NOAA Technical Memorandum NWS WR-168

FORECASTING THE ONSET OF COASTAL GALES OFF WASHINGTON-OREGON

Salt Lake City, Utah
August 1981

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UNITED STATES
DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION

National Weather
Service
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This Technical Memorandum has been reviewed and is approved for publication by Scientific Services Division, Western Region.

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CONTENTS

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ABSTRACT. Offshore buoys have been shown to be useful in detecting the likelihood of coastal gales. Whenever the pressure difference between Astoria, Oregon and buoy 46005 is 9-mb or more, coastal gales for Washington should be considered.

At times, however, a large pressure difference may be measured between Astoria and buoy 46005 and gales may occur many hours later, or in some cases, not at all. By applying screening regression to a large body of data, an objective technique was developed to determine when storms were likely to produce coastal gales and the time to gale onset. The derived regression equations were tested on independent data from the winter 1980-81 season.

I. INTRODUCTION

Coastal jets accompanying eastern Pacific cyclones are responsible for most gales which occur along the Washington-Oregon coast. In a previous paper, (Zimmerman, Burton: 1979) it was shown that the pressure difference measured from a coastal station to an offshore buoy serves as a practical monitor to alert weather forecasters of coastal gale development. The surface pressure-gradient is well known to be related to the wind speed by means of the gradient-wind equation. For the Washington coast, it was found that gales are likely to occur whenever the surface pressure measured at Astoria, Oregon is 9-mb or more higher than the surface pressure measured at buoy 46005 (46N, 136W).

The pressure-difference rule has worked well since its use. Sometimes, however, an eastern Pacific cyclone moves northward parallel to the coast, and a large coast-to-buoy pressure difference may be observed, yet it may either take a long time before gales are observed along the coast (more than 24 hours), or in some cases coastal gales may not occur at all; thus, experience has shown that in addition to the pressure-gradient rule which alerts the forecaster that gales are likely, an objective estimate of the time to gale onset is also desirable.

The technique applied to objectively estimate time to gale onset was to assemble data of a large number of meteorological parameters and then apply a screening regression computer program, (Labas 1979). Output from the computer program enabled the selection of those variables best related to the dependent variable, (time to gale onset). The program also provided regression coefficients, so that estimates of the dependent variable could be obtained from the expression,

$$Y = A_0 + A_1 X_1 + A_2 X_2 \ldots\ldots + A_N X_N$$

WHERE Y = TIME TO GALE ONSET (DEPENDENT VARIABLE)

$A_0, A_1, A_2 \ldots$ = REGRESSION COEFFICENTS

$X_0, X_1, X_2 \ldots$ = INDEPENDENT VARIABLES

The independent variables selected for study are listed in Table I. Variables investigated were: characteristics of the developing low center, (central pressure, speed, distance from coast, location, and others) as well as upper air conditions on the coast (Quillayute wind speed and direction at 850-mb and 500-mb levels and other upper air parameters). Data were collected from 1979-80 for those cases when the pressure at Astoria, Oregon was 9-mb or more higher than buoy 46005. In all, 38 observations were collected, each containing 18 variables.

1	TTG	Time to gale (dependent variable)
2	DTG	Date
3	PAB	Pressure difference, Astoria to buoy 46005
4	PAS	Pressure at Astoria
5	DP3	Astoria 3-hour pressure tendency
6	DP4	Astoria 24-hour pressure tendency
7	PAQ	Pressure difference Astoria to Quillayute
8	PCL	Central pressure of approaching low center
9	RCL	Distance of approaching low center
10	LAT	Latitude of approaching low center
11	LON	Longitude of approaching low center
12	VLO	Speed of approaching low center
13	DLO	Direction of approaching low center (16-pt compass 8 = South)
14	8DR	Quillayute 850-mb wind direction
15	8WS	Quillayute 850-mb wind speed
16	5DR	Quillayute 500-mb wind direction
17	5WS	Quillayute 500-mb wind speed
18	TS5	Quillayute thickness 1000-500-mb

TABLE I. Variables Used in the Regression Analysis

II. RESULTS

Before assembling data for computation of regression coefficients by the regression program, several experiments were necessary to determine how to proceed. First, it was necessary to decide what time to use as the value of the dependent variable for those cases when the pressure difference between Astoria and buoy 46005 was 9-mb or more, and gales did not occur along the coast. Several values were tried, 72, 60 and 48 hours. It was decided after experiment that 60 hours would be a practical value to use in such cases.

After additional trials, it was found desirable to arrange data into two groups and determine regression coefficients for the time to gale onset for these two separate groups.

Group 1. All data were examined whether gales were observed along the coast or not, and the Astoria to buoy 46005 pressure difference was 9-mb or more, whenever gales were not observed along the coast, time to gales was set to 60 hours. 38 cases.

Group 2. A subset of data from Group 1 was examined of only cases when the pressure difference between Astoria and buoy 46005 was 9-mb or more and gales were observed. 22 cases.

The first 5 variables selected by the screening regression program using Group 1 and Group 2 data are listed in Table II and Table III.

Order Selected	Variable	Mult Reg Coef	Std Error
1	LON	.50	22
2	PCL	.67	19
3	DLO	.72	18
4	5WS	.78	16
5	RCL	.85	14

TABLE II. The first 5 variables selected from Group 1 data. Pressure difference between Astoria and buoy 46005 was 9-mb or more and gales may or may not have been observed. If gales were not observed, time to gale onset was arbitrarily set to 60 hours.

Order Selected	Variable	Mult Reg Coef	Std Error
1	RCL	.68	8
2	8WS	.89	5
3	DLO	.92	5
4	5WS	.93	5
5	DP4	.93	4

TABLE III. The first 5 variables selected from Group 2 data. In all cases the pressure difference between Astoria and buoy 46005 was 9-mb or more, and coastal gales were subsequently observed.

As seen in the previous tables, multiple correlation coefficients obtained from Group 2 data are higher than those from Group 1 data (.93 versus .85). The regression equations based on Group 2 data should yield a reasonable estimate of the time to gale onset since standard errors were only 4 hours. The regression equation derived from Group 1 data is useful to help the forecaster decide whether coastal gales will actually occur or not. By further testing it was found that when the time to gale onset using the regression equation derived from Group 1 data was 40 hours or greater, it could be assumed gales would not occur. In any event, if the time to gale was 40 hours or more, no advisory would be required. The program was then run again at a later time, if the Astoria to buoy 46005 pressure difference remained 9-mb or greater.

With Group 2 data the first variable selected was RCL (distance of low pressure center to Astoria). The first variable alone produces the following regression equation,

$$Y = -1.36 + 1.43(RCL)$$

or approximately,

$$Y = 1.5(RCL).$$

This expression says that for every 15 degrees of latitude the low center is distant from the coast, approximately 24 hours is required before coastal gale onset. This compares favorably with actual experience.

The next variable, Quillayute 850-mb wind speed, also behaves in a reasonable manner. The regression equation for the first two variables selected is,

$$Y = 13.0 + 1.43(RCL) - .56(8WS).$$

Thus, with a low 15 degrees off the coast, (about a day away), the higher the Quillayute 850-mb wind speed, the quicker gale are likely to occur along the coast, as shown in Table IV.

850-mb Winds	Hours to Gale
10	28
20	23
30	17
40	12

TABLE IV. Variation of time to gale as a function of 850-mb wind speed. The low center is 15 degrees of latitude from the coast.

The next variable selected was the direction of movement of the low center, DLO. For example with the low center 15 degrees of latitude offshore, and the 850-mb wind speed of 30 knots, the regression equation,

$$Y = -1.7 + 1.3(RCL) -.54(8SW) + 1.5(DLO)$$

provides the results of Table V.

DLO	Hours to Gale
8 (South)	15
12 (West)	21
16 (North)	27

TABLE V. Variation of time to gale onset as a function of low center direction of movement.

If the direction of the low is from the south, time to gale onset is shortest. This again agrees with practical experience in the northwest.

The fourth variable selected was Quillayute 500-mb wind speed, 5WS. Assuming the low center is 15 degrees offshore, the Quillayute 850-mb wind speed is 30 knots, and the direction of low movement from the south, the regression equation,

$$Y = 6.9 + 1.3(RCL) - .54(8WS) + 1.1(DLO) - .11(5WS)$$

yields the results of Table VI.

500-mb Wind Speed	Hours to Gale
30	20
40	15
50	10

TABLE VI. Variation of time to gales as a function of 500-mb speed.

For each 10-knot increase of wind speed the arrival time of coastal gales is shortened by about an hour.

The fifth variable selected was the 24-hour surface pressure change at Astoria. Assuming the low center is 15 degrees offshore, the Quillayute 850-mb wind speed is 30 knots, the direction of low is from the south and the 500-mb wind speed is 40 knots, the regression equation,

$$Y = 8.0 + 1.4(RCL)-.6(8WS) + .97(DLO) - .11(5WS) - .17(DP4)$$

yields the results of Table VII.

24-Hour Astoria Pressure Change	Hours
-5.0	20
0.0	15
5.0	10

TABLE VII. Variation of time to gales as a function of 24-hour Astoria pressure change.

Thus gales are likely when a short wave ridge causes surface pressure at Astoria to rise significantly during the past 24 hours.

III. VERIFICATION

An independent test set of data was collected during winter 1980-81 to test the practicality of using the derived screening equations in predicting the time to gale onset. Altogether 55 observations were collected whenever the pressure difference between Astoria and buoy 46005 was 9-mb or greater. For each case two separate runs were completed, first using an equation with regression coefficients derived from Group 1 data and then with an equation with regression coefficients derived from Group 2 1979-80 data.

Weather regimes during winter 1980-81 were markedly different than during the preceding year. During 1980-81 an upper ridge persisted along the west coast most of the winter. As a result few cyclones were able to penetrate into the northwest but were shunted northward into British Columbia. The persistent upper ridge was responsible for several days of record breaking high temperatures in western Washington and below normal amounts of precipitation.

Two groups of data were again assembled from winter 1980-81 observations:

Group 1. All data whether gales were observed or not and the pressure difference between Astoria and buoy 46005 was 9-mb or more. If gales did not occur, time to gales was recorded as 60 hours, 55 cases.

Group 2. A subset of Group 1 data when the pressure difference between Astoria and buoy 46005 was 9-mb or more and gales were observed. 22 cases.

Figure 1 shows the results of using the regression equation derived from Group 1 data as applied to data of 1980-81. When the time to gales was predicted to be 45 hours or more, gales were unlikely to occur. When time to gales was predicted to be 25 hours or less, gales were likely to occur. Finally, predictions between 25 and 45 hours required the application of a little judgement as to whether gales would occur or not.

A plot of predicted versus observed results of predictions of time to gale onset using the regression equation derived from Group 2 data is shown in Figure 2. The correlation is .77 which is quite significant. Thus, once it has been determined that gales are likely, a reasonable estimate of gale onset can be obtained from the regression equation derived from Group 2 data.

It should be noted that verification of gale onset may be better than the results recorded here. It is difficult to obtain verifying data representative of gale conditions along the coast and the area seaward to 20 miles. In fact, after inquiry, it was determined that no representative coast guard observations were available at night after 7 p.m. In several cases when gales were expected late at night, Cape Disappointment recorded 30 knots on their last observation that evening. Thus gales probably occurred but could not be verified.

Quite often, gales occur a few miles out to sea but are not observed along the coast. This was dramatically seen during the gale of September 8, 1978, when small boats were fishing a few miles off shore in relatively calm waters while several miles farther out to sea, boats were struggling to reach safe harbor (Zimmerman Burton 1979).

As the weather during this past winter 1980-81 was rather anomolous, it is quite encouraging that the regression equations performed as well as they did. The regression equations will, of course, be updated for next year by combining the data from the two past years. Finally, data when gales occurred (Group 2) were combined for both years and a new set of regression coefficients found, Table VIII.

Order Selected	Variable	Mult Reg Coef	Std Error
1	8WS	.61	8.2
2	RCL	.83	5.8
3	DLO	.88	5.0
4	TS5	.89	4.9
5	TAB	.90	4.7

TABLE VIII. The first 5 variables selected from combined Group 2 data of winters 1979-80 and 1980-81. In all cases the pressure difference between Astoria and buoy 46005 was 9-mb or more, and coastal gales were subsequently observed.

Table VIII should be compared to Table III. Interestingly, the first 3 variables selected remain the same although the first two variables exchange places in the order selected. Thus, the 850-mb wind speed, distance of the low from the coast, and low direction of movement are important indicators of how quickly coastal gales will occur, Figure 3.

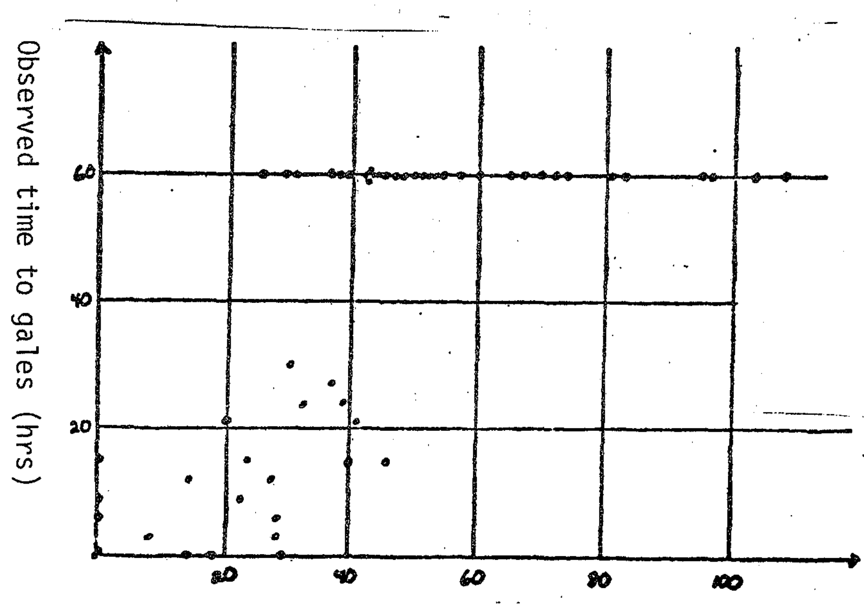

Figure 1. Predicted versus observed time to gale onset using Group 1 (1979-80) regression coefficients. Astoria to buoy 46005 pressure difference was 9-mb or greater. If gales did not occur, time to gale onset was recorded as 60 hours. Data were for Winter 1980-81 only.

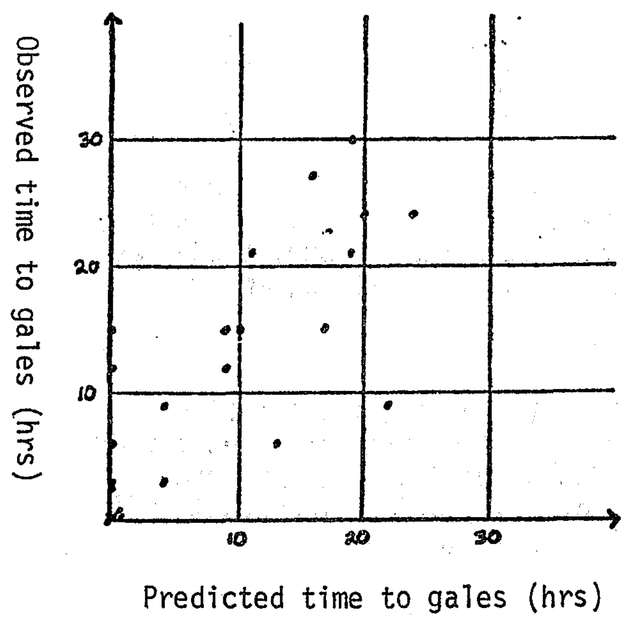

Figure 2. Predicted versus observed time to gale onset using Group 2 (1980-81) regression coefficients. Astoria to buoy 46005 pressure difference was 9-mb or greater and gales were subsequently observed. Data were for Winter 1980-81 only.

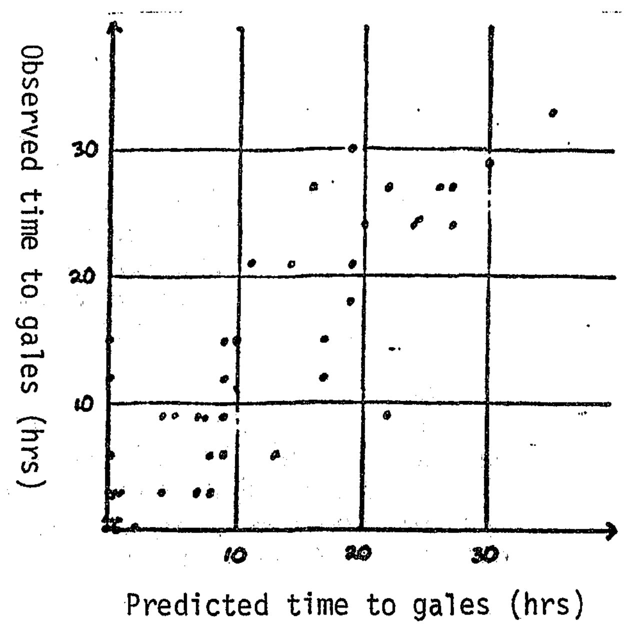

Figure 3. Predicted versus observed time to gale onset using Group 2 (1979-80) regression coefficients. Astoria to buoy 46005 pressure difference was 9-mb or greater and gales were subsequently observed. Data were combined for 1979 through 1981.

IV. EXAMPLES

To illustrate how the foregoing results may be applied to predicted gale onset time over coastal waters of the Northwest, two cases are presented. The first is a case when gales threatened, but did not occur, January 12, 1981. The second is a case when gales threatened and did occur, November 6, 1980. In each situation, a pressure difference of 9-mb or more was observed between Astoria and buoy 46005.

The 500-mb chart of January 12, is shown in Figure 4. A large ridge aloft had become established over the Northwest and was retrograding westward. At the surface, Figure 5, a deep 974-mb low center was located about 800 miles west of the coast.

Computer calculations of time to gale onset were accomplished using an AFOS procedure called "gale". When using procedure gale, a preformat is called to the AFOS screen, and data for the first set of variables is entered into the AFOS preformat.

The preformat and input data are shown in Figure 6. For the initial computer run, the estimate of time to gales was 44 hours, which indicated that gales were unlikely. No coastal gales were observed from this storm.

The second case of November 6, 1980 was quite different. At 500 mbs, Figure 7, strong westerlies were established over the Northwest. A surface low center of 964 mb, Figure 8, located at 47N 146W had tracked northeastward from the southwest and continued on this course for the next 24 hours. As it moved towards British Columbia, it began to weaken slightly, but central pressure remained below 970 mb.

Several small frontal waves formed slightly delaying the arrival of the front at the coast. Coastal gales were observed just as the front moved inland.

The prediction of gales using the regression equation from Group 1 data was 27 hours which indicated that coastal gales were possible, Figure 9. As this value was under 40 hours, the second regression equation was applied and predicted that gales would occur in 9 hours, Figure 10. Actual time to coastal gales was 12 hours.

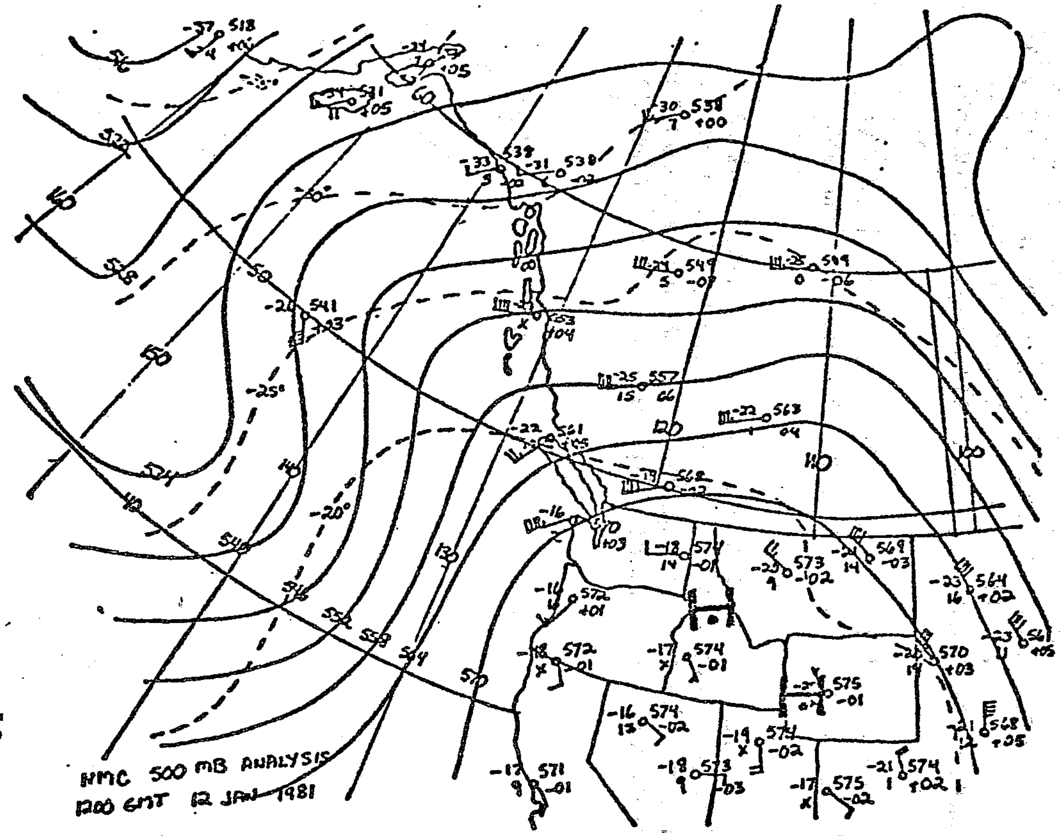

Figure 4. 500-mb chart of January 12, 1981 at 1800 GMT.

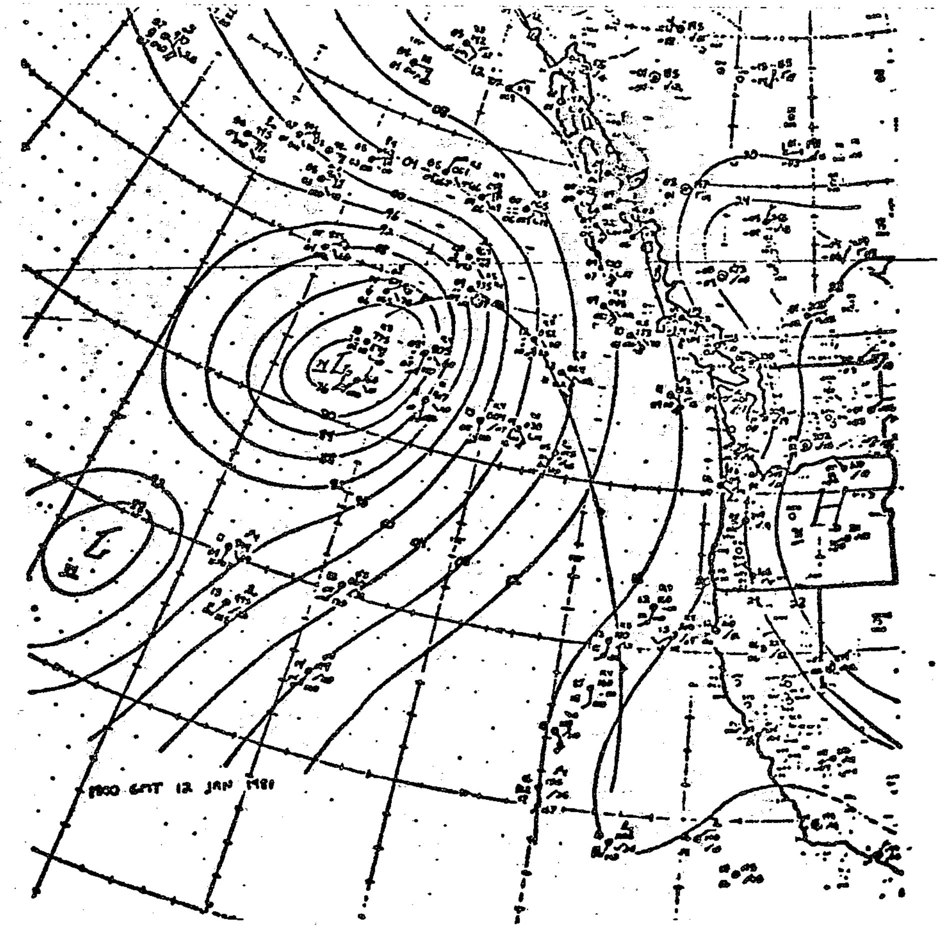

Figure 5. Surface chart of January 12, 1981 at 1800 GMT

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  INPUT DATA NEEDED TO DETERMINE WHETHER GALES WILL OCCUR ALONG
THE COAST.  PRESSURE DIFFERENCE ASTORIA TO BUOY 46005 MUST BE
9-MB OR MORE.  PLACE A DECIMAL POINT IN EACH VALUE OF INPUT
PARAMETER.  DEGREES=(DEGS LAT).  ENTER 1 IN BOX IF FIRST SEC-
TION IS TO BE RUN...FOR SECOND SECTION...ENTER 2.
                          1
FIRST SECTION:       WILL GALES REACH COAST...
.....LONGITUDE OF LOW       142.       DEGREES OF LATITUDE
     CENTRAL PRESSURE       972.       MILLIBARS
     DIRECTION OF LOW       7.         16-POINT COMPASS
     500-MB WIND SPEED..UIL 46.        KNOTS
     DISTANCE OF LOW TO AST 12.        DEGREES OF LATITUDE
                                       .....FIRST SECTION..... ]]
```

```
FIRST VARIABLE      142.0
SECOND              972.0
FIRST VARIABLE      142.0
SECOND              972.0
THIRD                 7.0
FOURTH               46.0
FIFTH                12.0

ESTIMATE OF TIME TO GALES  44.  HOURS
```

Figure 6. Preformat and input data of January 12, 1981 for Group I regression equation.

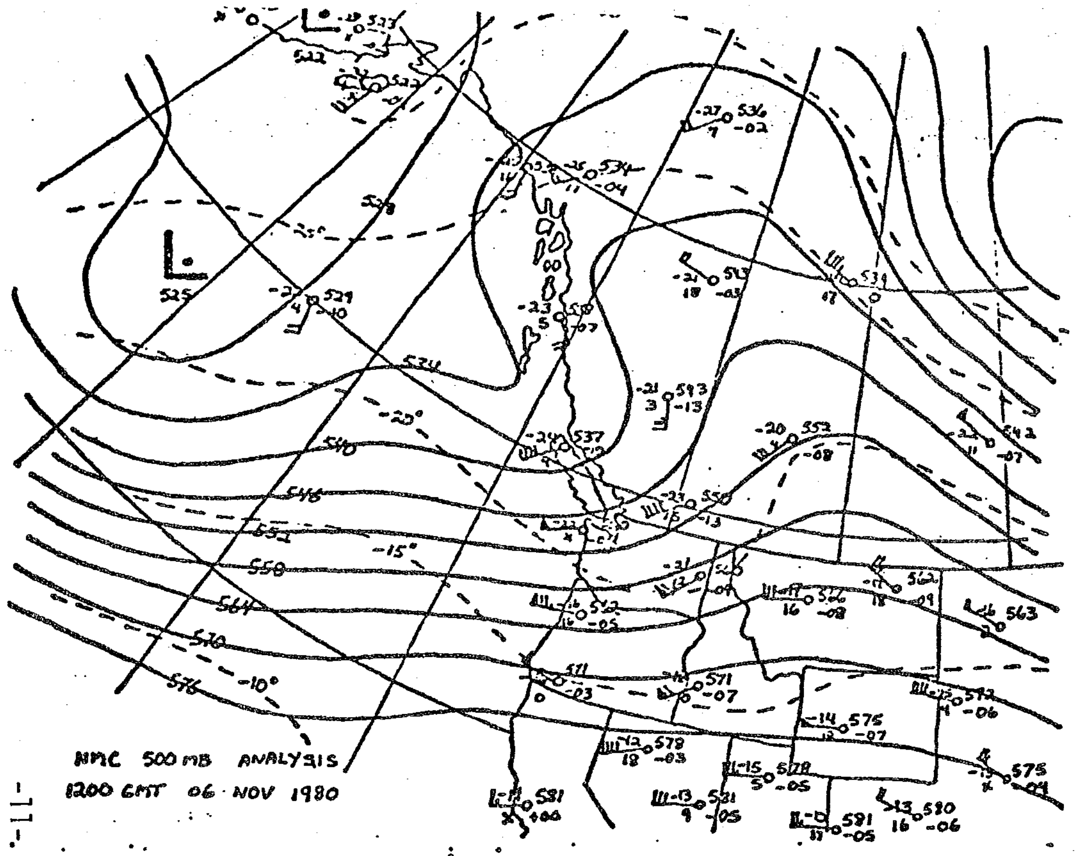

Figure 7. 500-MB chart of November 6, 1980 at 1800 GMT.

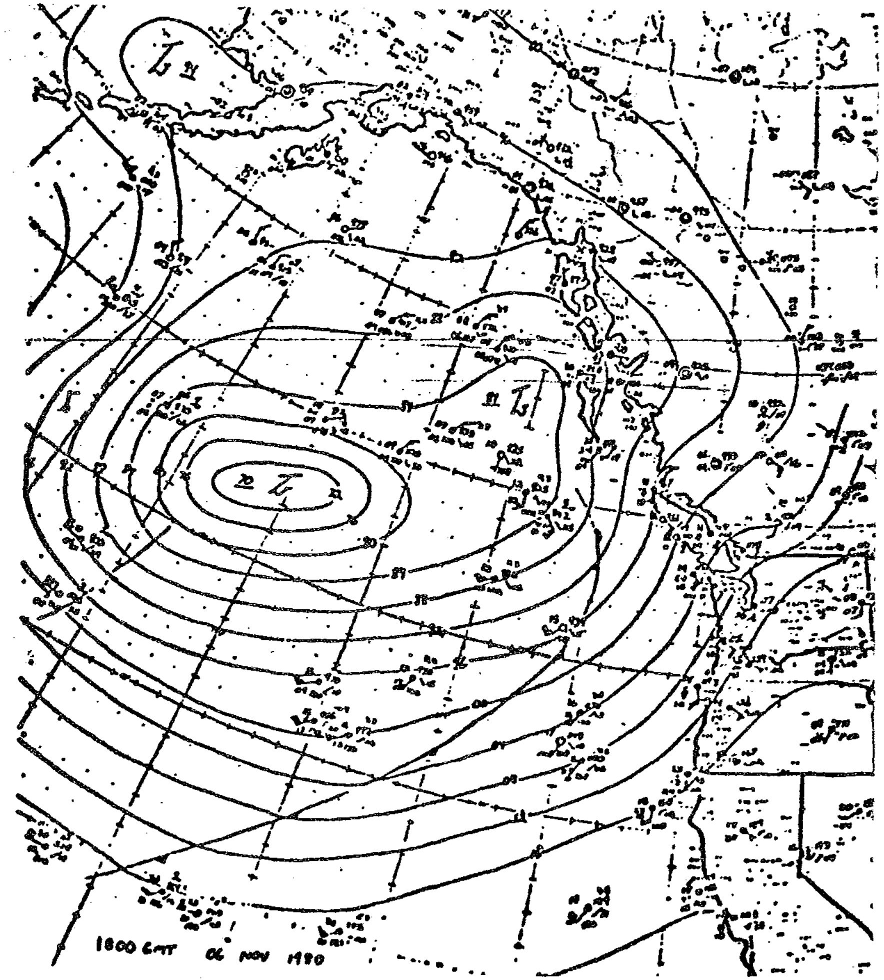

Figure 8. Surface chart of November 6, 1980 at 1800 G

INPUT DATA NEEDED TO DETERMINE WHETHER GALES WILL OCCUR ALONG THE COAST. PRESSURE DIFFERENCE ASTORIA TO BUOY 46005 MUST BE 9-MB OR MORE. PLACE A DECIMAL POINT IN EACH VALUE OF INPUT PARAMETER. DEGREES=(DEGS LAT). ENTER 1 IN BOX IF FIRST SECTION IS TO BE RUN...FOR SECOND SECTION...ENTER 2.

1

FIRST SECTION: WILL GALES REACH COAST...

.....LONGITUDE OF LOW	146.	DEGREES OF LATITUDE
CENTRAL PRESSURE	964.	MILLIBARS
DIRECTION OF LOW	11.	16-POINT COMPASS
500-MB WIND SPEED..UIL	52.	KNOTS
DISTANCE OF LOW TO AST	14.	DEGREES OF LATITUDE

.....FIRST SECTION.....]]

FIRST VARIABLE	146.0
SECOND	964.0
THIRD	11.0
FOURTH	52.0
FIFTH	14.0

ESTIMATE OF TIME TO GALES 27. HOURS

Figure 9. Proformat and input data of November 6, 1980 for Group I regression equation.

```
  INPUT DATA NEEDED TO DETERMINE WHETHER GALES WILL OCCUR ALONG
THE COAST.  PRESSURE DIFFERENCE ASTORIA TO BUOY 46005 MUST BE
9-MB OR MORE.  PLACE A DECIMAL POINT IN EACH VALUE OF INPUT
PARAMETER.  DEGREES=(DEGS LAT).  ENTER 1 IN BOX IF FIRST SEC-
TION IS TO BE RUN...FOR SECOND SECTION...ENTER 2.
                                        2

FIRST SECTION:       WILL GALES REACH COAST...
.....LONGITUDE OF LOW                   DEGREES OF LATITUDE
     CENTRAL PRESSURE                   MILLIBARS
     DIRECTION OF LOW                   16-POINT COMPASS
     500-MB WIND SPEED..UIL             KNOTS
     DISTANCE OF LOW TO AST             DEGREES OF LATITUDE
                                        .....FIRST SECTION.....

SECOND SECTION:  WHEN WILL GALES REACH COAST...
     DISTANCE OF LOW....AST   14.       DEGREES OF LATITUDE
     850-MB WIND SPEED..UIL   41.       KNOTS
     DIRECTION OF LOW         11.       16-POINT COMPASS
     500-MB WIND SPEED        52.       KNOTS
     DP/DP (24 HOUR)....AST   -5.1      MBS
                                        .....SECOND SECTION.... ]]

FIRST VARIABLE      14.0
SECOND              41.0
THIRD               11.0
FOURTH              52.0
FIFTH               -5.1

ESTIMATE OF TIME TO GALES  9.  HOURS
 ISSUE GALE WARNINGS IMMEDIATELY
```

Figure 10. Preformat and input data of November 6, 1980 for Group I regression equation.

V. SUMMARY

Accurate forecasting of gale conditions off coastal Washington is of considerable importance to the mariner. Fishing fleets working along the coast and beyond depend on NOAA Weather Radio warnings that gales are developing. Gales can very quickly create dangerous and steep seas. With the AFOS computer, it is now possible to develop objective aids which alert the weather forecaster of time to gale onset.

Using data from winter 1979-80, regression equations were developed to,

a) Determine whether gales are likely,
b) Determine the time to gale onset.

These equations applied to winter 1980-81 data verified reasonably well. This is especially encouraging since weather during this past winter was totally different from the previous year.

It is difficult to obtain data required to verify the occurrence of coastal gales. At night, coast guard stations do not relay weather obs and wind instruments at other coastal stations are sheltered from gales by local terrain. It has often been observed that gales may be experienced a short distance offshore while winds observed along the coast are below gale force.

Satellite images can be of great help to detect potential gale development. If a vorticity center develops on the approaching baroclinic zone, it is possible to determine whether gale development is likely. Using the surface chart, estimates of low central pressure, direction and speed can be made. This information can then be used in regression equations to objectively predict time to gale onset.

Regression analysis has been applied to forecast many meteorological parameters such as maximum temperature and probability of occurrence of meteorological events (precipitation). The use of regression analysis can be extended to objective prediction of other meteorological events as well. Nevertheless, use of objective aides will still require human input to maximize their utility.

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