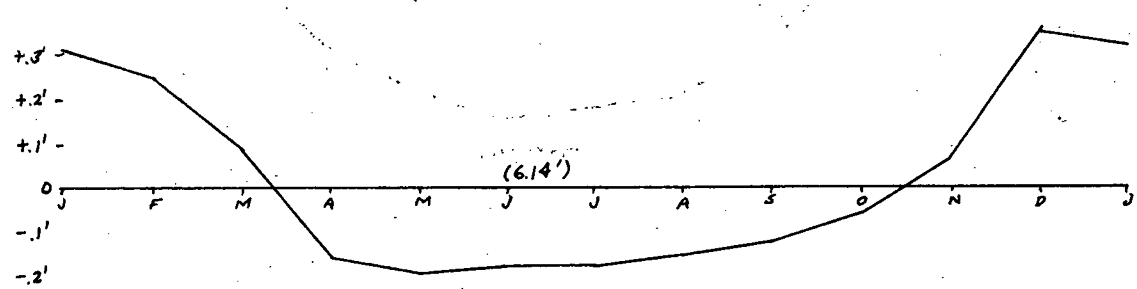


Fig. 1.



ALERT BAY.



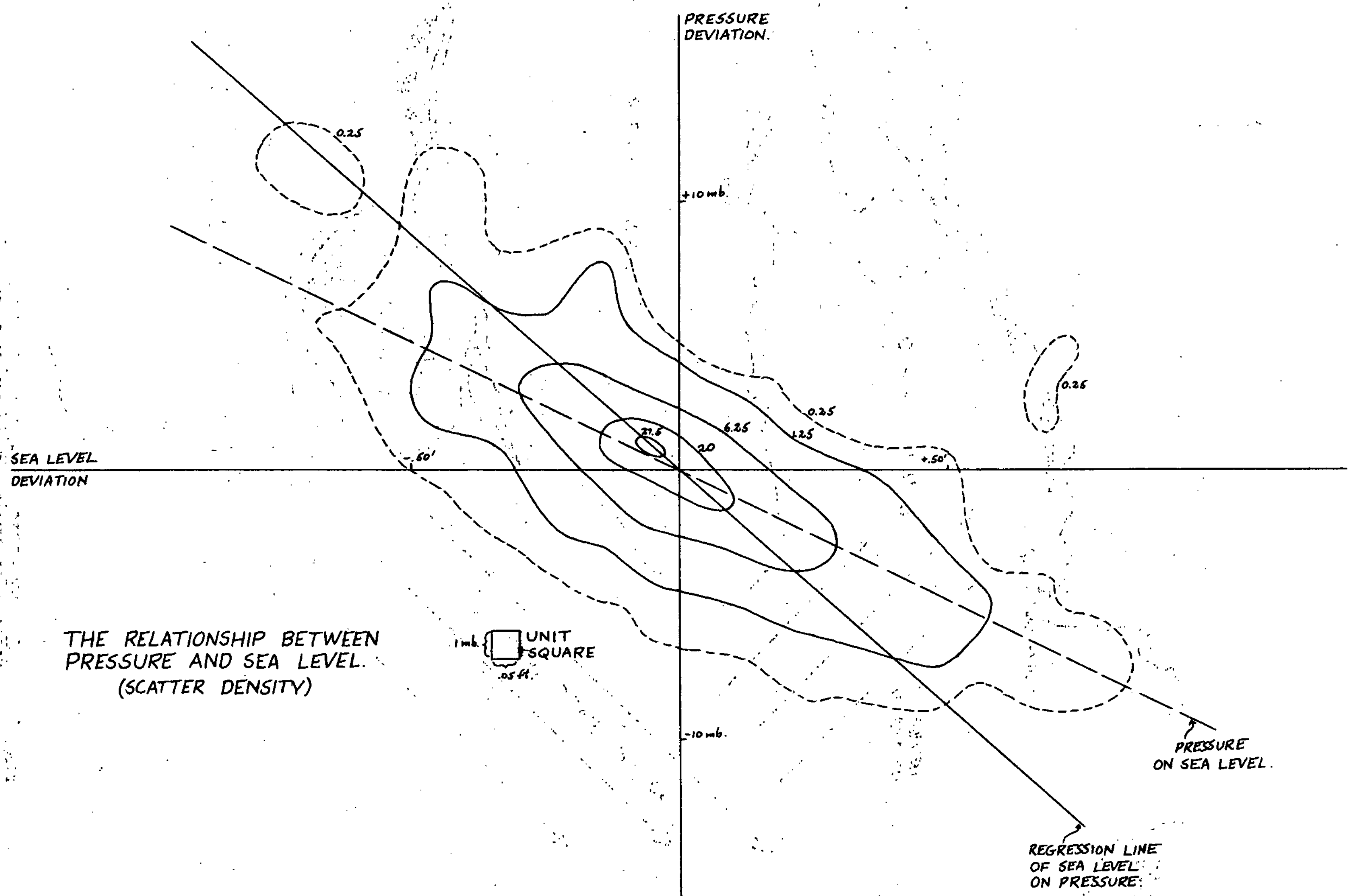
VICTORIA.

Fig. 1.

Table 1.

AVERAGE MONTHLY SEA LEVEL, PRESSURE, AND WIND.

	Alert Bay	Prince Rupert	Tofino	Vancouver	Victoria
January	9.79 ft. 1012.6 mb.	12.81 ft. 1011.2 mb.	7.49 ft. 1014.4 mb.	8.21 ft. 1017.0 mb. 20.30 mph.[2]	6.46 ft. 1016.5 mb.
February	9.69 1013.3	12.72 1011.0	7.34 1014.7	8.17 1016.5 9.95	6.40 1016.2
March	9.48 1013.2	12.50 1010.8	7.08 1014.1	7.98 1015.3 7.24	6.22 1015.0
April	9.25 1015.8	12.35 1014.2	6.84 1017.1	7.77 1017.3 1.83	5.97 1017.3
May	9.16 1017.2	12.31 1016.5	6.74 1017.4	7.84 1016.6 0.23	5.95 1016.9
June	9.16 1016.7	12.36 1016.6	6.72 1017.8	7.92 1016.7 1.71	5.96 1016.8
July	9.08 1018.6	12.26 1018.4	6.70 1018.5	7.93 1017.4 3.28	5.96 1017.6
August	9.14 1017.5	12.28 1017.0	6.77 1017.7	7.90 1016.8 2.51	5.98 1017.0
September	9.20 1016.6	12.36 1015.5	6.87 1016.9	7.88 1016.8 -0.54	6.01 1016.9
October	9.37 1014.7	12.66 1011.1	7.06 1015.6	7.93 1016.7- 3.76	6.07 1016.5
November	9.57 1014.3	12.82 1010.8	7.19 1015.3	8.06 1017.5 11.38	6.21 1017.1
December	9.79 1012.8	12.97 1008.7	7.46 1014.0	8.28 1016.3 18.28	6.48 1015.9
	9.39 ft. 1015.3 mb.	12.53 ft. 1013.5 mb.	7.01 ft. 1014.4 mb.	7.99 ft. 1016.7 mb. 6.66 mph.[2]	6.14 ft. 1016.6 mb.



THE RELATIONSHIP BETWEEN
PRESSURE AND SEA LEVEL.
(SCATTER DENSITY)

Fig. 2.

CIR-3747
TEC-429
1 NOV. 62

CIR-3747
TEC-429
1 NOV. 62

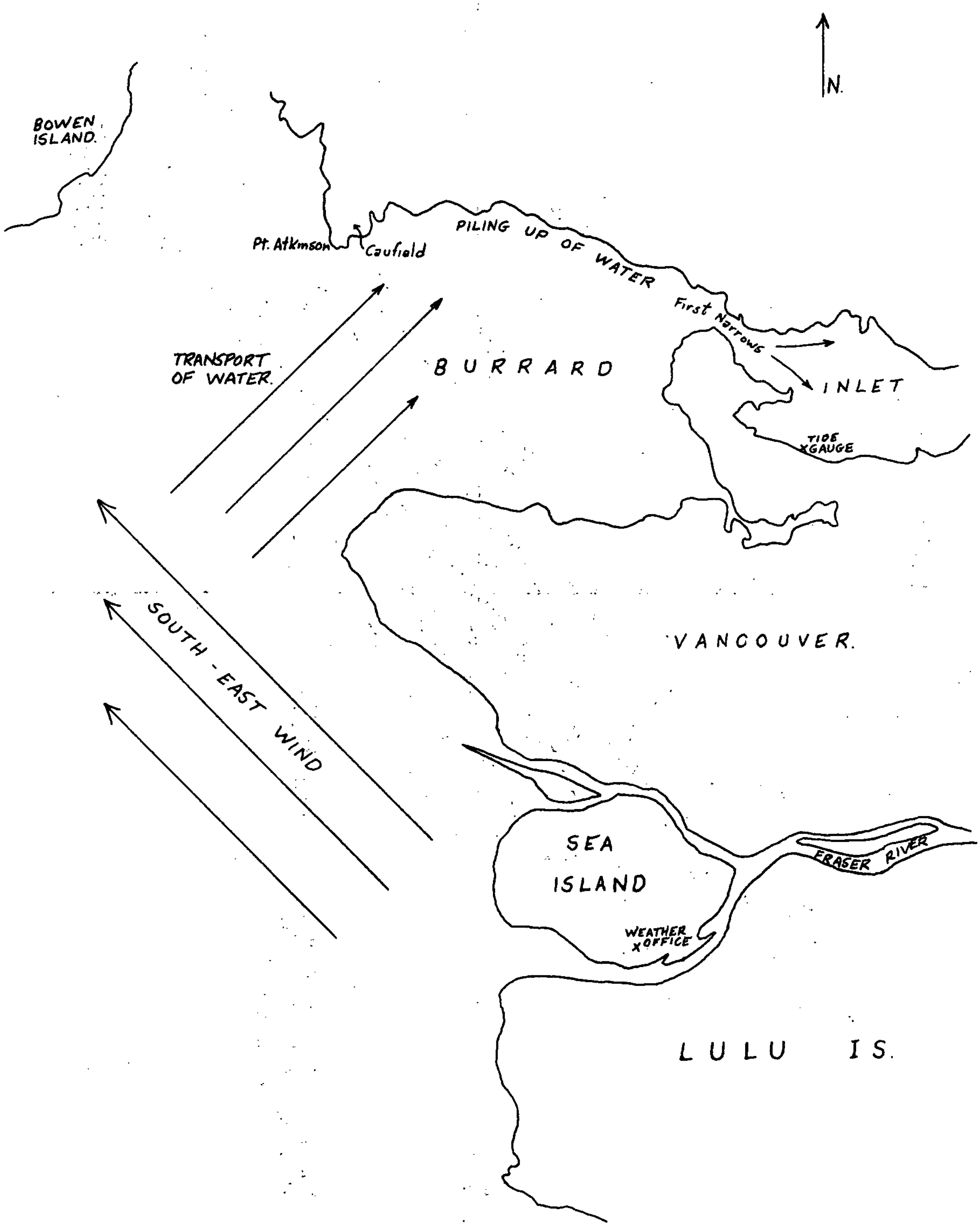
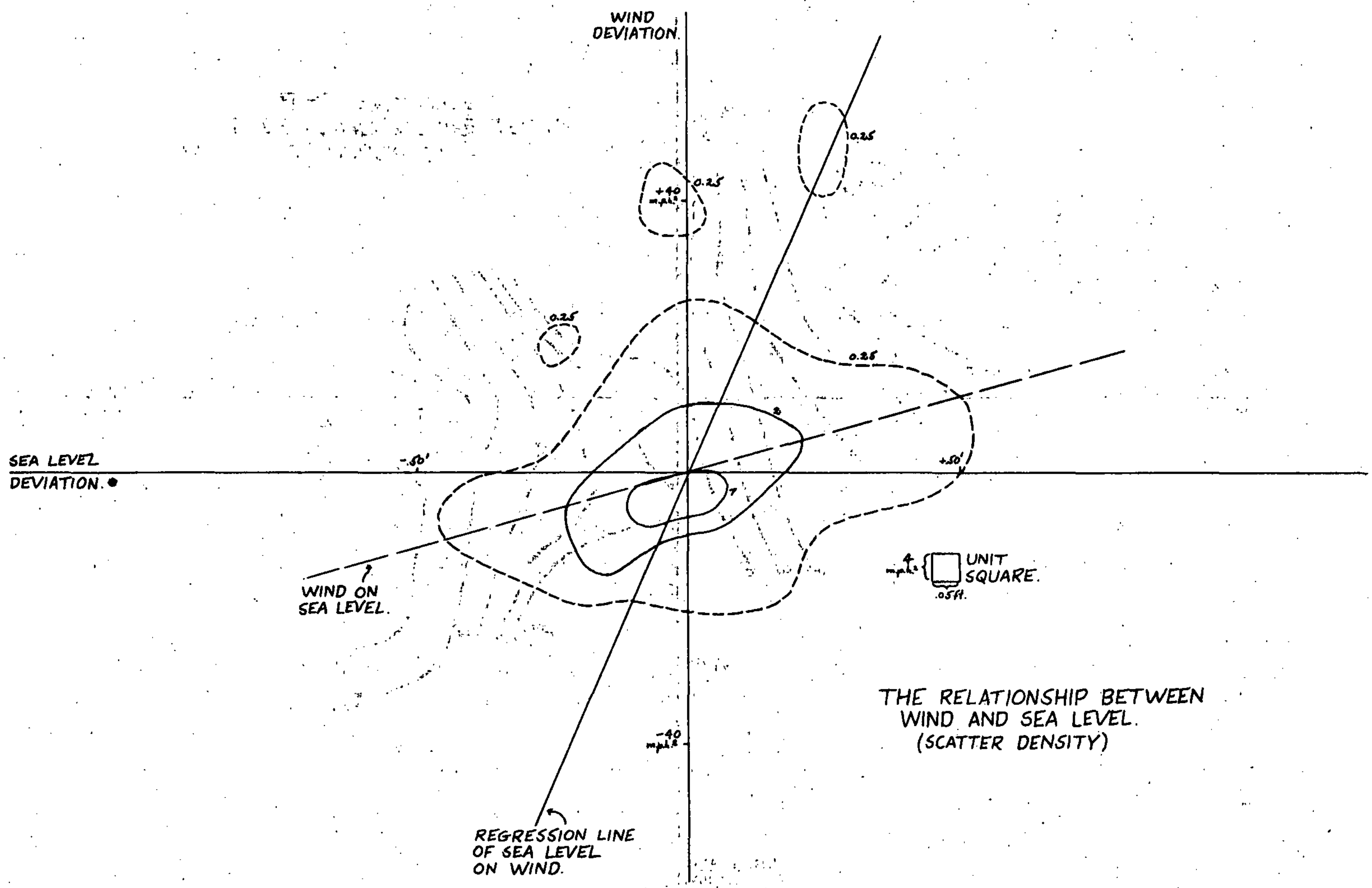


Fig. 3. <u>THE THEORETICAL EFFECT OF WIND STRESS IN THE VANCOUVER AREA.</u>

Fig. 4.

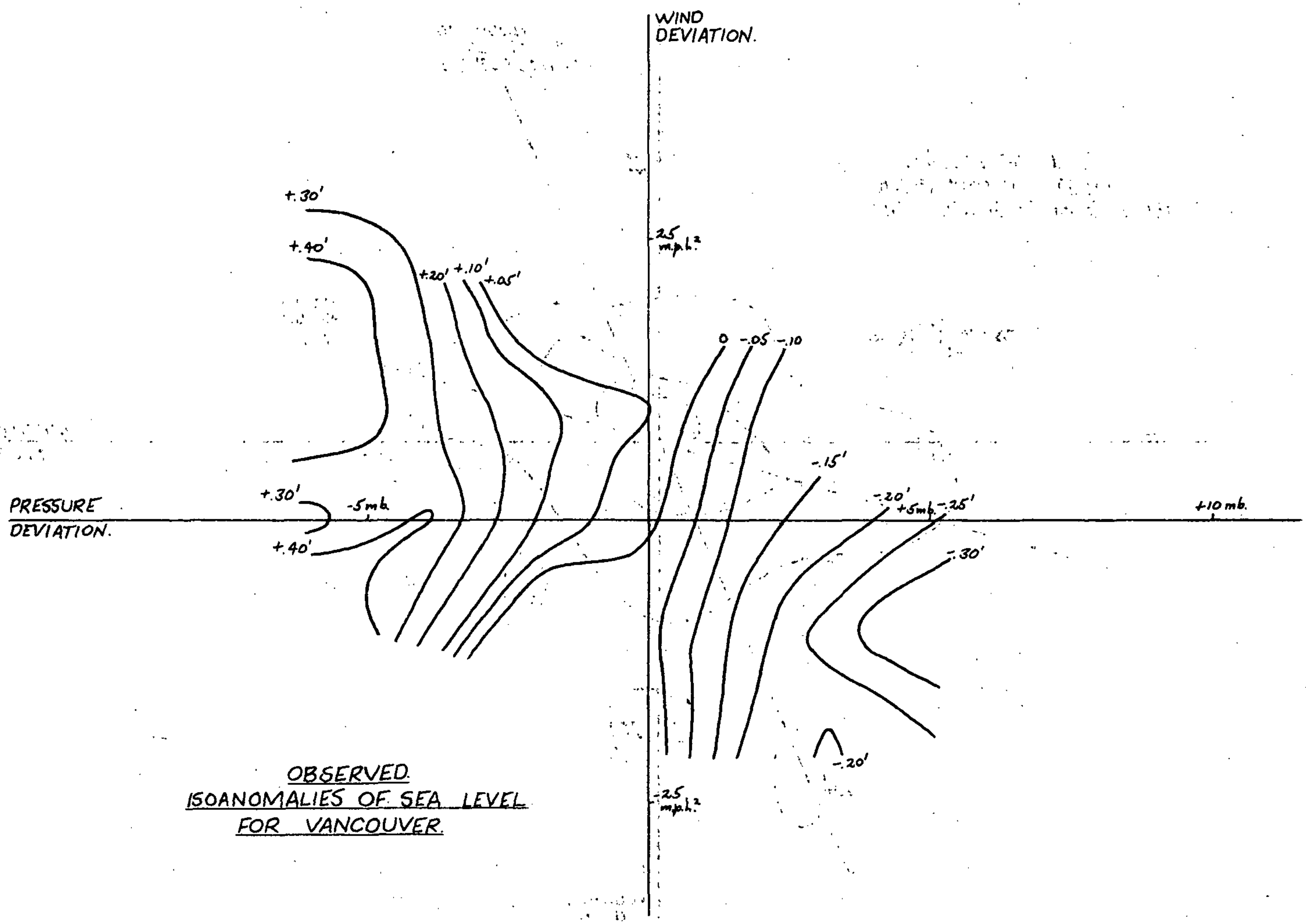


THE RELATIONSHIP BETWEEN WIND AND SEA LEVEL. (SCATTER DENSITY)

* NOT ATTRIBUTABLE TO HYDROSTATIC PRESSURE.

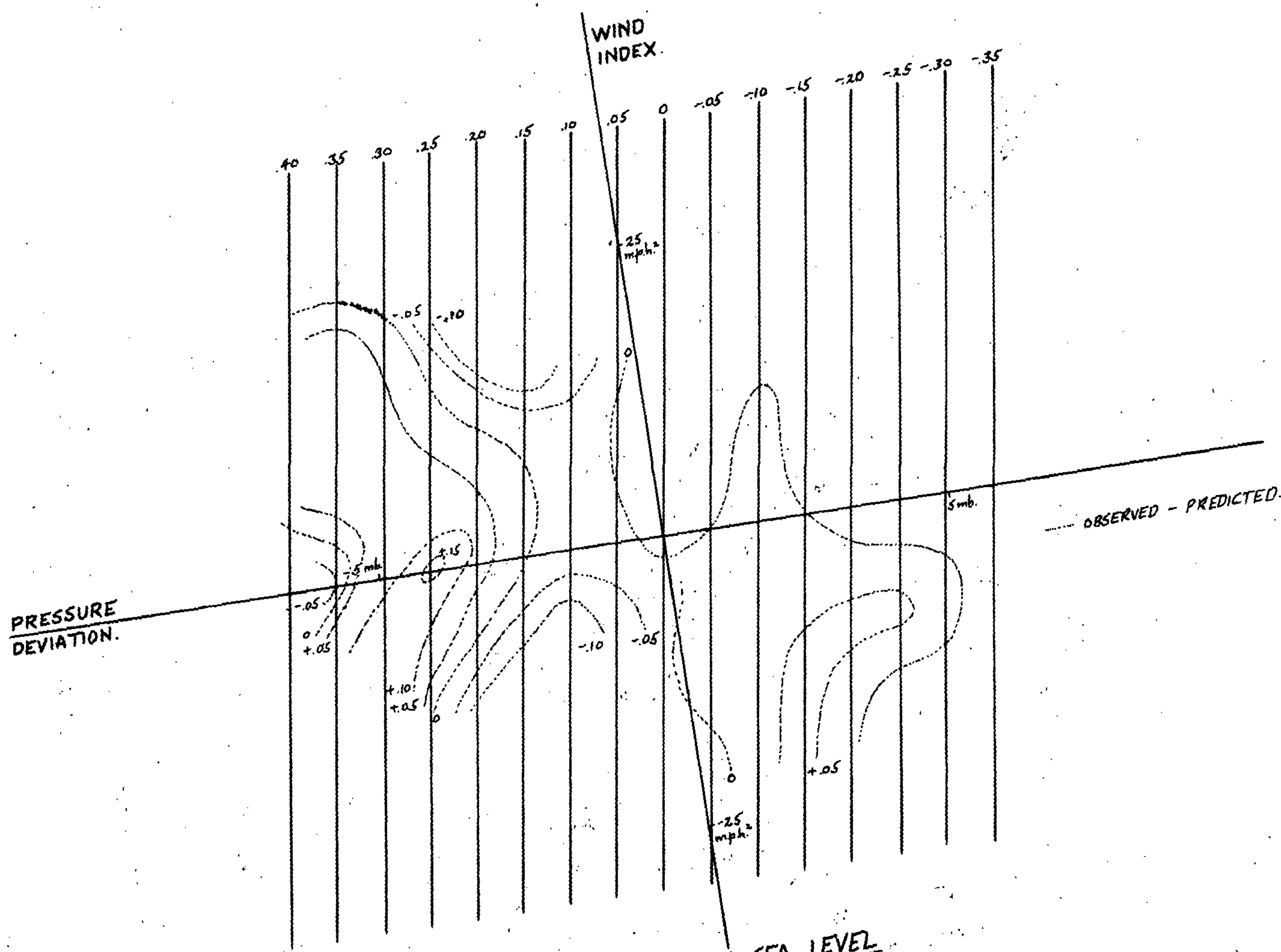
CIR-3747
TEC-429
1 NOV. 62

Fig. 5.



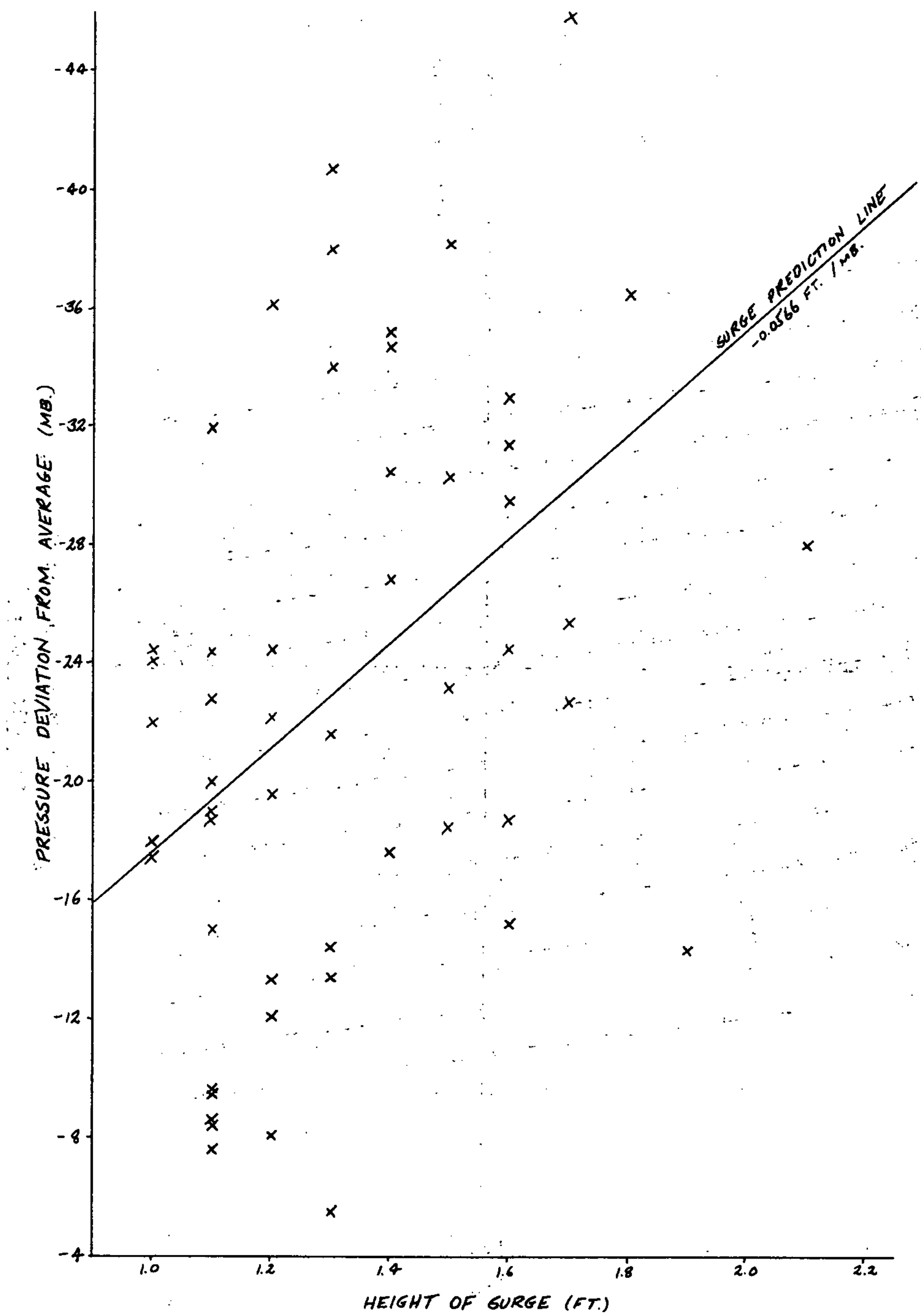
OBSERVED
ISOANOMALIES OF SEA LEVEL
FOR VANCOUVER.

Fig. 6.



ISOANOMALIES OF SEA LEVEL FOR VANCOUVER

CIR-3747
TEC-429
1 NOV. 62



STORM SURGE PREDICTION.

Fig. 7.

CIR-3747
TEC-429
1 NOV. 62

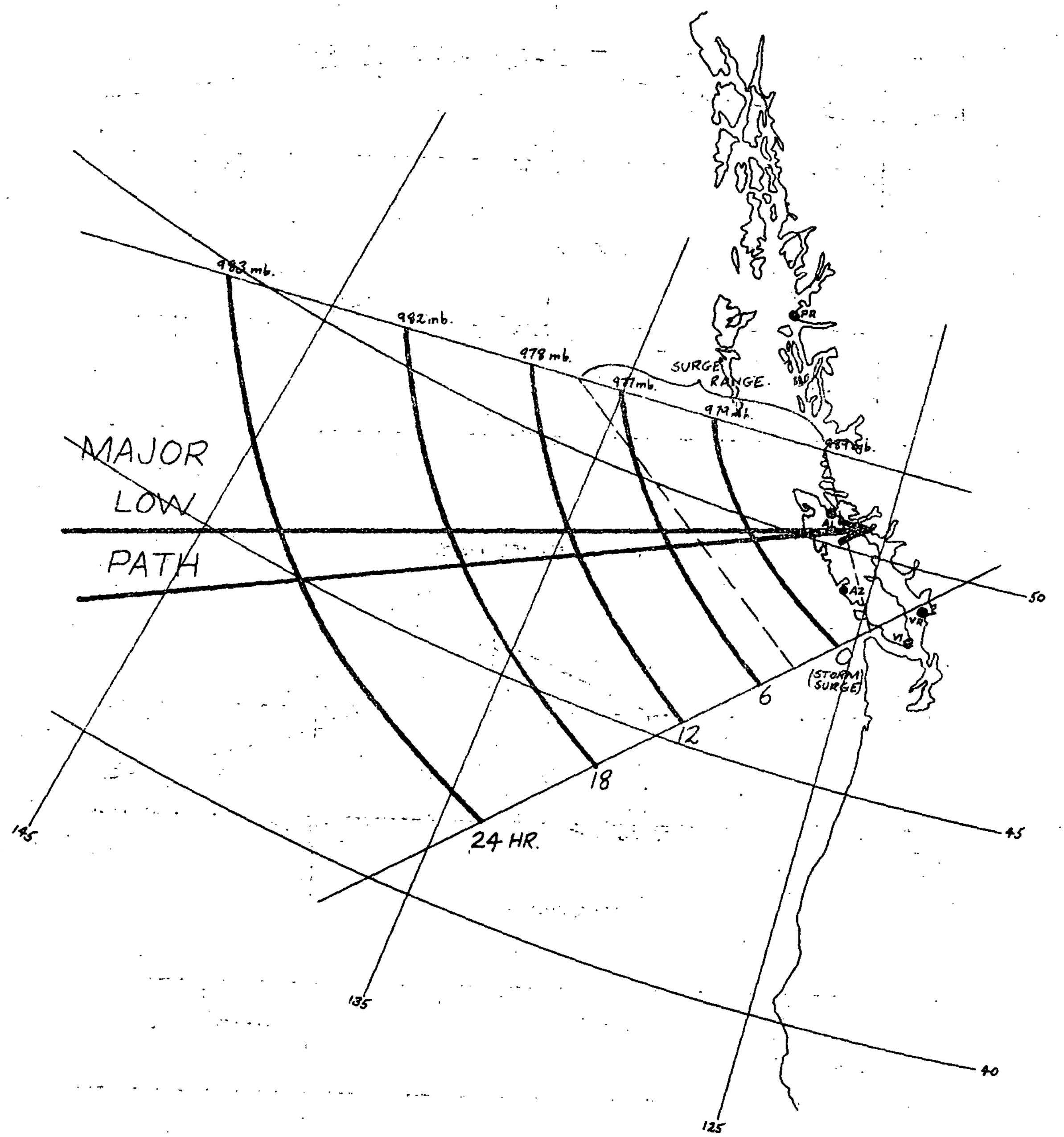
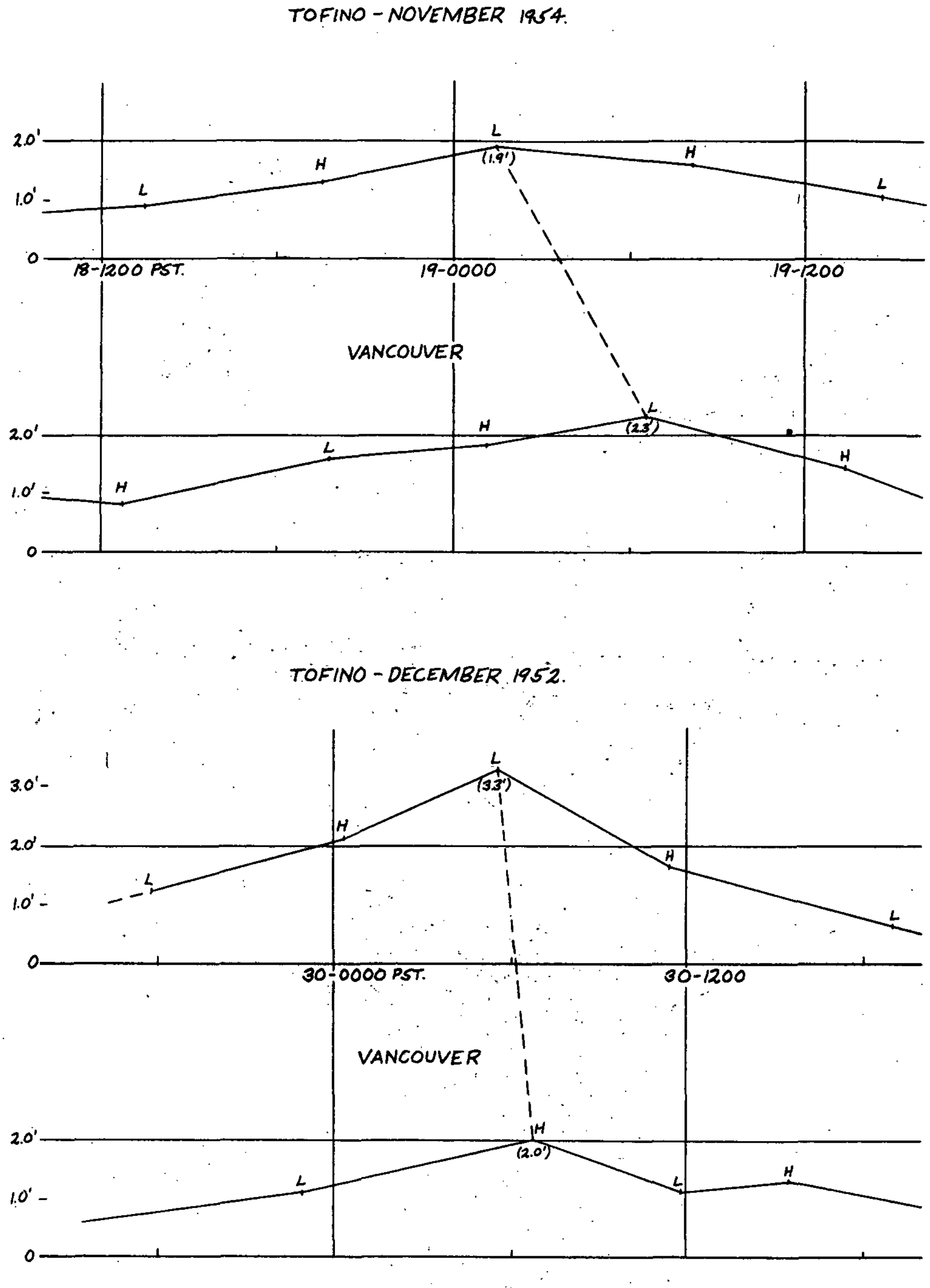


Fig. 8. AREA OF APPROACH OF STORMS CAUSING SURGES.
(see section 3.2.)

CIR-3747
TEC-429
1 NOV. 62



TWO STORM SURGES.

Fig. 9.