The Relationship of Sea Tides to Atmospheric Pressure at Astoria, Oregon, and Eureka, California

by

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THE RELATIONSHIP OF SEA TIDES TO ATMOSPHERIC PRESSURE AT ASTORIA, OREGON, AND EUREKA, CALIFORNIA

ABSTRACT: Predicted sea tide data for Astoria, Oregon are submitted to a formula which when graphed display the day-to-day intensity of change in sea tides. Also predicted sea tide data for Humboldt Bay are submitted to a formula and graphed, which illustrates the variation in length of the tidal day. Astronomical data, which indicate the phases and positions of the sun and moon, are also graphed. Wind data from Newport, Oregon are submitted to low-low passed filtering technique and graphed. These data are all compared to daily 0400 sea level pressure readings, from Astoria, Oregon and Eureka, California, graphed on the same scale. Certain relationships and common elements are found throughout the June 1 through August 31 test period covering the years 1966-1972. Correlations are found between the occurrence of higher pressure at Astoria than Eureka, to equatorial position of the moon, decreasing intensity of both high and low tide changes, maximum duration of the tidal day, and wind direction and intensity along the Oregon coast. Other factors are discussed.

I. INTRODUCTION

A multitude of research has been directed toward investigating the role of the sea on coastal weather conditions. However, the various studies have often treated the sea as a rather constant control. The motivation for this paper developed from discussions with Dr. James Lahey over an article written by Gordon Groves.[1] Groves' research, entitled "Day to Day Variation of Sea Level," attempted to show a correlation between the level of the sea and atmospheric pressure at Pacific coast stations. Our discussions focused mainly around one of Groves' conclusions which implied that the level of the sea was modified by the rise and fall of atmospheric pressure.[2]

Lahey's research, "Sea Tidal-Weather Interrelationships--Oregon Coast," shows results which modify Groves' argument. Dr. Lahey proposed that weather conditions along the Oregon Coast are linked to tides, the tide-producing forces which act as a control on sea level also being an important mechanism in influencing pressure and wind conditions along the coast.[3]

Such investigations indicate that further study of coastal weather is necessary, for additional measurement and comparison of tides and pressure changes could provide a more complete understanding of the relationship of the sea to coastal weather conditions.

Purpose of the Study

This paper will first show that wind direction and atmospheric pressure difference along the Pacific Coast have a close relationship, and that atmospheric pressure seems to be organized with certain aspects of sea tides. Next, common elements will be identified in the relationship between tides and atmospheric pressure. Portions of Dr. Lahey's research data have been included so that this study can be compared to and perhaps extend Lahey's investigations.

II. AREA OF STUDY AND METHODOLOGY

Area of Study

This investigation will confine itself mainly to predicted tide data for Astoria (Tongue Point), Oregon, and the daily pressure readings at Astoria, Oregon and Eureka, California. Lahey's wind flow data derived from the Coastal Upwelling Experiment (Cue 1) at Newport, Oregon are also included, along with his graphs on the duration of the tidal day for Humboldt Bay, California.

This study area was selected for various reasons. The main requirement was a weather station with a fairly complete set of data, found in the proximity of a tide recording station, which is the case for Astoria. Atmospheric pressure for Eureka is included so that a regional pressure sample could be studied. This also made it possible to compare north-south coastal pressure variations with Lahey's wind data at Newport, Oregon, which is centrally located in respect to the two weather stations. The Humboldt Bay data provides additional information on the characteristics of tide changes, and facilitates comparison of this research to Lahey's conclusions.

Only data from summer months are included in this research, because it was anticipated that extreme tide and pressure variations often associated with winter storm systems may make it difficult to obtain significant results.

Methodology

All data collected throughout this research are included in the Appendix of this paper in graphic form. Visual comparisons and associations will serve as the primary technique employed in identifying relationships between tides and atmospheric pressure at Astoria, Oregon and Eureka, California.

The initial problem encountered in this study was developing a technique for measuring changes in daily tides. A formula referred to as "day-to-day predicted tidal acceleration" was devised in order to measure the changing nature of the increasing or decreasing tides. First, predicted times and heights of tides for Astoria (Tongue Point), Oregon from June 1 through August 31 in the years 1966-1972 were recorded on computer tape.[4] Next, the computer was programmed to measure the change in each increasing or decreasing predicted tide from one day to the next. This formula assumes a linear rate between predicted tidal extremes:

Predicted Day-to-day Tidal Acceleration (PDDTA) =

$$\left[\frac{\text{Feet of change between each extreme tide}}{\text{Minutes of time elapsed between each extreme tide}} \times 10^{-3}\right] \quad - \quad \text{Day 2}$$

$$\bullet$$

$$\left[\frac{\text{Feet of change between each extreme tide}}{\text{Minutes of time elapsed between each extreme tide}} \times 10^{-3}\right] \quad \text{Day 1}$$

Simply stated, day-to-day predicted tidal acceleration data were then graphed in order to facilitate visual examination of the data. The first page of the Appendix contains a legend for the predicted day-to-day tidal acceleration graphs (PDDTA). Reference, throughout this paper, made to tidal accelerations and related terminology will always pertain to predicted day-to-day tidal accelerations. Furthermore, it should be emphasized that day-to-day tidal accelerations are not a measurement of sea level but only of the linear rate of increase or decrease of the tides from one day to the next.

Sea level pressures for Astoria, Oregon and Eureka, California were extracted from "Daily Weather Maps" and graphed on the same scale as the tidal data.[5] It should be noted that pressure readings were made only once each day at 0400 Pacific Standard Time.

A graph was also constructed which illustrates the difference in pressure between Eureka, California and Astoria, Oregon. These data were obtained by subtracting the sea level pressure at Eureka from Astoria pressure readings. This results in a positive value when the Astoria, Oregon pressure is higher in relation to Eureka, California pressure, and a negative value when Eureka experiences higher pressure than Astoria. This pressure difference value is hereinafter titled Δp and I will particularly emphasize the positive pressure peaks, i.e., higher 0400 PST pressures at Astoria, Oregon than at Eureka, California. The reason for this procedure will become evident during the discussion in the following section.

Astronomical data are presented on the charts to facilitate examination of relationships between tide-producing forces and pressure changes.[6] Appendix Table 3 specifies the meaning of each astronomic symbol.

Graphs on the duration of the tidal day for Humboldt Bay, California, a site close to Eureka, provided by Dr. Lahey, are also included.[7] These data illustrate the durations in minutes from one predicted tidal extreme to the same tidal extreme one lunar day later. Finally, wind flow data for 1972, taken by the OSU Cue I research team and provided by Dr. Lahey, are included and will be referred to during the discussion of the 1972 data.[8]

III. DISCUSSION AND ANALYSIS OF THE GRAPHED TIDAL AND PRESSURE DATA

Introduction

It is evident that, if one station shows higher atmospheric pressure than an adjacent station does, the atmosphere must readjust itself by moving toward the station with the lower pressure. If Astoria develops a higher pressure than Eureka (or Eureka a lower pressure than Astoria) there must be a concomittant increase in the north to south component of the wind between Astoria to the north and Eureka farther to the south. Therefore, each time that the 0400 PST ΔP becomes increasingly positive between Astoria and Eureka, the north wind component at, say Newport, Oregon, about midway between Astoria and Eureka, should become increasingly intense from the north. Let us see how this presumed relationship holds for the summer of 1972.

Wind and Pressure Data--1972

On Figure 1, top graph (see Appendix) are found the low-low passed filtered data of the V, or north-south, component of the wind at Newport, Oregon (June 1-August 31, 1972). The bottom curves show the 0400 PST pressures at Astoria (solid line) and Eureka (dashed line), while the mid graph curve shows the 0400 PST Δp

values between Astoria and Eureka. When the Δp values are positive the Astoria pressures are higher than the equivalent Eureka pressures, when the Δp values are negative the Astoria pressures are lower than at Eureka. (It should be noted here that the scale of the wind graph is slightly smaller than that of the pressure graph. The reader will note that the time scales have been so set as to be centered on the midsummer date of July 15, 1972.)

When the north-south wind component is compared to the sea level pressure difference between Astoria and Eureka, the general relationship between pressure differences along the coast and wind is evident. An increasingly positive Δp shows a corresponding increase in the north wind component, and an increasingly negative Δp displays a corresponding increase in the south wind component. Further analysis of the data, illustrates that these relationships are quite close, and that only slight differences in pressure between Astoria and Eureka may indicate a related change in the north-south wind component.

June 1, 1972, shows a positive Δp that is decreasing to a slightly negative value on June 3. Wind flow data for that same period illustrates an increasing north component from June 1-2, and a decrease in north wind intensity on June 3. A positive Δp occurs on June 4 and is increasingly positive to June 6. Wind flow data from June 4 through June 8 shows an increasing north wind intensity, but then changes to a southerly direction on June 9. The pressure difference is negative from June 8 through June 10, but becomes a positive Δp on June 12 and again becomes negative from June 13-15. These data clearly display a close relationship between winds and pressure, for on June 9 the south wind component is increasing then experiences a corresponding decrease on June 10 and next displays an increase between June 10-12. The pressure difference becomes more positive on June 16 and remains positive until June 22. A corresponding north wind component begins on June 16, increases through June 20, remains strong through the 22nd, and begins to display a south component only on June 23. From June 26 until July 3 a positive Δp is apparent on the pressure difference graph. During this same period the north wind component illustrates a corresponding increase in intensity. The pressure difference is minimal between July 4th and 5th, and a south wind component is observable during this period. On July 6 there is a slight positive Δp peak, which relates a corresponding north wind component. On July 7, the Δp becomes negative and continues to decrease through July 8, then rises to a slightly positive Δp peak on July 10, the pressure difference again becomes negative through July 12. The wind data show a close correlation to the July 7-12 period. The wind retains its south component throughout this time, but the intensity is clearly associated. On July 7-8 the south wind is increasing in intensity, and on July 10 it experiences its lowest south intensity associated with the slight positive Δp value. The south wind increases in intensity on July 11 and 12 with associated negative Δp values. On July 13 the Δp is becoming more positive. This continues to a peak on July 15, and decreases to a negative value on July 17. The wind flow data show a corresponding increase in northerly flow on July 13-15 with a decline in intensity through July 18 when there is a south wind component. A positive Δp occurs on July 18 and 19 which shows a corresponding north wind component on July 19 and 20. On July 20 there is a negative Δp and this can be associated with a south wind component on July 21; from July 21 until July 29 there is a positive Δp and the wind flow data also reflect this with stronger north wind components. On July 31 there is a negative Δp and a corresponding south wind component. From August 1-7 there is a positive Δp, which also is accompanied by a north wind component. August 8 shows a slightly negative Δp and this can associated to a simultaneous occurrence of the south wind component. August 9-11 shows a positive Δp and there is a corresponding north wind component at this time. August 12 has a negative Δp, which relates to a south wind component at that same time. On August 13 there is a positive Δp and a corresponding north wind component. August 14-15 have a negative Δp and again a corresponding south wind component occurs. August 16 has a positive Δp and there is again a north wind component at that same time. August 17 illustrates a negative Δp with a corresponding south wind component. August 18 displays a positive Δp and a north wind component. August 19 experiences a negative Δp and can be associated with a south wind component. August 20 has a positive Δp which can be related to decrease in the south wind component on August 21. The negative Δp on August 21 and 22 can be correlated to the south wind intensity peak on August 22. The remaining pressure difference data retain positive values and can be associated to north wind components of coastal winds at Newport, Oregon.

Tide and Pressure Data--1972

Having seen the very close relationship between Δp and wind intensity and direction change along the Oregon Coast let us turn next to the relationship between Δp and the tides.

It will be noted that the occurrence of pronounced positive Δp's occur at about fortnightly intervals (note here June 1-7, 16-22, June 29-July 2, July 13-17, July 26-30, August 10-13, August 23-26). Further note that these events tend to be at, or about, the times of equatorial tides. Strangly, also at about, or slightly after, the time of new and full moon, another set of positive Δp's occurs. In addition, the occurrence of equatorial phase near apogee seems to be related to a lag in the positive values of Δp with respect to equatorial position while the opposite effect seems associated with perigee,

i. e., if the equatorial position is just after perigee the occurrence of a positive Δp precedes or is simultaneous to equatorial tides.

Note then that in 1972 occurrence of equatorial phase of the moon (see Table 3 in Appendix) can be related to a positive Δp peak. The first equatorial position is on June 5, followed by a positive Δp peak on June 6, and perigee on June 9. The next equatorial position is on June 17, followed by a positive Δp peak on June 19 and apogee on June 21. A positive Δp peak occurs next on July 1, and is followed by an equatorial phase on July 2 and perigee on July 7. Equatorial position and a positive Δp peak occurs next on July 15, and apogee on July 19. On July 29 equatorial phase and a positive Δp peak occur simultaneously followed by perigee on August 3. Another positive Δp peak occurs on August 11, at the same time as equatorial position, and is followed by apogee on August 16. The final occurrence of a positive Δp peak occurs at the same time as equatorial position on August 26, and is followed by perigee on August 28.

Also observe that before the summer solstice the positive Δp peaks show up slightly after the equinoctual tides while after the summer solstice the positive Δp peaks occur at or slightly before the equinoctual tides. In addition, the day-to-day acceleration of the tides shows an association of increasingly less intense high tides and low tides, to the equatorial-related positive Δp peaks.

The duration of the tidal day for Humboldt Bay also shows that the equatorial-related positive Δp can be associated with maximum duration of one of the high tides in June. After the solstice a reorganization seems to occur and the positive Δp occurs in advance of the extreme duration of high tides in the latter part of July and August.

Tide and Pressure Data--1966

Data for the summer of 1966 clearly illustrate a relationship between certain aspects of sea tide and atmospheric pressure. General consideration of sea level pressure for Astoria and Eureka (Figure 3 in Appendix) shows a rhythmic pulsation of high and low pressure, with relatively high pressure readings occurring at approximately two-week intervals. The first pulse of high pressure for Astoria occurs on June 12 followed by June 25, July 11 and 20, August 6, and August 17. The pressure drop readings for Eureka seem to generally precede Astoria by one or two days. Eureka pressure also frequently decreased more rapidly and experienced more intense lows than Astoria. However, both stations show a periodic rise and fall in pressure, which could be associated with longer tidal periods.

Comparisons of sea level pressure differences (Δp) to actual sea level pressure readings at Astoria and Eureka seem to illustrate that positive Δp's correlate to an increase in pressure at Astoria and a decrease in pressure at Eureka. This association is a fairly common element throughout the data.

When the sea level pressure difference graph is compared to astronomic data, the correlation between the positive Δp and equatorial position is evident. Apogee first occurs on June 10, equatorial position is June 12 and a positive Δp peak occurs on <u>June 15</u>. Perigee occurs on June 22, and equatorial position and a positive Δp peak occurs on <u>June 25</u> slightly before equatorial tides. Apogee occurs again on July 7, followed by equatorial position on July 9 and a positive Δp peak is on <u>July 10</u>. Perigee is next on July 20, and a positive Δp peak occurs on <u>July 21</u> before equatorial position on July 22. Apogee is next on August 4, and is followed by equatorial position on August 5 and a positive Δp peak on <u>August 6</u>. Perigee is on August 16 followed by a positive Δp peak on <u>August 17</u> slightly before the equatorial position on August 19.

Day-to-day tidal accelerations for the summer of 1966 seem to illustrate the existence of some type of relationship between sea tides and pressure changes. When day-to-day tidal accelerations are compared to the equatorial related positive Δp peaks, which were previously identified, a definite correlation can be seen. Periods of rapidly declining intensity of the high and low tides correspond closely to the occurrence of a positive Δp peak on the pressure difference graph. Also, notice that there is an apparent change in the relationship between tides and the positive Δp peaks, after the occurrence of summer solstice. The positive Δp peaks seem to be occurring after the equinoctual tides before the summer solstice, and they occur in advance of the equinoctual tides after the summer solstice.

Duration of the tidal day for Humboldt Bay also has characteristics in common with the equatorial related positive Δp peak. Each event of the equatorial related positive Δp peaks can be associated with an increase in duration of the tidal day for one of the high tides at Humboldt Bay. The positive Δp peaks can be directly correlated to peaks in duration of the tidal day, previous to the summer solstice, but after the summer solstice the positive Δp peaks occur in advance of the peaks in duration of the tidal day for Humboldt Bay.

Tide and Pressure Data--1967

Data for the summer of 1967 (Figure 4 in Appendix) reflects characteristics similar to the previously discussed years. Eureka frequently experiences pressure changes in advance of Astoria, and a rhythmic fluctuation of the general sea level pressure is again evident.

Pressure difference data again point out a number of common elements. Throughout the 1967 data an occurrence of positive Δp's coincides with each equatorial phase. The first equatorial phase is on June 1 followed closely by apogee on June 2 and a positive Δp peak does not occur until June 5. Equatorial position occurs next on June 15, but perigee follows on June 18 with a positive Δp peak on the same day. June 29 is the next time of equatorial position with apogee occurring on June 30 which seems related to a positive Δp peak on the same day. The next equatorial phase is on July 13, perigee is on July 14, and a positive Δp peak is found on July 16. Equatorial position occurs next on July 26 followed by a positive Δp peak and apogee on July 28. The first occurrence of perigee before equatorial phase is on August 9, which shows a corresponding positive Δp peak on August 8 in advance of equatorial position. The final correlation shows equatorial position is followed by apogee on August 22 and 25 respectively, and the final occurrence of positive Δp peak is also on August 25.

The day-to-day tidal accelerations also show the same characteristics as the previous summer. When the various positive Δp's, that are related to equatorial position, are compared to day-to-day tidal accelerations, certain aspects coincide. Each occurrence of a positive Δp peak seems to be occurring when the low tide accelerations become more positive, and thus weaker, and the high tides are experiencing very negative day-to-day acceleration which implies that these tides are also becoming weaker. Again note the change in structure of the relationship before and after summer solstice of the positive Δp peaks to equinoctual tides.

Duration of the tidal day for Humboldt Bay data illustrates characteristics in common with the previously discussed summer data. Each of the equatorial tidal related positive Δp peaks can be correlated to areas of greatest duration of one of the high tides before summer solstice, and show an association of the positive Δp peaks previous to the peaks in duration of high tides, after the summer solstice.

Tide and Pressure Data--1968

Examination of sea level pressures for 1968 (Figure 5 in Appendix) maintains the common characteristics of generally lower pressures at Eureka, and the typical pressure change at Eureka in advance of Astoria pressure changes. The generalized pressure field again experiences a rhythmic rise and fall, which can be associated with longer tidal periods.

Sea level pressure difference for this summer illustrates a number of positive Δp's. Still, a positive Δp can be related to each occurrence of lunar equatorial position. The first correlation displays equatorial position which occurs on June 5, followed with a positive Δp peak on June 8, and perigee on June 9. The next equatorial position is on June 17, which is followed by a positive Δp peak on June 20 and apogee on June 22. Lunar equatorial position occurs again on July 3, followed by a positive Δp peak on July 5 and perigee on July 8. The next incidence of equatorial position is on July 15, with a positive Δp peak on July 18 and apogee on July 20. Equatorial position appears on July 29, with a positive Δp peak also on July 29 and perigee on August 4. The next occurrence of equatorial position on August 11 is again followed by a positive Δp peak on August 12 and apogee on August 16. The final equatorial phase is on August 25, the Δp peak occurs at the same time or slightly earlier but is muted here. The pattern has persisted throughout the 1968 data with a positive Δp peak at or following each equatorial position. It should be noted that throughout the summer data, equatorial position never occurred shortly after perigee, which according to the pattern established would show an accompanying positive Δp peak preceding the equatorial position.

The day-to-day tidal acceleration again illustrates that each equatorial related positive Δp peak can be correlated to a rapidly weakening intensity, of both high and low tides. Again this association displays a change in relationship from before to after summer solstice, with the equatorial related positive Δp respectively occurring after and the equinoctual tides before the summer solstice and or previous to the equinoctual tides after the summer solstice.

The duration of the tidal day for Humboldt Bay amazingly displays characteristics similar to those previously noted. Each occurrence of a positive Δp peak can be linked to the peaks in duration of high tides in early summer before the summer solstice and to an advance of these Δp peaks with respect to the duration of tidal day peaks in the period after summer solstice.

Tide and Pressure Data--1969

The relationship between atmospheric pressure and tides is very apparent in the 1969 data (Figure 6 in Appendix). The sea level pressures show the same general characteristics as in previous summers. Eureka pressure is usually lower than Astoria and tends to experience pressure changes in advance of Astoria.

The sea level pressure difference graph displays many positive Δp peaks, and a positive Δp peak can be related to each occurrence of equatorial position. The 1969 data are dissimilar to previously discussed data, because equatorial phase is centrally located between apogee and perigee throughout the summer. This makes it difficult to relate equatorial phase to either apogee or perigee. The first occurrence of perigee is on July 1 with a positive Δp peak and equatorial position occurring simultaneously on June 8. Apogee is on June 16 and equatorial position in on June 22, and at that time a small, positive Δp peak does occur. The next positive Δp peak is on July 7 and equatorial phase occurs on July 5, following perigee on June 29. Apogee occurs on July 13, equatorial position follows on July 19, and a positive Δp peak is on July 22. The next occurrence of perigee is on July 28, with equatorial phase and a positive Δp peak occurring on August 1. Apogee is next on August 9, with another simultaneous occurrence of a positive Δp peak and equatorial position on August 16. The final occurrence of perigee is on August 25, followed by equatorial phase on August 29, and a positive Δp peak across the same date.

Day-to-day tidal accelerations again display a relationship to the equatorial related positive Δp peaks. A rapid decline in intensity of the high and low tides can be correlated to each incidence of a positive Δp peak. The day-to-day tidal acceleration graph helps to visualize changes in tides related to apogee and perigee. The 1969 data are used in the following example, but the characteristics are common throughout the data. The period of June 1-10 can be associated with perigee, and displays a rapid day-to-day change in tides. This period is followed by a period of relatively less change in day-to-day acceleration of tides and can be associated with apogee.

Duration of the tidal day for Humboldt Bay displays the typical popularities that were previously discussed in earlier data. Periods of extreme duration of the high tides can be linked to the equatorial related positive Δp peaks in early summer data, and the positive Δp peaks in the latter part of summer following summer solstice seem to be occurring in advance of the longest duration of high tides.

Tide and Pressure Data--1970

Sea level pressure for 1970 (Figure 7) illustrates generally higher pressures at Astoria than Eureka, and the typical pressure change at Eureka in advance of Astoria pressure change. Also, the rhythmic rise and fall of pressure seem to be related to longer tidal periods.

Sea level pressure difference for 1970 displays similar properties to previous summers. Each incidence of lunar equatorial position coincides with a positive Δp peak. Apogee occurs on June 9, and a positive Δp peak and equatorial position occurs on June 12. Perigee is on June 21, and is followed by a positive Δp peak on June 24, and equatorial position on June 25. The next occurrence of apogee is not until July 7, which is followed closely by equatorial position on July 9, and the related positive Δp peak does not occur until July 14. Perigee is on July 19 and a positive Δp peak and equatorial position occur simultaneously on July 23. Apogee is next on August 4, and equatorial phase is August 6, a positive Δp peak is not apparent until August 9. The final occurrence of perigee and a positive Δp peak are on August 17, just previous to equatorial phase on August 19.

Day-to-day tidal accelerations for 1970 provide the same interesting qualities as seen in the previous data. Each equatorial related positive Δp peak which is identified can be related to the day-to-day tidal accelerations. An increasing positive value or weakening intensity of one or both of the low tides corresponds to each positive Δp peak which has become a common pattern throughout the data. High tides show an increasing negative value, which infers a rapid decline in intensity of high tides in relation to each positive Δp peak. In addition, the equatorial related positive Δp peak again shows a change in its relationship to tides, from before to after summer solstice.

Duration of the tidal day for Humboldt Bay again displays the common element of extreme duration of high tides associated with each positive Δp peak in early summer, and the typical advance of the positive Δp peak to these peaks in duration in the second half of the summer data following summer solstice. This characteristic has been an amazingly reliable indicator of the apparent relationship between pressure and tides.

Tide and Pressure Data--1971

Data for 1971 (Figure 8) display the same common characteristics that have been apparent throughout the discussion. Sea level pressure for Astoria is usually higher than Eureka, and Eureka pressure changes seem to occur in advance of Astoria pressure changes. The rhythmic pressure changes again indicate a relationship to longer tidal periods.

Sea level pressure differences also retain a pattern similar to the previously discussed data. The 1971 astronomic data illustrate the occurrence of apogee or perigee at almost the same time as equatorial phase. Each occurrence of equatorial position shows a related positive Δp. The first equatorial position is on June 1 followed by apogee and perhaps a muted positive Δp on June 2. The next apparent positive Δp peak on June 16 is preceded by equatorial position on June 15, and followed by perigee on June 17. The next occurrence of equatorial position with a simultaneous positive Δp peak is on June 28, and followed by apogee on June 30. Perigee and equatorial position occurs next on July 11-12, and is followed by a positive Δp peak on July 14. Equatorial position occurs again on July 26, followed by apogee on July 27, and a Δp peak on July 28. This Δp peak, similar to the first in the 1971 data, appears to be muted. Perigee again occurs on August 8, followed by equatorial phase on August 9, and a positive Δp peak on August 10. The final equatorial phase is on August 22, with a positive Δp peak on August 23, and apogee on August 24.

Day-to-day acceleration of the tide data illustrates that there is a relationship between the equatorial related positive Δp and tides. The high and low tides as seen in previous data are again becoming less intense when the equatorial related positive Δp peaks occur.

The duration of the tidal day for Humboldt Bay also shows typical common relationships. Each equatorial related positive Δp peak can be directly associated with extreme duration of a high tide in the data, before summer solstice, and in advance of these peaks in the data, after summer solstice.

IV. SUMMARY

Investigation of the data for the sample period of 1966-1972 resulted in a number of visible relationships between certain aspects of sea tides and atmospheric pressure at costal stations. In addition a number of common elements are apparent throughout the data.

First, the sea level pressures for Astoria and Eureka maintained the same general characteristics throughout the analysis period. A periodic rise and fall in pressure occurred, the pressure changes at Eureka being in advance of those in Astoria with amazing consistency.

The correlations between astronomic data and the pressure difference graph indicated significant relationships between tide producing forces and atmospheric pressure. The relationships fell into definite patterns which make it impossible to construe these associations as accidental. Positive Δp variations between Eureka, California and Astoria, Oregon seemed to be associated with equatorial tides, but modified by position in relation to apogee-perigee and summer solstice. Perigee seemed to relate to an early or synchronous occurrence of a positive Δp after equatorial tidal position. The relationship of equatorial positive Δp's with respect to summer solstice were very consistent. The positive Δp peaks were <u>after</u> equanoctual tides, before summer solstice, and at or before equinoctual tides following the summer solstice.

Next, day-to-day accelerations of the sea tides were compared to pressure variations. The consistency of relationships found in these data throughout the test period points to some sort of connective link between atmospheric pressure and tides. All of the equatorial related positive Δp peaks identified in this research could be associated with periods of increasingly positive low tidal accelerations and increasingly negative high tidal accelerations. This illustrates that a rapid decline in the intensity of both high and low tides is associated with the equatorial related positive Δp peaks.

Duration of the tidal day for Humboldt Bay data, taken from Lahey's research, served to support the relationships between sea tides and atmospheric pressure. The correlations were too consistent to be attributed to chance, but must be considered as further evidence of a relationship between sea tides and atmospheric pressure. These data clearly display a relationship of the equatorial related positive Δp peaks to the simultaneous occurrence of peaks in duration of tidal day of one of the high tides at Humboldt Bay before the summer solstice. After the summer solstice, the positive Δp peaks seem to be in advance of peaks in duration of tidal day.

This analysis of certain characteristics of tides, tide producing forces, atmospheric pressure and winds along the Oregon Coast has provided information on the relationship between sea tides and weather. Definitely, the common elements and patterns in associations found throughout the sample period were much too consistent to be considered accidental.

Finally, the reliability of the established patterns developed from predicted tide and astronomic data is important. First, by using predicted tide data it is impossible to conclude that relationships between sea tides and atmospheric pressure are the result of wind and pressure changes. Also the relationships are quite visible, and although more testing is necessary, this research introduces a new possible geophysical link for predicting pressure changes along the Oregon Coast.

FOOTNOTES

1. Gordon Groves is the Assistant Research Oceanographer, Scripps Institution of Oceanography, La Jolla, California.

2. Gordon Groves, "Day to Day Variation of Sea Level" in *Meteorological Monographs*, 2, no. 10 (Boston, 1957), 34.

3. James F. Lahey, "Sea Tidal-Weather Interrelationships--Oregon Coast," an unpublished paper (1974), p. 6.

4. *Tide Tables West Coast North and South America*, U. S. Department of Commerce (Washington, D. C.).

5. *Daily Weather Maps*, U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service (Washington, D. C., 1966-1972).

6. *Tide Tables.*

7. Lahey.

8. Adriana Huyer, "Observations of the Coastal Upwelling Region off Oregon during 1972," a Ph. D. thesis submitted to Oregon State University (1974). p. 75.

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APPENDIX

Table 1. Legend for Day-to-Day Tidal Accelerations, Astoria, Oregon.

Units: $\frac{\text{ft}}{\text{min}} \times 10^{-3}$ Assumes linear rate between predicted tidal extremes.

All data are plotted at the end of the second day's tide.

△∿∿△	Low low to low high tide on first sample day and every second low to high tide thereafter.
◇∿∿◇	High low to high high tide on first sample day and every second low to high tide thereafter.
▣—·—▣	Low high to high low tide on first sample day and every second high to low tide thereafter.
⊙——⊙	High high to low low tide on first sample day and every second high to low tide thereafter.

Table 2. Legend for Duration of Tidal Day, Humboldt Bay, California.

All durations in minutes from tidal extreme to same tidal extreme one lunar day later.

This sequence is maintained throughout the sample.

All time duration data are plotted at the ending time of the particular lunar day cycle.

▲	First low tide cycle.
◈	Second low tide cycle.
⊙	First high tide cycle.
⊡	Second high tide cycle.

Table 3. Key to Astronomical Data.

●	New moon
◐	First quarter
○	Full moon
◑	Last quarter
E	Moon on equator
N	Moon farthest north of equator
S	Moon farthest south of equator
A	Moon in apogee
P	Moon in perigee
$\odot_2$	Sun at summer solstice

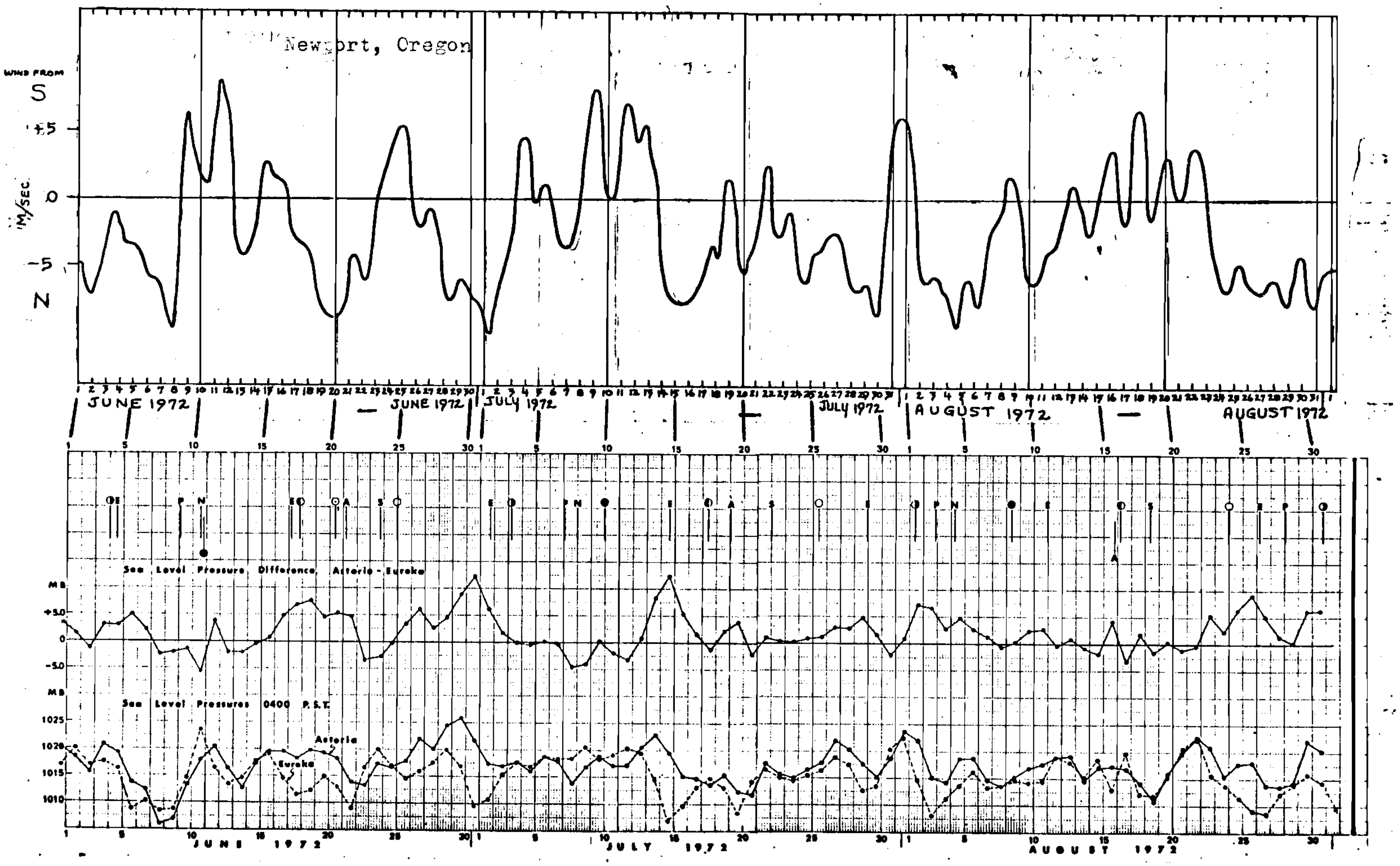

Figure 1. a. Newport, Oregon Wind Data.
b. 1972 Astronomical Data. Sea Level Pressure Difference, Astoria-Eureka. Sea Level Pressures 0400 P. S. T.

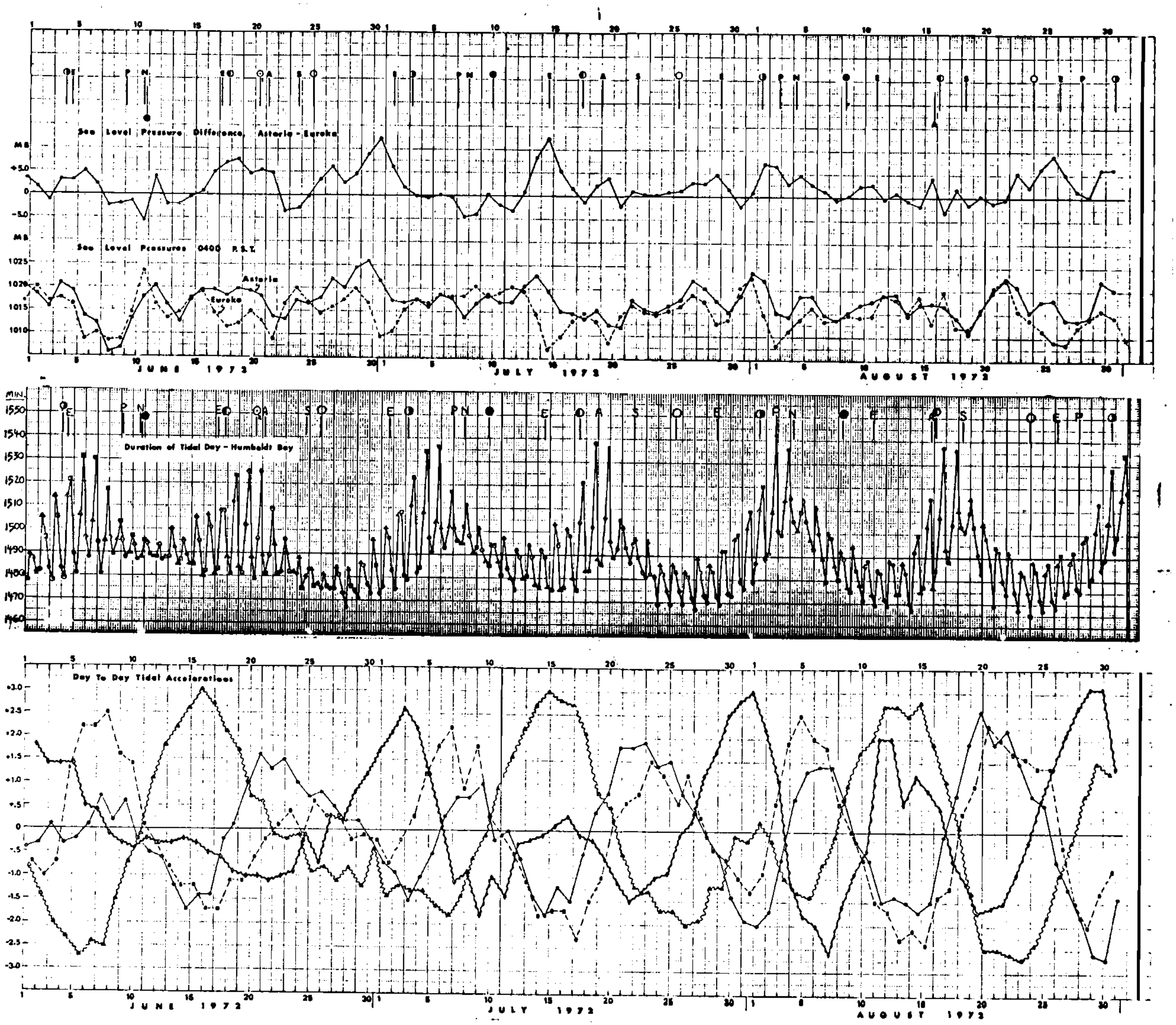

Figure 2. a. 1972 Astronomical Data. Sea Level Pressure Difference, Astoria-Eureka. Sea Level Pressures 0400 P.S.T.

b. 1972 Astronomical Data. Duration of Tidal Day, Humboldt Bay.

c. 1972 Day-to-Day Tidal Accelerations.

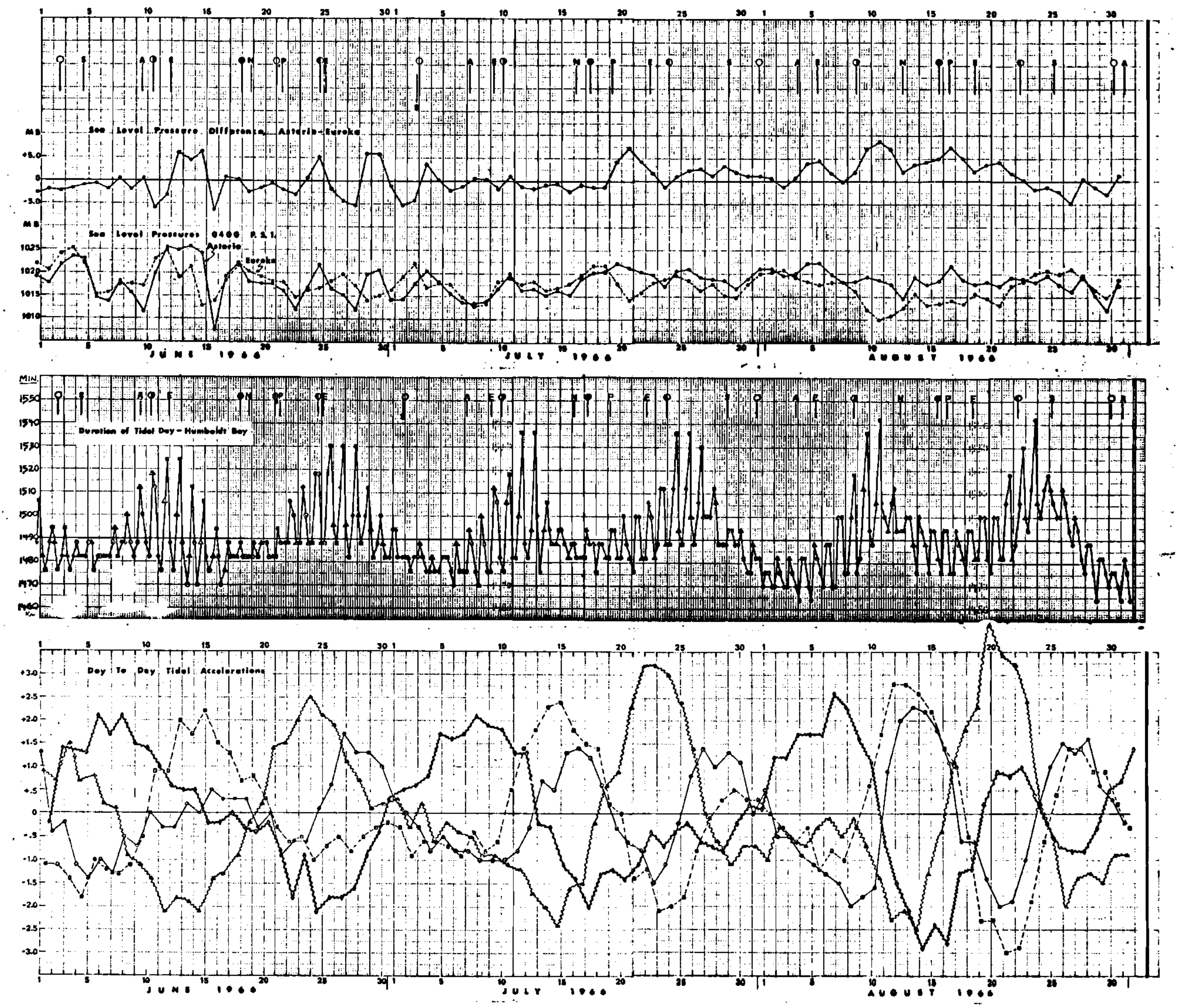

Figure 3. a. 1966 Astronomical Data. Sea Level Pressure Difference, Astoria-Eureka. Sea Level Pressures 0400 P. S. T.

b. 1966 Astronomical Data. Duration of Tidal Day, Humboldt Bay.

c. 1966 Day-to-Day Tidal Accelerations.

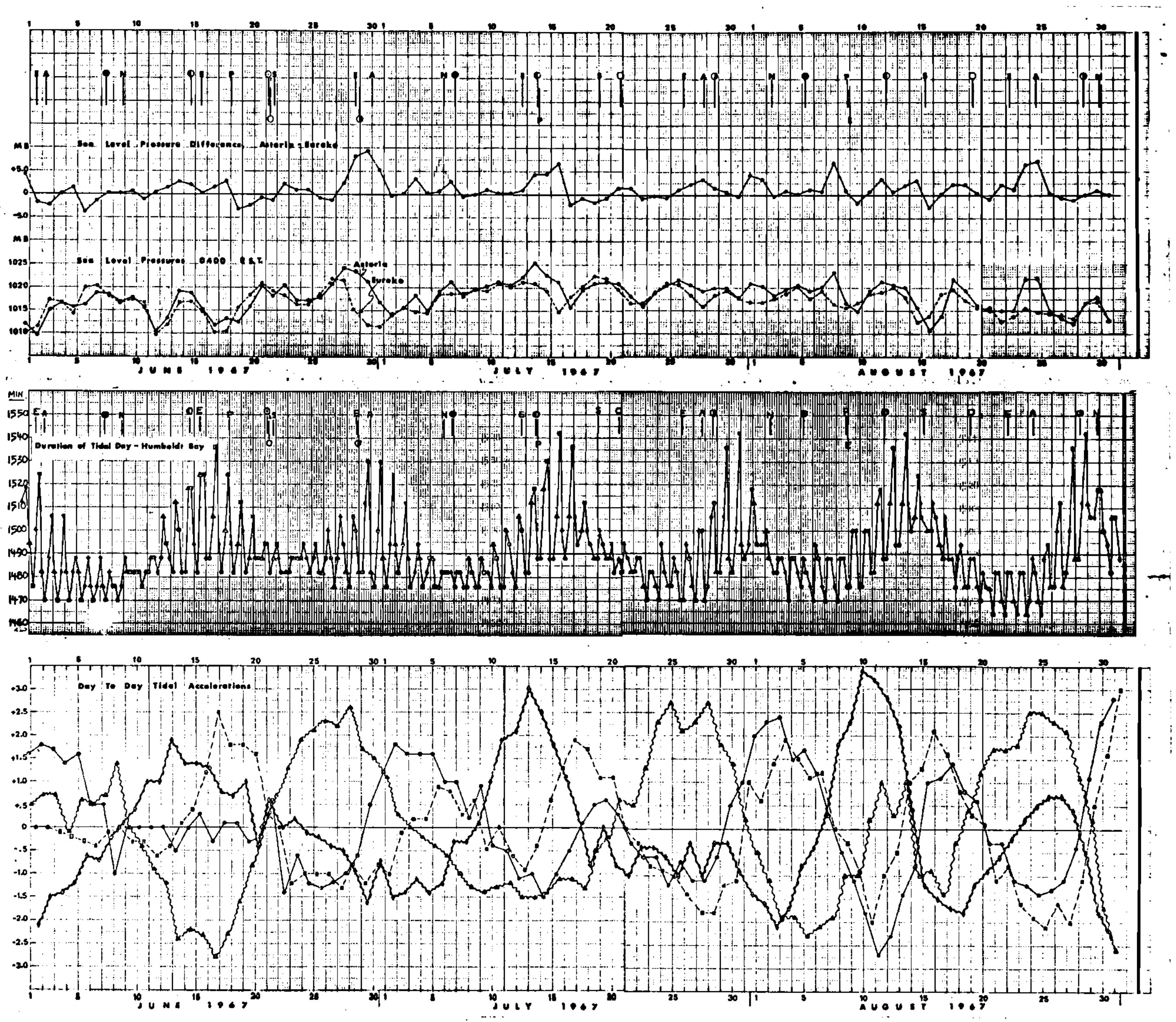

Figure 4. a. 1967 Astronomical Data. Sea Level Pressure Difference, Astoria-Eureka. Sea Level Pressures 0400 P. S. T.

b. 1967 Astronomical Data. Duration of Tidal Day, Humboldt Bay.

c. 1967 Day-to-Day Tidal Accelerations.

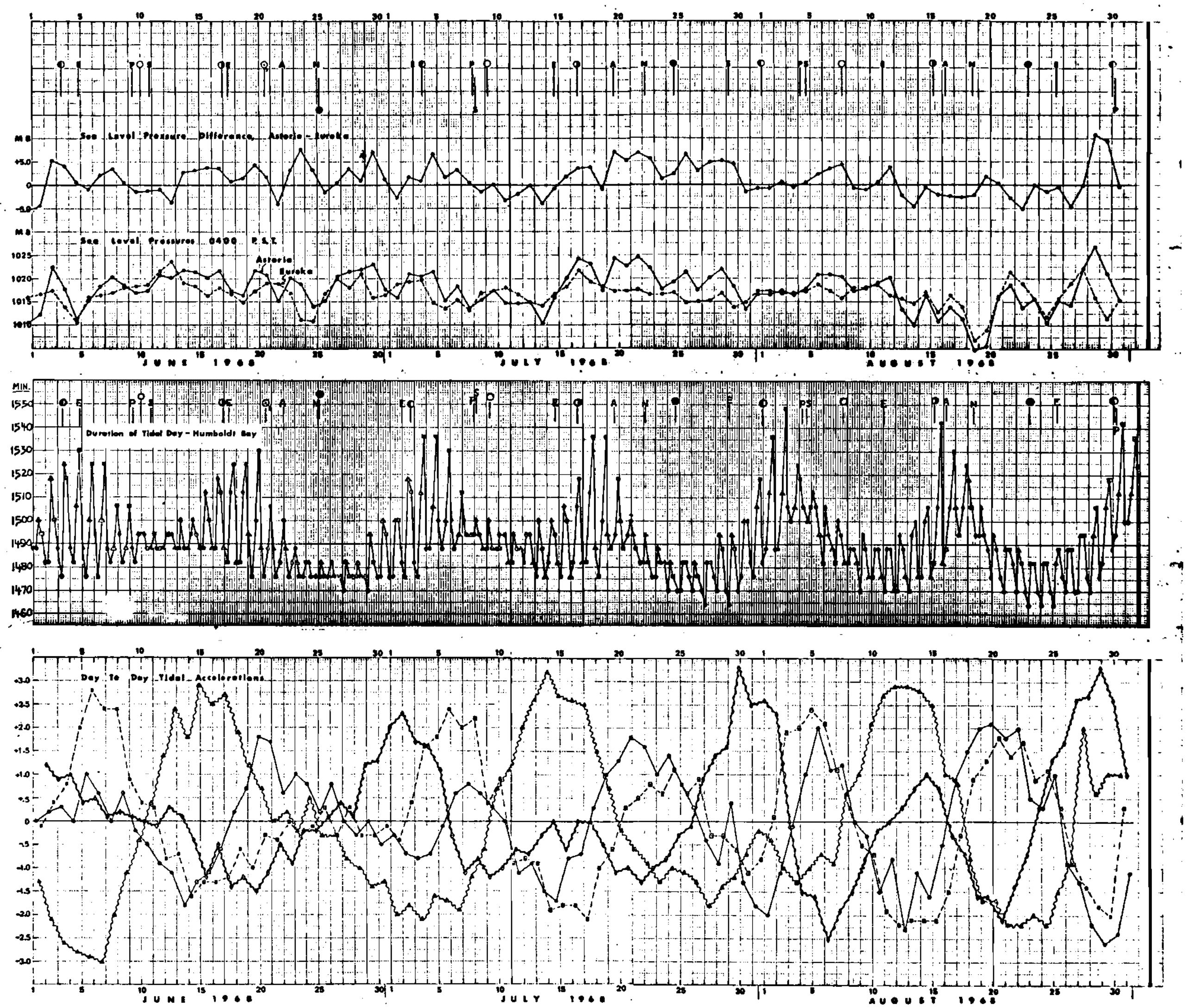

Figure 5. a. 1968 Astronomical Data. Sea Level Pressure Difference, Astoria-Eureka. Sea Level Pressures 0400 P. S. T.

b. 1968 Astronomical Data. Duration of Tidal Day, Humboldt Bay.

c. 1968 Day-to-Day Tidal Accelerations.

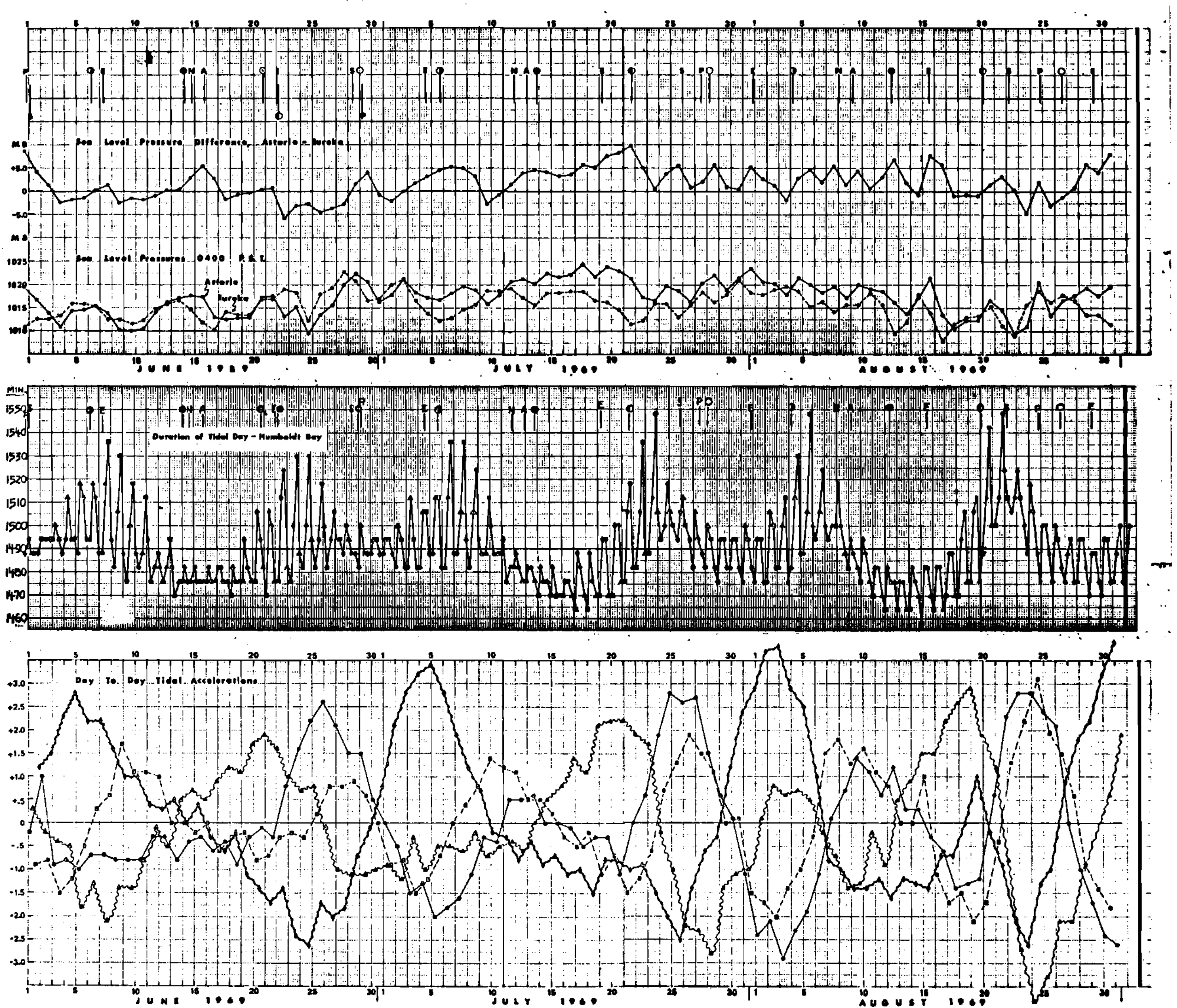

Figure 6. a. 1969 Astronomical Data. Sea Level Pressure Difference, Astoria-Eureka. Sea Level Pressures 0400 P. S. T.

b. 1969 Astronomical Data. Duration of Tidal Day, Humboldt Bay.

c. 1969 Day-to-Day Tidal Accelerations.

Figure 7. a. 1970 Astronomical Data. Sea Level Pressure Difference, Astoria-Eureka. Sea Level Pressures 0400 P.S.T.

b. 1970 Astronomical Data. Duration of Tidal Day, Humboldt Bay.

c. 1970 Day-to-Day Tidal Accelerations.

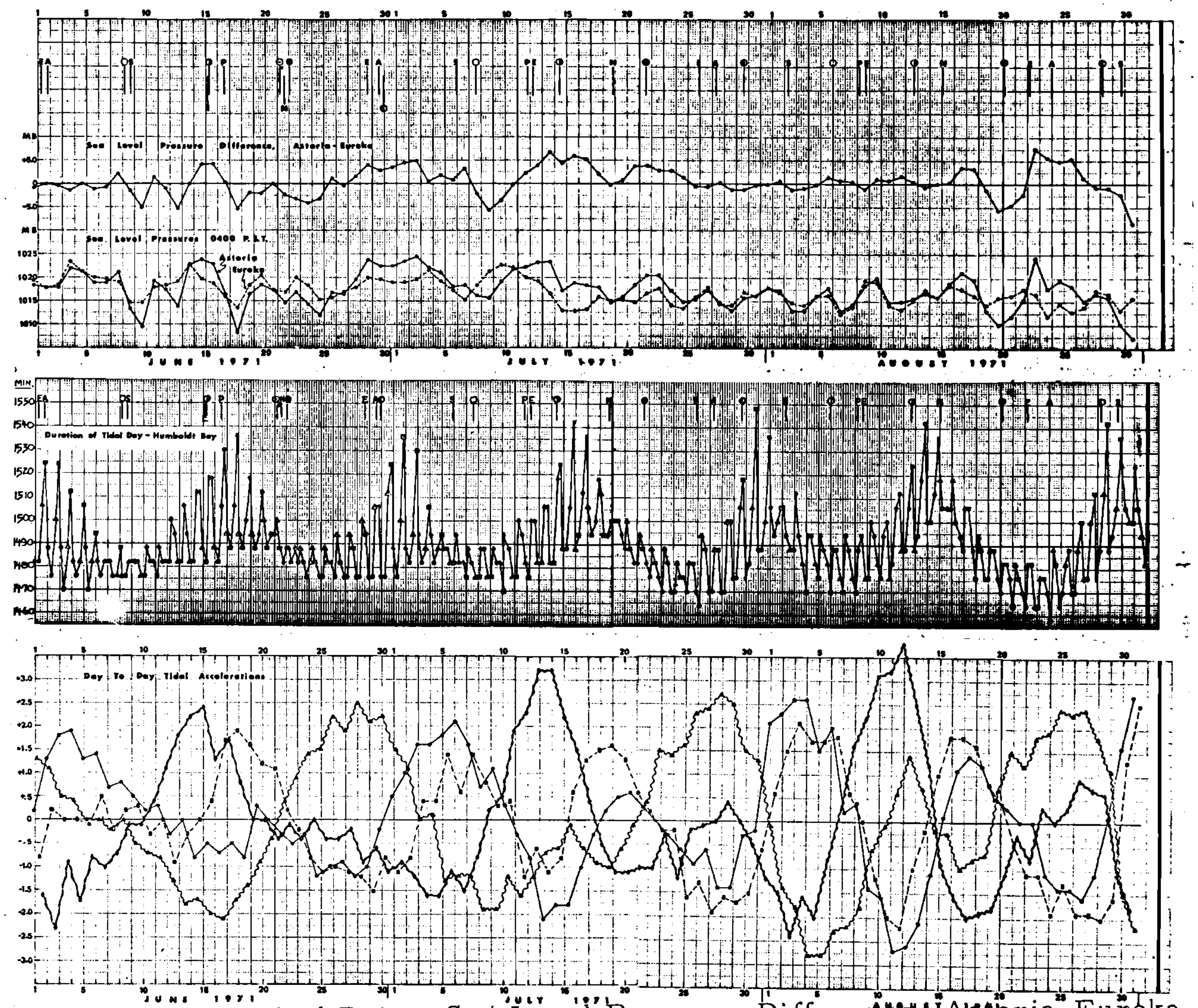

Figure 8. a. 1971 Astronomical Data. Sea Level Pressure Difference, Astoria-Eureka. Sea Level Pressures 0400 P. S. T.
b. 1971 Astronomical Data. Duration of Tidal Day, Humboldt Bay.
c. Day-to-Day Tidal Accelerations.