THE SEA BREEZE OF NORTHWEST OREGON AND ITS INFLUENCE ON FORESTRY OPERATIONS

by

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INTRODUCTION

Work on the theory of the sea breeze, as pointed out by Staley (59, p. 458), has been for the most part quite fruitful relative to most areas of meteorological research. As indicated in his statement of purposes, however, Staley recognized several shortcomings common to most such work. In particular, neither theoretical nor observational studies of the sea breeze circulation have dealt in any detail with other than straight coast lines with flat, low-lying coastal terrain. With only these observations to check against theoretical calculations sea breeze investigators have developed a variety of mathematical models which produce results agreeing nicely with the broad details of the observations. The assumptions included in the models with respect to coastline and terrain configuration are simplifications, for the most part, appropriate to the uncomplicated locales of the observations. Thus, as with many lines of research, the simplifying assumptions have led to a position in which the workers involved have been unable to say with any confidence whether discrepancies between theory and observation are due to the nature of the assumptions, to instrumental errors, to sampling techniques, or to basic inadequacies of the theory. As a result, while the general features of the sea breeze have been reproduced many times in calculations based on a variety of theoretical models, two fundamental types of discrepancy have appeared in the work on the sea breeze. The first type consists of departures of observational results from behavior predicted by theory. The second type appears as the production of the same theoretical results by different mechanisms. The presence of discrepancies of this second type in the literature on the sea breeze indicates that work remains to be done in explaining correctly the mechanisms involved in the generation and propagation of the sea breeze circulation. Since, as pointed out, several mechanisms invoked have produced results in general agreement with observations of the sea breeze made over simple terrain, it may be supposed that the theory which can best explain observations over complex terrain as well is the most fundamentally correct theory. It will be one of the principal purposes of the work reported here to present a variety of observations made of the sea breeze in complex terrain near an essentially straight coastline in midlatitudes. Thus theoretical meteorologists may have available data against which to check calculations based on work they may do. The major portion of this thesis, therefore, is a quantitative description of the sea breeze as observed in some detail in a complex environment essentially different from any other in which it has been observed and yet not so complex that it would not be amenable to mathematical treatment.

A second principal purpose of the work described here is to present and discuss changes in operational situations caused by the sea breeze or the absence of it, and to examine adjustments made by forestry personnel in response. Because of the dearth of published information in this connection, the writer has used a questionnaire to supplement the few sources available.

LITERATURE REVIEW: THE SEA BREEZE

General areal behavior. While the sea breeze cannot truly be said to begin in a certain way, being simply the result of a certain set of factors imposed on a sequence of events, the description by Kimble (37, p. 99) of the onset of the sea breeze is instructive. Though his treatment probably cannot be taken literally as "the cause" of the sea breeze circulation, the principle of a pressure force generated through differential heating is generally accepted as the underlying drive of the several forms of local wind, of which the sea breeze is one type.

In view of Kimble's conceptual model for the onset of the sea breeze, one might expect a certain minimum temperature difference between land and sea or a certain minimum surface pressure gradient to be necessary before the sea breeze would be set in motion. Haurwitz has stated this minimum temperature difference is indeed necessary (28) and that in addition the magnitude of the difference is proportional to the coefficient of surface friction over the sea. The observation of many writers (e.g. 17, p. 659) that under calm antecedent conditions the sea breeze arrives on shore as a "front" suddenly released after overcoming some restraining force agrees qualitatively at least with the notion of certain minimum contrasts being exceeded.

A second model embodying the basic drive of the sea breeze involves the principle of pressure-density solenoids. This interpretation of the mechanism of the sea breeze (e.g. 62, p. 432) is not essentially different from that of Kimble, both being based on the notion of accelerations imposed on moving air during its passage through a baroclinic segment of the atmosphere formed by local differential heating at the earth's surface. The main difference between the two models is that Kimble's implies the circulation can be realized with an initially static atmosphere, while that of Stewart emphasizes the accelerations may be realized only with already-moving air.

Pierson (53, p. 8) cautions that the models just mentioned may have limited usefulness, since they both postulate equal temperatures and heating rates for all levels in columns of air over land and sea. This, he says, eliminates the possibility of imposing theoretical statements of such factors as the vertical variation of eddy viscosity in the air columns. Smith (57, p. 384-387), on the other hand, implies this "height averaging" of temperature in the columns is not unrealistic in view of the idea currently receiving considerable support that the heat is introduced throughout the column over the land by means of heated "bubbles" of air rising from the surface to various levels before dissipating.

Edinger's model (20) accounting for the observed diurnal variations in the height of the marine inversion layer over the Los Angeles Basin contains three elements. The first is the diurnal divergence patterns associated with large scale atmospheric tides, undoubtedly akin to those described theoretically by Pearce (52, p.368-377). This element produces, in the Los Angeles area, a sort of "background" variation of inversion height amounting to a decrease in height of one hundred feet per hour from 08h to 12h followed by no change into the evening hours. The second element is a daytime deepening of the marine layer over the entire coastal area due to surface heating and convectional warming of the layer. This effect amounts to an increase in height of three hundred feet per hour from 08h to 12h followed by no change into the evening hours.

The third effect is that of height increase as a result of horizontal convergence over the coastal areas brought on by mass advection from the ocean. The zone of convergence is associated with the sea breeze and moves inland with increasing speed during the day. The net effect of these elements is a wave shape in the inversion layer whose crest moves inland from the coast during the day, arriving about 50 miles inland in late afternoon.

In the discussion of his model of the sea breeze Haurwitz says (28) the observed occurrence of maximum wind speeds in the coastal areas between the hours of maximum land-sea temperature difference (usually about midday) and those of zero temperature difference (about sunset) is due to the effects of surface friction on the system. While attempting no explanation, Kimble (37, p. 111) notes the same phase relationship, observing further that at the time of maximum wind speeds the low level temperatures are rising over both land and sea whereas their difference is falling. Thus, he says, the height of the sea breeze occurs before the time of maximum temperatures. In view of Defant's calculations (17, p. 663) we may conclude that the phase relationship of wind speed and temperature difference just noted is due not simply to the presence of friction but to its increasing magnitude into the afternoon hours.

As an historical aside, Defant notes the early model of Jeffreys (34) would give maximum wind speeds at the same time as maximum temperature difference, while the model based on solenoids mentioned above and exemplified by the work of Bjerknes (7, p. 689) predicts maximum winds at the hour of zero temperature difference. Neither, of course, agrees in general with observations.

Stern (61) notes the phase relationship of wind speed and temperature difference may be accounted for by the retention in an equation of momentum conservation of a linearized advection term while friction is disregarded completely. He refers to the introduction of the frictional effect by other authors as "lumping non-linear terms and calling this a viscous stress."

In dealing with one aspect of the often-noted effects of a general areal gradient wind flow in modifying the areal behavior of the sea breeze, Gentry and Moore (25) have studied the locations of zones of convergence and divergence in coastal regions of Florida. In essence this modification takes the form of heightening the abruptness of the arrival of the sea breeze front as well as delay of its onset by an off-shore gradient flow. In general the frontal nature of the circulation appears to be diffuse or absent under conditions of an on-shore gradient flow.

In a critique of the theoretical work on the sea breeze Defant (17, p. 659-660) observes that, while the work of many authors has brought good qualitative agreement of theory with observation, all of the models reviewed included in the form of a priori relationships many factors whose nature should instead be products of the models. A complete theory, says Defant, should include considerations of the influence of vertical turbulent heat exchange as a product of assumed conditions at the surface, the effects of turbulent friction, and the effects of the coriolis force. In his comments on the nature of a complete theory Haurwitz (28) says the results should include, besides the items given by Defant, considerations of the effects of sea breeze advection on the temperature field itself and should be able to account for the observed vertical shears in the wind field and the limited extent of the circulation toward land and sea. With regard to the theoretical approach to explanation of the general areal behavior of the sea breeze, Stern (61) suggests in a concluding remark that "so much hinges on assuming eddy coefficients to be constants and then assigning a 'reasonable value', the ways of investigating heating functions without considering the coefficients should be exploited."

Relative to the space devoted in the literature to the nature of the landward-moving surface branch of the daytime sea breeze circulation, little has appeared on the nocturnal land breeze generally thought to be a compensating part of the diurnal pattern of this local wind system. In general terms, the consensus seems to be, in the words of Defant (17, p. 657), the nocturnal land breeze "must be of smaller intensity and vertical extent because of the lack of instability and convection."

As to the effects of various geographical and topographical factors on the areal behavior of the sea breeze, both Wexler (72, p. 275-277) and Kimble (37, p. 103-107) have published good semi-quantitative summaries. As examples of effects likely to be important in this study on northwest Oregon, the influence of overall wetness of coastal areas discussed by Kimble and the various influences of coastal terrain mentioned by Wexler appear to be important. The greater the amount of evaporation taking place over land in coastal areas, the less energy there is available for producing temperature contrast between land and sea, and thus the less likely is the sea breeze to become intense. Thus, the sea breeze should be more noticeable over desert or semi-arid coasts than over forested coasts. As regards terrain, Wexler suggests mountains slightly inland should, as a result of the tendency for local valley winds[1] to blow during the day, heighten the intensity of the sea breeze. Located farther inland, these same mountains are likely to extend the horizontal dimensions of the flow but to have little effect on its intensity. As regards coastal mountains, Humphreys (33, p.157) expressed the opinion that their inland slopes should experience during the day a seaward moving flow in excess of that attributable to the valley wind alone, the differences being in connection with continuity requirements in the atmosphere across the boundary of this circulation and that of the land and sea breeze.

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[1] For a discussion of the local wind known as the mountain-valley wind, see Defant (17, p. 662-667).

Probably the classic example of an observational study of the sea breeze in an area of simple terrain is the work of Koschmieder (38) at Danzig. For an area in which the terrain is simple but the interplay of several distinct air masses is relatively complex, the discussion of the sea breeze on Cape Cod by Atlas (1) is most instructive. The sea breeze regimes in topographically complex areas are described in a second study by Edinger (21) and by Staley (59, 60).

Depth, inland penetration, and intensity. Among the first theoretical computations on the sea breeze were Jeffreys' (34, p.42) calculations of the depth of the circulation and the wind profile in the sea breeze layer. The latter results proved more in agreement with observations than his figure of 150 meters for the depth. Humphreys' (33, p. 158) calculated depth of 347 meters, based on a very simple hydrostatic model, is in close agreement with the 1000 feet reported by Atlas (1, p.257) as the depth of the "local sea breeze" at Buzzard's Bay, Massachusetts. Atlas states also that the depth of a larger scale circulation in the Cape Cod area, which he calls the "regional sea breeze", is about 2000 feet. He offers no comment on the reasons for the difference between depths.

A slight complication in what would otherwise be a simple conception of the depth of the sea breeze circulation comes as a result of a study by Berson (5, p. 4-10) of the cross-sectional shape of the sea breeze frontal surface. The "friction head" shape described by Berson takes the form of an upward bulge followed by a "saddle" on the frontal surface a short distance behind its leading edge.

This shape has also been reported by Wallington (71).

Another complication has to do with the definition of the depth of the circulation. Since Wexler (72, p. 283) reports the depth of marine air in the sea breeze is about 1.8 times the depth of the landward moving layer, some of the marine air must therefore be taking part in the offshore flow aloft when it is present. One cannot always be certain, then, whether depths reported by various authors refer to depth of onshore flow or depth of marine air. In any event, Defant (17, p. 661) has concluded the depth of the circulation, including that of the return flow aloft, is proportional to the magnitude of the friction at the surface and that this depth is inversely proportional to the relative importance of the coriolis effect in the field of motion. In addition, he has concluded the depth is a function of the coefficient of turbulent heat transfer and of atmospheric stability over the land, and that the depth of the return current seaward is four or five times that of the onshore flow.

As for extent of penetration inland, Wexler concludes (72, p.282) that in the absence of any effects of coastal terrain the sea breeze can penetrate a maximum of 40 km inland in midlatitudes. With an offshore gradient wind the sea breeze may penetrate no more than about one kilometer according to Wexler.

Wind speeds associated with the sea breeze, again in the absence of a strong gradient component, cannot exceed a maximum of about 22 mph in midlatitudes, according to Defant (17, p. 661).

There appears to be general agreement in the literature that the overall vigor of the sea breeze, including its intensity and its dimensions, is proportional to the instability of the air over the land. Kimble (37, p. 108) notes that in a very stable marine layer lying onshore a given amount of heat added should produce a greater pressure gradient in the shallow layer beneath an inversion the greater the stability. He then counters with the observation that the addition of heat through condensation in convective action in unstable air over the land overshadows the effects of greater stability. The net result, according to Kimble, is a more vigorous sea breeze when there is greater instability over the land. Wexler (72, p. 277) is in agreement that instability over land aids the generation of a more vigorous sea breeze circulation, as is Wallington (71), who says its vigor is greatest not when the temperature contrast between land and sea is greatest at the surface but when it is greatest on the average throughout the lowest kilometer. Pearce (15, p. 377) supports the direct proportionality of vigor and instability by noting that wind speeds increase markedly when the temperature inversion frequently found in the morning over coastal areas is dissipated.

Lapse rates and cross sections. Observations of the vertical structure of the atmosphere in coastal regions during sea breeze provide consistently striking evidence of the rapid rates at which air masses are modified in their lower layers by passage over areas distinctly different from those at their source. Lapse rates of temperature are quite stable as the marine air approaches and passes over the beach, an isothermal layer a few hundreds of meters deep being common (72, p. 285; 1, p. 257). Once across the beach and moving inland, the ocean air is heated rapidly and efficiently from below by means of heat convected from the warm land surfaces. Within a matter of a few tens of kilometers of the shoreline lapse rates frequently become adiabatic or even superadiabatic to a depth of several hundred meters (1, p. 257; 21, p. 13; and 23, figs. 6 and 14). Later in the day, when intense surface heating has ceased, temperature lapse rates generally become moderately stable again.

Insofar as moisture distribution is concerned, Wexler (72, p.285) says "the sea breeze is characterized by a decrease in relative humidity with elevation." Presumably this statement applies to the surface layers below either the level at which the return flow begins or the level at which the air has distinctly non-marine characteristics. As for absolute humidity, one may not safely make so clearcut a generalization as Wexler's on relative humidity. To judge from the observations of Craig et al (14) and of Atlas (1) the distribution of moisture in the atmosphere near the beach is complex. High concentrations apparently appear either as moist tongues ascending just inland from the beach and remaining relatively stationary (14) or as "sheaths" or "curtains" aligned parallel to the shore but moving inland (1). At any rate no simple form of layered moisture distribution has been found reported in immediate coastal areas experiencing sea breeze, and the writer has seen no reference whatever to moisture distribution in the vertical at points well downstream in a sea breeze flow.

As noted above, Jeffreys' early computations regarding the shape of the wind profile in the lower layers of a sea breeze system have been well supported by observations. The appearance of a low-level wind speed maximum not unlike those observed under certain circumstances at continental stations (8) has been observed by Sutcliffe (63, p. 140-141), by van Bemmelen (70), and by Fisher (23). More recent theoretical work by Pearce (52) and by Fisher (24) has left little doubt of the existence of such a low level jet as a common feature of the wind profile just inland from the beach. Altitudes of from 50 to 100 meters are typical for the level of maximum speeds in the profile.

The solenoidal model for the sea breeze cited above accounts very well for most predicted and observed features of the field of vertical wind in the sea breeze system near the beach. The zones of rising air inland from the shoreline and subsidence offshore are anticipated theoretically by Pearce (52, p. 366-367) and Fisher (24) and confirmed intrinsically in the observations of Craig et al (14). Such a gyre, however, is to be found only within 10 to 20 kilometers of the shoreline, and the field of vertical wind farther offshore and inland is much less clearly understood. Smith (57, p. 391) has given the results of theoretical calculations of this overall field of vertical wind, but observational evidence to substantiate the details of these results is for the most part lacking. A small feature of the calculated field appearing in Smith's Figure 8, however, may have been observed by Ayer (2), whose reported balloon ascent rates indicate strong upward motion below about 2500 feet and a layer of subsidence between there and about 4000 feet above sea level. The distances inland from the beach are of the same order in both papers; however, the presence of mountainous terrain and the fact that his observations were made during a period of general regional subsidence may rule out direct comparison of Ayer's work with that of Smith.

It is thought that in general a zone of low level convergence and rising motion moves inland from the shore during the day, having been initiated in the early morning by the onset of the sea breeze (3, 20, 49, 71). While Neiburger's paper on the inland movement of this wavelike zone is particularly convincing, extrapolation of his conclusions to areas other than Los Angeles may be open to question. Nevertheless, with the exception of Wallington's observations in southern England, little else has been written on the downstream field of vertical motion associated with the sea breeze.

Howell's description (32, p. 48) of the multiple haze layers he observed in conjunction with the sea breeze in Peru is interesting. Like so many atmospheric varves, these layers one atop the other apparently mark the boundaries between the advected contributions of each of a series of calm days in which no major migrating disturbances move through the area. Multiple haze layers were observed also over the Los Angeles Basin by Edinger (21, p. 5).

<u>Frontal nature of the sea breeze</u>. Probably the classic observation on the frontal nature of the sea breeze is that by Koschmieder (38) in which he computed the mean speed of the advancing front to be about six tenths that of the speed of the wind component normal to the front. Based on observations made at Danzig, this calculation led him to the conclusion that there must be some return

flow seaward within the marine air itself, in agreement with the conclusion of Wexler cited above.

Table 1 presents a summary of the published data available to the writer on the speed of the sea breeze front. With the exception of the cases involving "cool changes" reported by Berson, the results appear quite consistent, falling in a fairly narrow range between 2 and 3.5 mps. The single exception of the cool changes has a mean about twice as great as the others and a coefficient of variation distinctly smaller.

Pierson (53, p. 14) has reached a provocative conclusion as a result of theoretical considerations. Given a static atmosphere as initial condition for a period of differential heating, he obtained a general offshore flow lasting a few days before general onshore movement began. The former period was apparently associated with an interval when transient solutions of his model were in effect, while the latter came with equilibrium solutions. Pierson notes that had an overall non-zero gradient wind been superimposed on his model, the surface temperature gradients would have been reduced with the result that equilibrium would not have been reached in any reasonable time. While the model has shortcomings, it is intriguing to speculate that the "hot spells" from which the return of a sea breeze circulation often brings relief may themselves be part of the results of the pattern of differential heating.

In the results of calculations with his sea breeze model Smith (58, p. 256) finds the onshore movement of a "miniature cold front". The writer noted also in Smith's results that, over the windward

TABLE 1

SUMMARY OF PUBLISHED RESULTS ON THE SPEED OF THE SEA BREEZE FRONT

Source of data	Location	Speed			
		mph	km/hr	mps	C.V.*
Koschmieder (38)	Batavia, coast	7.9	12.6	3.5	
"	" , inland	4.9	7.9	2.2	
"	Danzig	4.4	7.2	2.0	0.59
Wallington (71)	Southern England (scaled from drawings)	3.1 to 4.7	5.0 to 7.5	1.9 to 2.1	
Berson (5)	So. Australia "cool changes"	12.8	20.9	5.8	0.25
"	So. Australia sea breezes	6.6	10.8	3.0	0.45

* Coefficient of Variation = sample standard deviation / sample mean

beach, perturbations of vertical wind became stronger and reached to greater heights in situ for several hours before the zone of perturbations moved inland at about ten mps. It is possible this effect may be associated with the diurnal passage inland of the zone of vertical motion noted above. Pearce's theoretical results (52, p.363) also show a cold tongue of marine air moving inland during the day preceded by a zone of vertical swelling of the marine layer.

The observational work of Berson (5) cited above in connection with the friction head shape of the leading edge of the sea breeze front confirms other points with regard to the nature of the front. Berson computed the speed of the front to be about one half that of the normal wind component, in good agreement with Koschmieder. In addition he concluded the maximum onshore wind speeds observed were just behind the front and at an altitude of 300 to 600 feet, while in this layer the wind backs after the frontal passage until it is nearly parallel to the front. This backing of the wind is confirmed in the results of Pearce (52, p. 366-367); of Fisher (23, p. 654) and of Wallington (71).

There is evidence that the so-called sea breeze front may not move smoothly and continually inland. In the words of Wallington (71) "gliding experience in sea breeze effects suggests that not infrequently sea breeze fronts appear to progress inland in a series of pulsations rather than with a steady movement; on occasions the sea breeze frontal effects appear to decline in one belt while intensifying in another belt a kilometer or two farther inland." Such pulsations are suggested intrinsically in the observations reported by

Kauper (36, p. 415) for the Los Angeles area. Since the observation of such an effect would require a relatively dense network of wind recorders, perhaps it is common and has simply escaped detection in areas without numerous continuous wind records.

Local temperature and moisture variation at the surface. It would seem reasonable to expect temperatures to fall sharply and atmospheric moisture content to rise rapidly at a station with the passage of the sea breeze front. While in general this is the case, identification of the sea breeze by these criteria is apparently not nearly so clearcut as one might at first imagine. With regard to temperature variation, Wexler (72, p. 281) notes that for data gathered at Winchester, England, 25 miles inland, one half of the sea breeze fronts observed resulted in no temperature change with passage and the other half produced falls of from 1 to 4 degrees F. Wallington (71) also writes of the slight changes in temperature upon passage of a sea breeze front in southern England. Without commenting on rate of change, Berson (5, p. 5) observed temperature falls at both coastal and inland stations experiencing sea breeze in southern Australia. Pearce's model (52), on the other hand, produces a temperature trace showing a sharp peak of temperature at the time of the frontal passage.

As for moisture variation, Wexler (72, p. 281) contends changes in vapor pressure and specific humidity best identify the sea breeze arrival. He notes as many as one third of his sea breeze days at Winchester had no change in relative humidity with passage and only a few had changes of as much as 25 percent shortly after passage, while nearly all sea breeze days experienced a distinct rise in vapor pressure accompanying passage of the front. Wallington (71) comments on the large changes in relative humidity recorded on the sea breeze days he studied, while Berson (5, p. 14-15) observed that the sea breeze front produced increases in both relative humidity and mixing ratio at coastal stations. At inland stations, on the other hand, Berson noted no change in relative humidity and decreasing mixing ratio with passage. Karapiperis (35) calculated that in the mean there is a rise in vapor pressure with passage of the sea breeze front at Athens, Greece, while Kauper (36, p. 416) gives records showing a sharp, if only temporary, drop in relative humidity with passage in the near-coastal areas of the Los Angeles Basin.

It appears, then, it would be difficult to generalize to all areas the nature of the sequences of temperature and moisture variation accompanying a sea breeze front. It seems, however, that criteria based on moisture change would be more reliable than those based on temperature change in identifying the passage of the front. For this reason, variations of moisture parameters are relied upon later in this thesis as indicators of sea breeze occurrence.

As noted above, Wallington (71) concludes, mostly on the basis of relative humidity records, that a sea breeze front may move inland in a series of pulses. He says also that there may indeed be several fronts leaving the beach in sequence during a day, provided certain conditions are met in which the stage is reset for the onset of a sea breeze after one wave has already moved inland. This occurrence of multiple northward-moving fronts on the south coast of England seems to Wallington particularly likely under a westerly gradient flow.

Fluctuations of temperature and moisture of higher frequencies than the diurnal waves of multiple fronts just described are mentioned by Wexler (72, p. 281), who refers to short period changes of 1-2 degrees C and 3-6 percent often observed within a few hundred meters of the beach as "small outbreaks." They are present but notably fewer during the night, and are apparently not associated with the main sea breeze front itself. Schroeder (55) has described four types of local variation in nocturnal sequences of relative humidity in which the oscillation of the landward edge of the marine air east of San Diego produces complex moisture records at near-coastal stations. Ellis (22, p. 1) and Lindquist (41, p. 6) have described similar sequences of relative humidity in which diurnal rhythm is absent or very weak and in which daily minima occur quite frequently at night in exposed sites in west coast mountains.

While the literature contains numerous observations of the local variations of temperature under sea breeze conditions, few writers have made mention of the heating rates in marine air moving over land, the total derivative of temperature with time. Wexler's calculations (72, p. 280) show parcels of ocean air at the surface being heated at the rate of about 1 degree C per minute during their first two minutes over land and 10 degrees C per hour thereafter until their temperature equals that of the land. Malkus et al (46) have computed comparable heating rates of between 8 and 15 degrees F per hour on Cape Cod.

Local wind behavior. In what follows the term "hodograph" will be used to refer to the locus of one end of a variable vector whose other end is fixed and which represents the wind velocity at various times at one altitude and one place, rather than to the more customary hodograph representing wind at several altitudes at one time and one place.

In a model ignoring acceleration and inertial terms, Haurwitz (28) computed the hodograph would be a single straight line. The dynamic theory accompanying this model included accelerations and produced an elliptical hodograph quite like those reported previous to Haurwitz's writing (e.g. 17, p. 656). Haurwitz concluded also that the greater the surface friction beneath the sea breeze system the greater would be the eccentricity of the hodograph. If one accepts Defant's conclusion (17, p. 662) that depth of circulation and friction are proportional, a deeper circulation should have, therefore, a more eccentric hodograph. The opposite conclusion is reached by Stern (61) whose model produces an elliptical hodograph but with greater eccentricity in the shallower circulation. With the production of elliptical hodographs in the models of Pierson (53, p. 23) and Fisher (24, p. 233) there can be little doubt of the generality of this feature of the sea breeze system, and therefore of Jeffrey's error in considering the sea breeze antitriptic (34, p.38).

An examination of local wind behavior over an entire region influenced largely by sea breeze has been presented by Staley (59, 60). This study brings to light several major geographical influences on the nature of the hodograph in coastal areas, notably some effects of embayments and of coastal topography. Results of the superposition of a wind system generated by bays and harbors on the regional wind system has been mentioned by Staley for the Puget Sound area and examined in some detail for Halifax, Nova Scotia, by Dexter (18), who called the local system the "harbor effect". Another type of component introduced by local geography is the force resulting from the "piling up" of air against a topographic barrier parallel to the flow by coriolis deflection. This effect was first noted by Gleeson (26), whose model of it was modified by Staley (59, 60). The comments of Wexler (72, p. 276) and of Humphreys (33, p. 157) with regard to coastal terrain parallel to the shore have been noted above and are elaborated further for the effects of the Cascades mountains on winds in the Puget Sound area by Staley.

Within the sea breeze flow local wind observations exhibit only very small direction oscillations according to Wexler (72, p. 278). Indeed, he says this is one of the identifying characteristics of the sea breeze and helps determine from autographic records its time of arrival. This same constancy of direction is implied for oscillations of periods of the order of 30 minutes in the results of Lowry (43) and of Staley (59, p. 460-465) who note the highest daytime persistence in direction of hourly observations in the period when the sea breeze arrives at a station. Shorter period oscillations appear prominently in the autographic records exhibited by Defant (17, p. 656), by Wallington (71), and by Pearce (52), but resemble strongly the regular type associated with purely mechanical turbulence at the surface (56).

As for the local behavior of the nocturnal land breeze at the surface, the comments of Wexler (72, p. 278) together with those of Defant cited above indicate a period of distinct calm relative to the daytime pattern. Wexler says "on land the land breeze is hardly discernible and is characterized by a few long wind thrusts interrupting at intervals the nightly calm. Over the sea the land breeze is steadier in velocity."

Clouds associated with the sea breeze. Most mention of clouds associated with the sea breeze has been in connection with the stratus found over western littorals of North and South America (3, 32, 49, 59). Cold offshore waters and the region-wide subsidence inversions of summer in these locales doubtless promote the dominance of stratus and make it anomalous relative to most other coastal regions of the world. Neiburger concluded after exhaustive calculations that the physically most reasonable of the alternative explanations for landward growth of the leading edge of the stratus deck over Los Angeles was the adiabatic cooling associated with the upward motion in the zone of convergence moving inland ahead of the marine air. Staley reached the same conclusion and says in addition that vertical motion in the form of subsidence plays the major role in dissipation of the stratus deck in the Puget Sound area, in partial contradiction of the idea of stratus "burning off" through surface heating in such localities. Staley concluded also that the dominant role of vertical motion in the sea breeze stratus is restricted to west coastal regions with mountains parallel to the shoreline.

As for the effect of a stratus deck on the behavior of the sea breeze circulation, Staley (59, p. 468) is of the opinion that the inland edge of the deck acts as a coastline with respect to differential heating at sunrise. As noted above, such effects have not been taken into account in theoretical work on the sea breeze to date. As to another effect of clouds on the circulation, Wexler (72, p. 277) asserts that nocturnal clouds, by retarding cooling of the ground, promote persistence of the sea breeze through the night, resulting in a gradual cessation of flow everywhere in the coastal and near-coastal areas at about the same time.

The formation of cumulus clouds in a sea breeze circulation was noted by Wallington (71) in southern England under conditions in which the sea breeze was at right angles and to the left of the gradient flow. He noted also vertical veils of cloud in conjunction with a narrow zone of sharp gradient of horizontal visibility at the leading edge of the marine air. Similar clouds formed when the sea breeze on the north shore of Cape Cod opposed the southerly gradient wind were described by Malkus et al (46), but direct connection of such clouds with the vertical sheaths of moisture described by Atlas (1) and mentioned above is probably unlikely.

In a revealing passage on cumulus associated with the sea breeze Wexler (72, p. 286) says "the later the time of day the further removed from the sea is the line of cumulus. The presence of the clouds often helps to identify the location of the sea breeze and is evidence of the vigorous ascent of air in advance of the sea breeze. Sea breezes have been known to aid the development of thunderstorms over the land when the land air is conditionally unstable."

Pressure variations associated with the sea breeze. Very little has been written about pressure behavior in conjunction with the sea breeze circulation. Wexler (72, p. 275) has described the occurrence of pressure jumps associated with the passage of the sea breeze front, but the theoretical model of Pearce (52) yields no such feature. Instead it produces a pressure pattern in which surface pressures rise along the coast and fall inland shortly after sunrise. Thereafter a zone of pressure rise moves slowly inland during the day, leaving slight pressure falls behind it but pressure levels higher everywhere over the area by afternoon than they had been at sunrise.

Pressure oscillations associated with a sea breeze system were observed at Guantanamo Bay by Donn et al (19). During the period immediately preceding arrival of the sea breeze front they recorded pressure oscillations of about a five minute period, followed by oscillations of about a thirty minute period after the time of the frontal passage. These pressure oscillations were accompanied, both ahead of and behind the front, by oscillations in wind speed of the same periods during which time no changes in wind direction were recorded. It was concluded these post-frontal oscillations were due to internal waves on the inversion surface atop the layer of marine air.

Kimble (37, p. 112) exhibits data on the diurnal variations of surface pressure at Batavia and at an offshore station nearby. These variations contain a definite period of about 12 hours, while the pressure difference between the stations has a period of 24 hours.

In the pressure data from the north German coast presented by Defant (17, p. 657) both the station pressures and the pressure difference between the land station and the offshore station show 24 hour periods.

LITERATURE REVIEW: FORESTRY OPERATIONS

Typical of published statements recognizing the importance of coastal climates in determining the components and structure of vegetation in such areas is that by Oosting (50, p. 87-88) in which he mentions especially the effects of fog and low stratus in their control over light, temperature, and moisture in the microclimate. Calculations by Lowry (42) of the several components of the heat budget in microenvironments subject to sea breeze advection indicate strongly the role of the sea breeze in maintaining relatively low sub-surface soil temperatures in the Coast Range mountains. Heat energy which is available to the microenvironment and which would otherwise be used to heat the soil and promote transpiration is utilized in warming marine air passing over the area. Daubenmire (15, p. 292) emphasizes the importance of wind in determining coastal vegetation, but in the role of salt carrier rather than as a heat absorbing medium.

The results of Ruth and Yoder (54, p. 5) show that blowdown in the Oregon Coast Range resulting from winds in the northwest quadrant is only about 5 percent of that from winds in the southwest quadrant. Compared to the southwesterly storm winds of winter, then, the northwesterly sea breeze is practically negligible as a blowdown agent, though its effectiveness in this role could doubtless be increased by improper cutting practices in areas of high water table.

Judging by the relative abundance of literature on the subject, the sea breeze has its most important effects on forestry operations in the area of fire weather. Hayes (30) alerted foresters years ago to the vagaries of the sea breeze and its implications for firefighting in coastal regions. After summarizing a description of the sea breeze by Wexler, Hayes pointed out its behavior was most troublesome in 1) producing sudden wind shifts, 2) producing excessive turbulence and higher wind speeds, and 3) promoting upwind spotting of fires by lifting firebrands into an upper counter-current. Colson (10) pointed out an additional element of surprise in firefighting which could well be associated with the sea breeze: that of rapid changes in a fire's behavior when its convective column penetrates a temperature inversion some distance above the surface.

Though they did not mention the sea breeze specifically, Countryman and Schroeder (12, p. 14 and 13, p. 10) described the adverse effects on controlled slash burning of frequent down-slope afternoon winds on lee slopes of the California Coast Range. Of particular interest in view of the discussion above is their observation that these winds are not accompanied by any major changes in either temperature or humidity.

Krumm (39, p. 153) mentions three special weather conditions causing downslope fire spread: 1) dry cold fronts, 2) large scale subsidence, and 3) thunderstorm downdrafts. While he does not mention the sea breeze nor even local winds as a group, his category of dry cold fronts might conceivably include the coastal winds being considered here.

The effects of the sea breeze on visibility in coastal areas have major implications in forest protection. Improved road nets in western coastal mountains have in recent years lessened the danger that hampering of aerial resupply operations by fog and low stratus as described in an earlier era by Colvill (11) and by Miller (47) would result in increased losses due to forest fires. Even today, however, detection of fires in their early stages by lookouts is undoubtedly impaired by low clouds associated with the sea breeze. With the recent increase in use of aerially delivered chemical fire suppressants, interference of sea breeze clouds with aircraft operations may again become critical.

Recently the effects of marine and continental factors on local weather were designated as the highest priority research problems in the National Plan for Fire Weather Service (48). This may be taken as a strong indication of the importance of the sea breeze in fire weather forecasting.

While the adverse effects of the sea breeze on fire fighting have been stressed up to this point, the even greater losses possible in its absence and the general relief brought by the arrival of marine air after a period of critical fire weather conditions in the Oregon Coast Range may be felt in the following description (73, p. 7) of the end of the famous Tillamook fire of 1933:

> "Cool, damp fog billowed in from the Pacific replacing the hot east wind. The high flames stopped, and the slower moving ground blazes were brought under control."

INSTRUMENTATION AND SPECIAL DATA COLLECTION

The Valsetz Basin. In the summer of 1956 special observations of the physical microclimate of ten locations were made in the Valsetz Basin, Polk County, Oregon. Descriptions of the sites where stations were installed, the instrumentation employed, and principal results of the study are presented in detail in a reference previously cited (42). Briefly, there were twin networks of five stations each. Each network included a station in the open at a high, a medium, and a low elevation together with low elevation and high elevation stations located in the timber. At these stations various combinations of measurements were made of air temperature and relative humidity, soil temperature and moisture content, net flux of radiation at the earth's surface, wind speed and direction, precipitation, and fuel moisture. Of particular interest here are the continuous records of temperature and relative humidity made during July and August of 1956 at the six stations located in the open. These data may be considered typical of summer conditions at locations in the dissected ridge and valley areas of the central Oregon Coast Range with elevations between 1000 and 3000 feet above sea level.

The Eddyville and Grand Ronde Gaps. During the months of May through August, 1957, a series of special observations was made in and above two major low elevation passes in the central Coast Range: between Corvallis and Newport (the Marys and Yaquina valleys) and between Perrydale and Oceanlake (the Yamhill and Salmon valleys). Locations and terrain in this roughly square area may be seen in

Figure 1.

Data were gathered in three groups during the field project:

1) at each of six ground stations located on prominent local terrain features the following data were recorded continuously and automatically at a position five feet above the ground (Figure 2):

a) air temperature   c) time of strong and gusty winds
b) relative humidity   d) incoming radiation

2) on top of two automobiles were mounted aerometeorographs of a standard U.S. Navy design intended for use with aircraft (Figure 3). These instruments automatically recorded temperature, relative humidity, and altitude as the automobiles were driven over roads extending generally east and west through the gaps in the mountains.

3) under the wing of an aircraft of the Corvallis Squadron, Civil Air Patrol, was mounted an aerometeorograph of the same design as those atop the automobiles, (Figure 4). Temperature, relative humidity, and altitude were recorded automatically while the aircraft was in flight.

The ground stations were divided into two groups of three, each group being located in an east-west line through the center of one of the two mountain gaps. Each group consisted of a station in the western edge of the interior Willamette Valley, one station on a bluff approximately 5 km from the ocean, and one station about half way distant between the other two.

On Tuesday of each week one automobile, with recorder in operation, was driven through each gap, the driver stopping at each ground station to change its recorder charts and make necessary instrument

FIGURE 1 Location map.

FIGURE 2

The special ground station operated between Oceanlake and Otis Junction, showing "Black Box" radiometer and bridled anemometer atop an instrument shelter containing a recording hygrothermograph. Cascade Head is in the background.

FIGURE 3

Aerometeorograph mounted atop an automobile in a sandwich made of plywood and foam rubber and attached to an ordinary cartop luggage carrier.

FIGURE 4

Aerometeorograph mounted under the wing of a light aircraft in an L-shaped bed of aluminum and held in position by airplane shock cords.

adjustments. Thus on Tuesdays two records were gathered of the temperature and relative humidity at ground level through each gap -- one in midmorning and one in midafternoon.

On Wednesdays the automobiles and their recorders were operated along the same center-line routes with doubled frequency -- one round trip in the morning and one in the afternoon. In addition, the aircraft was flown during the approximate hours 1100 to 1500 PST over a predetermined course above the automobile routes through the gaps. These aircraft records gave information on the structure of the atmosphere between 2500 and 5000 feet above sea level over the area. In cases with low clouds, no data were obtained above the cloud bases.

Combined with current U.S. Weather Bureau airways sequence reports, data from the radiosonde flights at Salem, and notes made enroute by automobile drivers and aircraft crew members, the information from the three groups of recorder charts provided a basis for reconstructing a three-dimensional picture of the local atmosphere at about midday on 15 days during the summer of 1957.

Information on the design and operation of the wind gust and radiation recorders will be found in Appendix A.

RESULTS

A derived climatology of the sea breeze. In order to write a climatology of the occurrence of a complex meteorological event for which there is no explicit definition in terms of the published climatological data, it is necessary first to arrive at such a definition.

The scheme chosen for this study began with the selection from the intensive records gathered in 1957 those days which exhibited certain definitive features characteristic of the sea breeze. Comparison of various combinations of the standard published climatological data of the U.S. Weather Bureau with the list of sea breeze days chosen in the first step yielded one combination which best separated those days with a sea breeze from those days without one. The third and final step was the application of the definitive combination of climatological data to the climatological records of the years of record other than 1957. An objective statement of which days during the period of record had experienced a sea breeze resulted, and compilation of a derived climatology became possible.

The definitive features characterizing a day with sea breeze based on the chart records gathered in 1957 were chosen as follows: The records from both the Corvallis ground station and the Sheridan ground station must have shown 1) an uninterrupted fall in relative humidity to a distinct minimum near midday, 2) a rapid and sustained rise in relative humidity following the minimum, and 3) a registration of heightened wind activity on the gustiness record beginning at or just after the time of the relative humidity minimum and continuing generally into the early evening hours, with no wind activity registered before the time of the relative humidity minimum. This definition, it may be imagined, is only semi-objective in nature, but the relative frequency of days on which it could not be applied with confidence was low. As regards relative humidity minima near midday, two rather distinct types were noted in the record: 1) days on which there was a sharp V-shaped minimum in the hydrograph trace and 2) days on which the minimum was U-shaped. Typical examples of these traces appear in Figure 5, and they will be discussed later together with the third type having a W-shaped trace. This last type was not observed at either Corvallis or Sheridan, so it did not enter into application of the definition of a sea breeze day. Table 2 gives the days in July and August 1957 which met the criteria just presented and were considered to be days with a complete sea breeze. These 28 days are further divided into "U" type and "V" type on the basis of their midday relative humidity traces at the Sheridan and the Corvallis special ground stations. It will be noted that in the definition the features of the sea breeze were to have been noted in the Willamette Valley. Thus a circulation reaching only part-way into the interior valleys of northwest Oregon would not qualify as a sea breeze, and in this sense the cases selected consist of the days exhibiting a complete inland flow not restricted to the near-coastal areas.

Figure 6 shows the comparison of the combination of climatological data chosen for further application and the occurrence of the

TABLE 2

DAYS DURING JULY AND AUGUST 1957 WITH COMPLETE SEA BREEZE

July					August				
Date	SHERIDAN		CORVALLIS		Date	SHERIDAN		CORVALLIS	
	U	V	U	V		U	V	U	V
5 Jul	x			x	14 Aug*		x		x
8	x			x	15*		x		x
10	x		x		16*	x		x	
19	x		x		18*	x		x	
20	x		x		19*		x		x
21	x		x		20*		x		x
22	x			x	22		x		x
23	x			x	23		x		x
24		x		x	25		x	x	
25	x		x		26		x		x
26	x		x		27	x		x	
28		x		x	28*		x		x
29		x	x		29*	x		x	
31*	x		x		30*	x		x	

* Days forming 2 samples of 5 days each: 5 of type U and 5 of V. Only these days have nearly complete data for all special observations.

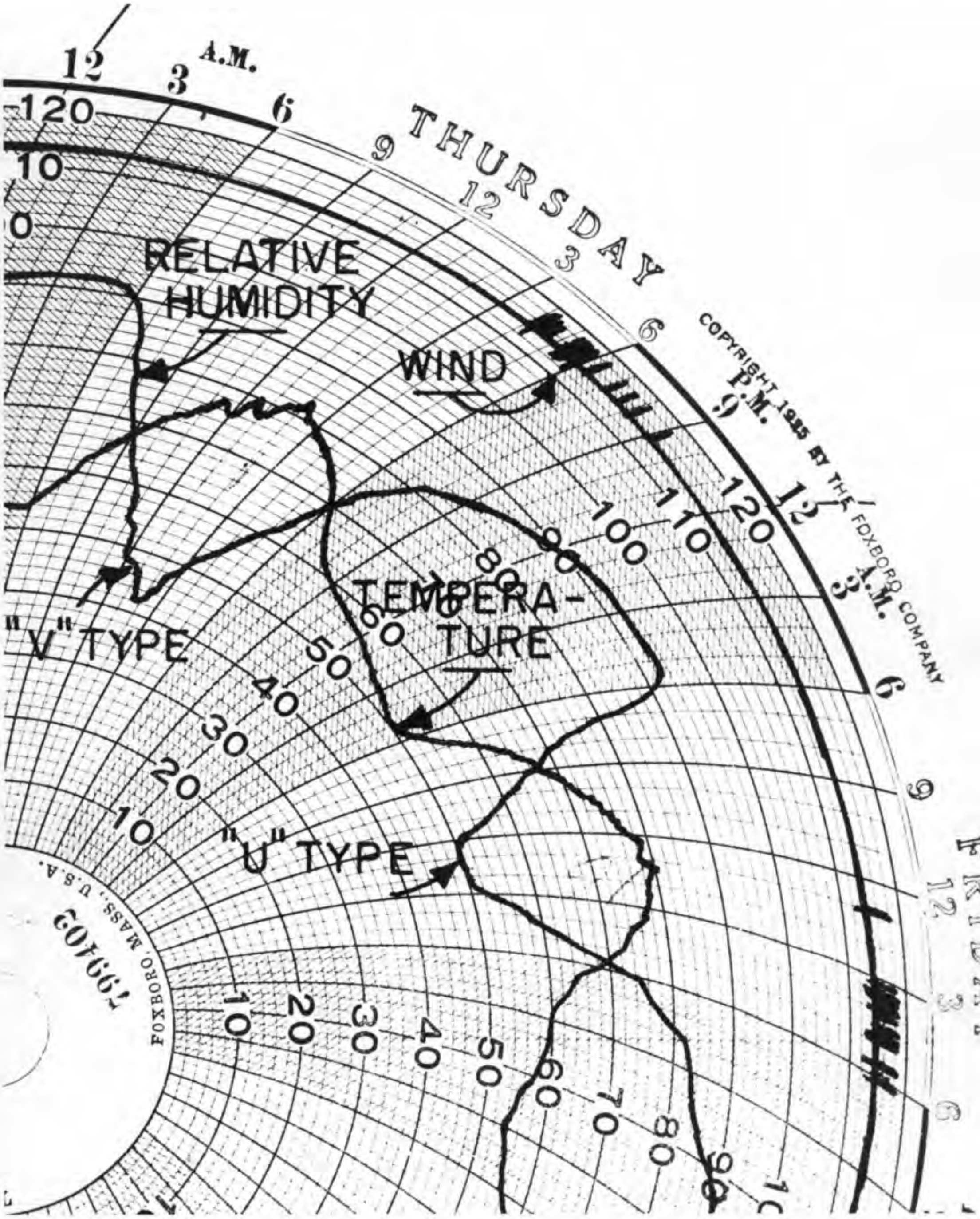


FIGURE 5

Portion of weekly hygrothermograph chart showing recordings of temperature, relative humidity, and times of strong wind gusts.

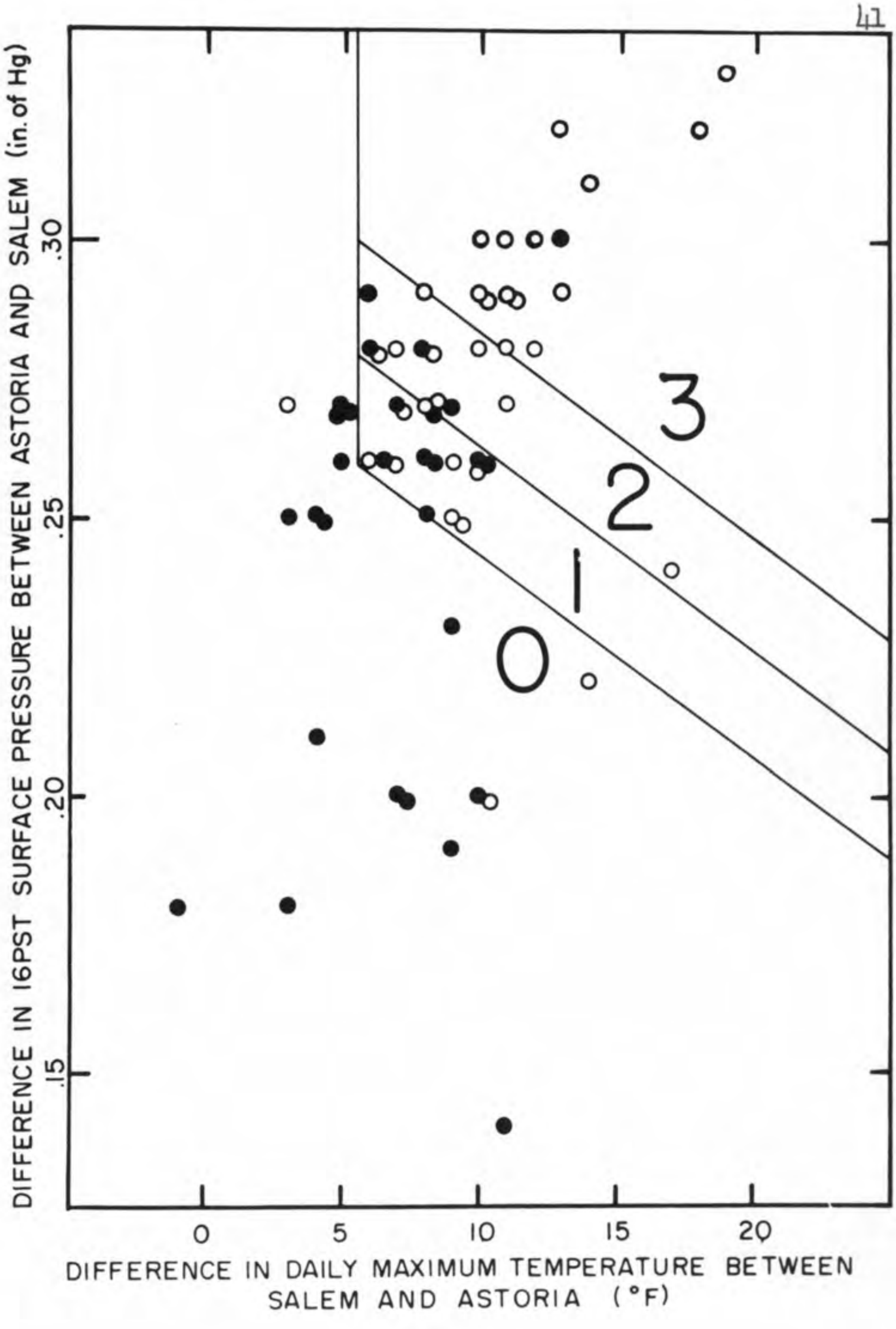


FIGURE 6

Objective method for estimating likelihood of a sea breeze from current data.

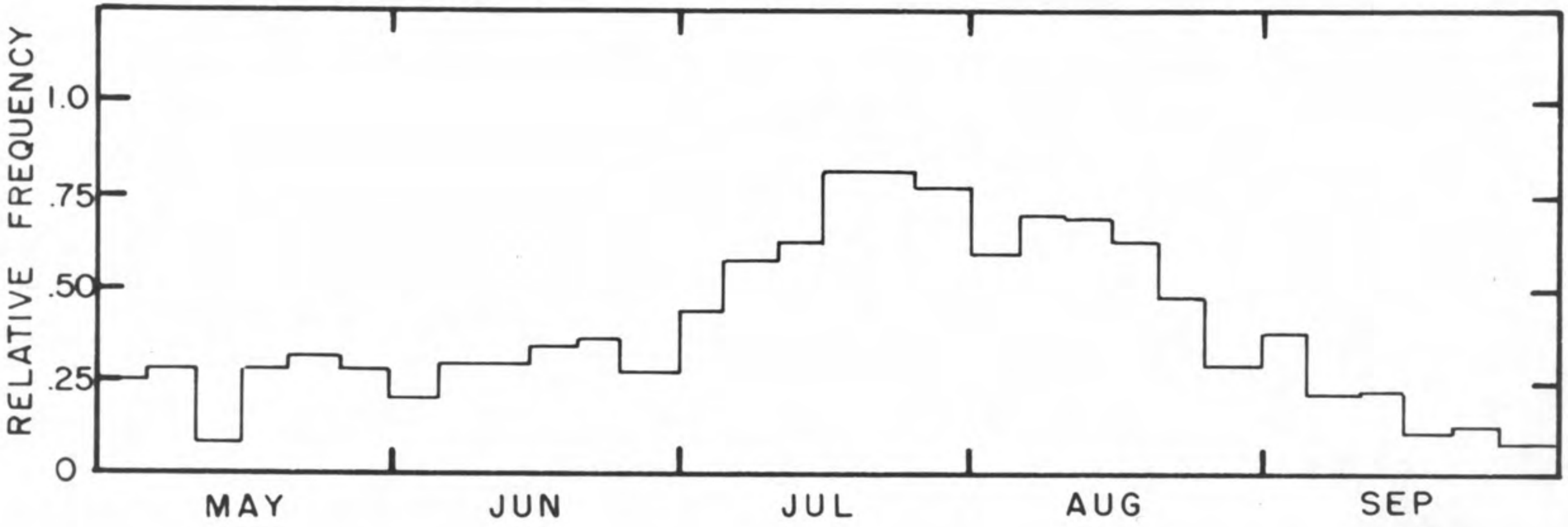
complete sea breeze. The large numerals 0, 1, 2, and 3 indicate the four areas of the chart and are roughly comparable at any point to the empirical probability of a sea breeze having occurred. Thus a point in area 3 would have probability 3/3 of a sea breeze, a point in area 1 a probability of 1/3, and so on.

The combination of both a pressure difference (67, 68) and a temperature difference (65) between coast and inland valley in the definitive combination of climatological data chosen tends to rule out cases 1) in which there is a large temperature difference between the valley and a fog-shrouded coast but no pressure gradient force to move the marine air inland, and 2) where a migrating storm system produces a definite pressure gradient force but no temperature differential for generation of other than synoptic scale wind flow. Experience in observing the area studied has shown that on many occasions the sea breeze is restricted for one reason or another to the one or two kilometers nearest the beach. On days when the circulation does indeed move inland from the beach it tends to become a complete flow inland, so that the selection of Otis, located in a sheltered cove some 5 km from the beach, as the representative coastal station tends to eliminate from the consideration those days when the cool air is limited to the beach itself.

The designation as part of area 0 for the entire portion of the chart representing a temperature difference less than 6F has a physical basis in Haurwitz' notion of a minimum temperature differential between land and sea for generation of the sea breeze. Because the observed relative frequency of sea breeze occurrence diminishes nearly to zero in the neighborhood of a 6F temperature difference, it may be said that for the geographical area sampled the minimum temperature difference necessary to generate a sea breeze, in the sense postulated by Haurwitz, is about 5.5F or 3C.

As outlined above, each day of record of the months May through September of the years 1953 through 1960 was examined (65, 67, 68) with the aid of Figure 6 and classified according to one of the four numerals on the chart. From this listing Figure 7 was constructed to represent the probability of occurrence of a complete sea breeze at any time during the summer months in northwest Oregon. The data are grouped by 5-day periods to smooth out day-to-day fluctuations. It is clear from the record that heightened sea breeze activity begins in early July and continues, with a slight decrease in early August, until the end of August. May, June and September exhibit a small but non-negligible probability of about 20 percent.

As with meteorological events in general and with events in the Pacific Northwest in summer in particular, the occurrence of complete sea breeze tends to persist from day to day. If days having a classification of 2 or 3 in Figure 6 are said to have had a sea breeze occur and others not to have had one, persistence of the sea breeze may be evaluated and tested for significance. If we let the subscripts "0" represent non-occurrence and "1" occurrence of the sea breeze, then the observed frequency of a day with no sea breeze following a previous day with no sea breeze would be f_{00}, a day with a sea breeze following one without would be f_{01}, etc. Similar designations for the hypothetical frequencies would be h_{00}, h_{01}, h_{10}, and



RELATIVE FREQUENCY OF DAYS WITH A "2" OR "3" RATING
DURING 1953-60
(see Figure 6 for rating scheme)

FIGURE 7

A derived climatology of the sea breeze in northwest Oregon.

h_{11}. The assumption of random sequences of days with and without sea breeze would yield hypothetical frequencies as follows:

$$h_{00} = (n_0/N)^2 \qquad h_{01} = (n_0/N)(n_1/N)$$

$$h_{10} = h_{01} \qquad h_{11} = (n_1/N)^2$$

where N is the total number of days in the sample, n_0 is the total number of days without sea breeze, and n_1 is the total number of days with sea breeze. For the years 1953-1960 the five summer months in northwest Oregon, a Chi-square test of goodness of fit (40, p. 404) yielded the results in Table 3 when the hypothesis of random sequences of sea breeze days was tested. As may be seen the degree of persistence of the sea breeze from day to day apparently increases from May through August. September exhibits apparent randomness, that is to say lack of any persistence.

Computation of the coefficient of persistence of Brooks and Carruthers (9, p. 310) in the form

$$r_B = 1 - \left[\frac{1 - \left(\frac{f_{11}}{f_{10} + f_{11}} \right)}{1 - \left(\frac{n_1}{N} \right)} \right]^2$$

yielded the results in Table 3 from the same data for the eight summers in northwest Oregon. This coefficient has a value of zero for random sequences and 1 for complete persistence day-to-day. The results agree with those of the Chi-square test in showing May and June to have comparable persistence of the sea breeze, July and August to have a comparable higher persistence, and September to have a very low persistence approaching randomness.

Table 4 shows for the same three groupings of the five months the frequencies in eight years of various lengths of runs of consecutive days with sea breeze; that is, days classified 2 or 3.

In summary, then, the sea breeze of intensity great enough to invade the Willamette Valley appears to increase in probability on a given day from about 0.2 in May and June to about 0.7 in July and August with persistence of the occurrence from day to day increasing over the same period. September experiences a drop in daily probability again to about 0.2 accompanied by a lack of any persistence of the sea breeze from day to day.

Intensity of the sea breeze and instability of the atmosphere. The preponderance of results published support the idea that the greater the instability of the lower atmosphere inland, the greater will be the intensity of the sea breeze circulation across the coastline nearby. In northwest Oregon the only source of upper air temperature data available on a routine basis for the summer of 1957 was the Weather Bureau radiosonde flights four times daily at Salem (69). In a test of the hypothesis of positive correlation of sea breeze intensity and instability of the lower atmosphere, four measures of atmospheric instability and four measures of sea breeze intensity were chosen. Instability was represented by temperature differences between the 1000 mb level and both the 950 mb and 850 mb levels at 1000 PST and 1600 PST. Intensity was represented by 1) the wind speed at Astoria at 1600 PST, the approximate time of the climatological wind speed maximum, 2) the maximum wind speed of the day at Astoria, 3) the wind speed at Salem at 1800 PST, the time

TABLE 3

RESULTS OF THE TEST OF HYPOTHESIS OF RANDOM SEQUENCES OF DAYS WITH SEA BREEZE (1953-60)

Month	May	Jun	Jul	Aug	Sep
Chi-square value	31.33	34.01	42.54	58.23	1.60
Significance level*	< 0.5%	< 0.5%	< 0.5%	< 0.5%	> 5.0%
Coefficient of Persistence	0.59	0.62	0.73	0.71	0.05
Conclusion: persistence is	present	present	high	high	absent

* All tests have one degree of freedom

……

TABLE 4

LENGTHS OF RUNS OF CONSECUTIVE DAYS WITH SEA BREEZE (1953-60)

	Number of consecutive days															
	1	2	3	4	5	6	7	8	9	10	11	12	18	20	23	25
May and June	32	15	4	6	3	2			1							
July and August	12	12	9	9	5	1	1	2	1	1	1	1	1	1	1	1
September	25	5	2													

climatological maximum, and 4) the maximum speed of the day at Salem. Data from the 28 days of Table 2 were used in the first portion of the test, and data from the remaining 34 days of July and August, 1957, were used in the second portion.

Table 5 shows the results of these comparisons in the form of coefficients of linear correlation. For the 28 sea breeze days there seems to be in general a moderately strong connection between the wind speed at Astoria and the instability in the lowest 2000 feet or so above Salem. Correlations of wind with instability through the lowest 5000 feet or so over Salem are absent or at best very weak. The intensity of the sea breeze passing over Salem apparently bears no relation to the instability there.

In order for the correlation between wind at Astoria and instability over Salem to be reasonably related in a cause and effect hypothesis, information on the same relationship for non-sea breeze days was considered necessary. In the lower portion of Table 5 the coefficients for wind at Astoria and temperature differences in the bottom 2000 feet over Salem are given. Because of the lack of correlation on sea breeze days for wind and instability at Salem, no correlations were examined for these variables on non-sea breeze days.

The presence of statistically significant coefficients on sea breeze days and their absence or suppression on non-sea breeze days in the correlation of winds at Astoria and instability at Salem offer direct support for the hypothesis that instability of the lower atmosphere inland heightens the intensity of the sea breeze circulation

TABLE 5

COEFFICIENTS OF LINEAR CORRELATION FOR WIND SPEEDS AT ASTORIA AND SALEM VERSUS TEMPERATURE DIFFERENCES BETWEEN 1000 mb AND 950 mb AND BETWEEN 1000 mb AND 850 mb AT SALEM

Temperature Difference at Salem	Wind Speed (mph)			
	Astoria		Salem	
	1600 PST	Daily Maximum	1800 PST	Daily Maximum
TWENTY-EIGHT SEA BREEZE DAYS				
(1000 mb - 950 mb)				
At 1000 PST	0.53**	0.31	-0.01	0.10
At 1600 PST	0.48**	0.49**	-0.004	0.25
(1000 mb - 850 mb)				
At 1000 PST	0.22	0.18	0.09	0.10
At 1600 PST	0.38*	0.30	0.30	0.39*
THIRTY-FOUR NON-SEA BREEZE DAYS				
(1000 mb - 950 mb)				
At 1000 PST	0.24	0.07		
At 1600 PST	0.38*	0.13		

* Statistical significance at the 5% level.

** Statistical significance at the 1% level.

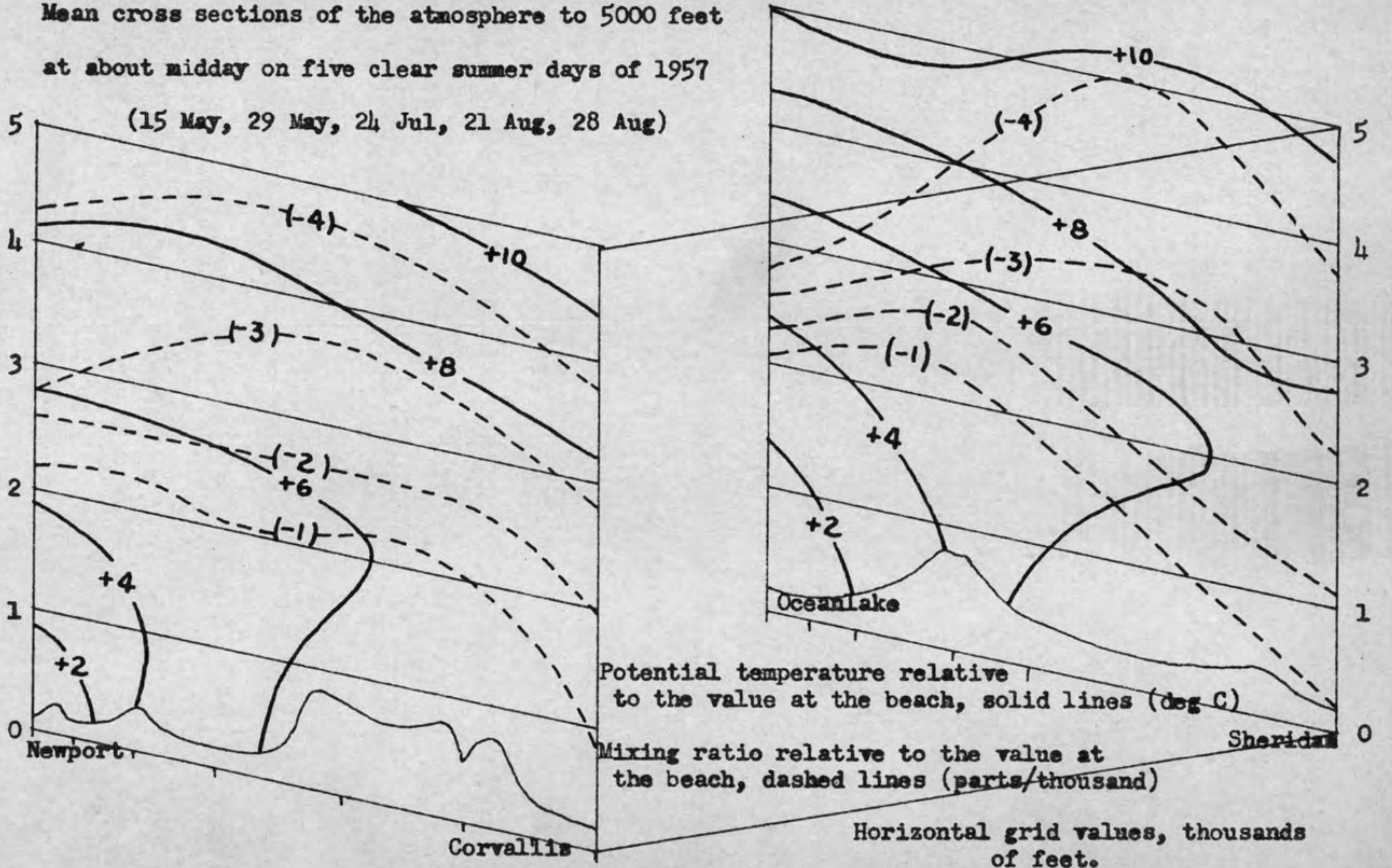
across the coastline nearby. In this case the conclusions must be qualified by saying the "lower atmosphere" is that below the temperature inversion at about 3000 feet over Salem and the intensity of the sea breeze is influenced only on the seaward side of the coastal mountains.

Cross sections through the Coast Range. Figure 8 presents two mean cross sections of potential temperature and mixing ratio through the Coast Range at midday: the one to the left through the gap between Corvallis and Newport, the one to the right through the Sheridan-Oceanlake gap. The viewer is looking northwest through the two transects, each of which is presented as an oblique plane with a 5000 foot depth. At the bottom of each transect appears the cross section of the road bed through the mountains, along which the automobiles were driven during the times of the aircraft flights overhead. The reader will recall, while examining the cross sections, that the major ridge lines of the Coast Range lie generally in the range of 2500 to 3000 feet above sea level.

The isopleths are labelled in values of difference of potential temperature or mixing ratio between the isopleth and the beach in the same cross section. The figure represents average midday conditions for the five clear days of 1957 on which special observational flights were made: 15 May, 29 May, 24 July, 21 August, and 28 August. From the cross sections of these five individual days, which appear in Appendix B along with those of the other observational days of 1957, values of the differences of potential temperature and mixing ratio were extracted at equally spaced mesh points

FIGURE 8

Mean cross sections of the atmosphere to 5000 feet at about midday on five clear summer days of 1957 (15 May, 29 May, 24 Jul, 21 Aug, 28 Aug)



Potential temperature relative to the value at the beach, solid lines (deg C)

Mixing ratio relative to the value at the beach, dashed lines (parts/thousand)

Horizontal grid values, thousands of feet.

on a 6 x 6 grid for each of the two transects. At each mesh point the mean value of the five differences was obtained, and the isopleths through these mean values appear as Figure 8.

In construction of the cross sections for individual days, data on altitude, relative humidity, and temperature from the aerometeorograph charts aboard the aircraft and the automobiles were converted to values of potential temperature and mixing ratio on the assumption the atmosphere was U.S. Standard. Conversions were made at each 1000 foot level during vertical portions of the aircraft's route, over each major check point during level flight, and more frequently where abrupt changes in the conservative variables was observed. Conversions of data from the automobile records and from special ground stations were made on the same assumption of the U.S. Standard Atmosphere and using known altitudes of the check-points. Clearly, the traverse of neither aircraft nor automobile was instantaneous, but allowance was made in the analysis for any temporal changes in the variables disclosed at cross-over points on the aircraft routing. Being the halfway point with respect to time, the hour of passage over the beach on each transect is entered on each individual cross section as "the time of observation."

Interpretation of the mean, midday cross section in Figure 8 reveals certain definite features. At about 2500 to 3000 feet in each transect there is a sharp gradient of moisture, the mixing ratio isopleths paralleling one another in large arcs which slope downward toward the inland valley. Below this level the lapse rate of temperature is dry adiabatic or slightly superadiabatic, as shown by the nearly vertical isentropes. Above the level of the moisture discontinuity the temperature lapse rate is more stable, as shown by the nearly horizontal equally spaced isentropes. The absence of any gradient of mixing ratio in the layer below the discontinuity and the adiabatic conditions there delineate the marine air in its thoroughly mixed condition.

No discussion of the cross sections for individual days will be undertaken, except to note the variety of patterns encountered and the generally well-mixed air layers sampled below cumulus and strato-cumulus clouds. Some markedly unstable temperature lapse rates were encountered just inland from the Coast Range crest on several days, but they were limited in vertical extent and topped by layers of great stability, as might be expected in this region.

As far as the writer knows, the cross sections in Appendix B are unique in the literature. Other published cross sections based on observations are restricted to the areas near and just seaward from the shoreline (5, 14, 21, 23) while published cross sections representing conditions inland are theoretical and not observational (52, 57, 58, 61). In none of these are coastal mountains and mountain passes present.

Haze patterns. As deduced from notes made by air crews during the special flights in the summer of 1957, several distinct patterns of discontinuities in atmospheric haze occurred over the central Oregon Coast Range during the period.

On both 19 June 1957 and 29 August 1957 a vertical discontinuity of haze extending throughout at least the lowest 5000 feet of the atmosphere was observed parallel to and about 60 km inland from the coastline. The visibility was distinctly better on the western, or coastal, side of the surface, similar to the case reported by Wallington (71). On both days the atmosphere was relatively cool and very well mixed throughout the bottom 5000 feet (see cross sections Appendix B), and windflow throughout this depth was gentle from the northwest above Salem. Both days exhibited little tendency to generate a sea breeze, 19 June being classed as "0" and 28 August as "1" on the rating scale of Figure 6. In this last respect, this case was unlike that of Wallington, whose "front" was accompanied by a sea breeze.

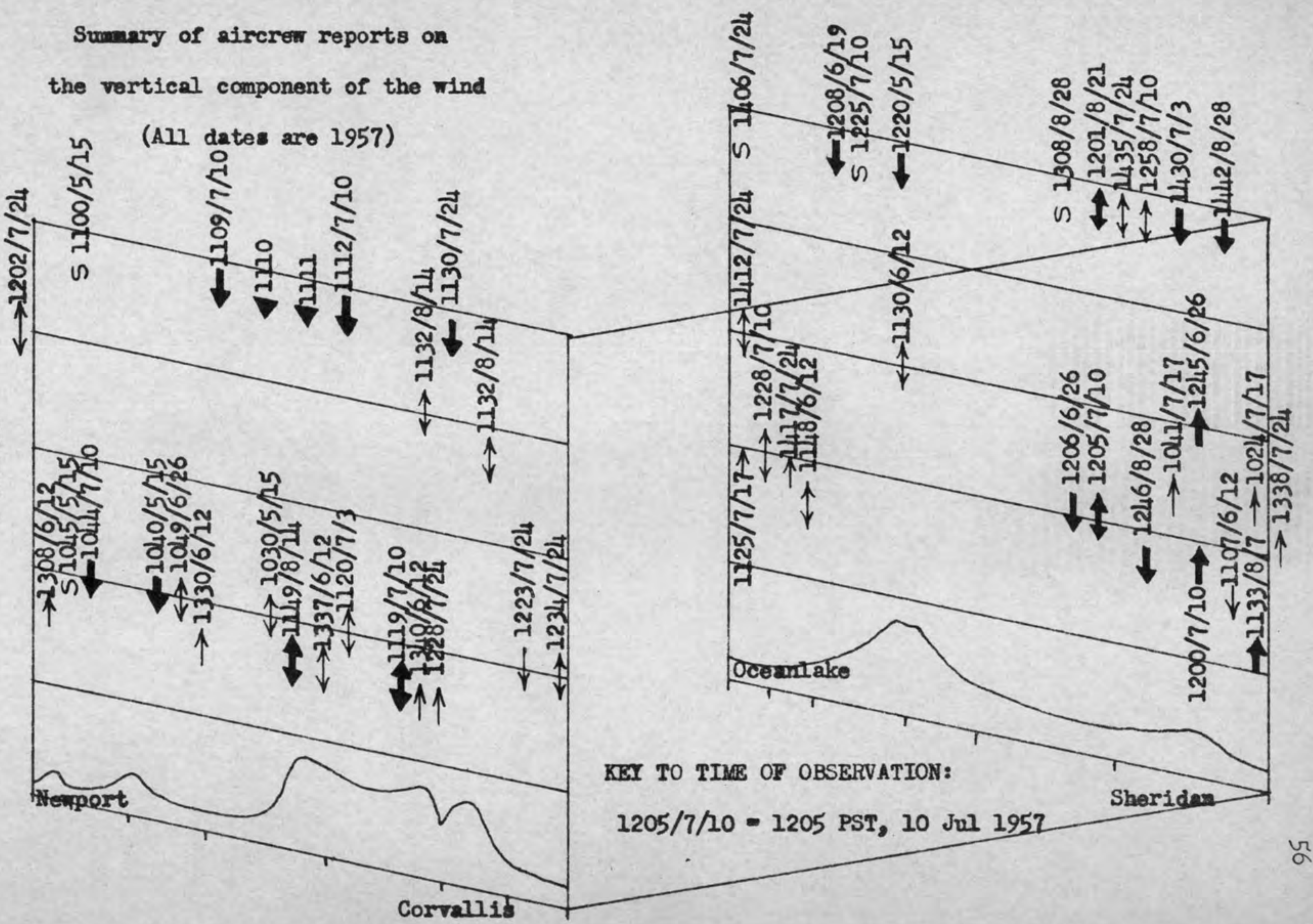
Two midsummer days, 24 July and 21 August 1957, each had two distinct horizontal surfaces of discontinuity in haze, the lower one at about 3000 feet and the upper at about 5500 feet. The haze was observed to be distinctly thicker below each surface, and both surfaces extended from over the beach to beyond 60 km inland. Both of these days exhibited strong temperature stratification in the lower atmosphere and gentle north-northeast winds blowing from the eastern side of a high pressure area over Washington and British Columbia throughout the bottom 5000 feet over Salem. Each of these days occurred near the end of a series of sea breeze days lasting a week or so, 24 July being classed as "3" and 21 August as "2" on the scale described above. In general terms, the sequence of events appears to be similar to that producing the multiple layered haze systems noted by Howell (32).

A third type of haze discontinuity was noted on 10 July 1957.

An apparently single surface with greater visibility above it covered the entire Coast Range area and remained approximately 3000 feet above the terrain everywhere. Thus, it was observed at 3000 feet over the Willamette Valley and over the beaches and rose, conforming to the shape of the topography, to about 5000 feet over the Coast Range ridge lines. Though clear skies remained throughout the day, the synoptic situation for this case showed large scale frontal activity over the Pacific Northwest and, in particular, moderate southerly flow up to at least 5000 feet over Salem during the daylight hours.

Of the eight flying days between 29 May and 21 August 1957 when a haze top was reported by the aircraft observer over Corvallis, in the hours just before noon, it appeared on six days near 3000 feet. The altitudes of the haze top on the other two days were 1900 feet and 5500 feet. On all eight days the visual discontinuities appeared exceptionally abrupt, and during the day usually rose a matter of 1000 feet or so by afternoon and became slightly more diffuse, indicating a period of notable subsidence over the valley in the morning hours.

The field of vertical wind. Figure 9 is a summary of all notes on vertical wind made by the observers on the special aircraft flights over the central Oregon Coast Range in the summer of 1957. It should be emphasized the magnitudes of vertical components of wind speeds encountered are suggested only by the descriptive words used in the observers' notes and are not only irreducible to quantitative form but cannot even be assumed described in the same way by



Summary of aircrew reports on
the vertical component of the wind
(All dates are 1957)

KEY TO TIME OF OBSERVATION:
1205/7/10 = 1205 PST, 10 Jul 1957

FIGURE 9

different observers. Each entry in Figure 9 contains an arrow denoting the direction of the vertical wind encountered, the hour and the date of the encounter. Heavy arrows signify vertical motion which prompted the observer to note it as "heavy", "strong", "extreme" or some similar term indicating greater than ordinary intensity of "bumpiness". Lighter arrows represent notes containing no such reference. Downward pointing arrows correspond to entries indicating downdrafts, upward pointing arrows updrafts, and two-headed arrows signify entries of "turbulence" with no direction indicated.

While details and completeness of coverage varied widely with the various observers, there appear several features of the field of vertical wind component which appear consistently and may be assumed to be real and quasi-permanent patterns:

a) Subsidence, at times strong, appears over the interval from about 10 to 60 km inland at 5000 feet above sea level.

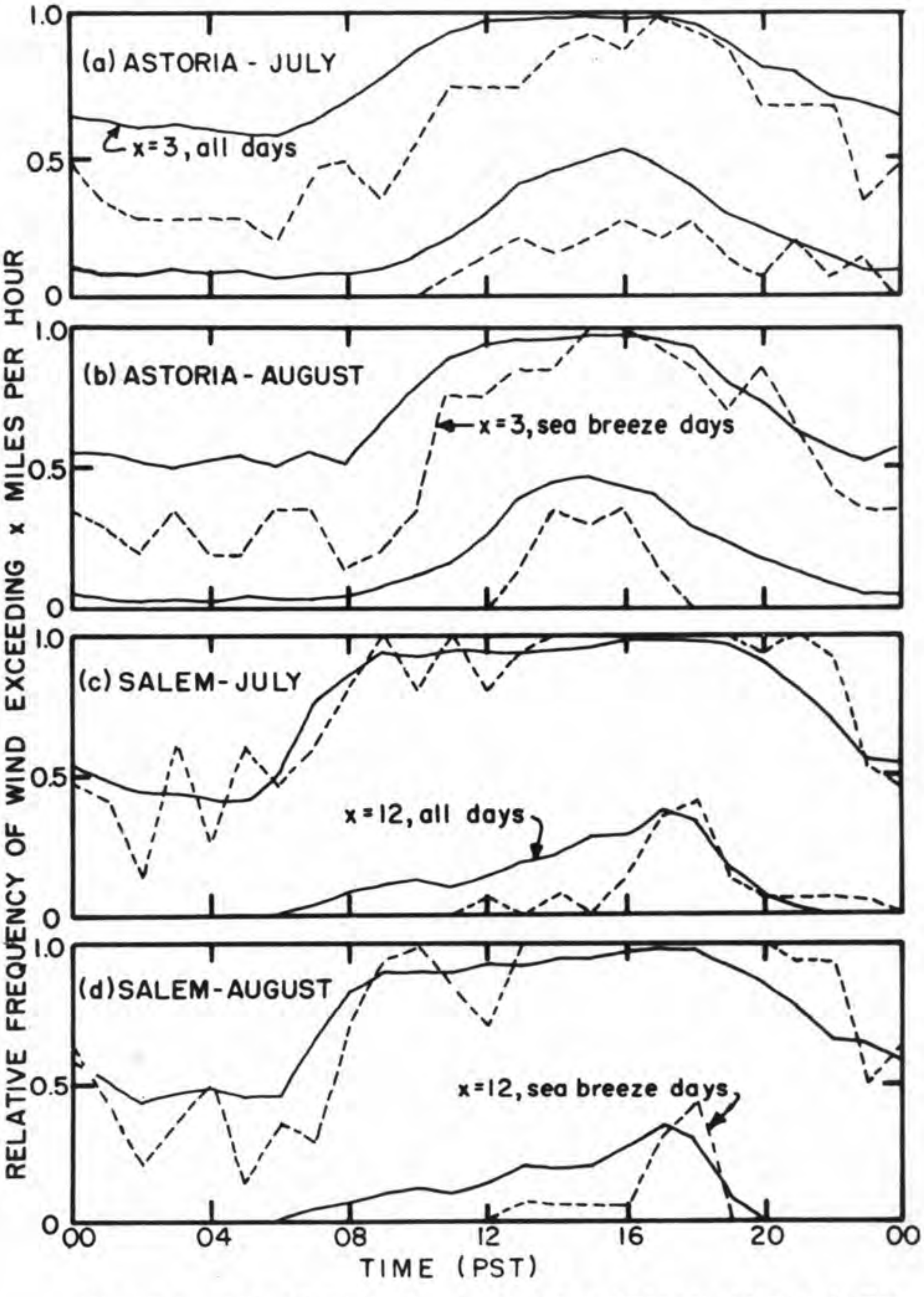
b) Updrafts between 50 and 60 km inland and between 1000 and 3500 feet appear over the Yamhill Valley near Perrydale and Sheridan.

c) Strong turbulence exists about 1500 feet over and just east (downwind) of the principal north-south ridge lines of the Coast Range.

d) A zone of moderate but reliable turbulence with a tendency to downdrafting exists at about 2000 feet just inland from the coastline.

It is worth noting that a combination of features a) and b) would resemble the pattern of vertical winds predicted by Smith and observed by Ayer (2).

Diurnal variation of wind speed at the surface. As noted above, it is generally agreed that coastal areas experiencing marked sea breeze have a definite diurnal maximum of wind speed in the afternoon hours. Figure 10, showing wind speed data from Astoria on the coast and Salem in the Willamette Valley, demonstrates that this afternoon maximum occurs in northwest Oregon. The data presented are representative of general wind speed behavior at the two stations during July and August and of wind speeds on days with sea breeze for the same months. A description of Figure 10a for July at Astoria will suffice for all four parts of the figure. The upper solid line gives the empirical probability through the day that the wind speed will be at least three mph and is based on hourly observations at Clatsop County Airport for the years 1953-60 (67). The lower solid line gives the empirical probability of the wind speed being at least 12 mph and is based on the same records. The upper dotted line gives the probability of the wind speed being at least three mph on a day with complete sea breeze and is based on the records for July 1957. The lower dotted line shows the probability of at least 12 mph for the same days. While use of probability statements here is not exactly equivalent to some sort of average wind speed, the results leave no doubt of the existence of an afternoon wind speed maximum and are much more readily obtained than hourly means from the climatological summary as published. The remaining three parts of Figure 10 present the same information for Astoria in August and for Salem (68) in July



DIURNAL VARIATIONS OF WIND AT ASTORIA AND SALEM DURING JULY AND AUGUST

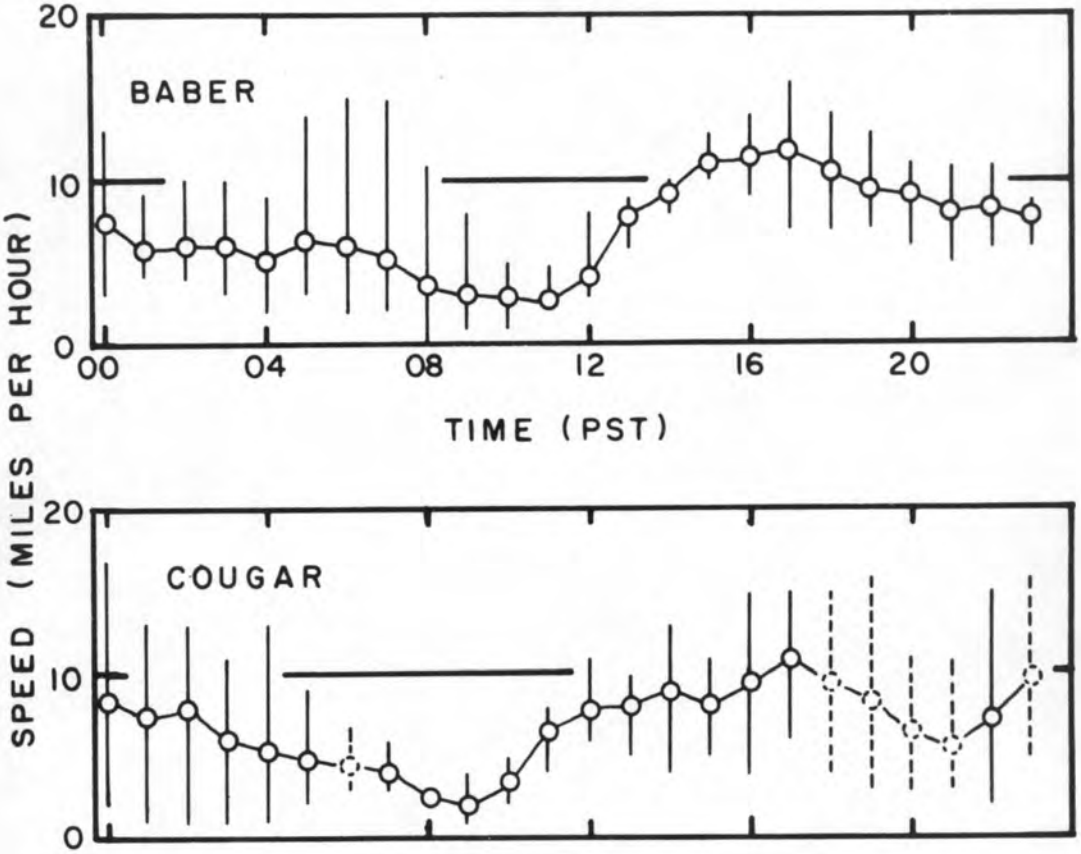
FIGURE 10

and August. Examination of the data show, as might be expected, that days with sea breeze are more likely than days in general to experience light winds in the hours between midnight and sunrise at the coast. In addition, the inland valley, as represented by Salem, is likely to have a more abrupt rise and fall of wind speed during a few afternoon hours on a sea breeze day as compared with days in general.

It was stated previously that according to Wexler the nearer to the beach are coastal mountains, the greater the intensity of the sea breeze experienced, and the farther from the beach they are, the greater the inland penetration of the circulation. These modifications of the basic pattern are theoretically due to the effects of local reinforcement, in the first case, and areal extension, in the second case, by the valley winds blowing up the mountain slopes on the coastal side.

Figure 11 gives wind speed data (64) from two forest fire lookout stations in the central Oregon Coast Range for five consecutive days with sea breeze, 18-22 August 1956. Cougar Mountain Lookout is located about 13 km from the beach (see Figure 1) in an area where the general mountain mass extends to near the coastline. Baber Mountain Lookout, while at nearly the same elevation as Cougar, is about 22 km from the beach and on an isolated hilltop in an area of generally low lying terrain, the broad Yaquina Valley. The two observation points, therefore, represent the two cases mentioned by Wexler.

The intensity of the sea breeze flow appears to be slightly less, if anything, at Cougar than at Baber, in contradiction to



MEAN HOURLY WIND SPEED DURING 18-22 AUGUST 1956 AT BABER MOUNTAIN AND COUGAR MOUNTAIN

(Dash lines are partial samples)

FIGURE 11

Wexler. In the hours just before sunrise Cougar seems to have higher wind speeds in the mean; however, this may be misleading since the variability of wind speeds, as indicated by the vertical bars connecting the maximum and minimum speeds observed in the sample, is distinctly greater at Cougar. In general, then, there seems to be no support in this limited sample for the notion that the intensity of the sea breeze is heightened by near-coastal mountains.

As for the greater inland penetration of the sea breeze in areas where the coastal mountains are farther from the beach, no definitive data are available. Tending to support the idea, however, are the fact that a complete sea breeze was observed during the summer of 1957 slightly more frequently at Corvallis than at Sheridan, and never at Sheridan unless also at Corvallis, according to the three-part criterion outlined on page 37. Also in support of the idea is the fact that forecasters in the region are known to look at the hourly wind reports from the Corvallis Airport for the first signs of a penetration of marine air into the inland valleys at the end of a period of several days when no such penetration occurred.

In summary, the following appear to be reasonable conclusions in light of the evidence gathered in northwest Oregon:

a) Stations in the area experience a definite afternoon maximum in wind speed in the summer months.

b) A coastal station is likely to experience lighter than normal wind speeds between midnight and sunrise on days with a complete sea breeze.

c) An inland station in the area is likely to experience a more than normally abrupt rise and fall of wind speed during the afternoon hours on days with a complete sea breeze.

d) Mountains near the coast do not heighten the intensity of the sea breeze circulation.

e) Mountains slightly inland from the coast do extend the inland penetration of a sea breeze as compared with mountains nearer the coast.

Speed of the sea breeze front. Except as noted, the term "front" will hereafter be used in reference to a mesoscale weather front associated with the sea breeze circulation.

As mentioned previously and shown in Figure 5, a number of sea breeze days during the summer of 1957 exhibited V-shaped patterns in their midday relative humidity trace. As some indication of the objectivity of the assignment of a day to the U- or the V-class, the writer found that reexamination of the traces from two stations on 28 days (Table 2) about one year after the original classification resulted in the conclusion that about 85 percent of the decisions in both the full 28-day sample and the 10-day sub-sample were sufficiently beyond doubt as to be considered objective. Of the three doubtful decisions in the 20 decisions of the sub-sample, two were assigned to the U-type and one to the V-type. Inasmuch as both stations were classified the same on all ten days, and since on all ten days at least one of the two stations had a trace definitely of one type or the other, it is probable the statistics developed in this thesis from the sub-sample represent in an unbiased fashion two distinct types of day.

Assuming the minimum in a V-type trace of relative humidity marked the time of passage of a sea breeze front at the station, the writer tabulated these times at the six special ground stations and at the U.S. Weather Bureau Airport Station in Salem, the latter time based on published hourly data (68). Table 6 shows the results and the calculation of speeds of the front between stations. Discounting for the moment the lowest speed of 9 km/hr between Sheridan and Salem as being typical of the rapid deceleration of fronts between 70 and 100 km inland (see e.g. Wallington, 71), the speeds calculated appear to be distinctly higher than the majority of speeds summarized from the literature in Table 1. True, the speed of 12.6 km/hr between Oceanlake and Grand Ronde is the same as the value given by Koschmieder for a coastal area in high latitudes, but the rest are of the same order of magnitude observed by Berson in "cool changes" over the coast of southern Australia. Berson makes a distinction (5, p. 1-2) between cool changes and sea breeze fronts and concludes that the former are distinctly faster moving. It may be, then, that in sampling here only the "V-days" with abrupt increases in relative humidity the writer may have examined only the Oregon equivalent of cool changes and not sea breeze fronts in general. In would be difficult to assign a time of frontal passage on the sea breeze days with U-shaped humidity traces, and so the objective calculations of frontal speed based on the data of 1957 in northwest Oregon may not safely go beyond the results of Table 6. Consolation for a possible loss of generality here may come, however, in the notion that

TABLE 6

SPEEDS OF FRONTS FOR "V-DAYS" IN NORTHWEST OREGON, 1957

Date	ONP	BRW	CVO	c_1	c_2	OCL	GRR	SHR	SLE	c_3	c_4	c_5
	times of passage			(km/hr)		times of passage				(km/hr)		
				1* to 2	2* to 3*					4* to 5	5* to 6	6* to 7*
8 Jul	0900	1030	1330	23.3	9.3	0730	1230	1430	1730	6.0	10.5	8.7
22	1100	1500	1630	8.8	18.7	0900	1130	1530	1830	12.0	5.3	8.7
23	-	-	1600	-	-	0930	1400	1530	1830	6.7	14.0	8.7
24	0930	1030	1500	35.0	6.2	0900	1300	1500	1730	7.5	10.5	10.4
28	1000	1100	1400	35.0	9.3	1100	1200	1400	1630	30.0	10.5	10.4
14 Aug	0900	1330	1500	7.8	18.7	0900	1200	1400	1730	10.0	10.5	7.4
15	0800	1330	1530	6.4	14.0	0900	1200	1400	1730	10.0	10.5	7.4
19	0900	1330	1600	7.8	11.2	1000	1200	1400	1830	15.0	10.5	5.8
20	0930	1400	1630	7.8	11.2	0830	1430	1500	1730	5.0	42.0	10.4
22	0900	1330	1630	7.8	9.3	0900	1400	1500	1800	6.0	21.0	8.7
23	1000	1200	1330	17.5	18.7	0930	1030	1100	1500	30.0	42.0	6.5
25	0900	1330	1430	7.8	28.0	0930	-	1430	1630	-	-	13.0
26	0900	1300	1530	8.8	18.7	-	1300	1500	1700	-	10.5	13.0
28	1100	-	-	-	-	0900	-	1330	1700	-	-	7.4
mean	0928	1248	1514	14.5	14.5	0911	1235	1354	1644	12.6	14.2	9.0
C.V.**	0.59	0.30	0.15	0.74	0.43	0.65	0.25	0.33	0.30	0.72	0.87	0.24

**C.V. = Coefficient of Variation = Sample standard deviation/mean

*1 - Newport; *2 - Burnt Woods; *3 - Corvallis; *4 - Oceanlake;

*5 - Grand Ronde; *6 - Sheridan; *7 - Salem differences in frequency and aspect of "U-days" and "V-days" may be interpreted as the differences between sea breeze days and "cool changes". Further research into these differences might be very instructive. Meanwhile, in the writer's opinion considerable credence should be placed in the work of Berson because it is so meticulous and because he is the only worker the writer came across who explicitly allows for the possibility of more than one type of sea breeze mechanism.

Further examination of Figure 11 shows there is a distinct rise in wind speed at about 1000 PST at Cougar Mountain Lookout, the same kind of rise appearing two hours later at 1200 PST at Baber Mountain Lookout. The small range of the data during these hours at both stations attests to the stability of this behavior. Assuming a sea breeze front oriented parallel to the coastline, and assuming the rise in wind speed is due to the passage of this front, the mean speed of the front between 13 km inland (Cougar) and 22 km inland (Baber) is 4.5 km/hr. This value is rather low as compared with the values summarized in Table 1 and especially compared with the value of about 14.0 km/hr computed for frontal speeds on V-days in this area.

Taking 14.0 km/hr as a typical value for the speed of the sea breeze front in northwest Oregon, one may compute that the time interval between frontal passage at Cougar and at Baber should be about (9 km)/(14 km/hr), or 0.64 hr instead of the 2 hr observed. This may be interpreted as arrival of the front at Cougar 82 minutes earlier than would be expected or at Baber 82 minutes later than expected. In view of the theoretical effects of near-coastal mountains it seems the former interpretation is the more reasonable and that the terrain near Cougar induces a sea breeze circulation about 1 1/3 hr earlier than would occur if it were not there. This conclusion is supported at least qualitatively by the observation that the mean time of arrival of the sea breeze front at Oceanlake is 17 minutes earlier than at Newport, the range of differences being from 2 hr earlier at Oceanlake (22 July 1957 and 28 August) to 1 hr later (28 July and 19 August).

In summary, the following appear to be valid conclusions with regard to the speed of the sea breeze front in northwest Oregon:

a) Speeds of about 14 km/hr are to be expected on days exhibiting abrupt rise in relative humidity in midday.

b) These speeds probably represent cases of "cool change" rather than sea breeze cases in general.

c) Zones with mountainous terrain near the beach induce a sea breeze circulation whose front-like behavior is experienced earlier than in zones having such terrain farther inland.

Local temperature and moisture variation at the surface. The basis has been mentioned above for distinguishing between sea breeze days of the "U" type and those of the "V" type, and the five days of each type taken to constitute samples have been indicated (Table 2). On the basis of this two-way classification of sea breeze days, Figures 12a through 12d present as sample mean values the diurnal variations of four variables representative of temperature and moisture in the geographical area under study.

The variables are 1) dry bulb temperature as recorded at

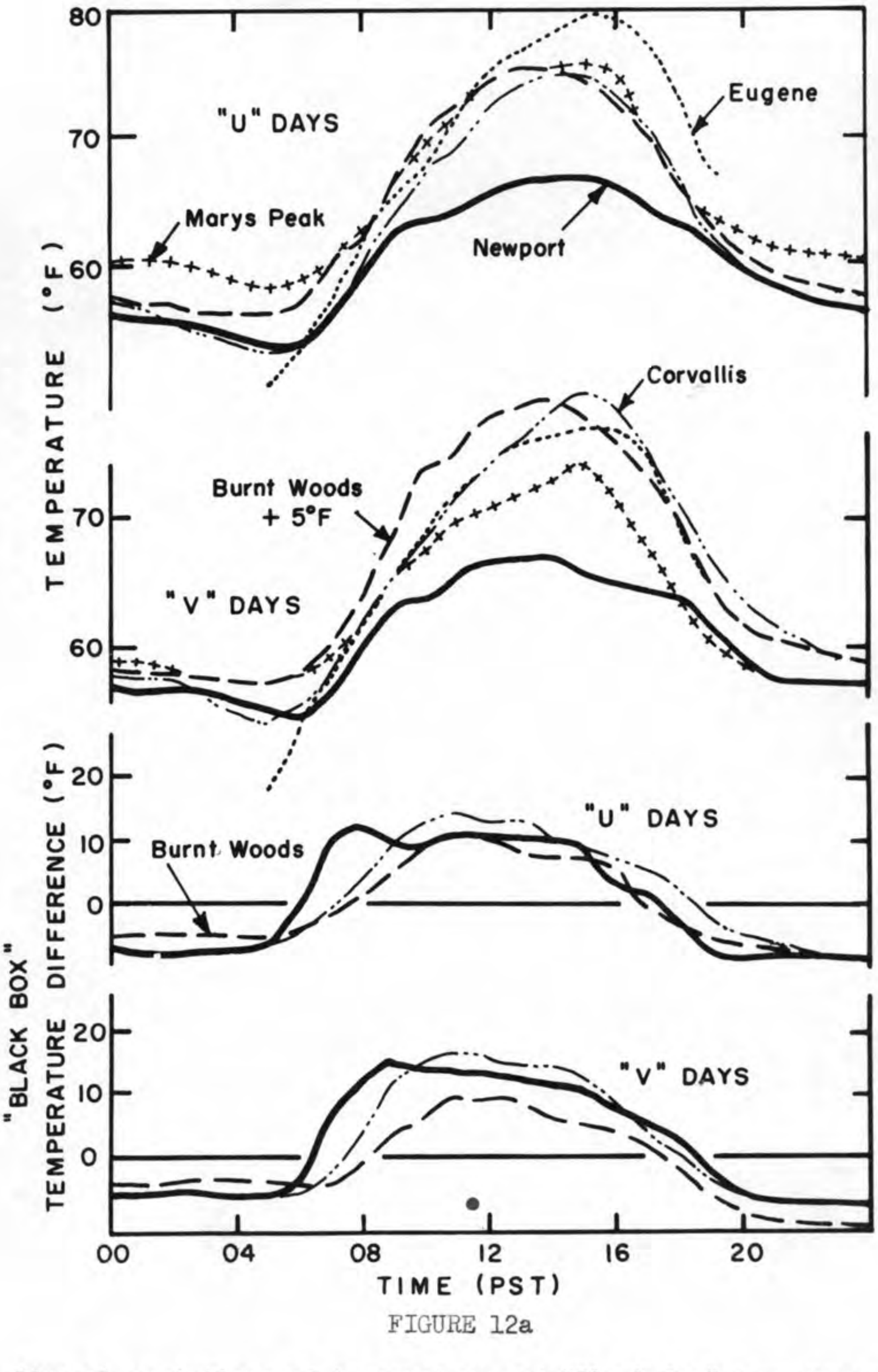


FIGURE 12a

Diurnal variations of temperature and "Black Box" temperature difference, Newport-Corvallis transect.

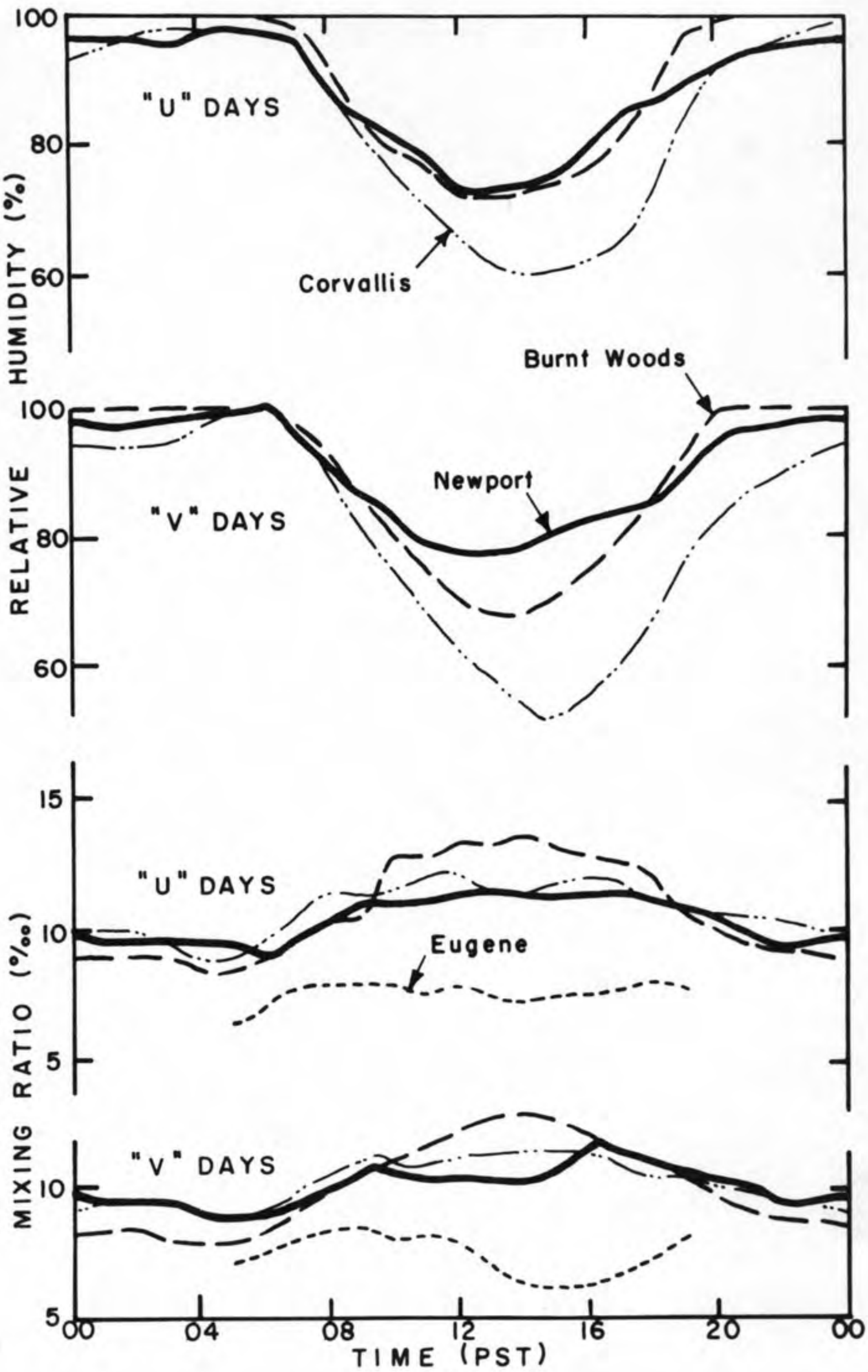


FIGURE 12b

Diurnal variations of relative humidity and mixing ratio

Newport–Corvallis transect.

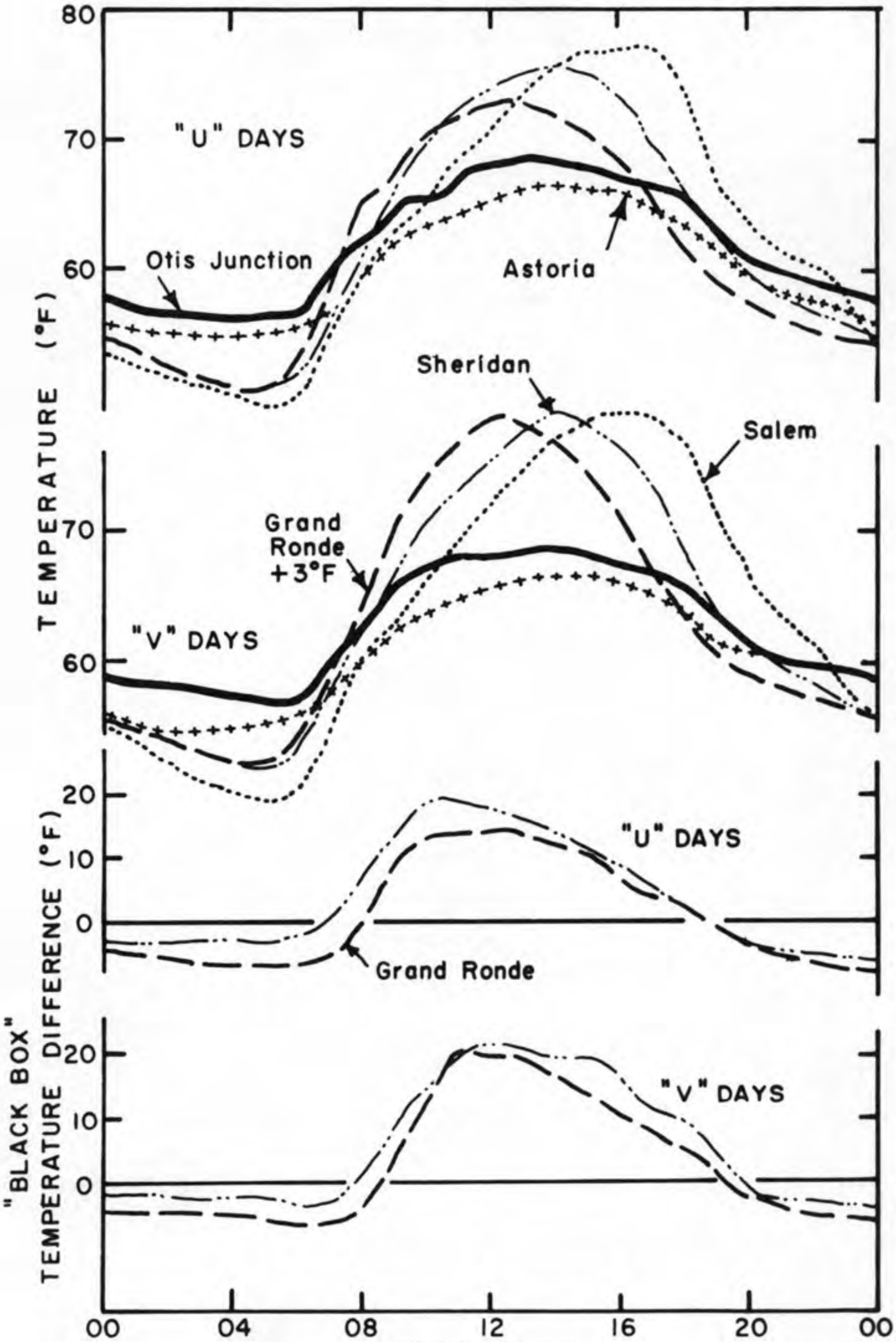


FIGURE 12c

Diurnal variations of temperature and "Black Box" temperature difference, Oceanlake-Salem transect.

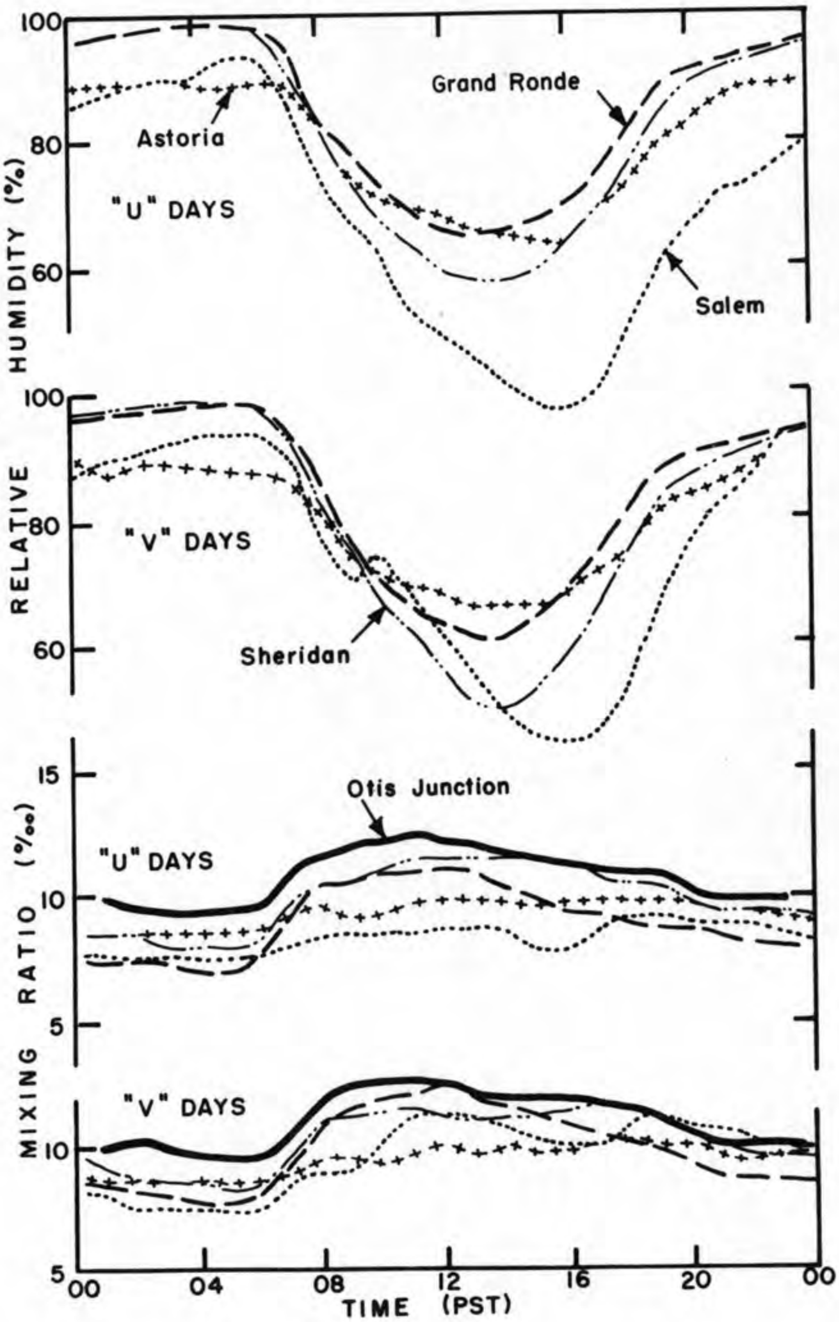


FIGURE 12d

Diurnal variations of relative humidity and mixing ratio

Oceanlake-Salem transect.

standard shelter height (about 1.5 m) above the ground, 2) the temperature difference between the dry bulb in the shelter and the dry bulb temperature in a small black box exposed to the sky on the roof of the shelter, 3) the relative humidity in the shelter, and 4) the mixing ratio in the shelter, computed from the temperature and relative humidity with pressure assumed to be the standard for the altitude of the station.

The sources of raw data for these calculations were 1) the temperature, relative humidity, and "black box" temperatures from the six special stations installed during 1957, 2) the hourly values of temperature and relative humidity published by the Weather Bureau for Salem and Astoria (67, 68), 3) the temperature and dewpoint data from original airways teletype sequences from Eugene, and 4) temperature recordings from a special weather station being operated in a south facing clearing at an altitude of 1800 feet on Marys Peak (31) in conjunction with another project.

In the presentation of mean hourly temperatures in Figures 12a through 12d, 5 degrees have been added to the values for Burnt Woods and 3 to those of Grand Ronde to allow for their altitude and to make the resulting values more nearly comparable on the basis of heat content. The figure for the Marys Peak station would be about 9 degrees, but since little would be gained for comparative purposes in applying the figure except to show that apparently the Marys Peak station lay in an airmass or exposure regime distinctly different from the other, lower elevation stations, the 9 degrees have not been added in these graphs. Assumption of the dry adiabatic lapse rate of 5.5 F per 1000 feet is the basis for the adjustments applied.

The exact physical meaning of the temperature differences between dry bulbs in the shelter and in the exposed black box is not clear. The difference is directly dependent upon net radiation, being positive for a higher black box temperature during the day and negative at night. The difference is made smaller in absolute value both day and night by the effects of clouds and wind. In the sense of the energy budget concept, (42), the temperature difference might be considered proportional to the energy being used in heating the local environment, the advective component being subtracted from the radiation component by the wind action. The "black box" records were originally obtained because the large and abrupt changes in this temperature difference brought about by the onset of cloudiness and/or wind made decisions as to when a sea breeze front arrived much easier and more reliable. By its nature, the temperature difference is roughly conservative with respect to elevation, so the data presented are directly comparable with no modification necessary.

Relative humidity, a non-conservative element, is presented not so much to enable comparison of the distribution of a physical quantity as to illustrate the variations of a descriptive element in widespread use among persons working on fire control problems. The mixing ratio, on the other hand, is a conservative element whose analysis permits comparisons of absolute moisture content between stations.

Figures 12a through 12d present visual units each containing information on one type of day ("U" or "V") and one transect (Corvallis-Newport or Sheridan-Oceanlake). This set of figures permits spatial comparisons of one variable on one type of day along a gradient from the coast inland. Appendix C contains the same data as Figures 12a through 12d, the information being reorganized into two groups permitting two other kinds of comparison. The first group (Figures C-1a through C-1e) presents information on one variable at one station for both types of day. This permits examination of the differences between types of sea breeze day at a single station. The second group (Figures C-2a through C-2e) is organized by type of day and by groups at different distances from the coast: coastal, Coast Range, inland edge of the Coast Range (piedmont), and valley. This group permits comparisons within strips having different intensities and timing of maritime influence. One such comparison might disclose differences due to the fact that the southern transect (Corvallis-Newport) is through a valley which narrows inland while the other transect is through a valley which widens inland.

No detailed analysis or discussion of the data in Figures 12a through 12d and the figures of Appendix C will be given here. Several general features are worth noting, however, at this point. The traces of temperature in Figures 12a and 12c show clearly the effect of marine influences in reducing the range of diurnal temperature variation. In particular the unit showing the northern transect for a "U" day resembles a set of temperature traces from different depths in the soil, the coastal stations being comparable to the deeper strata and the inland stations to those near the surface.

Even allowing for the possibility of slight calibration errors in the hygrograph records from the six special stations, the low values of mixing ratio at the valley stations (Salem and Eugene) relative to the mixing ratios at the piedmont stations is striking, especially during the daylight hours. This suggests strongly that the marine influence reaches to the whole of the Willamette Valley only during the night, there being a distinctly different moisture regime there during the day.

An examination of the differences between types of day at individual stations reveals that in the Coast Range and piedmont areas the "V" type day experiences slightly higher temperatures and distinctly less advective cooling, as indicated by the "black box" temperature difference, around midday. These differences between types of sea breeze day will be discussed at greater length later.

The traces of mixing ratio through the day resemble rather closely in some cases the mean trace presented by Karapiperis (35). The interesting thing here is that apparently the three relative maxima he noted at Athens appear as far inland as Salem on a "V" day. The absence of so clear-cut a pattern at the Coast Range stations is puzzling, as is the large difference between mixing ratio trends at Salem on the two types of day, and the difference in mixing ratio between Salem and Eugene during a "V" day.

The data from which Figures 12a through 12d and the figures of Appendix C were constructed appear in Appendix D.

The diversity of reports on rate of change of temperature and moisture variables following passage of the sea breeze front has been mentioned above. For the six special stations operating during 1957 and for Salem, various values of change following a frontal passage were computed and are presented in Table 7. For each station on each of the 14 days of the "V" type (Table 2) the following changes were tabulated (Appendix E):

a and b) temperature change during the 1 hour and during the 3 hours following the time of minimum relative humidity, considered to be the time of frontal passage,

c and d) relative humidity change during 1 hour and during 3 hours following passage,

e and f) mixing ratio change during 1 hour and during 3 hours following passage, and

g and h) change in "black box" temperature difference during 1 hour and during 3 hours following passage.

Table 7 shows values of the mean, standard deviation, and range of each of these various samples together with the sample size. Sample sizes smaller than 14 resulted from the temporary malfunction of several recording instruments.

In general only small changes in temperature seem to have taken place after frontal passage, especially when account is taken of the time of the day at which the passages occurred at the various points. For example, one may discount part of the mean temperature fall of 4.4F during the first hour after passage at Salem as being due to the customary fall of temperature during the

TABLE 7

ONE- AND THREE-HOURLY CHANGES OF FOUR VARIABLES AT THE SURFACE FOLLOWING SEA BREEZE FRONTAL PASSAGE ON "V" TYPE DAYS

Variable	Station*	Mean	Standard Deviation	Range	Sample Size	Mean time of passage
ΔT_1, change of temperature during 1 hour after passage (deg F)	1	0.1	1.3	5	12	0928
	2	0.4	0.8	2	13	0911
	3	-1.1	1.2	4	10	1248
	4	-2.9	1.4	5	12	1235
	5	-3.0	1.8	7	13	1514
	6	-2.6	1.7	7	14	1354
	7	-4.4	1.9	5	14	1644
ΔT_3, change of temperature during 3 hours after passage (deg F)	1	2.0	1.7	6	12	
	2	1.4	1.9	6	13	
	3	-4.6	3.2	12	10	
	4	-6.8	2.6	10	12	
	5	-11.4	3.4	9	13	
	6	-7.6	3.1	14	14	
	7	-13.9	2.3	9	14	
ΔR_1, change of relative humidity during 1 hour after passage (%)	1	-1.3	2.8	11	12	
	2	-2.4	1.1	3	13	
	3	3.0	1.6	4	10	
	4	2.7	3.7	11	12	
	5	9.0	3.5	13	13	
	6	7.5	4.2	17	14	
	7	12.6	4.5	13	14	
ΔR_3, change of relative humidity during 3 hours after passage (%)	1	-4.3	7.4	21	13	
	2	-5.7	2.8	8	13	
	3	9.2	4.9	14	10	
	4	7.9	5.2	16	12	
	5	20.4	5.2	18	13	
	6	17.3	5.5	17	14	
	7	29.1	5.4	18	14	

* Key to station numbers in Table 7:

1 - Newport

2 - Oceanlake

3 - Burnt Woods

4 - Grand Ronde

5 - Corvallis

6 - Sheridan

7 - Salem

TABLE 7 CONTINUED

Variable	Station	Mean	Standard Deviation	Range	Sample Size	Mean time of passage
Δm_1, change of mixing ratio during 1 hour after passage (o/oo)	1	-0.1	0.6	2	12	0928
	2	-0.1	0.5	2	13	0911
	3	0.1	0.8	2.5	10	1248
	4	-0.6	0.5	2	12	1235
	5	0.8	0.9	3	13	1514
	6	0.5	1.2	4	14	1354
	7	1.4	0.8	2.5	14	1644
Δm_3, change of mixing ratio during 3 hours after passage (o/oo)	1	0.1	0.2	1	12	
	2	-0.5	0.7	2.5	13	
	3	-0.8	1.5	4	10	
	4	-1.2	1.1	3.5	12	
	5	-0.4	1.0	3.5	13	
	6	0.6	1.2	4.5	14	
	7	1.5	1.1	4.5	14	
$\Delta(T_B-T)_1$, change in "Black Box" temperature diff. during 1 hour after passage (deg F)	1	-1.6	3.1	11	10	
	2	-	-	-	-	
	3	-3.0	1.0	3	8	
	4	-4.9	3.4	11	9	
	5	-5.3	4.0	16	13	
	6	-7.2	3.6	14	13	
$\Delta(T_B-T)_3$, change in "Black Box" temperature diff. during 3 hours after passage (deg F)	1	-3.6	4.5	15	10	
	2	-	-	-	-	
	3	-5.7	3.7	13	8	
	4	-11.2	4.2	11	9	
	5	-11.3	6.1	19	13	
	6	-15.3	5.0	18	13	

late afternoon, while at the coastal stations the diurnal temperature rise slightly overcompensates any fall due to the sea breeze in the morning hours.

The sizeable changes in relative humidity at the piedmont and valley stations are doubtless produced in part by the criteria by which the days in the sample were selected: rapid and uninterrupted rises in relative humidity following a midday minimum. The interesting thing here, though, is the variability in the amounts by which the relative humidity changes during the first hour at Corvallis, Sheridan, and Salem as compared with the relatively less variable changes during the three hours following passage.

It is in the changes of the most conservative variable studied, mixing ratio, that one sees the absence of great contrast between the air passing the station at the time of the frontal passage and the air following the front. Also, there seems to be no consistent pattern in the direction (i.e. positive or negative) of change as one goes from coastal to inland stations. This lack of contrast in the conservative mixing ratio seems to the writer strong evidence for the notion that in northwest Oregon sea breeze fronts are not so frequently changes of air mass as they are what Berson calls "non-advective wind surges". As an indication of the relative frequency of these two front-like mechanisms, consider the data from Salem in Appendix E. Of the 14 days in the sample represented in Table 7, only 5 had temperature changes of as much as 6F and mixing ratio changes of as much as 2 o/oo in the first hour after the time of relative humidity minimum, or frontal passage. One may conclude from this that in the Willamette Valley the non-advective wind surge occurs roughly twice as often as the true change of air mass, at least on the "V" type of sea breeze day.

Heating rates of air at the surface. As mentioned above, the literature shows few published values of heating rates calculated from observations made under conditions of sea breeze advection. It can be concluded from a careful reading that Malkus et al (46) used a one-dimensional model of the form of equation (1) to obtain their calculated results of between 8C/hr and 15C/hr on Cape Cod:

$$\underset{(A)}{\frac{d\theta}{dt}} = \underset{(B)}{\frac{\partial\theta}{\partial t}} + \underset{(C)}{v\left(\frac{\partial\theta}{\partial x}\right)} \qquad (1)$$

Here θ is the potential temperature, t the time, v the component of the wind perpendicular to the coastline and positive inland, and x the axis along which v is positive.

From the data recorded on the aerograph charts atop the automobiles operated during the summer of 1957, values of the temperature gradient in term C were obtained over distances of a few km on five clear days after making the reasonable assumption that the passage over this distance was essentially instantaneous. From the hygrothermograph charts obtained during the same period of record at the fixed ground stations, values of term B were estimated with good accuracy. With estimates of the wind component v, then, values of the heating rate, term A, were computed.

With the obviously great complexity of wind flow over the surface in the 60 km inland from the coastline of northwest

Oregon during the daylight hours of days on which a sea breeze circulation exists, almost any reasonable value of the wind component, v, could be defended and used in computations of the heating rate. Based on the mean calculated speed of 14.5 km/hr for the movement of the sea breeze front inland during July and August 1957, and Koschmieder's statement (38) that the wind speed perpendicular to the front is 1.6 times the speed of the front, the writer made the assumption that the maximum value of v on days with sea breeze was (1.6) (14.5) km/hr, or 23 km/hr. The value of 1.6 was generally confirmed by Berson (5, p. 7). In the absence of recorded wind speeds over the areas for which values of the temperature gradients and the local temperature change rates were available, the writer assigned values of v on a scale from 0 to 23 km/hr after careful consideration of field notes made during the traverses of the routes between the coast and the Willamette Valley. These notes described directions and angles of inclination of smoke plumes and the behavior of flags and pennants along the route. While clearly the least accurate data used in the computations of heating rates, these values of the wind component would have been hard to improve upon without excessively expensive instrumentation, and the values used are clearly reasonable when compared with observations made by the Weather Bureau at Astoria and at Salem (67, 68).

Results of the computations of heating rates are presented in Figures 13, 14 and 15. In Figure 13 are drawn isopleths of mean values of the heating rate, term A, on a space-time coordinate

FIGURE 13

Mean value of the heating rate (Term A, Equation 1) as a function of time and of distance from the beach for five clear days of summer 1957

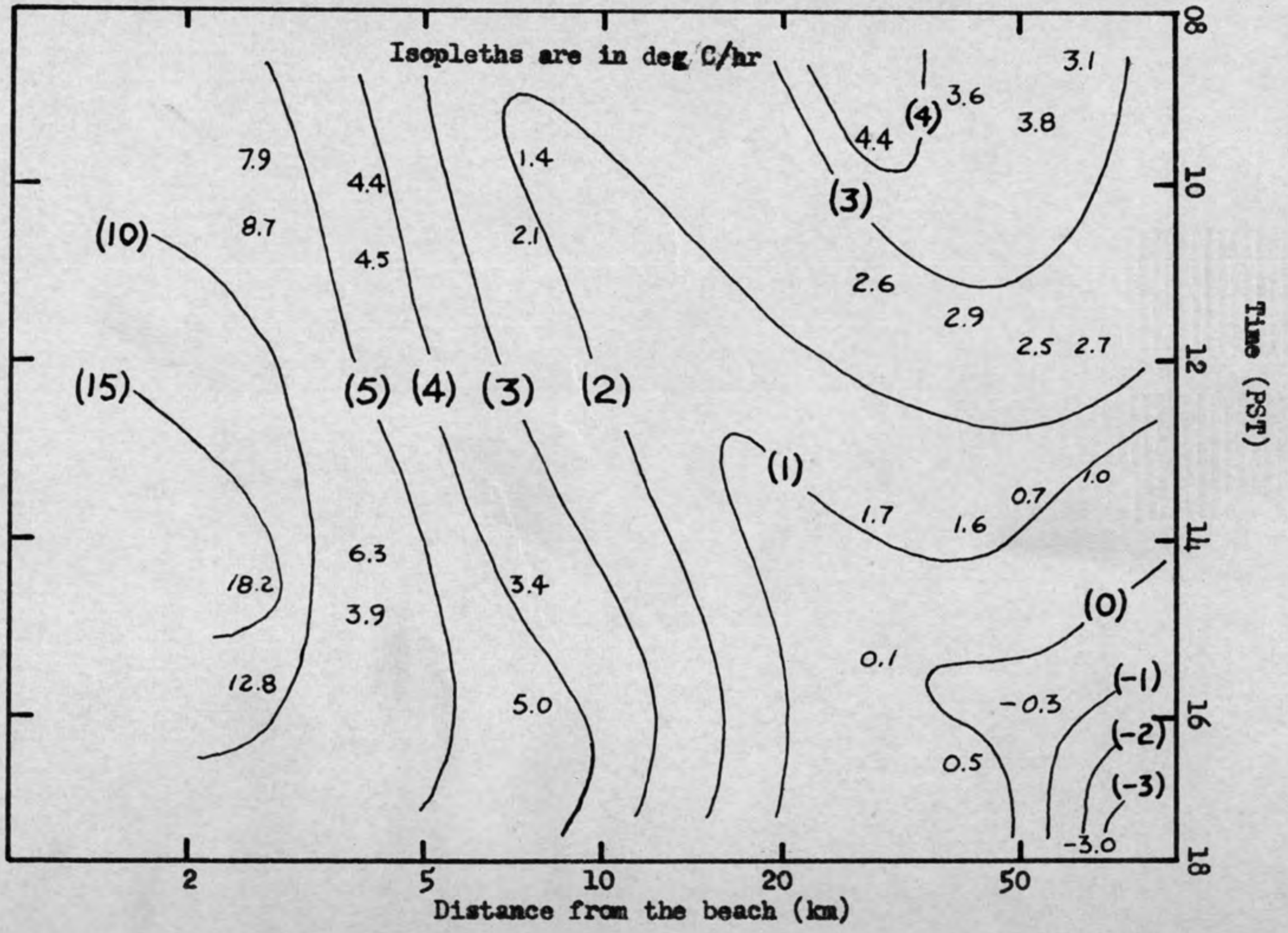
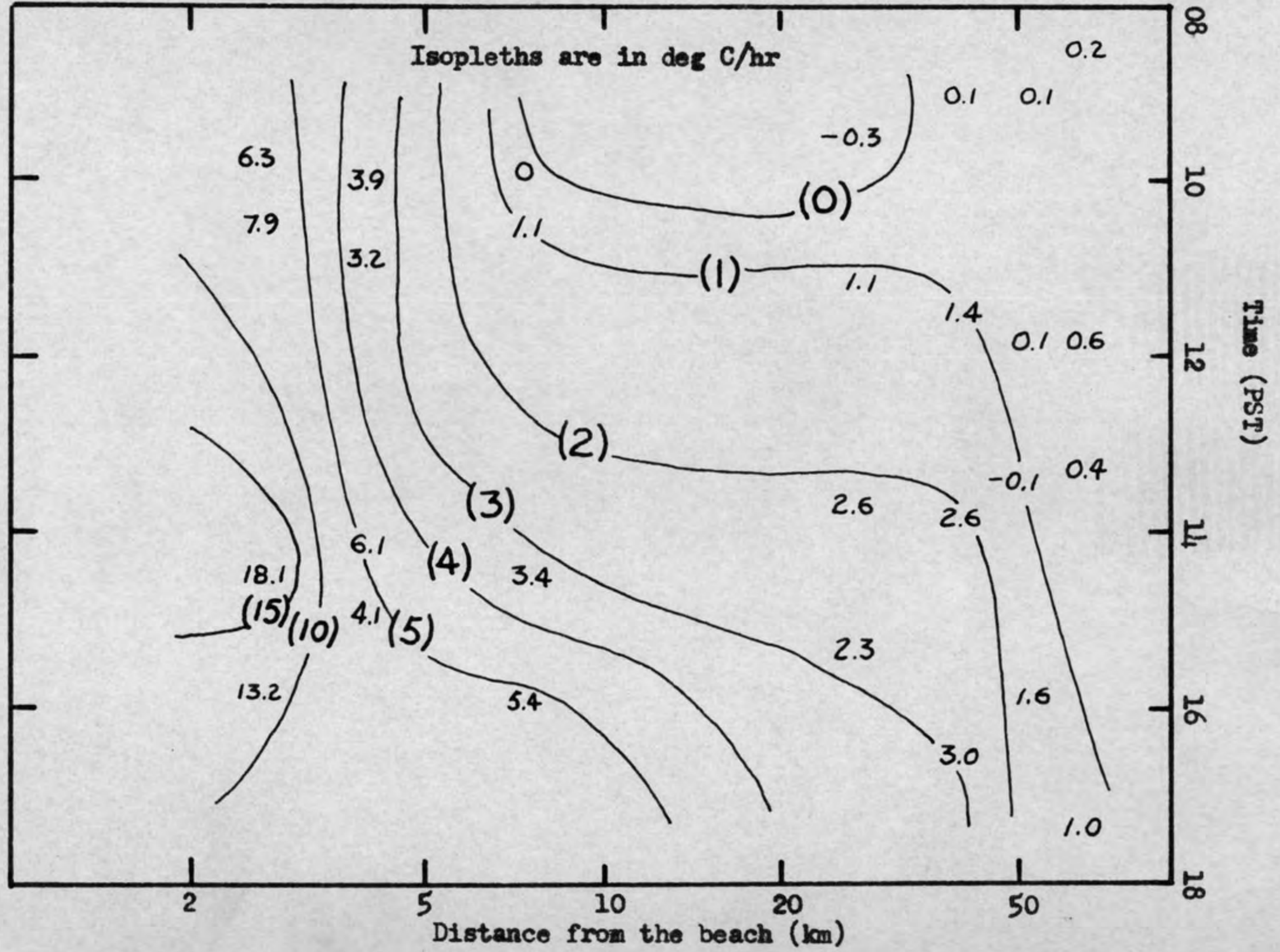
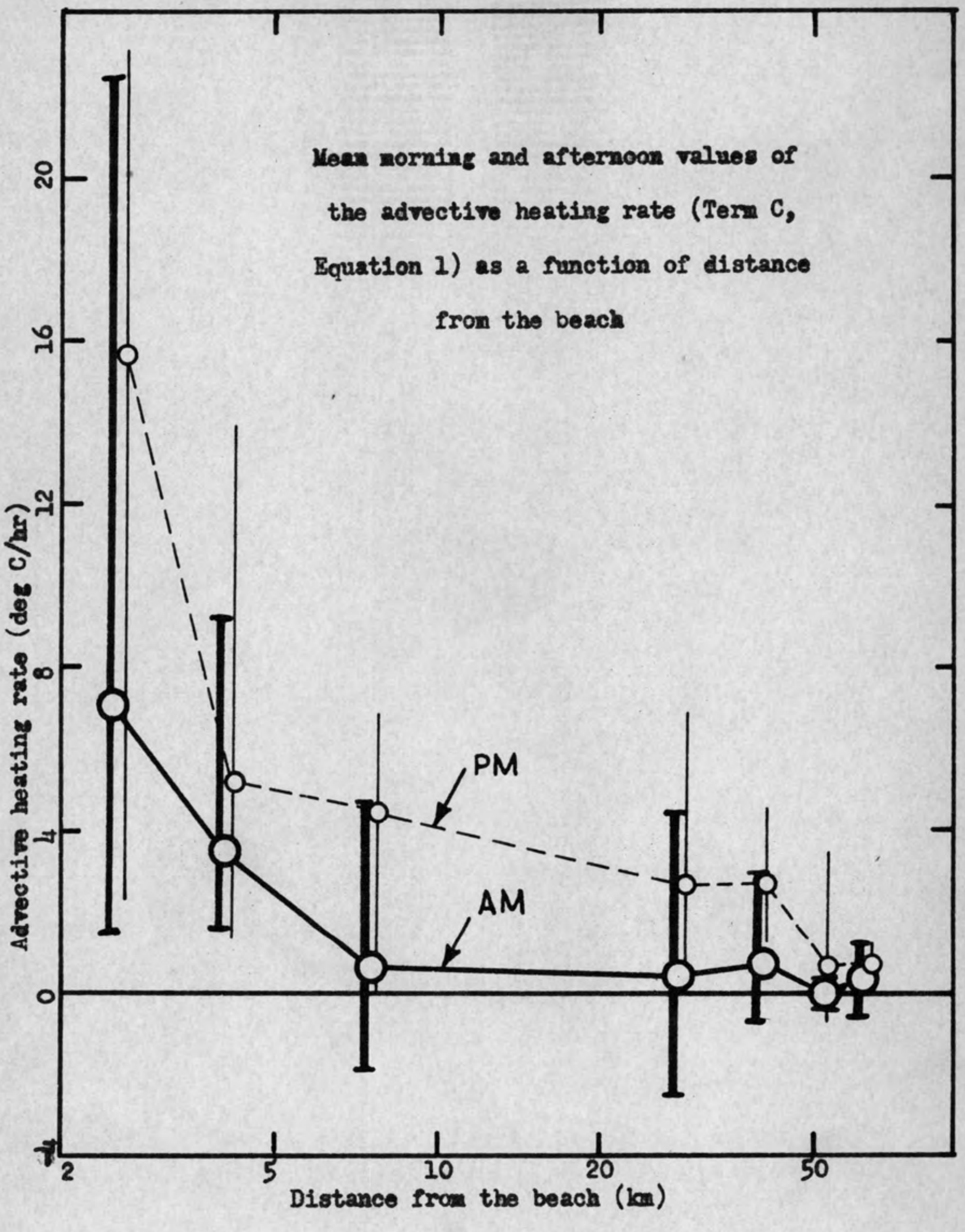


FIGURE 14

Mean value of the advective heating rate (Term C, Equation 1) as a function of time and of distance from the beach for five clear days of summer 1957





Mean morning and afternoon values of the advective heating rate (Term C, Equation 1) as a function of distance from the beach

FIGURE 15

system. The mean values plotted on the grid and used as the basis for the isopleths are in turn based on observations for the five clear Wednesdays on which vehicle traverses were made in 1957: 15 May, 29 May, 24 July, 21 August, and 28 August. Figure 14 shows isopleths of the advective term C for the same days. Figure 15 presents two cross sections of the advective term over the 60 km just inland from the beach. Data from the Yaquina-Marys River gap and from the Salmon-Yamhill River gap are combined in these figures in the absence of any clear discrepancies between them. The computations appear in Appendix F.

Examination of the isopleths of the advective term in Figure 14 discloses that, to the extent the model of equation (1) is correct, strong advective cooling is restricted essentially to the 5 km nearest the beach until about 1400 PST, the time of greatest cooling there. Thereafter, the zone of significant advective cooling moves rapidly inland as the cooling falls off near the coast. The highest rates calculated do not approach the seemingly very high value of 60 C/hr of Wexler, but they agree quite well with the values of 15 C/hr given by Malkus et al for the south shore of Cape Cod. Perhaps Wexler's value could have been approached had the writer felt justified in using a smaller interval Δx just inland from the beach, but the nature of the data does not warrant a value smaller than the 5 km used.

To interpret the results in Figures 13, 14, and 15 in terms of rates of energy distribution, consider a column of air of depth H, unit cross sectional area A, effective density ρ, specific heat at constant pressure c_p, and with a dry adiabatic lapse rate. Assume any heat energy added to the column is distributed instantaneously throughout the column with a resulting rate of change of its potential temperature, $\partial\theta/\partial t$. The temperature change and the rate of energy input are related by the equation:

$$\frac{1}{A}\frac{dQ}{dt} = \rho c_p H \frac{\partial\theta}{\partial t} \tag{2}$$

where Q is energy. A heating rate of 1 C/hr, a typical value for a point about 30 km inland at about midday according to Figure 13, will result from a certain energy input rate, given constant values of the density, specific heat, and depth.

In what follows assume 295 K and 950 mb as representative values of potential temperature and pressure for a marine layer lying on the surface. From this we obtain an air density of 1.12 x 10^{-3} gm/cm^3. Taking the value 1 j/gm-deg C for c_p, the value of ρc_p to be used in equation (2) is 4.7 x 10^{-3} cal/cm^3-deg C.

According to the mean cross section of Figure 8 a reasonable value for H at midday inland would be 0.6 km. Inserting these values in equation (2) yields an energy input rate of 0.27 ly/min (langleys per minute), corresponding to a heating rate of 1 C/hr. Lowry (42) has computed rates of sensible heat transfer from sites in the central Coast Range on several sea breeze days. The mean value of his midday rates for open sites on the clear days 8, 9, 14, 21, and 22 August 1956 is 0.65 ly/min, and for wooded sites 0.09 ly/min. A weighted mean value, assuming the ratio of open areas to wooded areas to be 1/3 in the central Coast Range, is 0.23 ly/min, which agrees well with the value of 0.27 ly/min computed above using equation (2).

At a point near the coastline, where the midday heating rate is about 15 C/hr according to Figure 13, the corresponding depth of an adiabatic layer would be only 0.04 km if the rate of energy input is assumed the same as that inland: 0.27 ly/min. While Pearce's model (52, p. 366) shows a computed depth for the adiabatic layer near the coastline of this same order of magnitude near midday, it is likely the model of equation (2) is not so appropriate near the coastline inasmuch as the lapse rate is probably much more stable than the dry adiabatic. The interpretation of the heating rates of Figures 13, 14, and 15 in terms of energy input, then, is less clear near the coastline than inland. In general, however, if one assumes the same energy input rate exists everywhere along a transect perpendicular to the coastline, the heating rate of equation (1) and the depth of heating will be inversely related, as seen in equation (2).

In summary, several conclusions seem to be warranted concerning heating rates under sea breeze advection in northwest Oregon:

a) Calculations of midday heating rates yield values ranging from about 1 C/hr inland to about 15 C/hr near the coast in good agreement with published values.

b) Estimation of energy input at midday inland yields a value of 0.27 ly/min, in good agreement with published values for the same area.

c) Computation of the depth of the marine layer near the coast using an energy input value of 0.27 ly/min yields a value of 0.04 km, in good agreement with published theoretical values.

Diurnal variability of cloud cover. Figure 16 presents several curves depicting the diurnal variability of clouds above Astoria and Salem during July. The upper group of three curves represents Astoria and the lower Salem. The heavy curve in each group connects hourly mean values of the per cent of possible days on which the cloud cover was greater than 7/10, the data from which these means were computed being all the July days during the years 1953 through 1960 (67, 68). The light solid curve in each group connects hourly mean values of the per cent of possible sea breeze days on which the cloud cover was greater than 7/10, the sample being the sea breeze days of July 1957 (Table 2). The pecked lines connect hourly means for sea breeze days on which the cloud cover was greater than 7/10, and the ceiling was less than 6000 feet. July may safely be considered typical of the sea breeze season as a whole.

An early morning maximum and an afternoon minimum in the likelihood of clouds is evident at both stations, the relative frequency at Astoria being about twice that at Salem for any given hour. The most striking differences between the patterns for all July days and those for sea breeze days are the increased abruptness of fall in the frequency of clouds after about 0900 PST, the rise in the frequency at about 1600 PST at Astoria, and the double peaks of probability of low clouds at about 0400 and 0900 PST at Salem. Consideration of observed frequency of early morning clouds on

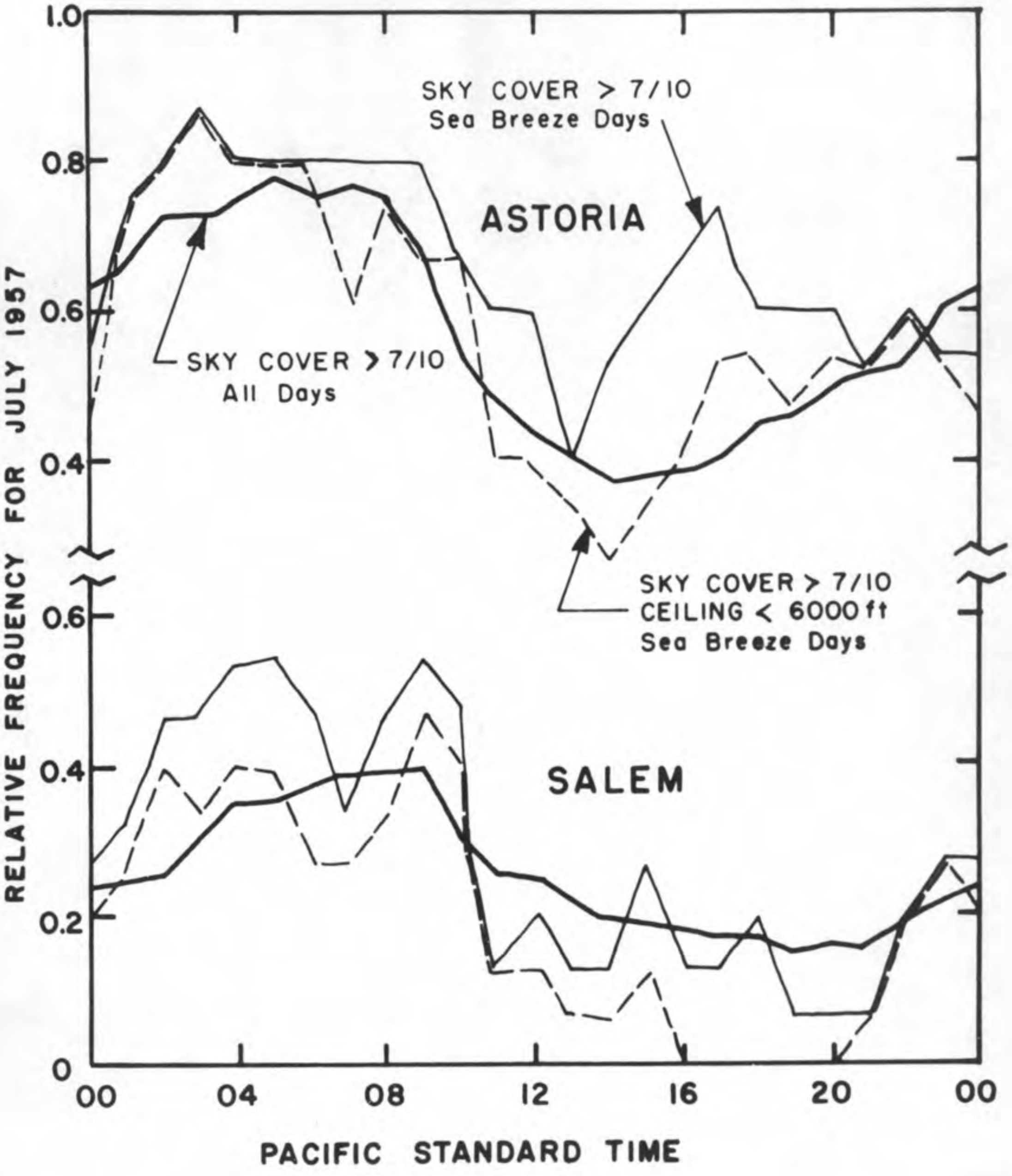


FIGURE 16

Diurnal variation of cloud cover at Astoria and Salem in July.

U-type days and on V-type days shows there is a moderate tendency toward greater cloudiness on U-type days at Salem (68). Considering only the hours from 0400 to 0900 PST and cloud cover greater than 5/10 with ceilings less than 6000 feet, U-type days during July-August 1957 experienced 54% of 13 days with at least one hour of these low clouds, while V-type days had 18% of 11 days with low clouds. The mean duration of such clouds was 1.8 hours per day for U-type days and 0.7 hours per day for the V-type. While the difference between 54% and 18% becomes statistically significant only at the 8% level (40, p. 408) there is the moderate tendency noted above. Implications of this tendency will be considered later.

Diurnal pressure variations. Figure 17 presents diurnal pressure variations in the form of means for seven days of August 1956. These days were the only ones rated 2 or 3 on the sea breeze scale (Figure 6) for the period during which special observations were being made in the Coast Range by the U.S. Forest Service and the U.S. Weather Bureau. Data for Valsetz and Grand Ronde in Figure 17 were taken from microbarograph records of this set of special observations, while data for Astoria and Salem were taken from climatological data of the U.S. Weather Bureau (67, 68). In an attempt to eliminate longer period variations from the records, the results are presented as departures of pressure from a base line connecting the pressure at 0400 PST on the day in question with the pressure at 0400 PST the following morning. Though the hour 0400 was chosen because it would probably represent a time when any sea breeze effects from the previous day would have been damped

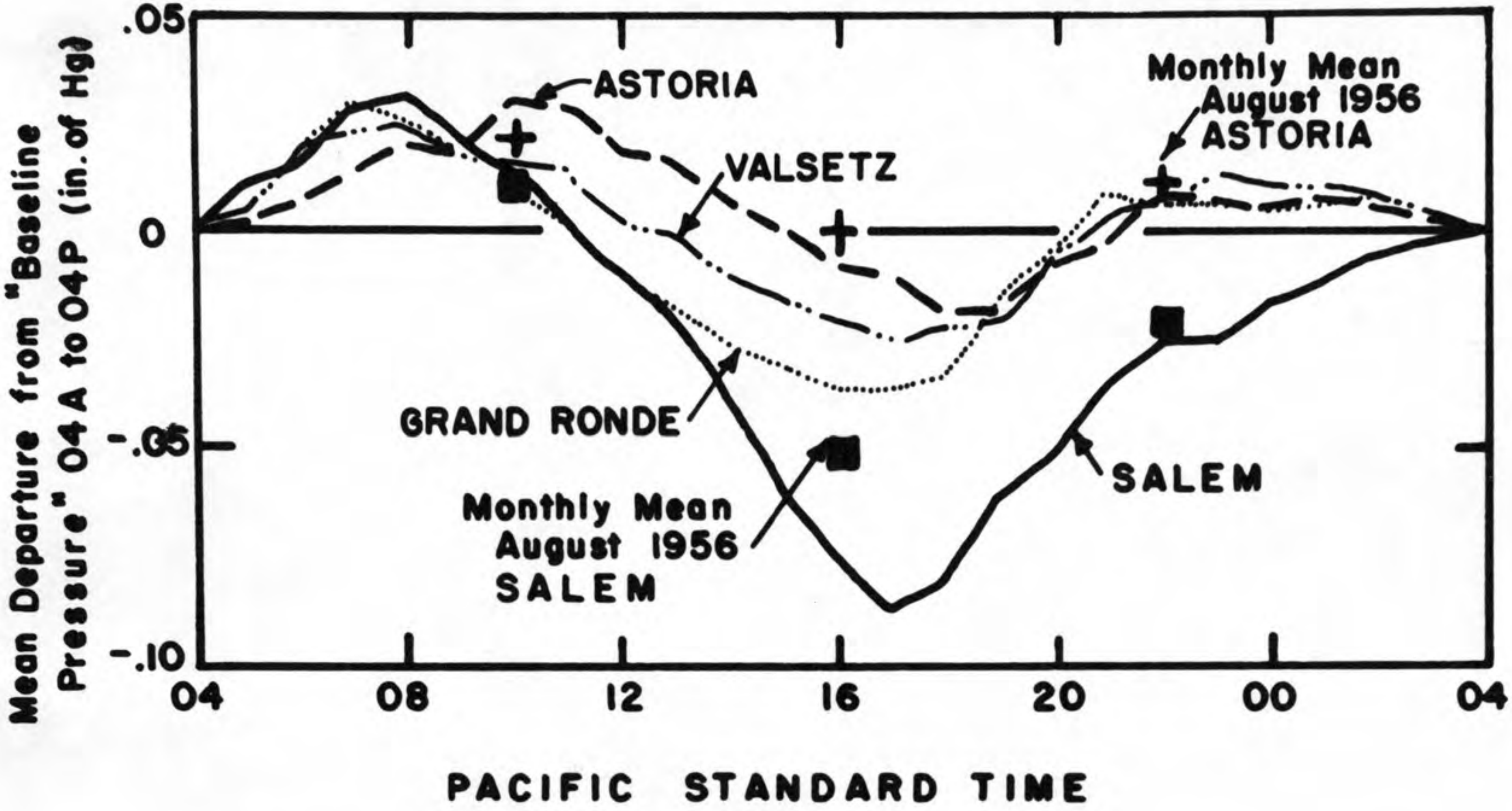


FIGURE 17

Diurnal variations of station pressure during August 1956.

out and those from the present day would just be beginning, it is really practically immaterial what hour is chosen. The reader is cautioned, however, that in Figure 17 no absolute pressure differences between stations may be obtained, since each station has a different value on its base line at any given time.

Several things are at once apparent from Figure 17. All four stations exhibit a definite and similar periodicity. Also, in general the magnitudes of the variations increase with increasing distance from the beach, ranging from 0.05 inches of mercury, or 1.7 mb, at Astoria to 0.12 inches, or 4.1 mb, at Salem. Judging from the relationships of the mean 6-hourly pressures to those of the seven sea breeze days, morning pressures are higher and afternoon pressures are lower on sea breeze days than on days in general, at both Astoria and Salem. The sea breeze regime, then, apparently accentuates the diurnal cycle. Finally, Grand Ronde, lying in a valley widening inland toward the Willamette Valley, has a pattern more nearly like Salem than does Valsetz, located at about the same distance from the ocean but in a mountain-rimmed basin not connected by lowlands to the inland valleys or to the coast.

As for absolute pressure differences between stations, Table 8 gives differences between monthly means at Astoria and Salem and at Eugene and Salem. While each of these differences is a monthly mean and therefore not representative of sea breeze days specifically, the intensification of the diurnal variation on sea breeze days just noted reinforces the conclusion that the sea breeze regime tends to produce, or be accompanied by, diurnal variations of east-west

TABLE 8

MONTHLY MEANS OF STATION PRESSURES AT ASTORIA, EUGENE, AND SALEM AND OF PRESSURE DIFFERENCES BETWEEN ASTORIA AND SALEM AND BETWEEN SALEM AND EUGENE AT SIX HOUR INTERVALS DURING SELECTED SUMMER MONTHS

(Inches of mercury)

Month	Station	0400 PST	1000 PST	1600 PST	2200 PST
May 1957	Astoria	29.94	29.96	29.95	29.95
	Salem	29.74	29.75	29.70	29.73
	(AST-SLE)	0.20	0.19	0.25	0.22
Jun 1957	Astoria	30.04	30.05	30.05	30.05
	Salem	29.83	29.84	29.81	29.83
	(AST-SLE)	0.21	0.21	0.24	0.22
Jul 1957	Astoria	30.06	30.08	30.07	30.07
	Salem	29.85	29.86	29.80	29.84
	(AST-SLE)	0.21	0.22	0.27	0.23
Aug 1957	Astoria	30.04	30.06	30.05	30.05
	Salem	29.84	29.86	29.79	29.83
	(AST-SLE)	0.20	0.20	0.26	0.22
Sep 1957	Astoria	29.96	29.99	29.95	29.97
	Salem	29.76	29.78	29.71	29.75
	(AST-SLE)	0.20	0.21	0.26	0.22
Jul 1953	Salem	29.88	29.89	29.82	29.86
	Eugene	29.70	29.71	29.64	29.67
	(SLE-EUG)	0.18	0.18	0.18	0.19
Aug 1953	Salem	29.79	29.80	29.75	29.79
	Eugene	29.61	29.62	29.57	29.61
	(SLE-EUG)	0.18	0.18	0.18	0.18
Jul 1954	Salem	29.85	29.86	29.80	29.83
	Eugene	29.66	29.67	29.62	29.65
	(SLE-EUG)	0.19	0.19	0.18	0.18
Aug 1954	Salem	29.82	29.84	29.79	29.82
	Eugene	29.64	29.66	29.61	29.64
	(SLE-EUG)	0.18	0.18	0.18	0.18

pressure gradients across the Coast Range much greater than the diurnal variations of north-south pressure gradients experienced at the same time in the Willamette Valley. This is precisely opposite to the conclusion reached for the Puget Sound area by Staley (59, p. 468), but the shoreline geography there is so much more complex this difference should not be surprising.

Figure 18 shows hourly means of pressure difference between Astoria and Salem for the two 5-day samples in Table 2 representing the U-type and the V-type of sea breeze day. These results support the conclusion that pressure gradients between coast and valley are even greater on sea breeze days than in general. While for the sample used here it appears the afternoon pressure gradient developed on a V-type day is distinctly greater than on a U-type day, verification of this should probably come from a considerably greater sample and a much more detailed study of the two types of sea breeze day.

On the two microbarograph traces available for study, those at Valsetz and Grand Ronde, about 35 km inland, no indications of distinct pressure jumps were present. A few instances of rather rapid rises in pressure occurred, all at either about 0400 PST or about 1900 PST, but these could scarcely be associated with passage of a sea breeze front.

Diurnal variation of surface wind velocity at Astoria and Salem. Figure 19 shows the hodographs of hourly mean perturbations on the mean wind velocities for two types of sea breeze days at Astoria and at Salem. Steps in constructing the hodographs are described in

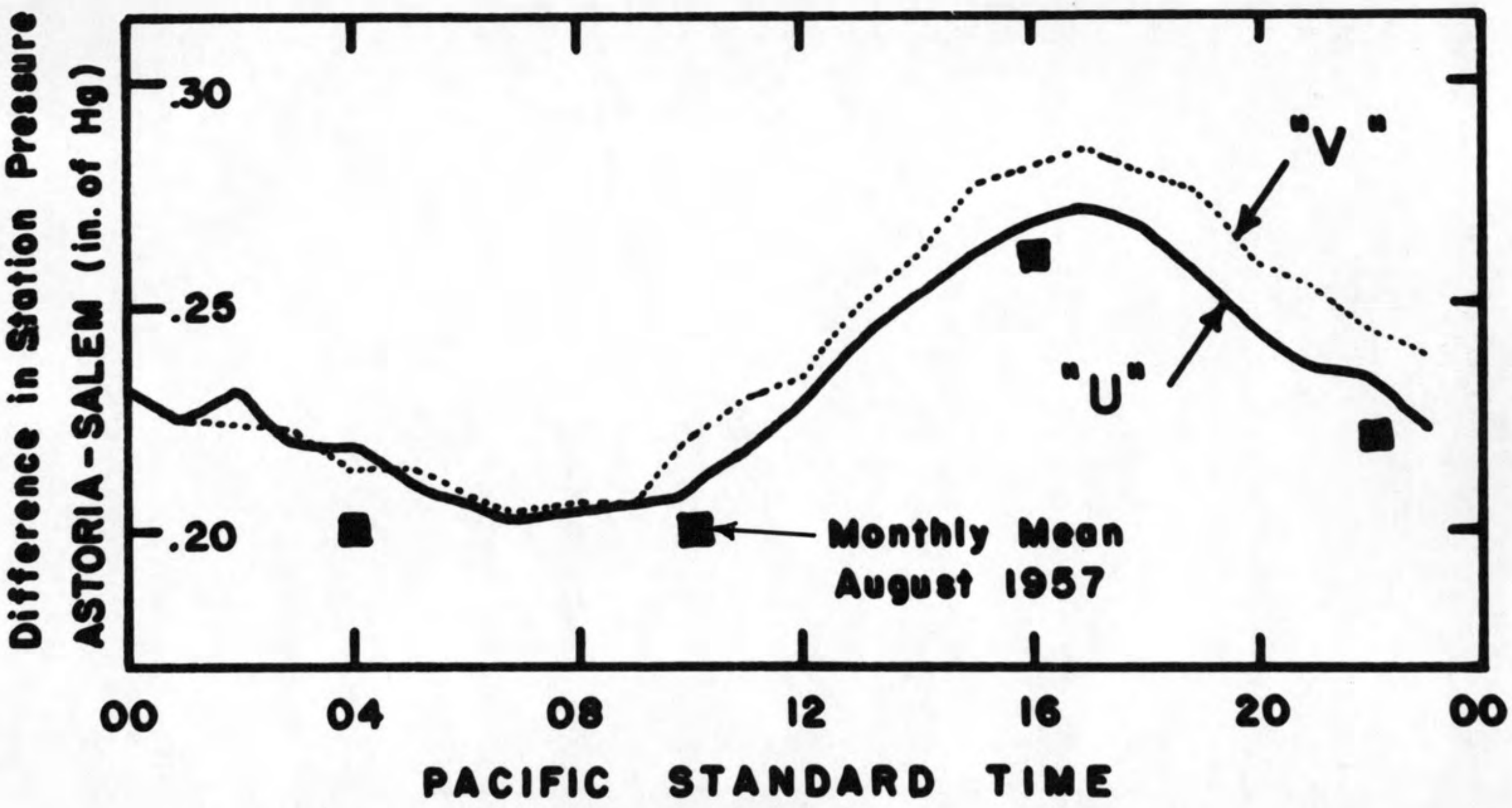
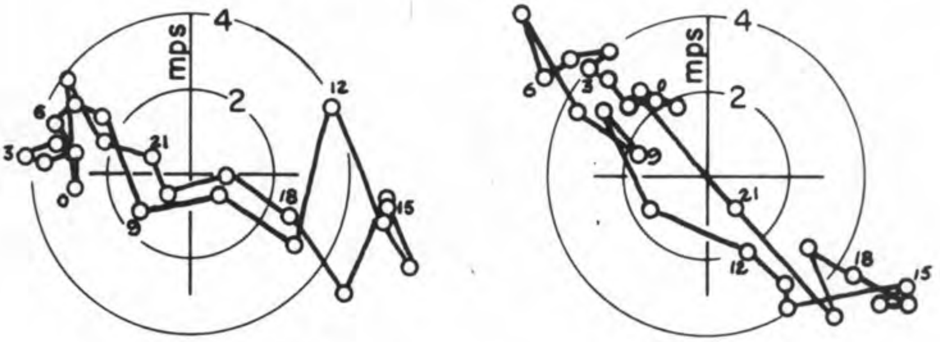


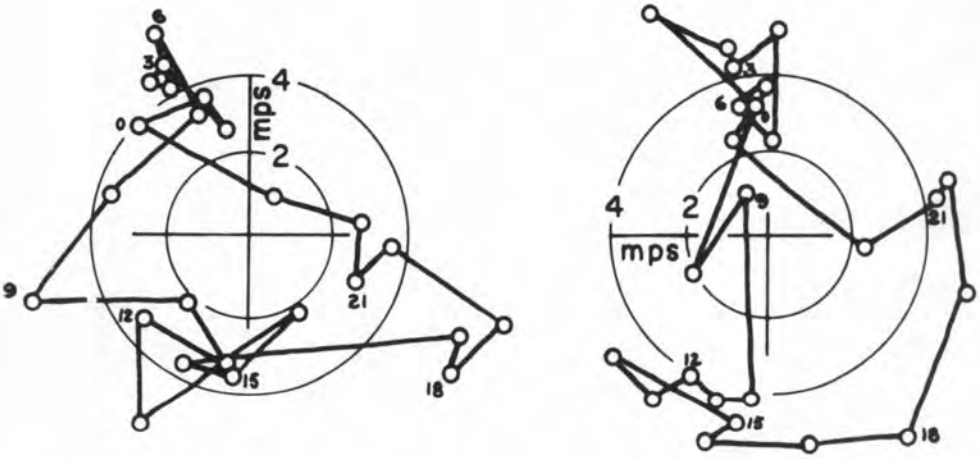
FIGURE 18

Diurnal variations of pressure difference between Astoria and Salem for two types of sea breeze day, 1957.



ASTORIA - "U" DAYS   ASTORIA - "V" DAYS

SMALL NUMBERS ARE HOURS (PST)



SALEM - "U" DAYS   SALEM - "V" DAYS

HODOGRAPHS OF MEAN HOURLY PERTURBATIONS ON THE SURFACE WIND FOR SEA BREEZE DAYS AT ASTORIA AND SALEM

FIGURE 19

detail by Staley (59) but are outlined as follows to clarify their meaning. For the two samples of five days each, representing the two types of sea breeze day, mean velocity vectors were obtained for each hour. The vectorial mean of these 24 vectors was then obtained in each case, and then differences between this mean and each of the 24 hourly means were obtained. These differences, or perturbations, are plotted in Figure 19. These hodographs may be considered the diurnal variations of wind velocity on sea breeze days in the absence of any general gradient wind, or in other words the components of the wind generated locally.

It is at once apparent that the Astoria and the Salem hodographs differ from one another in that the former is elongated while the latter is more open, especially during the day. They are alike, however, in that they both exhibit counterclockwise rotation of the wind during the daylight hours, contrary to the theoretical and the observed behavior of a pure sea breeze at and near the coast (see page 21).

The Astoria hodograph. Staley (59, p. 462) concludes the elongated form of the Astoria hodograph is due to the restrictions on possible wind directions imposed by local terrain. In view of Table 9, this conclusion may not be altogether tenable. In this table Salem is used as a standard of comparison representing a station exposed to the same large scale weather patterns as Astoria but having no major topographical constraints to windflow in the vicinity. Restrictions due to topography at Astoria are doubtless present, as suggested by the fact that the relative frequency of winds in the

TABLE 9

ECCENTRICITY OF HODOGRAPHS AT ASTORIA AND SALEM DURING 1957

Month	Ratio of frequency of winds in SW and NE quadrants to frequency of winds in NW and SE quadrants*	
	Astoria	Salem
May	.56	1.33
June	.47	1.47
July	.34	.55
August	.26	.83
September	.81	1.10
October	.80	.93
November	.75	.91
December	1.05	1.38

* Data are hourly wind observations summarized in Local Climatological Data (67, 68).

restricted (SW and NE) quadrants at Astoria is smaller than at Salem in all the months of the sample. The fact that the wind roses at both Astoria and Salem become nearly circular (value of the ratio in Table 9 near 1.0) during the months not dominated by the sea breeze, however, indicates there may be constraints other than topographic acting on the wind flow at Astoria.

The counterclockwise rotation of the wind at Astoria on sea breeze days suggests the presence of an effect due to piling up of air against terrain to the right of flow, while the city's location on the Columbia estuary suggests there may well be a component present due to the "harbor effect" (see page 22).

In Figure 20 appears a graphical analysis based on the same technique as that of Dexter (18), in which is presented the diurnal behavior of several wind components and of the theoretical resultant of the components (see Figure 1 for Astoria's geographical setting). There appear three closed curves whose counterparts for Astoria bear the same labels as do Dexter's at Halifax. These curves represent theoretical hodographs for the harbor effect, A, the general coastal sea breeze, B, and the probable hodograph due to these two effects, D. The other two curves are the observed hodograph generalized from the V-type perturbations of Figure 19, E, and a curve F representing the vectorial difference between curves E and D.

The proportions for the overall relative dimensions of the curves A:B:E were taken to be 5:4:5.3 on the basis of the proportions of the hodographs for harbor effect and ocean effect in Dexter's

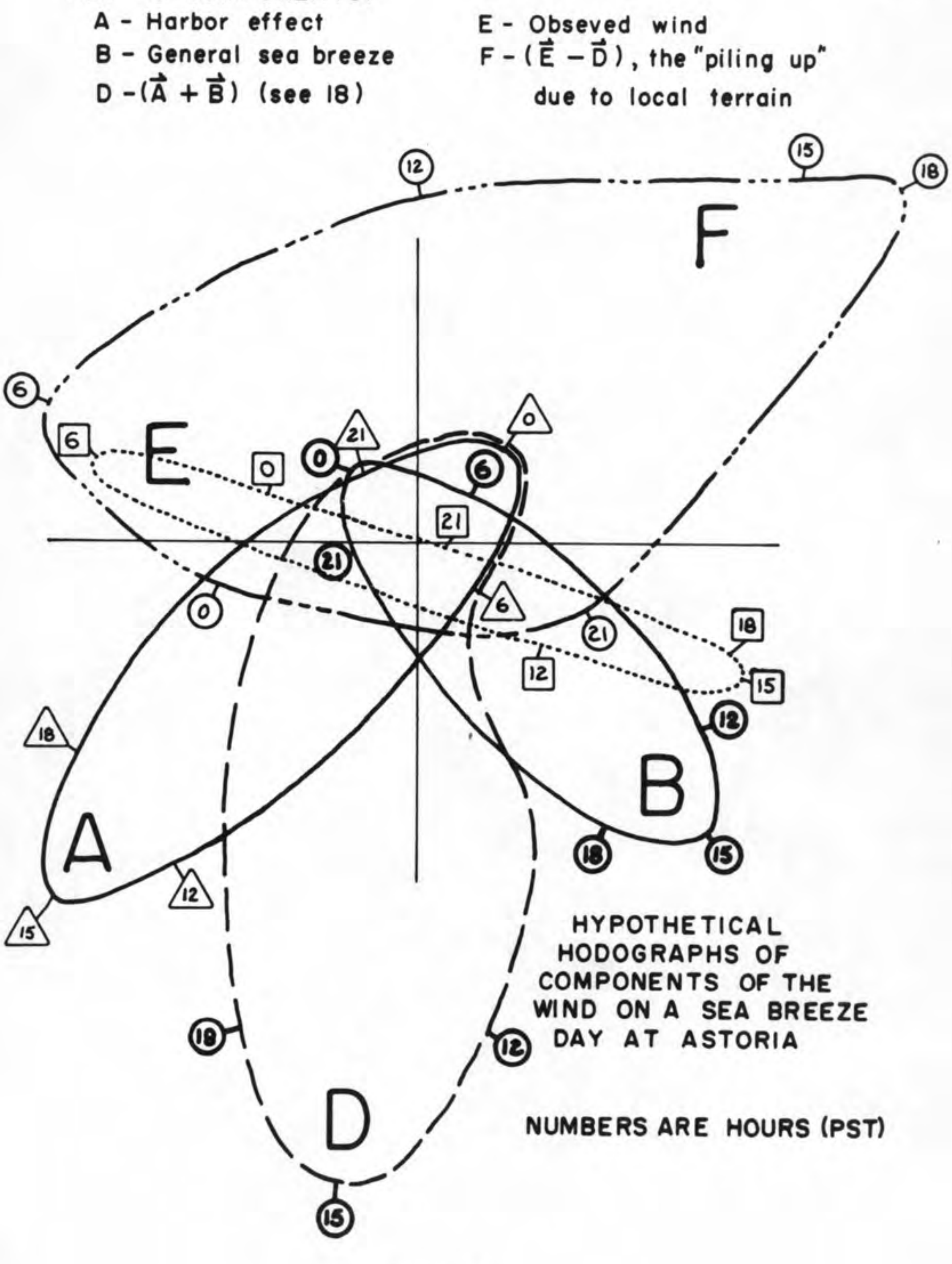

KEY TO COMPONENTS:
A - Harbor effect
B - General sea breeze
D - $(\vec{A} + \vec{B})$ (see 18)
E - Obseved wind
F - $(\vec{E} - \vec{D})$, the "piling up" due to local terrain
A
B
D
E
F
0
6
12
15
18
21
HYPOTHETICAL HODOGRAPHS OF COMPONENTS OF THE WIND ON A SEA BREEZE DAY AT ASTORIA
NUMBERS ARE HOURS (PST)

FIGURE 20

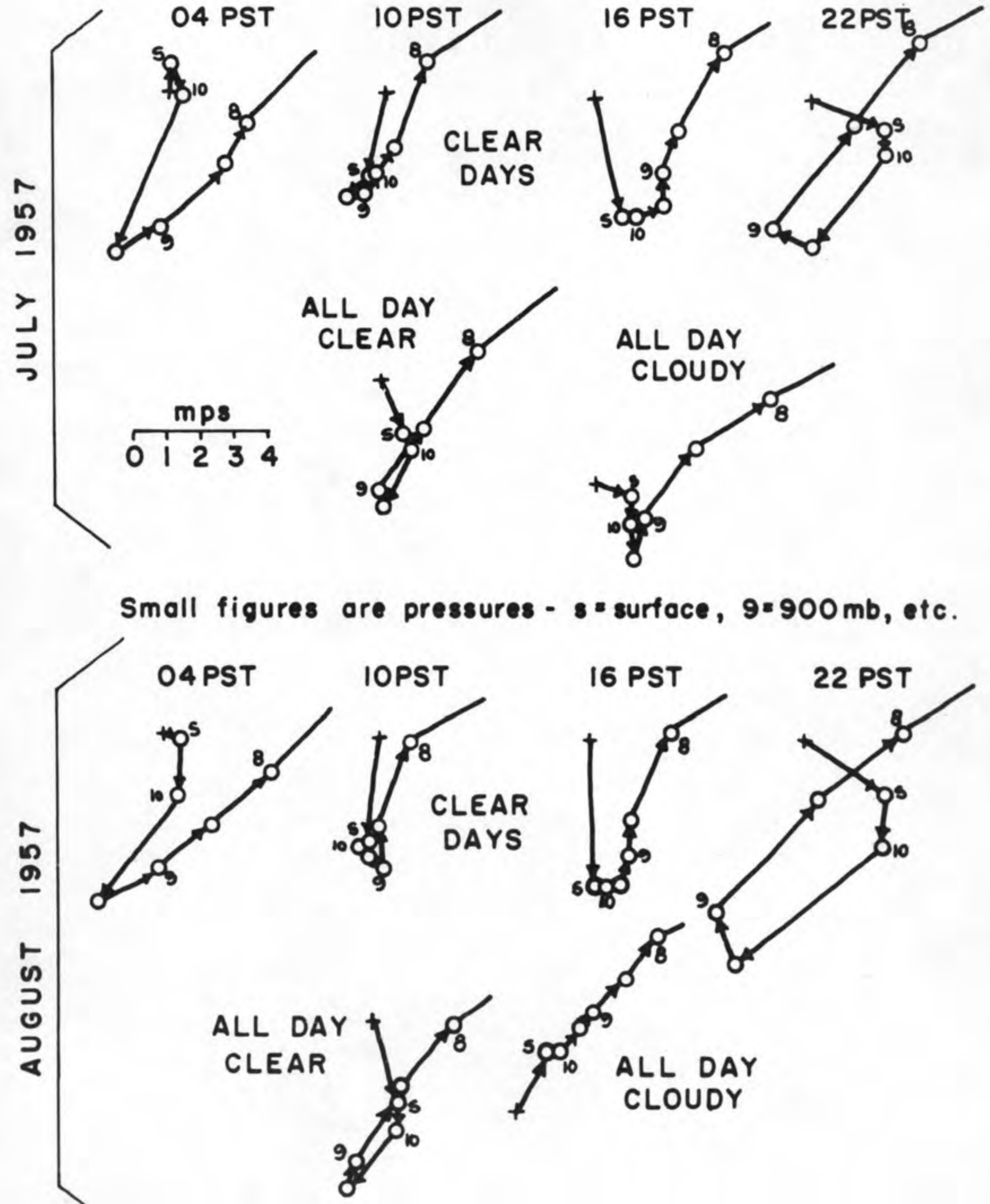
paper and those of the hodographs for Destruction Island and Astoria in Staley's paper. According to Dexter curves A and B should be about in the ratio 5:4, while the long dimension of the pure regional sea breeze hodograph as typified by the wind at Destruction Island should be about 3/4 that of the observed hodograph at Astoria according to Staley. As pointed out by Dexter, even though the sizes of the curves are not known precisely "the general effect is the same within a large range of sizes".

If curve D represents the true sum of the harbor and ocean effects, and if the observed hodograph, E, consists of the resultant of the ocean, harbor, and "piling up" forces, then curve F should be the hodograph of the force due to the topographic constraint. Though asymmetrical with respect to the shoreline at Astoria, the daytime components are away from the terrain south of Astoria, as would be expected, and the nighttime components are smaller and away from the terrain across the estuary from Astoria, as would be expected. Qualitatively, then, the curve F agrees with what would be expected for dynamic results of deflected air piling up against terrain to the right of flow. If quantitatively correct, curve F shows the magnitude of the "piling up" is slightly larger than the harbor effect, and therefore is the largest of the three components comprising the observed wind.

Vertical hodographs at Salem. In this section the term "vertical hodograph" is used to indicate a hodograph representing winds at various altitudes at one time and one place, in contrast to the use of the term "hodograph" in the previous two sections. Staley suggested (59, p. 464) a study of vertical hodographs based on observations from mountainous west coastal regions would be a distinct aid in studying the sea breeze circulation in such an area. While this section is not a study of such results, it does present a set of vertical hodographs and a few general conclusions as to their significance.

Figure 21 depicts the mean vertical hodographs at Salem for the four times each day when radiosondes were released during July and August of 1957. The top and third rows of sketches refer to the hours 0400, 1000, 1600, and 2200 PST during the clear days of the period. In this case, following Staley (59, p. 463), "clear" is defined as having less than 5/10 sky cover from sunrise to sunset. In the second and fourth rows of sketches are vertical hodographs of daily mean winds for "clear" and "cloudy" (i.e. non-clear) days of July and August 1957. A point in the left hodograph in the second row, for example, is the result of averaging the four vectors for a particular pressure level in the four hodographs in the first row.

Several things are at once apparent upon examination of Figure 21. First, distinct changes in the orientations of the shear vectors indicates a multi-layered structure of the atmosphere over Salem. At a level between 950 and 900 mb these changes indicate a definite difference between the thermodynamics regimes below and above that level. Undoubtedly the changes at that level are related to the facts that the crestline of the Coast Range and the thermal inversion over the Willamette Valley both lie at about 900 mb.



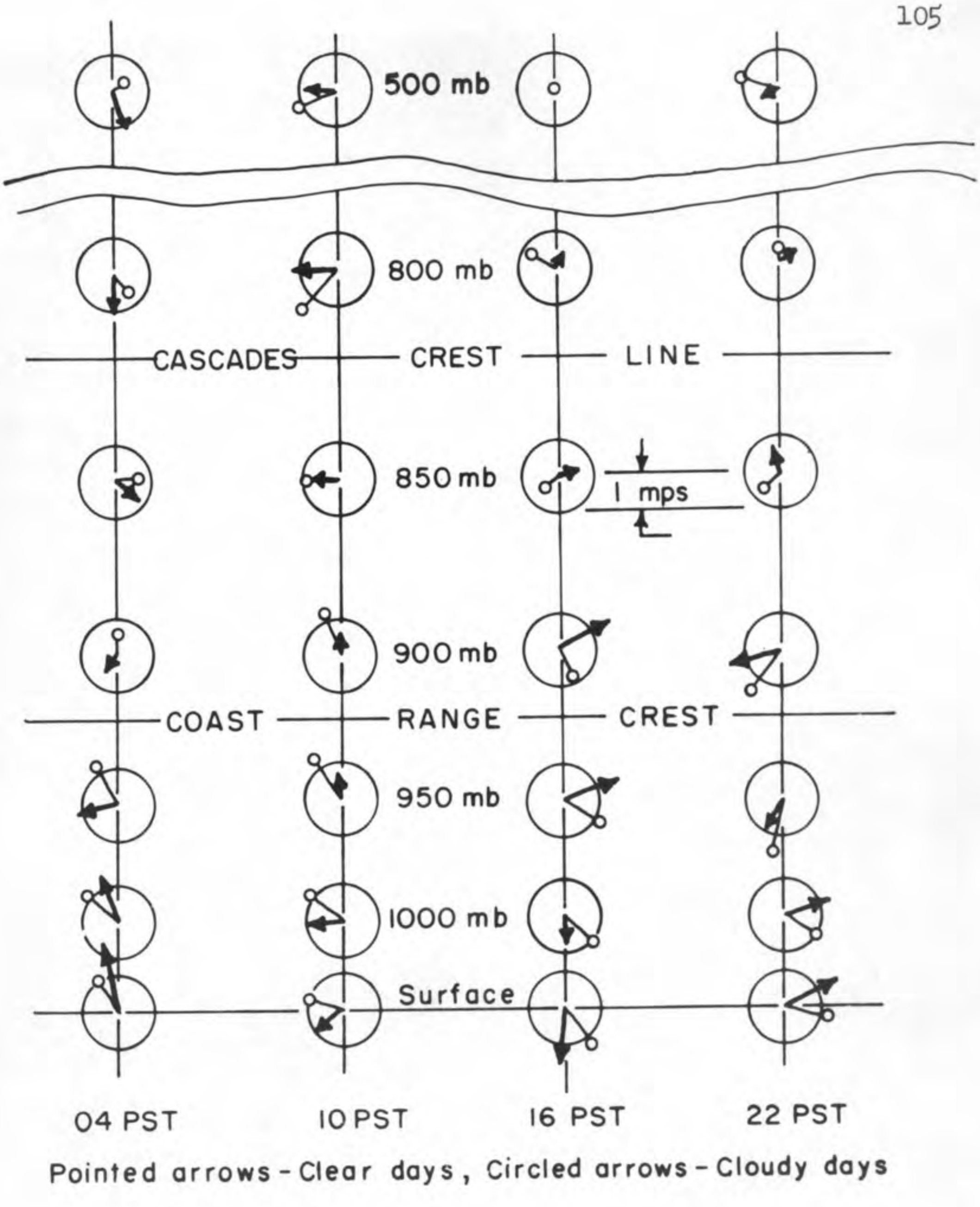
MEAN VERTICAL HODOGRAPHS AT SALEM

FIGURE 21

Another feature of the set of vertical hodographs for Salem is the fact that each hodograph for August is almost identical with its counterpart for July, with the exception of that for "cloudy" days. This would indicate the general homogeneity of the atmosphere with respect to time over the area during the portion of the sea breeze season not experiencing cloudy periods. The nature of the vertical hodograph for cloudy days in July indicates the presence of a two-layered system, the boundary again at about 950 mb, while that for August suggests a deep and uniform system. It may be concluded that cloudiness such as to persist all day is associated with one type of weather pattern during July and a different pattern during August.

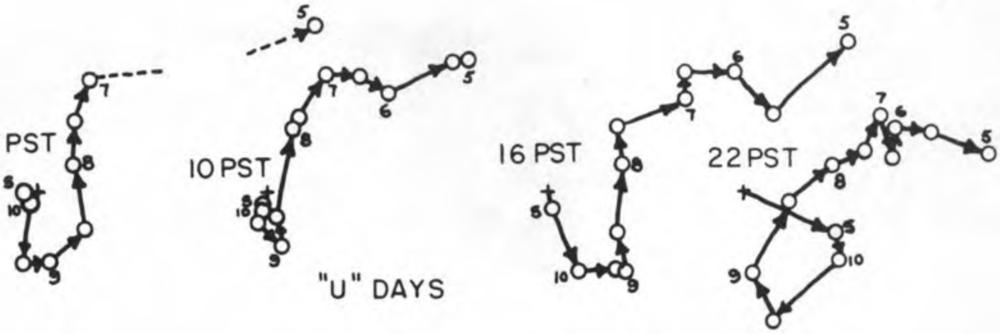
In Figure 22 the perturbations on the mean wind at each level are given for each of the four observation times. The perturbations were obtained in the same manner as those in Figure 19, from the results for clear days and for cloudy days for July and August 1957 combined. Judging by the perturbations below about 900 mb, the sea breeze appears to arrive above the surface by 1600 PST at Salem, arriving at the surface some time later and continuing until at least 2200. By 2200 the land breeze has apparently replaced the sea breeze at the level of the Coast Range crest, continuing at 950 mb until at least 0400 PST.

As brought out previously, "clear" days are not necessarily sea breeze days during the summer in northwest Oregon. Figure 23 shows the hodographs obtained for the two five-day samples representing the two types of sea breeze day (see Table 2). The figure

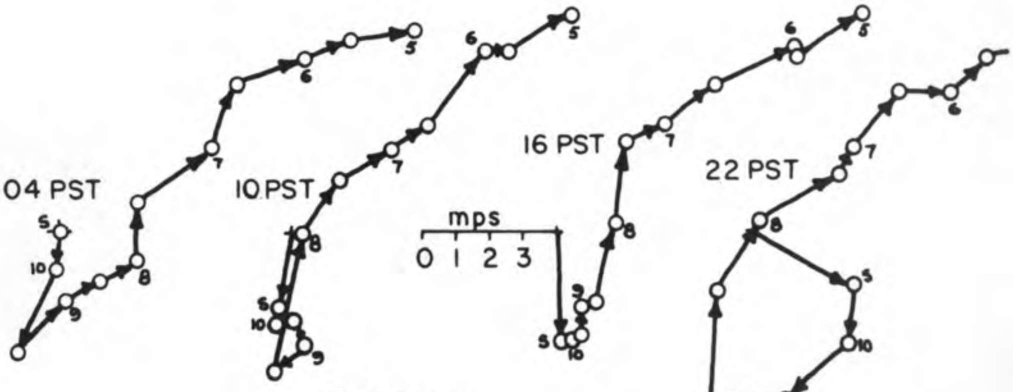


MEAN PERTURBATIONS ON THE WIND AT SALEM
JULY — AUGUST 1957

FIGURE 22

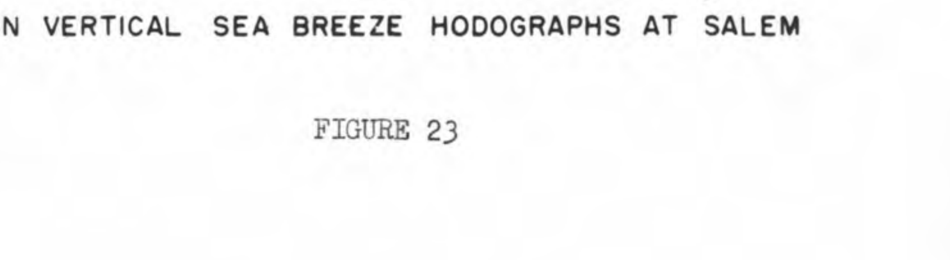


"U" DAYS



"V" DAYS

Small figures are pressures - s = surface, 9 = 900 mb, etc.



AUGUST 1957
CLEAR DAYS

MEAN VERTICAL SEA BREEZE HODOGRAPHS AT SALEM

FIGURE 23

contains the four hodographs for clear days in August from Figure 21, and the similarity of these to the hodographs for the V-type days is striking. Filling in the hodographs between 800 and 500 mb, as was done in Figure 23 but not in Figure 21, gives results indicating a second discontinuity between thermodynamic regimes lying at about 750 or 700 mb. Consideration of this feature is beyond the scope of this work.

Moisture variations above the surface. The work of Ellis (22), of Lindquist (41), and of Schroeder (55) makes it clear that on prominent terrain features in the coastal mountains of the western United States there appear during the summer months two characteristics of moisture fluctuation which are frequent and widespread: a) relative humidity traces which exhibit, in the words of Ellis, "lack of regularity and absence of diurnal rhythm", and b) daily minima of relative humidity during the night or early morning hours. These two characteristics appear quite distinctly also in the original records gathered on ridgetops and peaks in the Oregon Coast Range by the U.S. Forest Service (64) and by the writer (42) during the summer of 1956. During the two week period common to both these sets of records there were six days classed as 2 or 3 on the sea breeze scale according to the scheme of Figure 6. From the temperature and relative humidity data available for these six days, the mixing ratio was calculated hourly for twelve stations in the central Coast Range area. These results appear in Figures 24 and 25.

It is evident that in these records of mixing ratio there is for several of the stations in Figure 24 and for all of the stations

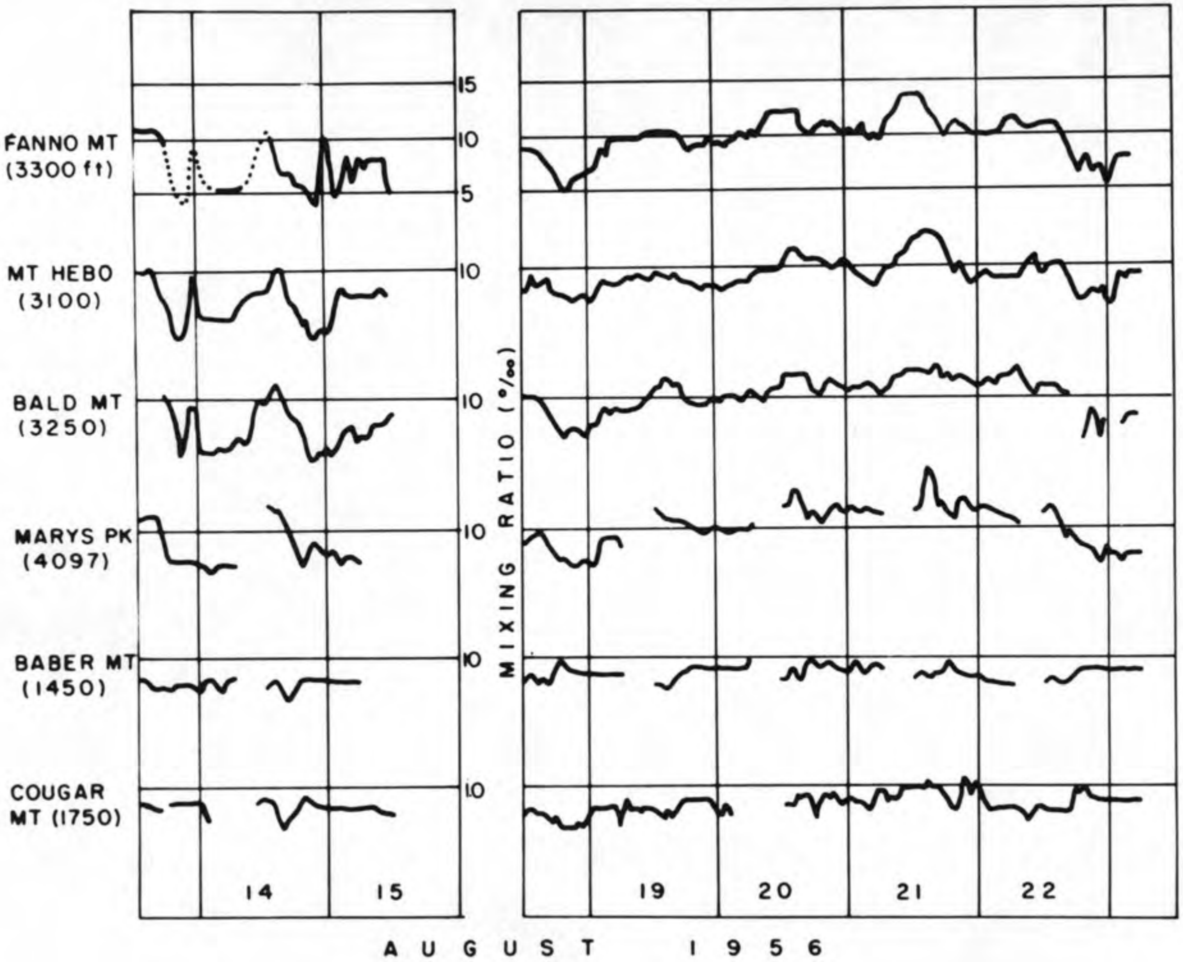


FIGURE 24

Variations in mixing ratio at Coast Range peak stations.

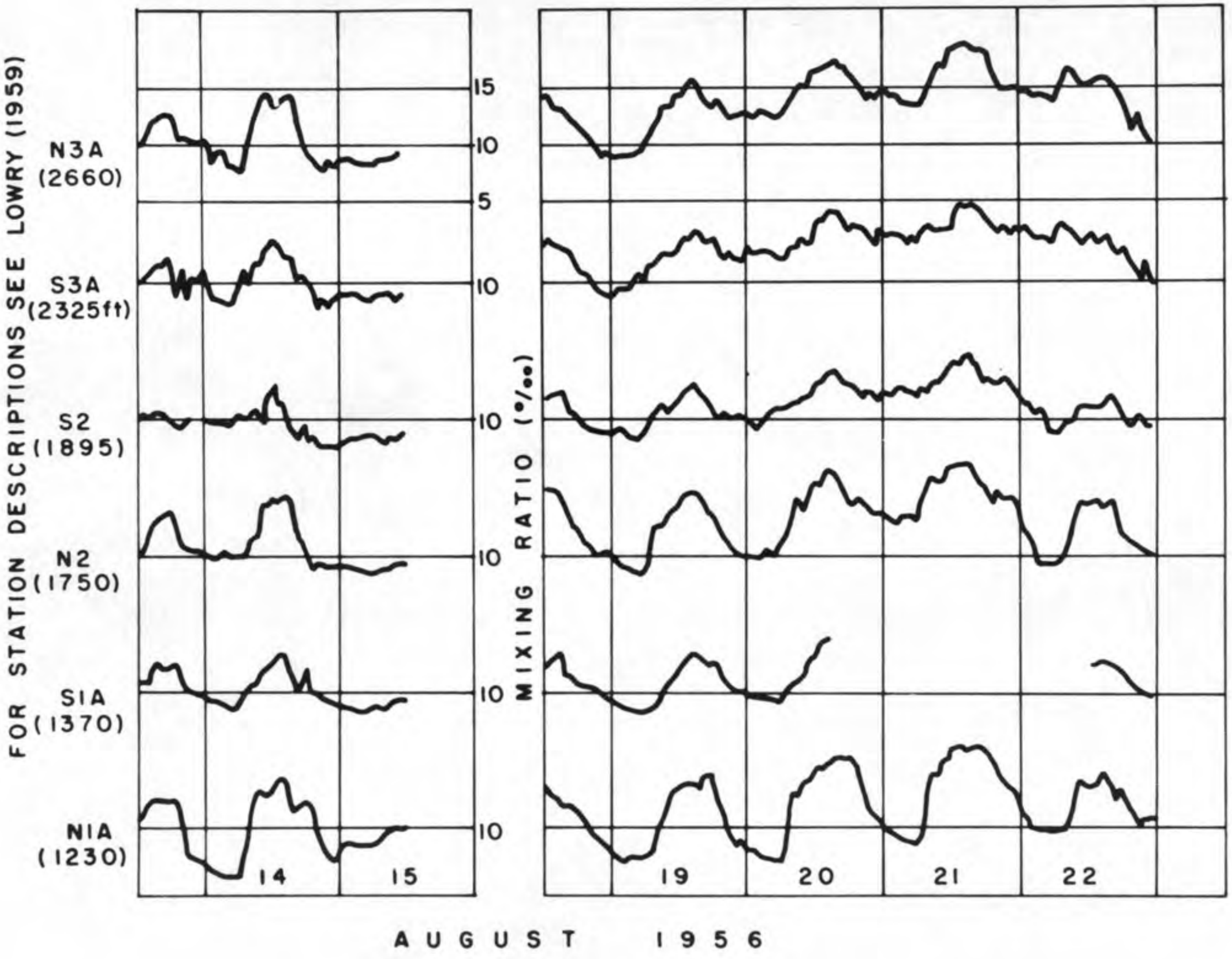


FIGURE 25

Variations in mixing ratio at stations in the Valsetz Basin.

in Figure 25 a strong tendency for a diurnal rhythm having maxima in the early afternoon and minima in the early morning. In the case of Figure 24 the stations having the strongest tendency during the period 13-15 August lie between 3000 and 4100 feet in elevation (Fanno, Hebo, Bald and Marys Peak) and during the period 18-22 August at about 3200 feet (Fanno, Hebo, and Bald). At these stations during the nighttime hours and during all hours at the stations not exhibiting a rhythm there seems to be a rather uniform level of moisture, changing perhaps slowly through a period of several days.

In Figure 25, representing stations at various elevations in a single topographic basin, the diurnal rhythm is most intense at the lower elevation stations and almost disappears on the ridgetops.

The appearance of a diurnal rhythm in a narrow altitudinal zone with none above or below as in Figure 24 may be explained by the appearance of an internal wave with period of 1 day on a surface of moisture discontinuity, in this case lying in the mean at about 3200 feet above sea level. If this mechanism is indeed the cause of the diurnal oscillations in Figure 24, it appears that there was during 18-22 August an increase in mixing ratio upward from about 8.5 o/oo at 1500 feet to about 14 o/oo at some level near 3200 feet, then an abrupt decrease in mixing ratio to around 11 o/oo just above that. During 13-15 August the entire "sounding" seems to have been drier by about 4 o/oo. Several details as to the behavior of such a surface may be deduced from the figure:

a) The surface appears to rise above the middle elevation stations during the daylight hours and to subside below them during the nighttime hours, as evidenced by the increase in moisture during the day at those stations having a diurnal rhythm.

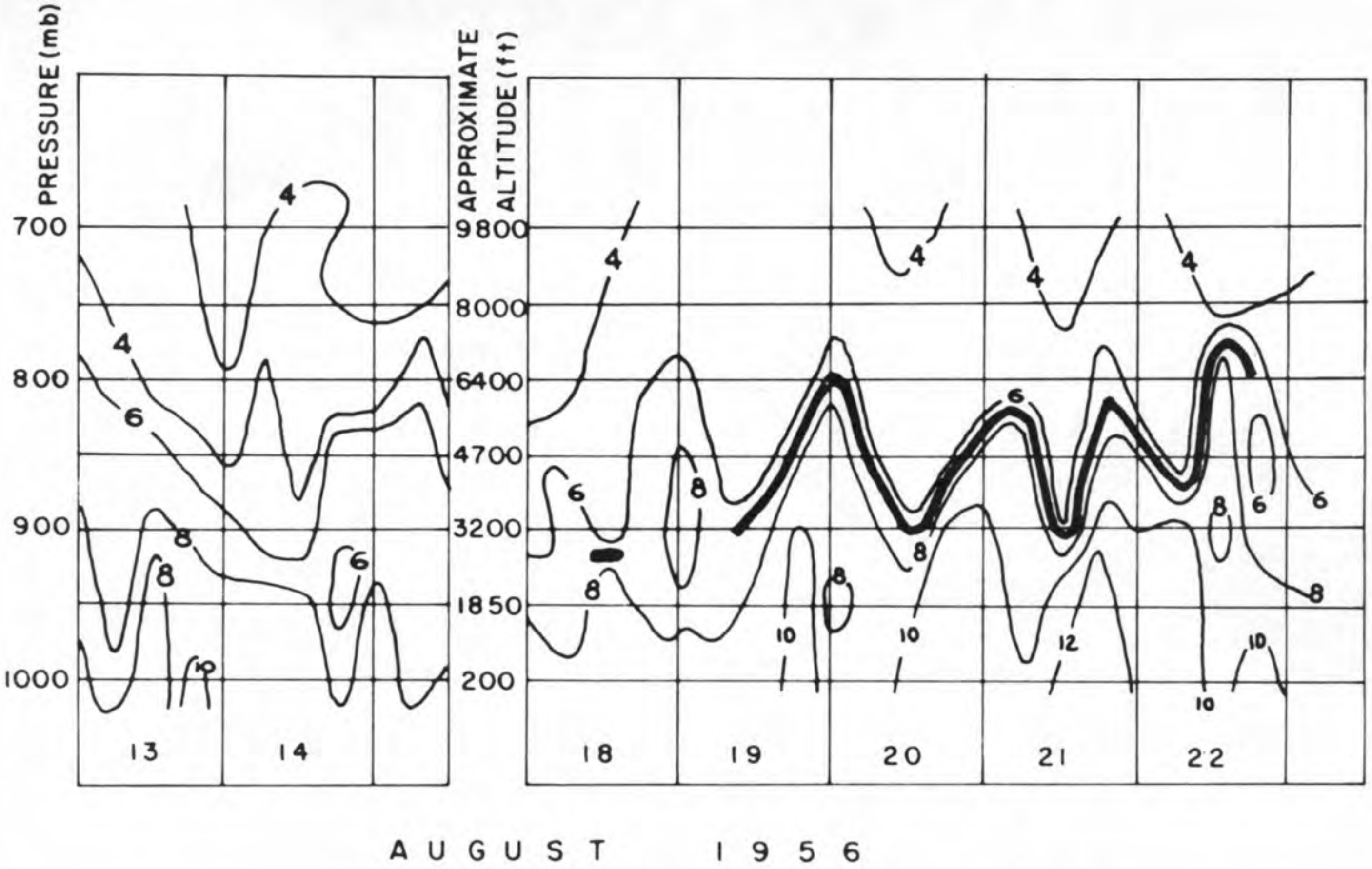
b) The zone of discontinuity and high moisture content appears to have spanned the elevational range from 3200 feet to 4100 feet on 14 August, since Marys Peak's record resembles rather closely those of Fanno, Hebo, and Bald on that day.

c) The surface appears barely to have reached the elevations of Fanno, Hebo, and Bald just before midnight on 13-14 August in what was apparently an anomalous rising of the surface during a time when it was customarily subsiding.

d) The surface seems to have risen just barely to the elevation of Marys Peak in the early afternoon of both 20 and 21 August, as shown by the brief but abrupt increases in mixing ratio at those times.

The large amplitude of diurnal variation of moisture at stations in the bottom of the Valsetz Basin (Figure 25) and the generally higher values of the mixing ratio around midday here as compared with the peak stations of Figure 24 point to the role of evapotranspiration and condensation in moisture changes over the Coast Range. This effect probably accounts for the observed diurnal cycle having increased moisture during the day and less at night at stations so located as to be down within the forested folds of the Coast Range terrain. Separate from the effects of the undulating surface of discontinuity, which probably represents a structural feature of the atmosphere over the entire region, this pattern of water exchange at the earth's surface is probably detectable within the lowest few hundred feet above any of the more heavily vegetated parts of the area. The two processes, the internal waves and the moisture flux at the surface, undoubtedly interact in various ways which, when combined with other transitory and random effects of passing synoptic scale elements, produce exceedingly complex patterns of moisture distribution over the Coast Range. That the former exists seems very likely from the nature of the data presented; that the latter truly exists in a magnitude large enough to be detected by the measurements presented must remain a subject for further investigation. In any case they combine to produce a reasonable model to explain the observations.

Another aspect of the distribution of moisture above the area under study becomes apparent in Figure 26, which presents a time cross section of mixing ratio over Salem (69) during the same periods depicted in Figures 24 and 25. Though the patterns and values of the mixing ratio are not in exact accord with the vertical distribution deduced from Figure 24 for the Coast Range area, there certainly appears consistently a distinct moisture discontinuity, as indicated by the heavy line through the field at about the location of what would be the 7 o/oo isopleth. The interesting thing about this discontinuity, rising and falling in a nearly perfect period of 1 day, is that it rose during the nighttime hours and subsided during midday. It was, in other words, about 12 hours out of phase with the cycle over the coastal mountains.



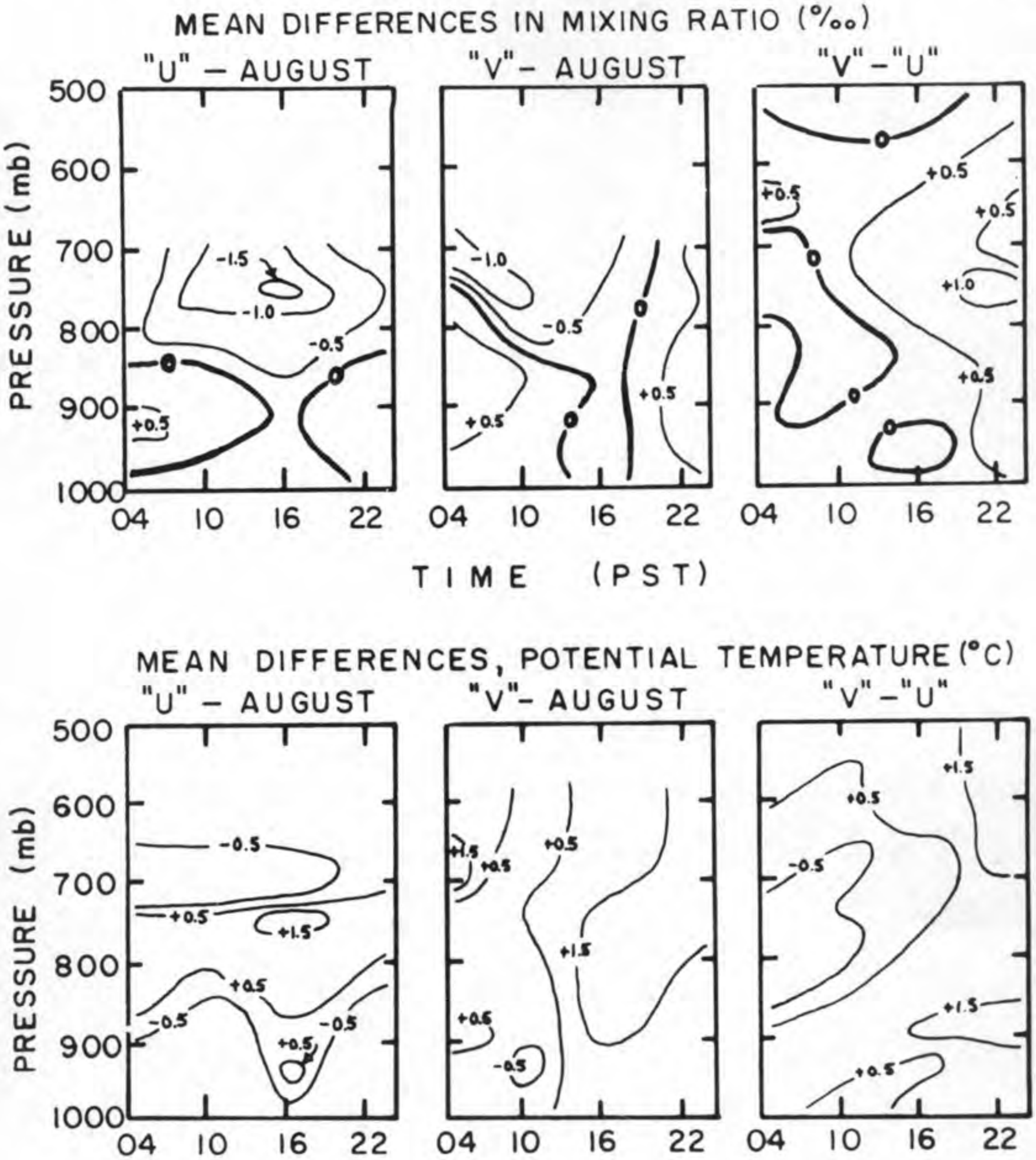
MIXING RATIO OVER SALEM

FIGURE 26

If one can accept the notion that the differences in moisture distribution between Figures 24 and 26 are due to the source of surface moisture flux being near the level of the discontinuity in the former case and near sea level in the latter, the resulting model features a surface of discontinuity at about 3000 feet with a wave form moving inland each day so as to produce passage of a crest over the coastal areas about midday and over the inland regions roughly 80 km inland after sunset. This pattern agrees in a striking way, as to timing, rate of wave motion, and spatial dimensions, with the model proposed by Edinger (20) to explain the variations in height of the marine inversion over the Los Angeles Basin.

The fact that the moisture discontinuity over Salem does not appear so clearly during the period 13-15 August 1956 is probably due to minor frontal passages on a scale larger than the sea breeze on 13 and 14 August (66). During the period 18-22 August, however, the surface is quite marked. The appearance of more and more moisture with time in the levels below 900 mb may be due to the daily flow of marine air into the Willamette Valley during this period. This explanation of increasing moisture at the surface appears the more valid when one notes how the discontinuity at about 850 mb remains almost unchanged in both location and mixing ratio while the moisture content builds up below it.

As shown in Figure 27, the two types of sea breeze day exhibit different patterns of moisture distribution above the surface. The ordinate in each of the drawings is pressure, the abscissa time. In the upper group of drawings the isopleths are of differences in mean



ANOMALIES IN VERTICAL DISTRIBUTION OF
MIXING RATIO AND POTENTIAL TEMPERATURE
OVER SALEM

FIGURE 27

mixing ratio between the sample of five U-type days and all the days of August 1957. The lower left drawing is the same, but with differences in mean potential temperature presented. The other drawings exhibit differences between the sample of V-type days and August days and between the U-type and V-type days. Absence of entries above 700 mb in two of the drawings is because of "motorboating" of the radiosonde in very dry air on such a high proportion of the August days.

Interpreting the drawings of Figure 27 broadly, there seems to be a persistence throughout the day of relatively warm, dry air between 850 and 700 mb in the case of the U-type, but a general change to a warm, moist air from the surface up to 700 mb in the late afternoon in the V-type. This interpretation supports the idea that the V-type is associated with a true "cool change" representing a deep and distinct change of air mass, while the U-type represents a non-advective wind surge superimposed on a relatively static set of stratified air masses.

In summary, the following appear to be tenable conclusions concerning the field of moisture above the northwest Oregon area during the summer months:

a) Recordings of relative humidity on peaks and prominences in the Oregon Coast Range exhibit very little indication of regularity or diurnal rhythm, in agreement with published results from other west coast areas.

b) When moisture data are presented as values of the mixing ratio, a strong diurnal cycle becomes apparent in the atmosphere over both the Coast Range and Salem, an inland station.

c) The fact that the moisture is introduced into the atmosphere through a flux at the surface at about 200 feet in the Willamette Valley and at about 3000 feet above sea level in the Coast Range produces distinctly different vertical distributions of moisture in the lower layers over the two areas.

d) When allowance is made for the evapotranspirational flux mentioned in c), observations reveal a horizontal surface of moisture discontinuity over the area upon which is imposed a wave form moving inland during each sea breeze day.

e) During a period through which the sea breeze cycle persists from day to day, moisture is advected from the coast to the inland valleys where it accumulates in the lower layers with very little vertical transport through the surface of discontinuity.

f) V-type sea breeze days, as compared with U-type days, experience a deep and distinct change of air mass from warm and dry to warm and moist up to at least 700 mb in the late afternoon. The U-type experiences essentially a simple diurnal pattern with moisture changes taking place only near the surface.

Nocturnal dry periods. The work of Ellis (22), of Lindquist (41), and of Schroeder (55) showed, as mentioned above, that in coastal mountains in the western United States the daily minimum of relative humidity frequently occurs during the night. Records gathered in the Valsetz and Bald Mountain areas of the Oregon Coast

Range (42, 64) and during the special observational program in 1957 (see p. 31) all show there is a strong tendency for nocturnal drying periods in the coastal mountains of northwest Oregon. The effect is most marked at peak and ridgetop stations above about 2000 feet. While they do experience distinct periods of nocturnal drying, stations at lower elevations and on less exposed sites tend to have a more normal diurnal cycle of relative humidity with the daily minimum during the afternoon. The nocturnal minima, then, become only relative minima.

Because they provided the only available series of data of sufficient length from the elevation zone near 2000 feet, the results of the 1956 observational program in the Valsetz Basin (p. 30) were analyzed in this study of the nocturnal drying periods. As an indication of the general level of nocturnal relative humidity at different elevations in the coast range terrain, Table 10 presents for the two months of record at Valsetz the distributions of mean relative humidity during the hours 1800 to 0600 PST at the six stations located in the open. The stations whose designations begin with "S" lay on a north facing slope and those with "N" on a south facing slope. The entries in the table come in pairs, the first number being a percentage of all days in the series and the second a percentage of all days classed as 2 or 3 on the sea breeze scale. As may be seen from the table, there is a relative increase in values in the range 70% to 90% on sea breeze days at the expense of the very moist and very dry classes, especially at the higher stations. This indicates some drying at exposed stations is more likely during a

TABLE 10

RELATIVE FREQUENCY OF MEAN RELATIVE HUMIDITY FOR THE PERIOD 1800 TO 0600 PST DURING JULY TO SEPTEMBER 1956 IN THE VALSETZ BASIN, OREGON

(PER CENT)*

Station	Elevation	Mean Relative Humidity, 1800-0600 PST (Per cent)							
	(Feet, MSL)	30-39	40-49	50-59	60-69	70-79	80-89	90-94	95-100
N3A	2660		6/7	6/7	4/ 7	21/28	21/28	11/17	32/ 7
S3A	2325	2/0	5/3	2/3	12/22	23/29	18/24	12/ 6	28/15
S2	1895	2/0	3/3	2/3	5/12	17/21	24/29	19/18	28/15
N2	1750		4/0		4/ 7	7/ 7	16/17	11/17	59/53
S1A	1370		5/3	2/3	3/ 6	5/ 6	9/ 6	29/33	48/42
N1A	1230	2/0				2/ 3	0/ 6	8/12	86/85

* The first entry in each pair refers to frequency relative to the entire sample, while the second entry is a conditional frequency for the sub-sample of sea breeze days.

night following a sea breeze than during summer nights in general.

Table 11 presents for the same period and for the same six stations as just discussed the distributions of the actual minimum of relative humidity experienced during the hours 2200 to 0400 PST. Again the entries appear in pairs, the first being for all days and the second being for days classed as 2 or 3. Table 12 condenses somewhat the results of Table 11 by showing the effect of the sea breeze in changing the likelihood the nocturnal relative humidity minimum will be below two selected thresholds: 80% and 50%. It is clear the occurrence of a sea breeze is followed during the night by some mechanism producing greater likelihood of a dry period at stations above about 2000 feet and less likelihood of a dry period at lower stations as compared with summer nights in general. A proposed mechanism explaining these results is discussed later.

In summary, the sample examined indicates that in the coastal terrain on northwest Oregon the occurrence of a sea breeze is followed during the night by a greater likelihood of moderate drying at well exposed sites and a decreased likelihood of both extreme drying and the absence of drying. At the lower, less exposed locations, the sea breeze simply reduces the likelihood of any nocturnal drying.

<u>Calculated variations in the depth of an hypothetical marine layer</u>. In view of the approximate congruence of the top of the layer having an adiabatic lapse rate and the top of the layer having about the same moisture content observed at the beach, as shown in Figure 8, it should be reasonable to assume the adiabatic layer and the marine layer identical. Let us also assume, usefully though probably less

TABLE 11

RELATIVE FREQUENCY OF MINIMUM RELATIVE HUMIDITY FOR THE PERIOD 2200 TO 0400 PST DURING JULY TO SEPTEMBER 1956 IN THE VALSETZ BASIN, OREGON (PER CENT)*

Station	Elevation (Feet, MSL)	Minimum Relative Humidity 2200-0400 PST (Per cent)						
		less than 50	50-59	60-69	70-79	80-89	90-94	95-100
N3A	2660	15/21	15/ 9	7/24	20/18	10/18	15/ 3	20/ 9
S3A	2325	11/14	13/20	18/11	13/17	14/23	16/ 6	16/ 9
S2	1895	8/ 7	2/ 3	16/25	15/19	13/19	25/17	21/11
N2	1750	4/ 0	2/ 3	5/10	14/10	11/20	20/17	45/40
S1A	1370	7/ 3	3/ 8	7/ 3	10/ 8	13/22	19/17	42/39
N1A	1230	3/ 3				3/ 3	5/ 8	89/87

* The first entry in each pair refers to the frequency relative to the entire sample, while the second entry is a conditional frequency for the sub-sample of sea breeze days.

TABLE 12

RELATIVE FREQUENCY OF NIGHTS WHEN THE MINIMUM RELATIVE HUMIDITY DURING THE PERIOD 2200 TO 0400 PST WAS BELOW 80 PER CENT AND BELOW 50 PER CENT (PER CENT)

Station	Elevation	Threshold 80 percent		Threshold 50 percent	
		All days	Sea breeze days	All days	Sea breeze days
N3A	2660	56	71	15	21
S3A	2325	54	63	11	14
S2	1895	41	53	8	6
N2	1750	25	23	4	0
S1A	1370	26	22	7	3
N1A	1230	3	3	3	3

realistically, that the marine layer is bounded below by the sea level surface and above by a constant pressure surface. The rationale for the latter assumption will appear later.

Taking the equation for the depth of a layer in the atmosphere (27, p. 50):

$$H = \frac{T_o}{\gamma}\left[1 - \left(\frac{p}{p_o}\right)^{\frac{R_d\gamma}{g}}\right] \qquad (3)$$

and combining it with the equation defining the potential temperature:

$$\theta = T\left(\frac{1000}{p}\right)^{R_d/C_p} \qquad (4)$$

yields the following when the derivative is taken with respect to the x-axis, perpendicular to the coastline, and when both p and γ are assumed constant:

$$\frac{dH}{dx} = \left[\frac{1}{\gamma}\left(\frac{p}{1000}\right)^{K}\left(1 - \left(\frac{p}{p_o}\right)\right)^{L}\right]\frac{d\theta}{dx} + \left[\frac{L\theta p^{K+L}}{\gamma(1000)^{K} p_o^{L+1}}\right]\frac{dp_o}{dx} \qquad (5)$$

In these equations H is the depth of the layer and the altitude of its top if the bottom surface is assumed horizontal and at sea level. T_o is the temperature at the surface, γ the lapse rate of temperature, p_o the sea level pressure, p the pressure at the top of the layer, θ the potential temperature of the adiabatic layer, R_d the gas constant for dry air, g the acceleration due to gravity, and c_p the specific heat of dry air at constant pressure. Also $K = R_d/c_p$ and $L = \gamma/g$.

Assume, as mentioned, that γ is everywhere equal to the dry adiabatic lapse rate; that θ is 290 K, a reasonable value for the area near the beach; and that p is equal to 940 mb, representing an approximate depth of 2000 feet. Assume also, as a convenient if slightly inconsistent approximation, that p = 1000 mb. Equation 5 then reduces to:

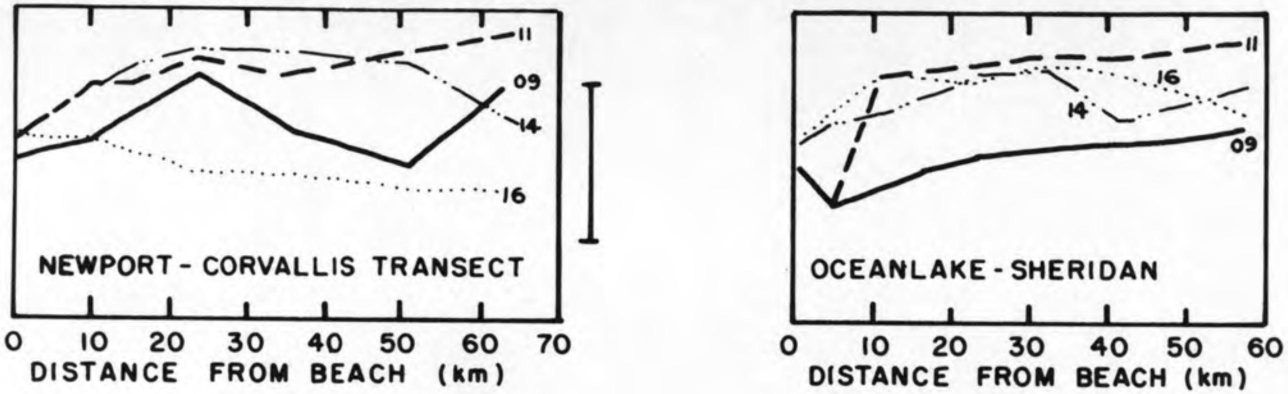
$$\frac{dH}{dx} = \left(.0175 \times 10^4\right)\frac{d\theta}{dx} + \left(.082 \times 10^4\right)\frac{dp_0}{dx} \qquad (6)$$

when the following values are also inserted: K = 0.288, L = 0.287.

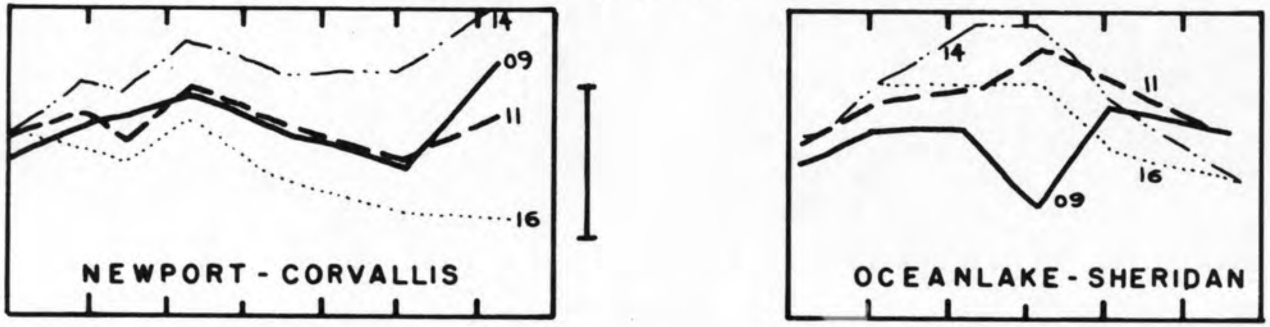
From recordings and observations of temperature and pressure altitude obtained along the two surface transects during the summer of 1957 the writer obtained for four times during each of the five clear days of record, values of $\frac{d\theta}{dx}$ and $\frac{dp_0}{dx}$ between each pair of adjacent stations on both transects. Conversion of temperatures to potential temperatures was based on known station altitudes and assumption of the Standard Atmosphere. Conversion of pressure altitude to pressure was accomplished by assuming pressure changes linearly with altitude in the bottom 1000 feet of the atmosphere at the rate of 1 mb per 30 feet.

The results of these computations of the slope of the top of the sea breeze layer, which has a pressure of 940 mb everywhere, are presented in Figure 28. The figure shows the shape of the top of the layer as a mean of five days and for a representative one of the five, 24 July 1957, the assumptions having been made that the surface rises above the beach 200 feet per hour until noon and remains constant thereafter (20), and that the shape may be drawn

MEAN OF FIVE CLEAR DAYS



24 JULY 1957



DIURNAL CHANGE IN TOP OF ADIABATIC LAYER MODEL

FIGURE 28

by beginning at a point over the beach and applying the computed slopes consecutively inland to a continuous surface. The computations of the slopes are shown in Appendix G.

The cross sections in Figure 28 suggest the top surface of the hypothetical marine layer heaves up in its middle portion (over the Coast Range) during midday and then subsides more rapidly during the afternoon. The striking similarities in shape and dimensions of the top of the adiabatic layer in Figure 8 and the surfaces depicted in the top of Figure 28 have been taken by the writer as justification for the assumptions regarding the lapse rate and pressures associated with the hypothetical marine layer.

The crest-to-trough dimension of the oscillations in Figure 28 is of the order of 1 km, in agreement with the dimension in Figure 8. Edinger (20) calculates the range of oscillation of the marine inversion over Los Angeles during the hours 0800 to 1800 PST is about 900 feet, or 0.27 km. During the same relative portion of the day, the surface over Salem (Figure 26) had a range of 11/14 of its complete diurnal range. Proportionally, then, the full range over Los Angeles, had the observations there been around the clock, should have been about (14/11)(0.27) km, or 0.34 km.

The amplitude of an internal wave is of an order of magnitude inversely proportional to the density difference between the two fluids or to the square root of that difference, depending upon the exact conditions producing and propagating the internal wave (29, p. 742), (45). If we assume the oscillations of the surface over Salem and the Coast Range are analogous to those of a true internal wave, and if we invoke the equation of state together with the proportionalities just cited, we find the vertical dimension of oscillation over Salem, A_s, may be calculated as follows:

$$A_S = A_L \left[\left(\frac{p_L}{p_S}\right)\left(\frac{T_2-T_1}{T_2T_1}\right)\left(\frac{T_4T_3}{T_4-T_3}\right)\right]^{\frac{1}{2} \text{ or } 1}$$

if we also assume equal impulses producing the waves in both places. Here $A_L = 0.34$ km, the vertical dimension over Los Angeles; $p_L = 960$ mb, the approximate mean pressure at the base of the marine inversion over Los Angeles; $p_S = 900$ mb, the approximate mean pressure of the surface over Salem; $T_1 = 294$ K, the potential temperature beneath the Los Angeles inversion; $T_2 = 304$ K, the potential temperature above the Los Angeles inversion; $T_3 = 296$ K and $T_4 = 300$ K, the potential temperatures below and above the surface over Salem. These values yield $A_S = 0.55$ km in the case of the square root proportionality and 0.93 km in the case of the simple inverse proportionality to density difference. While not completely bridging the gap between the value of 0.34 km over Los Angeles and the observed value of about 1 km over Salem, these computed values of the range of oscillation over Salem seem reasonable considering the following implicit assumptions: 1) the waves are internal waves, 2) the sea breeze was the only impulse producing oscillation in both places, 3) the impulse energies were the same in both places, and 4) the two observation points are the same distance downstream from the respective points of application of the impulses. In brief, it is felt that differences in intensity and height of the two surfaces explain most of the difference in their observed ranges of oscillation.

Forestry operations. As mentioned earlier, the writer used a questionnaire to supplement scant published information on the effects of the sea breeze on forestry operations. The questionnaire appears in Appendix H. It was mailed first to twenty executives who represented a variety of industrial forestry operations distributed across the entire northwestern portion of Oregon. No governmental foresters were approached with the questionnaire. Of the twenty, twelve individuals responded to the questionnaire. There was almost no mention made in the replies of any effects on mill and plant operations. Accordingly, a second set of questionnaires was mailed, each marked "Please note: we are particularly interested in information with respect to Mills and Plants." Of the fifteen sent, eight were returned; however, little additional information on plant operations was obtained.

With twenty questionnaires returned and with the second group showing essentially the same information as the first, the writer decided the distinct patterns emerging from the accumulated responses would be unlikely to change with further mailings.

The questionnaire included a description of the sea breeze in an attempt to insure the respondents would all be thinking of the same phenomenon while answering. It is probable the nature of this description detracted from the objectivity of the results; however, several of the patterns of reaction revealed by the answers are so clear-cut, the writer feels they are valid despite the reduced objectivity.

Of the twenty replies, only one indicated no recognition of the sea breeze in Question 1. The reply was from Independence, Oregon. Even allowing for the pre-conditioning of the response by the information contained in the description of the sea breeze, this result attests to the widespread recognition of the sea breeze as a distinct element of the summer climate in the area.

The replies to Questions 2 and 3, regarding frequency and timing of the sea breeze, certainly agree closely with the description of the sea breeze included in the questionnaire, but they were probably so subject to being affected by the description that discussion of them would probably be fruitless.

Of the twenty replies to Question 4, five indicated no effect of the sea breeze on the respondent's operations, but ten indicated an effect which might best be described in the following reply: "It keeps humidities high and enables us to log when normally we would be forced to shut down." The necessity to shut down referred to is brought about through the force of Oregon law (51) which specifies that harvesting operations on forest lands shall cease when the relative humidity at the operating site falls below 30 per cent. The respondent probably meant to say "otherwise" rather than "normally", for humidities lower than 30 per cent are exceptional in the area (44). That half the respondents noted this effect of higher relative humidities on operations and no other effect was noted by more than two respondents confirms the earlier conclusion that the sea breeze effects forestry operations most extensively in the area of fire weather.

Other responses to Question 4 indicate, however, that effects of the sea breeze are at least noticeable in other areas of forestry:

> Regeneration: "Survival of seedling fir trees appears to be better than in other parts of the state."
>
> Regeneration and protection: "Influences time of day of aerial spraying and seeding."
>
> Industrial psychology: "Tendency to reduce heat thereby more efficiency from workmen."
>
> Fire behavior: "Affects slash burning and fire fighting."
>
> Plant layout: "Our log pond is laid out so that the strong northwest wind helps push log supply toward our mill."
>
> Plant security: "During (the sea breeze season) we have to keep an unusually sharp lookout for spot fires around mill and yard caused from our refuse burner."

Of the responses to Question 5 concerning nature of adjustments made in response to presence or absence of the sea breeze on a particular day, 8 respondents indicated no adjustments made, 6 made no comment, 4 mentioned cessation or rescheduling hours of logging and 2 mentioned addition of personnel to plant fire patrol.

One response is particularly interesting. Of several such replies, it suggests the most clearly that there are in fact many adjustments made to the sea breeze but that the phenomenon is not recognized explicitly as a weather element to be reckoned with.

> "I don't believe the sea breeze is often and regular enough to depend on it to influence our conduct of operation. Although we count on this changing wind in slash burning and firefighting."

It is an interesting commentary, if true, that many people clearly recognize the existence of a weather factor but do not recognize its impact on their work even when the impact exists and they are asked specifically to examine it.

In response to Question 6, concerning the availability of records and accounts to research personnel, 14 respondents said no records were available and 6 made no reply. No records were proffered for further scrutiny by research personnel.

A conference with the Supervisor and the Fire Control Officer of the Siuslaw National Forest, the only National Forest having jurisdiction in the Coast Range portion of the area under study, revealed three points of adjustment of operations by the U.S. Forest Service in response to the sea breeze.

With respect to wild fires, the operating plan on the Forest includes a specification that the hours between 1000 PST and 1600 PST next following discovery of a fire are to be considered the critical period in its suppression. As for controlled, or slash, fires, it is the general policy of the Forest to ignite the fire so it will burn into the night and complete the "mop-up" before 1000 PST the next day. In addition, summer is recognized by the Siuslaw personnel as a season in which fuels will dry out slowly but steadily, thus leading to flexibility of scheduling and to a more complete burn, while at the same time being a season with a relatively low probability of rapid drying conditions and high rates of fire spread under the influence of the area's foehn: The East Wind.

DISCUSSION

The two types of sea breeze day. In order to evaluate and synthesize pertinent results of the foregoing, the writer would like to give here a brief summary of those results. It has been noted that relative humidity traces at stations in the Willamette Valley exhibit two rather distinct types of behavior on sea breeze days. On "U" days the midday trace has a U shape with no distinct minimum, while on "V" days there is a sharp and definite minimum giving the trace a V shape.

Several differences between the two types of days have been noted. V-type days experience higher midday temperatures and less advective cooling in the Coast Range and on the piedmont of the Coast Range. Also, V-type days experience on the average greater pressure differences between Astoria and Salem beginning about 1000 PST. With regard to wind behavior at Salem, V-type days apparently are more typical of the average midsummer day than are the U-type days.

At one point the writer has speculated V-days are the Oregon equivalent of what Berson calls "cool changes", or definite changes of air mass, while at another he ventured that among V-type days non-advective wind surges are about twice as frequent as "cool changes". These two tentative conclusions are in partial conflict, but may be resolved presently.

The tendency for a more frequent and persistent occurrence of early morning low clouds covering most of the sky at Salem has been noted on U-type as compared with V-type days. In addition, the occurrence of a distinct change of air mass properties up to at least 700 mb during the afternoon on "V" days has been brought out. This pattern has been contrasted with the change of air mass characteristics only below about 850 mb on "U" days, with no apparent change above that level.

As for the occurrence of higher mean temperatures and lower mean relative humidities at midday on V-type days, the following may offer at least a partial explanation. If Staley is correct in saying that the inland edge of a stratus deck in the morning acts like a shoreline with respect to differential heating and locally generated circulation near the surface, it appears days of the "U" type should, with their greater incidence of early morning low clouds, experience a sea-breeze type of circulation at both the coastline and the inland slopes of the Coast Range. The V-type day, without this second local circulation, would be a more nearly "pure" sea breeze regime. It follows that on U-type days there should be advective cooling at inland stations all through the daylight hours, brought first by the circulation generated inland and later by the landward moving one generated at the coastline. V-type days would not experience cooling until the wind generated at the coastline reached inland in the afternoon, and the relative calm at Coast Range stations under an area of convergence ahead of the "frontal passage" in the afternoon would tend to allow temperatures to rise locally with resulting falls in relative humidity.

If, at Coast Range stations the last effects of the circulation generated at the edge of a cloud deck were felt simultaneously with the first effects of the sea breeze from the coast near midday, there should be a temporary rise in relative humidity resulting in a W-shaped trace of relative humidity during the day. Appearance of such traces at Coast Range stations, generally on days with a U-shaped trace at inland stations and not on days with V-shaped traces inland tends to support this idea. As noted previously, W-shaped traces were scarcely ever observed at Corvallis or Sheridan while being rather frequent at Burnt Woods and Grand Ronde in the Coast Range.

As for the partial contradiction involving the association of the "cool change" with one or the other of the two types of sea breeze day, the matter may be resolved in large measure by the suggestion that while the "cool change" may produce a pattern which would be classed as a "V" day, not all V-type days experience a "cool change". U-type days, it should then be added, experience "cool changes" only very rarely. From this point of view, then, the primary difference between the two types of day lies in whether or not a cloud deck generates a secondary circulation inland; and the "cool changes", when they occur, produce a V-type regime at the surface. Resolution of the matter of whether higher than usual speeds of sea breeze "fronts" occur generally in northwest Oregon or only in association with V-types and "cool changes" will not be attempted in this thesis.

Whatever the reasons for the differences in the two types of sea breeze day, they are related to very subtle differences in behavior of the atmosphere in general over the area, even though they produce differences in relative humidity of as much as 25% in the early afternoon at the surface. Except after further investigation of the proposed model involving early morning clouds, attempts to forecast one type of day or the other would probably be disappointing. In view of the implications for fire danger, however, any degree of success in such forecasts would probably be very much worth the while.

A proposed model of the low level sea breeze in northwest Oregon. Seven of the principal features of the sea breeze regime in northwest Oregon may be explained by a descriptive model. These features are:

a) the strong morning temperature inversion and vertical moisture gradient at about 3000 feet above the Willamette Valley,

b) the arrival of distinctly marine moisture characteristics at the surface in the Willamette Valley only after sunset,

c) the 24-hour cycle of mixing ratio at Coast Range stations in which maximum values occur at midday and minimum values at night,

d) the 24-hour cycle of mixing ratio at about 900 mb over Salem in which minimum values occur at midday and maximum values at night,

e) the nature of diurnal periodicity of station pressure throughout the area, with increasing amplitudes of oscillation inland,

f) the 24-hour cycle of east-west station pressure differences, with maxima in midday and minima at night, and

g) the double maximum in relative frequency of low clouds over Salem between 0400 and 1000 PST on sea breeze days.

The proposed model explaining these seven and other, less definite features of the sea breeze regime appears in Figure 29. The figure depicts cross sections of the lower atmosphere between the coastline and the crest of the Cascades Mountains as seen by an observer looking north. From top to bottom, the drawings represent conditions at six-hour intervals beginning at about 1600 PST. Two surfaces in the free atmosphere are depicted in each drawing: the marine inversion base or top of the "marine layer" shown by the solid line, and the condensation level shown by the pecked line. East-west components of the wind at various levels as gleaned from the observations of the Forest Service - Weather Bureau program in 1956 (64) and computed from upper air data of the Weather Bureau (69 and page 105 of this report) are shown as small, horizontal arrows whose lengths are roughly proportional to speed. "C" represents zero east-west component of the wind, but not in general "calm".

In the top drawing for 1600 PST, the condensation level rises abruptly inland because of non-adiabatic heating over the inland portions of the area. There is a wave crest imposed upon the base of the marine inversion and located at this hour over the crestline of the Coast Range. The energy initiating this moving wave crest enters the system through a combination of insolation, resulting convection, and a moving zone of convergence as hypothesized by Edinger in his model of the Los Angeles sea breeze and marine

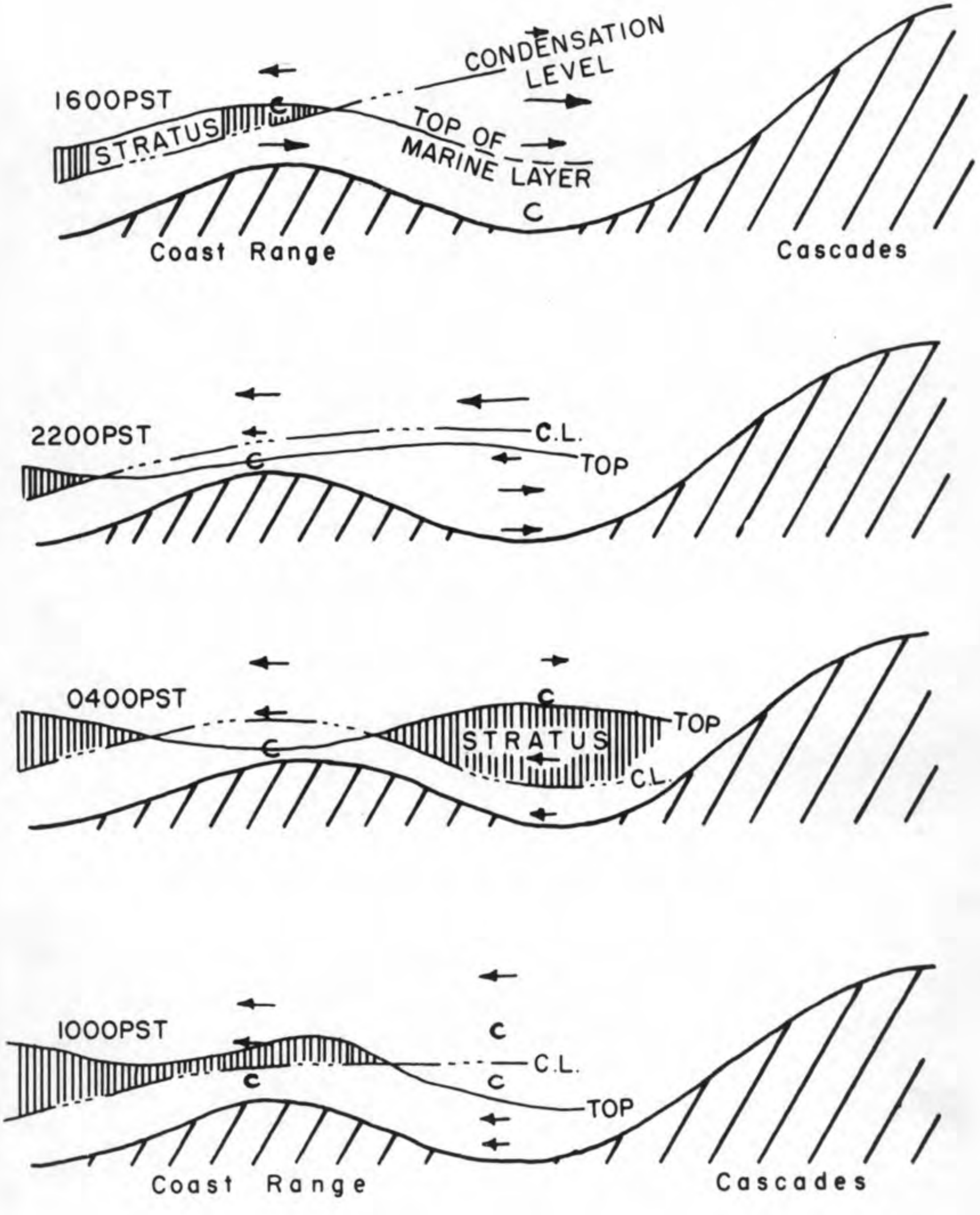


FIGURE 29

Proposed model of the sea breeze of northwest Oregon.

inversion (20, 21). The result of the spatial relationship between the top of the marine layer and the condensation level is a deck of stratus clouds reaching inland from the beach and terminating just inland of the Coast Range, as so often observed on sea breeze days in the area.

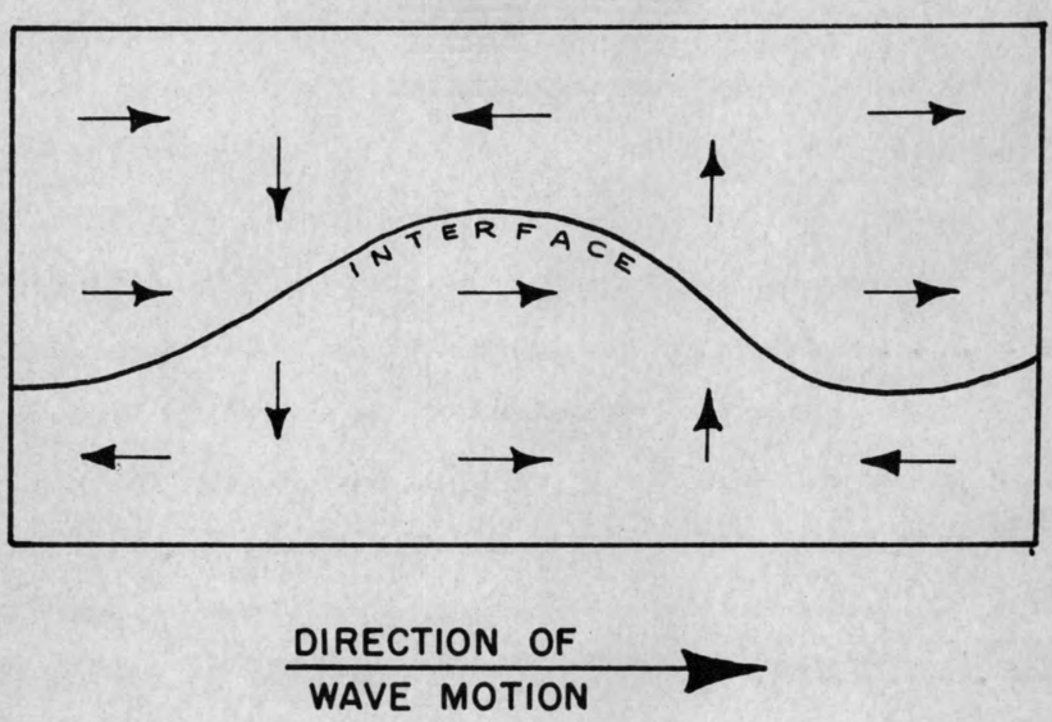
In the second drawing, for 2200 PST, the condensation level has subsided over the inland areas, and the crest of the moving wave form on the marine inversion base now lies over the Willamette Valley. Because the condensation level is still above the inversion base, there are no stratus clouds over the valley. The marine layer is becoming quite shallow over the Coast Range ridges.

The third drawing, representing conditions at about 0400 PST, shows a condensation level quite low over all portions of the area as a result of previous nocturnal radiant cooling under clear skies during the midnight hours. The wave crest on the marine inversion base is now above the Willamette Valley and moving toward the coast. The condensation level being now below the inversion base over the valley, a deck of stratus appears there and thins out toward east and west from the center of the valley. The prominent peaks and ridges of the Coast Range now protrude above the inversion base and are experiencing warmer, drier conditions than formerly. The amplitude of the wave crest now moving out to sea is sufficient to produce a slight secondary oscillation of about 12-hour period in surface pressure but insufficient to modify significantly the oscillation of 24-hour period in mixing ratio above Salem.

At 1000 PST, in the last drawing, the condensation level has risen markedly above the region of greatest surface heating: the piedmont region of the Coast Range. The crest of the wave form moving toward the coast is over the central Coast Range, while the rudiments of the current day's wave are taking shape over the coastal strip and starting to move inland. Over the seaward slopes of the coastal mountains, then, there are two wave forms colliding: a weak one moving out to sea and a new and vigorous one moving inland.

Figure 30 depicts a cross section of an internal wave on the interface between two fluids of different densities. Lines of fluid flow, based on models proposed for water waves (e.g. 6, p. 4) are included together with a large arrow indicating direction of movement of the wave crest. If one combines the field of flow in this model, appropriately placed as to location of wave crest and direction of crest movement, with a component representing a gentle flow out to sea above about 850 mb during the nighttime hours, the resulting field of flow will agree almost exactly with that described by the wind arrows in Figure 29. Such a gentle land breeze at higher levels has not been postulated before to the writer's knowledge, but, when thought is given the possibility of a drainage wind off the Cascades above the marine inversion at night, appears quite a reasonable mechanism.

Following the model of water waves, the speed of a fluid particle in a circular orbit produced by a moving wave would be $2\pi R/T$, where R is the amplitude of the wave and T the period. In the case of the wave on the marine inversion, the amplitude is about 0.25 mi, and the period 12 hr, so the speed would be of the



MOTIONS DUE TO MOVEMENT
OF AN INTERNAL WAVE ON AN
INTERFACE BETWEEN FLUIDS
(AFTER BIGELOW & EDMONDSON)

FIGURE 30

order of 0.1 mph or 6 cm/sec. Appropriate to vertical winds observed under such circumstances, this figure is about 1/20 the observed horizontal east-west components of the wind in the system.

Consideration of the moving wave form in the model as a gravitational wave results in a similar difficulty with respect to rate of movement. Employing a wavelength of 100 km (about twice the distance from the Coast Range crestline to Salem) and a density difference of 0.2 per cent between the air below the base of the inversion and the air above results in a speed for the crest of a gravitational wave* of about 225 km/6 hr, or between 4 and 5 times the hypothesized speed of the wave form in the model.

It is clear, in view of the above, that the hypothetical wave in the model of Figure 29 cannot be treated as a purely gravitational wave. Its qualitative agreement with the theoretical wind field of a gravitational wave, its agreement during daylight hours with the model proposed by Edinger (20), and its ability to account for such a variety of observations, however, have led the writer to conclude the wave is present in the form described, though it is caused by an unspecified combination of mechanisms. It is, in brief, a wave form

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* The formula used in computing the theoretical speed of the gravitational wave is:

$$c = \sqrt{(gl/2\pi)\left[(\rho-\rho')/(\rho+\rho')\right]}$$

where c is the speed of the wave, g the acceleration due to gravity, l the wavelength, ρ the density of the air below the surface of the wave, and ρ' the density above. The formula may be found, among other places, on page 285 of "Dynamic Meteorology" by B. Haurwitz, New York, McGraw-Hill, 1941. 365 p.

having the appearance of a gravitational wave but actually one impressed on the undulating surface marking the top of the marine layer, in a manner similar to Edinger's "wave of positive anomaly .... followed by a trough of negative anomaly." (20, p. 226)

Though the mechanisms producing the daytime portions of the model seem well established by Edinger, the effective mechanisms producing the oscillations at night require further clarification. A "surge" of marine air up the slopes of the Cascades during the night, followed by a return flow off these slopes during the early morning, analogous to the action of surf on a beach, seems in general a reasonable basic mechanism to explain this portion of the model. This motion combined with drainage winds from the Cascades and Coast Range into the Willamette Valley during the night and valley winds up these same slopes during the morning could explain the deepening of the marine layer over the center of the valley at night and its shallowing during the morning.

Examination of the calculated shape of the top of the marine layer in Figure 28 tends to verify two particular features of the proposed model. One feature is the general shallowing of the layer during the afternoon following a midday pattern featuring a thicker layer with a wave crest over the Coast Range. Another feature apparently verified is the existence at about 0900 PST of two wave crests over the Coast Range, these being the two colliding crests hypothesized for the morning hours.

In concluding discussion of the proposed model, it should be pointed out that it disagrees with the hypothesis of Staley (59, p.468) in that the land-sea breeze flow is not in a simple phase relationship with the mountain-valley winds on the Cascades. In Staley's model of the sea breeze in western Washington north-south pressure gradients dominate those east-west in the formation and dissipation of stratus, while in the present model east-west gradients dominate those from north to south, resultant vertical motions being the causes of stratus patterns in both cases.

Further remarks on the sea breeze front. As brought out in the literature review above, the idea that in general the sea breeze is experienced at a station first by the arrival and passage of a front-like circulation is accepted quite generally by investigators of local wind circulations, and it is supported by considerable evidence. The reader will note also that the front is taken as fact for the purposes of various of the analyses presented above, even though definite contrasts in the conservative mixing ratio were absent across what would be the frontal zone. It may now be pointed out that this tacit acceptance of the idea of the sea breeze front in what has gone before in this thesis has been merely an expedient device necessitated by the reservation of discussion until after presentation of results. There is more to be said on whether or not there is a front associated with the sea breeze.

Technically, a front is defined in the atmosphere as a density discontinuity (27, p. 297), and is accompanied in general by local changes of wind, temperature, moisture content, visibility, etc. In common parlance a front is thought of as a boundary between two contrasting air masses (e.g. 16, p. 14), and the passage of the boundary at a surface station necessarily produces abrupt local changes of the more common meteorological variables just mentioned. It does not follow, however, that the occurrence of abrupt changes in one or two of the variables indicates the passage of a true front.

Three basic phenomena appearing consistently in the literature on the sea breeze and brought out in the discussion thus far could individually produce front-like behavior at stations in an area of sea breeze: 1) the region of relatively high wind speeds and sharp temperature gradient just inland from the center of circulation found in the work of Pearce (52, p. 366-367) and of Fisher (23, 24); 2) the distinct boundary marked principally by changes of relative humidity and of visibility described by Wallington (71) and Berson (5, p. 14-15); and 3) the wind shift line probably associated with the zone of horizontal convergence moving inland described by Edinger (20, p. 224-225), by Neiburger (49, p. 38), and by Staley (60, p. 370). Other explicit references to a front in connection with the sea breeze are noted above, but they do not appear to have been made clearly in the context of one or the other of these three patterns. In brief, though all three phenomena may exist on a given sea breeze day and each by itself produce results recognizable as a sea breeze front, there seems to be neither a reason why all three must exist together nor a general recognition among students of local winds of a distinction between them.

As evidence that there really is such a distinction, but that it is as yet only dimly recognizable in the literature, the writer wishes to cite several passages. As positive evidence consider an interpretation of his own results by Staley (60, p. 370):

> "A strong sea breeze of large scale which responded in part to eastern Washington heating was noted west of the Cascades. ....On individual days, the onset of winds in the evening (in eastern Washington) is often abrupt. These events may be interpreted as an inland progression of a massive circulation associated with differential heating between the Columbia Basin and Puget Sound and the Pacific Ocean to the west. East of the Cascades the circulation manifests itself almost entirely in the wind field, although even in the Puget Sound area no abrupt temperature fall accompanies the onset of the sea breeze itself. Estimates of average surface wind speeds between Seattle and Ellensburg make it uncertain that air parcels can travel this distance during the interval from 0900 to 1800; nevertheless, it seems evident that air of intermediate temperature inland from Puget Sound, but west of the Cascades, will become a part of the circulation centered to the west and move farther inland in advance of the coolest air. .....(These) results suggest that differential heating between the ocean and land produce sizeable diurnal wind variations as far as 200 km inland.

Second, consider a passage from Berson's introduction (5, p. 1) to his article concerning summertime "cool changes" in southeast Australia:

> "During the summer differential heating between sea and land exerts a strong influence on the behavior of 'cool changes' which regularly break the hot weather in southern Australia. Two, or sometimes more, discontinuities (change-lines) in sequence may accompany the passage of a main trough, the leading change being as a rule the more pronounced. .....It was concluded that a sea breeze effect is instrumental in activating and carrying on to land a mass of cold air presumably separated from off-shore streaming continental air by an initially weak convergence line. .....To prove the correctness of the hypothesis of a coastal front is difficult, especially since the necessary observations over the ocean are not available. There is, on the other hand, much evidence for the occurrence in southeastern Australia of pressure-jump lines of the Freemen-Tepper type ahead of cold fronts, the cooling

> with the leading change being on occasions due to rainfall or evaporating rain, but more frequently to the incursion of shallow cold air overlying the sea. Evidence for non-advective wind surges affecting the hinterland as far as 200 mi from the coast and originating on, or related to, sea-breeze fronts has also been presented by Clarke and Reid."

As a piece of negative evidence, the writer has not seen any indication, implicit or explicit, in the several theoretical papers dealing with the regional behavior of the sea breeze circulation (e.g. 24, 52, 53) that a zone of air mass discontinuity either existed prior to, was formed by, or was associated with the formation of the circulation.

One further piece of negative evidence seems in order. The elliptical hodographs mentioned above as typical of sea breeze days at coastal stations should, it would seem, exhibit some suggestion of an abrupt wind shift if such a shift is indeed strongly associated with the existence of a sea breeze circulation pattern. Being ellipses, the hodographs do not exhibit such a suggestion. Thus, one of the commonly accepted hallmarks of a sea breeze day appears inconsistent with the notion of a true frontal passage.

In view of the foregoing discussion, the writer offers the following as a resolution of the apparent disparity with regard to the frontal nature of the sea breeze. The circulation patterns displaying solenoidal behavior across coastlines, as typified by Pearce's Figure 10 (52, p. 366-367), are doubtless formed in the presence of differential heating and in the absence of significant gradient winds. The front-like behavior near the center of this circulation, referred to as phenomenon #1 of three just above, does indeed occur, but not at any points farther inland than the 50 km or so predicted by such models. This frontal behavior has no distinct zone of air mass contrast associated with it and accounts in the main only for heightened midday wind activity and local advection of marine air in coastal areas.

Phenomenon #2, the distinct air mass boundary, is not present on all sea breeze days, but only on those days when the action of differential heating and phenomenon #1 release or activate a pre-existing boundary offshore, in the manner suggested as "cool changes" by Berson (5, p. 2).

Phenomenon #3, the wind shift line moving far inland ahead of the region of strongest temperature gradients near the beach, accounts for the wind behavior experienced far inland and having its origin in the onset of the sea breeze at the coast. It is, in brief, a non-advective wind surge propagated downstream from an impulse generated at the coastline. The nature of the special conditions necessary for this downstream propagation should be elucidated, but it is likely they occur rather commonly under conditions which also produce significant differential heating in a coastal area. If true, then, this scheme would account for the commonly observed diurnal patterns of wind and advection in coastal areas, the slightly less frequent occurrence of wind surges inland, which require phenomenon #1 as an antecedent condition, and the far less frequently observed occurrence of the true air mass boundary in conjunction with a sea breeze circulation.

Consideration of the results presented above in light of the suggested triad of mechanisms leads the writer to conclude that it would probably be impossible, at least under present knowledge, to state which of the three mechanisms or combination of the three occurred on a given day. In brief, the three probably intergrade and interact most of the time to produce the complex patterns observed. Nevertheless, several tentative conclusions as to the appearance of the three in northwest Oregon may be ventured.

The conclusion that the class of sea breeze days designated as the "V" type includes within it most of the cases of "cool change", or phenomenon #2, has been mentioned already.

It is likely that sea breeze days on which the incursion of marine air does not reach to the Willamette Valley, that is when the sea breeze is not "complete", are days on which phenomenon #1 predominates. Conversely, complete sea breeze days must have experienced either #2 or #3, a true front or a wind surge.

The model proposed in the previous section to explain various observations relating to clouds, pressure variation, and the vertical and temporal variations of moisture appears compatible with both the true front and the wind surge. In the case of the former, the frontal zone would be found beneath the wave crest on its way inland during the day; in the latter the travelling zone of convergence would occupy the same position in the wave train. The fate of the true front and the wind shift zone after reflection of the wave crest from the Cascades would be a subject for further investigation. It is reasonable to suppose, however, that there should be front-like behavior experienced to the east of the Cascades, under proper conditions, after this reflection takes place. Staley has shown this behavior to be fairly common in eastern Washington (60), and because the passes in the Washington Cascades are in general lower and broader than those in the Oregon Cascades, it should be less common in eastern Oregon. The writer has, however, been told that such front-like behavior is experienced in eastern Oregon. Perhaps, then, the model proposed above should include a reflection of only part of the energy in the wave crest, the remainder being partly dissipated on the Cascades and partly propagated beyond the Cascades in a sort of "leakage" through the lower gaps in the mountain range. As mentioned, this partition is beyond the scope of this thesis.

Forestry operations. As noted, Countryman and Schroeder (12, 13) made the observation that the downslope afternoon winds they found troublesome in fire control on lee slopes of the California Coast Range are not accompanied by any major changes in either temperature or relative humidity. Their reluctance to implicate the sea breeze may have resulted from their accepting the commonly held idea that the sea breeze brings distinct changes in these variables. Phenomenon #3, the moving wind shift line propagated downstream from the sea breeze circulation at the coast, could explain these observations quite readily. It is hoped this study will provide useful insight for future studies of the kind reported by these workers.

Krumm's omission (39, p. 153) of the sea breeze, or even local winds as a group, from his list of special weather conditions causing downslope fire spread seems unfortunate. Since the chapter which includes his list is likely to be a principal text source in the meteorological training of a great many professional forest fire control personnel, and since a large proportion of the forest land of the United States is within the range of locally generated wind action, the sea breeze being a specific case, it would seem appropriate to recommend that teachers of forest management take note of the omission.

As indicated by both the relative frequency of published literature and the responses to the writer's questionnaire, the forester and the lumberman consider the impact of the sea breeze on their operations to be greatest in the area of fire weather. It is possible, however, that the sensational nature of a fire and its high time rate of consumption of resources makes this area of impact seem large out of the true proportion which might be revealed by careful, objective study of the economics of forestry operations. The value of forest regeneration losses in the absence of the sea breeze, for example, might far outweigh the costs incurred in the area of fire use and control. In brief, the final judgment of the true impact of the sea breeze, or any other weather factor, on forestry operations should not be based on such subjective data as are the most widely available today and which are presented here.

Though not mentioned explicitly in the literature, it is undoubtedly the dominant influence of the sea breeze complex as a climatic determinant in coastal areas of northwest Oregon which makes these areas so desirable for summer recreation, an aspect of forestry receiving greatly increased attention among those concerned with optimum use of forest lands and resources. Design and placement of recreational facilities in these coastal areas should take into account the nature of the sea breeze in order to achieve a balance between its envigorating and its unpleasant features.

In summary, it appears from the dearth of published material on the subject that, while the potentially great influence of the sea breeze on forestry operations is present, it will probably not receive the intense scientific scrutiny of measurement and objective discussion until the pressures of human use on forest lands become considerably greater than they are at present.

CONCLUSIONS

In northwest Oregon, July and August form the period of the year when the sea breeze becomes one of the dominant elements of the area's climate. Sea breeze activity of lesser intensity and reliability appears in May and June and in September. During the height of the summer, the sea breeze is quite reliable in areas windward of the Coast Range, invades the inland portions of the Willamette Valley about 7 days out of 10, and is occasionally observed as a wind surge inland of the Cascades perhaps 200 km from the coastline.

There are three commonly observed mechanisms, each capable of producing sea breeze-like circulation in coastal areas. Being only partly interdependent, they must be dealt with separately in unravelling the complex patterns of atmospheric behavior in regions where the sea breeze appears. The vertical circulation cell featuring onshore flow at the surface, ascending motion just inland, and a completed circuit just above and seaward of these portions is the first of these mechanisms and has been a product of a variety of theoretical studies in almost identical form in each study. The circulation reaches about 50 km inland by late afternoon and produces rapid rises in wind speeds at the surface during the day, but it has no true front associated with it. The second mechanism is a true front, or "cool change", delayed offshore and released to move shoreward at the height of development of the first mechanism. The third is a non-advective wind surge propagated downstream by either or both of the first two mechanisms under the proper conditions. This last circulation may be felt much farther inland than the true marine advection.

There is very little overall modification of the sea breeze circulation by coastal mountains with summits near 3000 feet, except at times and places when a very delicate frictional and/or thermal balance is affected locally. The passages of the sea breeze through and over low-level mountain passes narrowing inland and widening inland are practically identical, at least insofar as speed of movement and gradients of heat and moisture produced are concerned.

As a corollary of the previous conclusion, it seems clear that relatively short-lived and subtle differences in the thermodynamics of the sea breeze circulation can produce large differences in observed values of some of the individual weather elements. No clear-cut differences were found, for example, in the systems producing the U-type sea breeze day with its broad, indefinite midday minimum of relative humidity and the V-type day with a distinct minimum perhaps 25 per cent lower than the U-type.

Contrary to the popular opinion, sea breeze days do not as a usual thing result in a complete envelopment of northwest Oregon in a cool, moist air mass during the following night and morning. The exception comes with a major synoptic change following an extended period with no sea breeze activity, such a "cool change" bringing the few true cases of a complete, if only brief, inundation of the area west of the Cascades in marine air. The more usual pattern of sea breeze day features rather indistinct changes in heat and moisture content of the air in inland valleys and moderately intense periods of nocturnal drying in most areas above about 2000 feet.

Forestry operations are sensitive to the sea breeze in a variety of ways and to an extent not generally realized by the personnel engaged in the operations. The sea breeze affects such activities as fire control, scheduling of controlled burns, regeneration of forests, aerial operations, and plant layout. The true relative importance of these various kinds of impact, as judged by economic criteria, should not be arrived at by procedures equivalent to simple opinion sampling among industrial personnel. True of the sea breeze, it is doubtless true of other weather phenomena that the study of the economic impact of the phenomenon must go beyond understanding of the physical nature of the phenomenon and sampling offhand opinions of industrial personnel as to the impact.

RECOMMENDATIONS

Detailed recommendations as to application of several of the findings of this study in the operational procedures of forest protection have already been made (4, p. 35).

The following recommendations pertain to areas of research on the sea breeze of northwest Oregon most in need of further work and at the same time most likely to yield fruitful results.

Research should be initiated to clarify the nature of the energy budget of the earth-atmosphere system within 10 km of the beach and in the lowest 10,000 feet of the atmosphere.

Research is needed to produce observational data on the detailed three-dimensional structure of the wind field associated with the sea breeze, especially farther downstream than about 20 km from the beach.

Both theoretical and observational studies are needed to clarify the effects of differential heating at the inland edge of a stratus deck inland of coastal areas.

Theoretical and observational studies of motion and mass continuity are needed over and at the boundaries of the area examined in this study, especially just seaward of the crest of the Cascades.

Theoretical studies of motion should be undertaken on the mesoscale based on the proposed model of the low-level sea breeze in northwest Oregon.

Consideration should be given to the design of an investigation of the true economic impact of the sea breeze on forestry operations, more as a pilot study involving one weather phenomenon and one industry than as an end in itself.

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APPENDICES

APPENDIX A

DESIGN AND OPERATION OF WIND GUST AND RADIATION INSTRUMENTS

Wind gust meter. Figure A1 shows schematically the arrangement used to bridle a standard U.S. Forest Service four-hemicylinder anemometer and to make an electrical contact when the instrument was rotated beyond an adjustable threshold. After completion of the prototype modification, the instrument was placed in the wash of an electric fan whose approximate speed at the anemometer was measured with a pitot-tube type wind gauge. The measured speed was consistently 15 ± 2 mph at the threshold making electrical contact. All six instruments, once modified, were checked in similar fashion and found to respond within this range of speeds. Subsequent damage to the contacting mechanisms of several anemometers by very high wind speeds in the field undoubtedly changed the threshold in several cases during the summer of 1957. The fact that the record obtained was used only qualitatively in deciding whether a day was a sea breeze day or not, combined with the tendency for wind activity at the six special ground stations to be either well above or well below the threshold, makes it improbable the use of the records obtained led to any major erroneous conclusions.

To record the times the wind was above the threshold of about 15 mph, a third arm-and-pen unit was mounted within the case of the Foxboro recording hygrothermograph at each ground station. The arm was connected mechanically by means of a length of pre-shrunk nylon fishing line to the arm of an electrical relay also mounted in the case. The relay was in turn connected electrically to the contact on the anemometer so the relay would be thrown when contact was made at the threshold speed. Power for the system was a 22.5 volt dry cell housed in the instrument shelter.

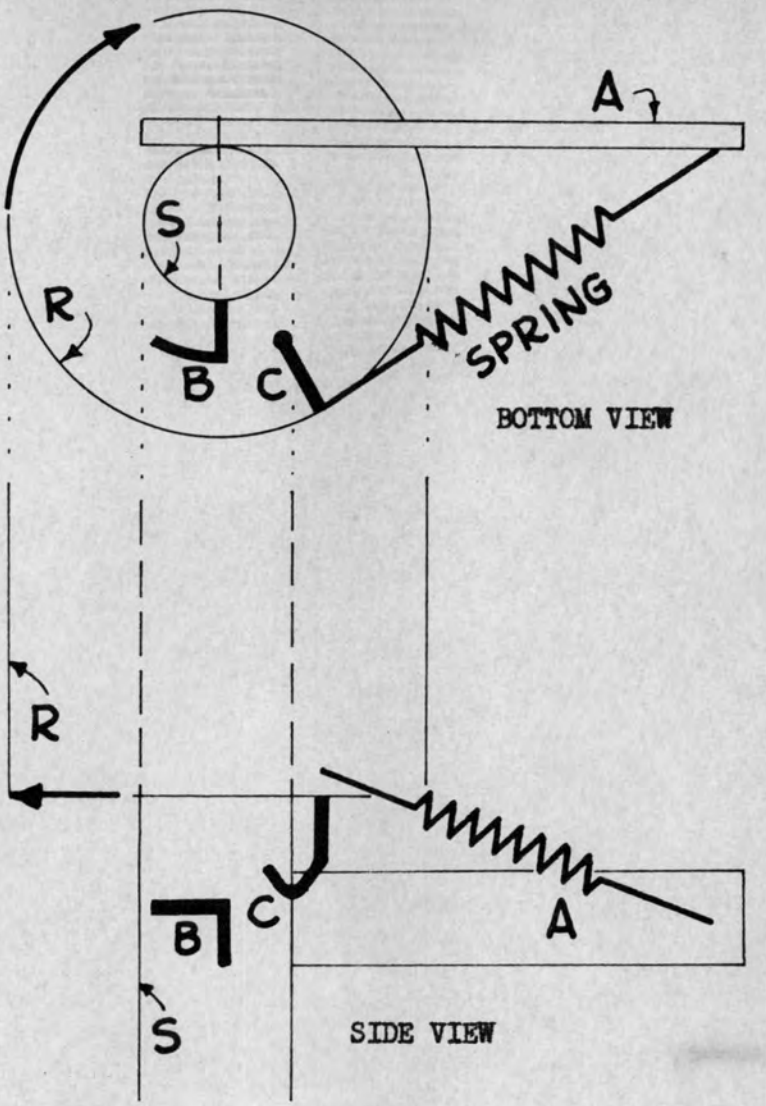
Aside from the occasional damage to the electrical contact on the anemometer, the system was quite reliable. Adjustment of the nylon line linkage to prevent occurrence of an excessively long stroke of the pen when contacts were being made was necessary to assure the pen having sufficient ink to produce a full seven day record with one filling. Until this adjustment was made several periods of record were lost during windy spells.

"Black Box" radiometer. A "Tempscribe" thermograph housed in and nearly filling a small black-painted cubical box and mounted atop the instrument shelter formed the radiation sensor at each ground station. The box was approximately 6 inches on a side and had all sides except south face and top face made of ¼ inch plywood. The south face and the top were made of thin brass sheets, the entire unit being painted black on the outside.

The temperature element of the "Tempscribe" is a spiral bimetal unit, and the circular chart contains seven days' record on a sheet about 4 inches in diameter. Although the small size of the chart made reading of the record more difficult and less accurate compared with that of the hygrothermograph in the shelter, the results were quite suitable for the use made of them.

No exhaustive study was made of the relationship between the environmental radiation flux, wind, and the temperature difference between the "Black Box" and the weather shelter. The nature of the records indicates, however, that in the absence of either cloud or wind the diurnal curve of temperature difference would be rather flatter during the day than the curve for net radiation at the same time. This is doubtless due to the cubical shape of the box, which presents a virtually normal face to the solar beam at all times.

In the absence of a study accounting for the temperature difference between the black box and the shelter, little may be said about the system as a radiometer. In its use as a device for registering the time at which large and rapid changes take place in the temperature difference, the arrangement was quite suitable.



SCHEMATIC OF BRIDLED, GUST-RECORDING ANEMOMETER

Metal arm A and electrical contactor B are fastened by a common bolt to the stationary main anemometer support S. The contactor C is attached to the rotating weather shield R, which turns with the wind in the direction indicated by the large arrows. The motion is bridled by the spring. Wind speeds above a certain threshold will cause the contactors B and C to meet, completing an electrical circuit.

FIGURE A 1

APPENDIX B

CROSS SECTIONS OF POTENTIAL TEMPERATURE AND MIXING RATIO ON FIFTEEN DAYS DURING THE SUMMER OF 1957 OVER THE CENTRAL OREGON COAST RANGE, FROM THE SURFACE TO 5000 FEET

The following fifteen figures present cross sections of the lower atmosphere over the central Oregon Coast Range. The observations from which the isopleths of potential temperature (solid lines, deg K) and of mixing ratio (dash lines, parts per thousand) were deduced are described on pages 31 through 36, while the method of construction of the isopleths is outlined on pages 50 and 52. Major cloud formations and their approximate sky coverage are indicated by double lines, the kinds of cloud being designated as follows: altocumulus (AC), altostratus (AS), cumulus (Cu), stratocumulus (SC), and stratus (St).

The reader is reminded these figures represent two oblique planes, each 5000 feet high, the left-hand one being based on the line between Newport and Corvallis, the right-hand one between Oceanlake and Sheridan. As in Figure 8, page 51, the horizontal scale is approximately 10 statute miles per inch. The horizontal lines in the form of coordinates indicate altitude levels from sea level to 5000 feet, the uppermost line. The profile of the roadbed through each of the two transects is represented by the irregular line appearing between sea level and 1000 feet in each figure.

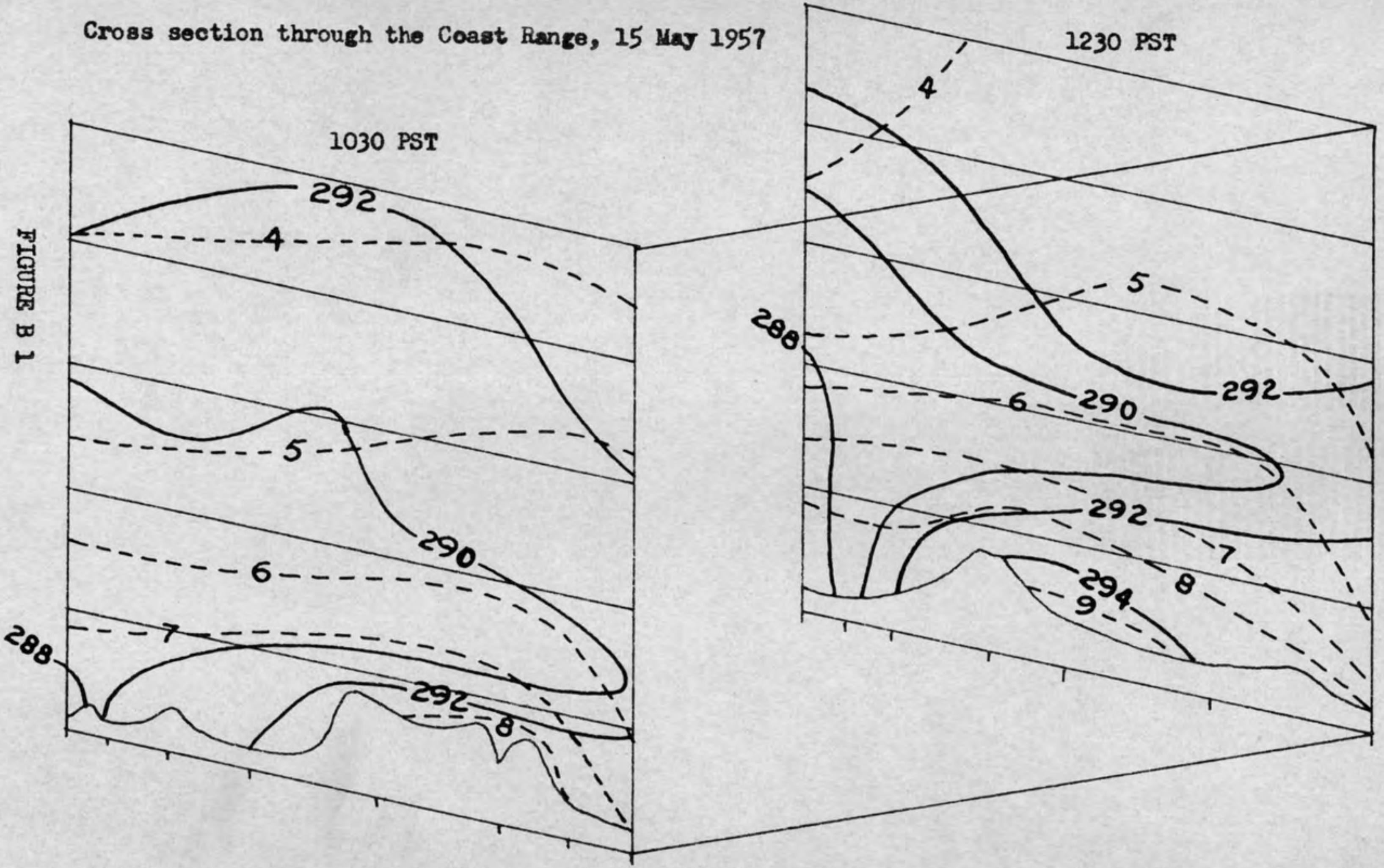
APPENDIX B (CONTINUED)

List of dates and times represented in the cross sections.

Figure	Median observation time PST		Date
	Southern (Left) Section	Northern (Right) Section	
B 1	1030	1230	15 May 1957
B 2	1100	1300	22 May
B 3	1215	1400	29 May
B 4	1130	1230	5 June
B 5	1330	1130	12 June
B 6	1400	1215	19 June
B 7	1100	1215	26 June
B 8	1100	-	3 July
B 9	1100	1230	10 July
B10	1200	1100	17 July
B11	1200	1400	24 July
B12	1330	1200	7 August
B13	1200	1400	14 August
B14	1430	1230	21 August
B15	1530	1330	28 August

FIGURE B 1

Cross section through the Coast Range, 15 May 1957



Cross section through the Coast Range, 22 May 1957

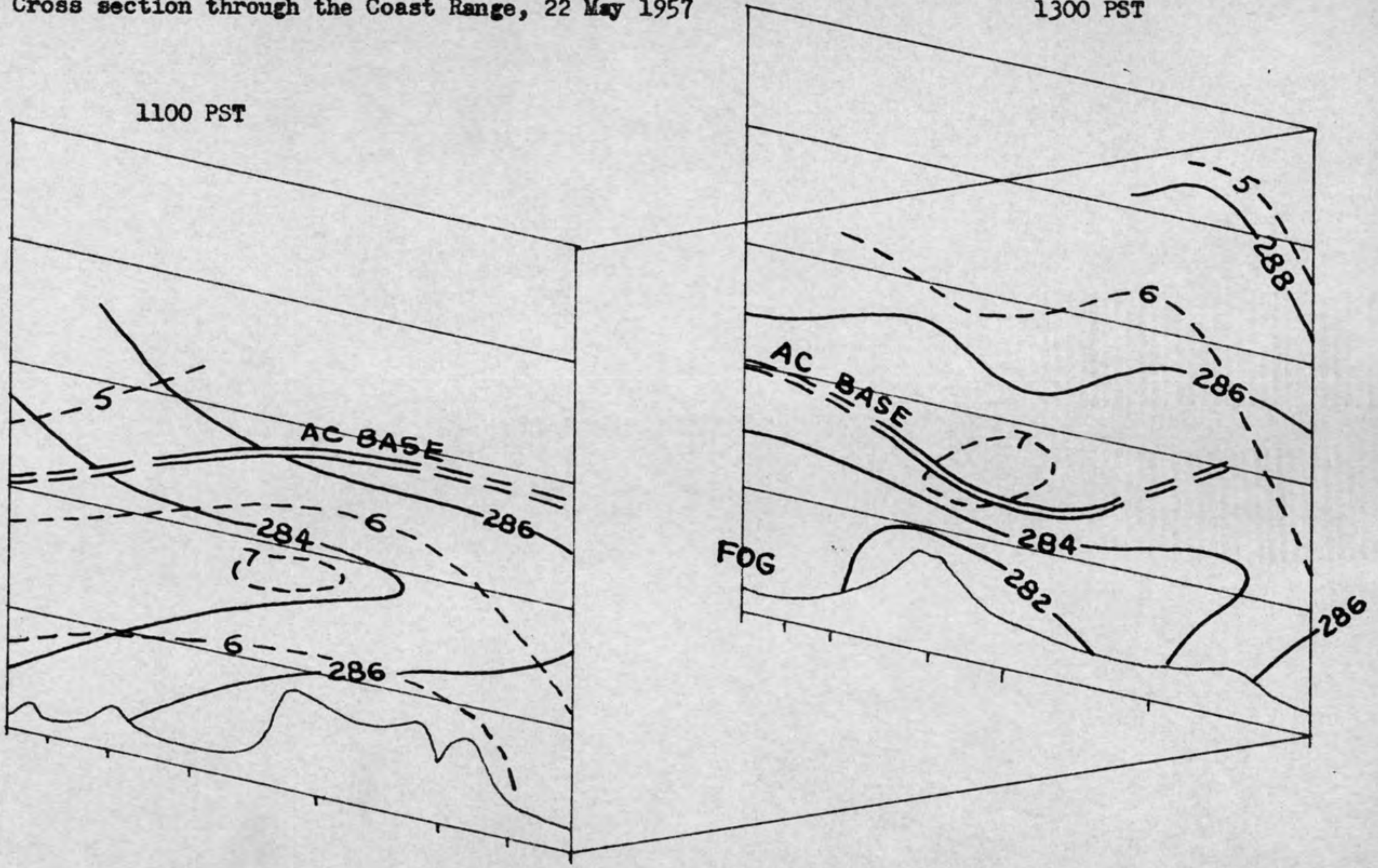
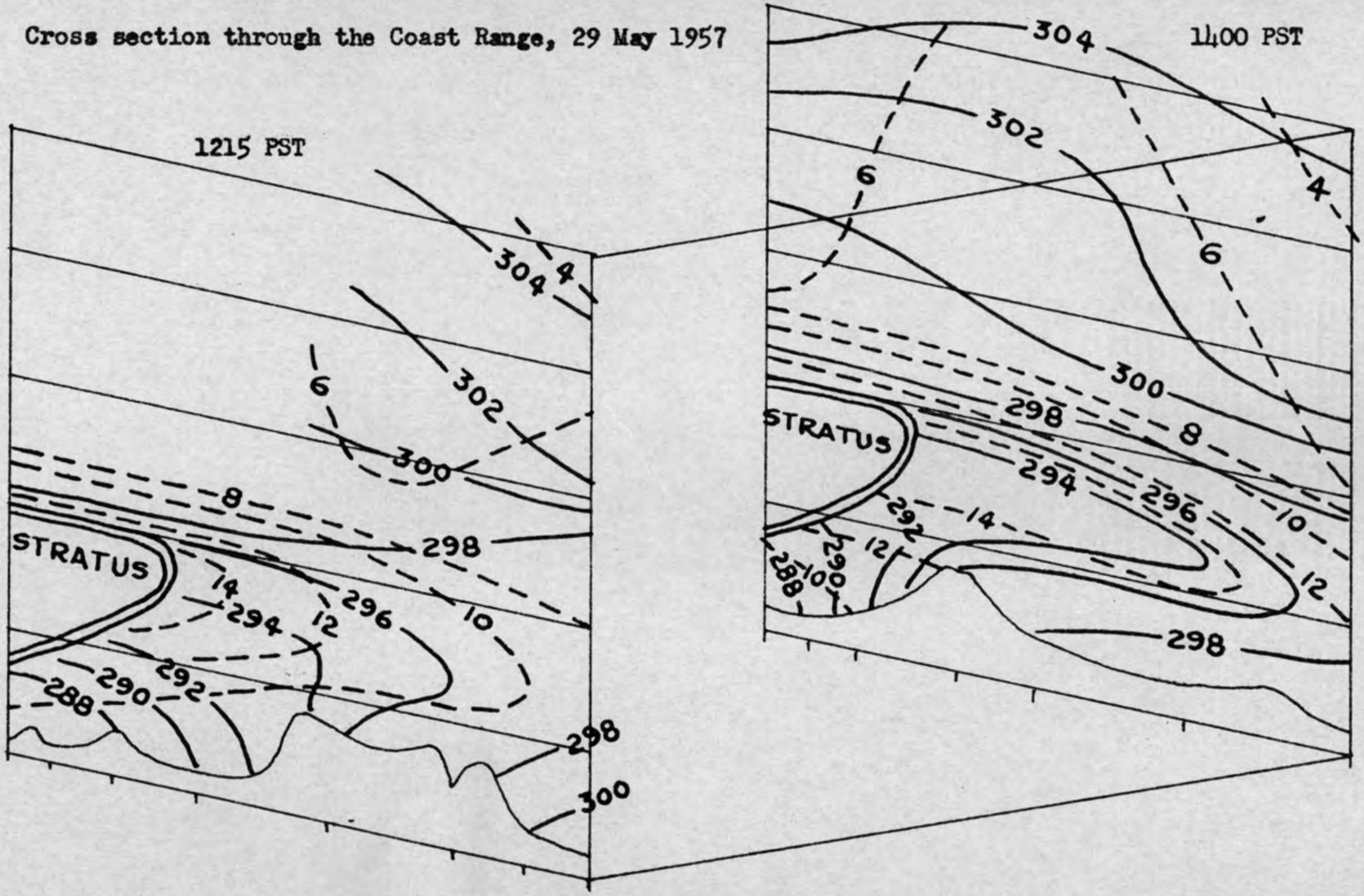


FIGURE B 2

FIGURE B 3

Cross section through the Coast Range, 29 May 1957



Cross section through the Coast Range, 5 Jun 1957

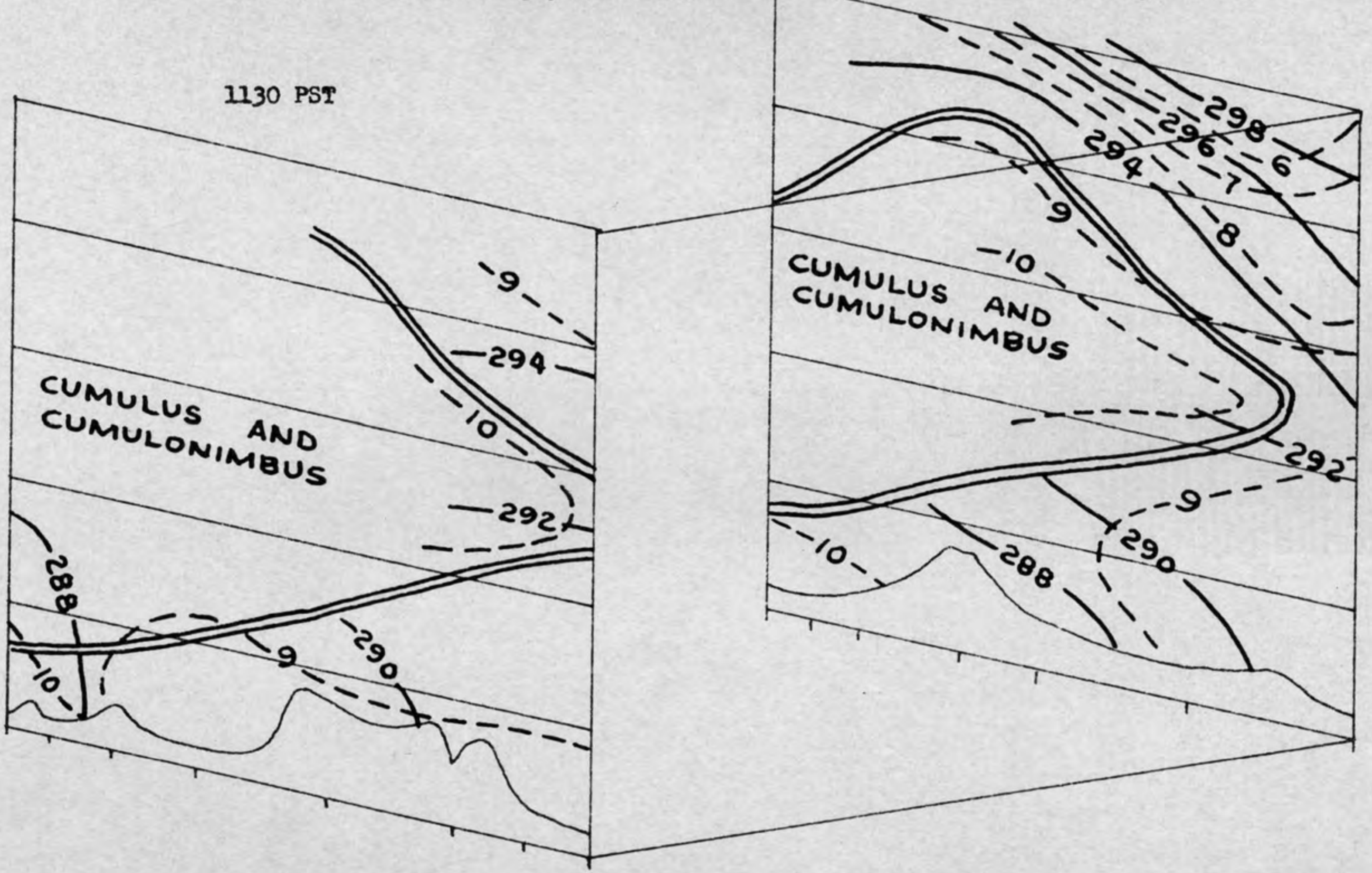


FIGURE B 4

FIGURE B 5

Cross section through the Coast Range, 12 Jun 1957

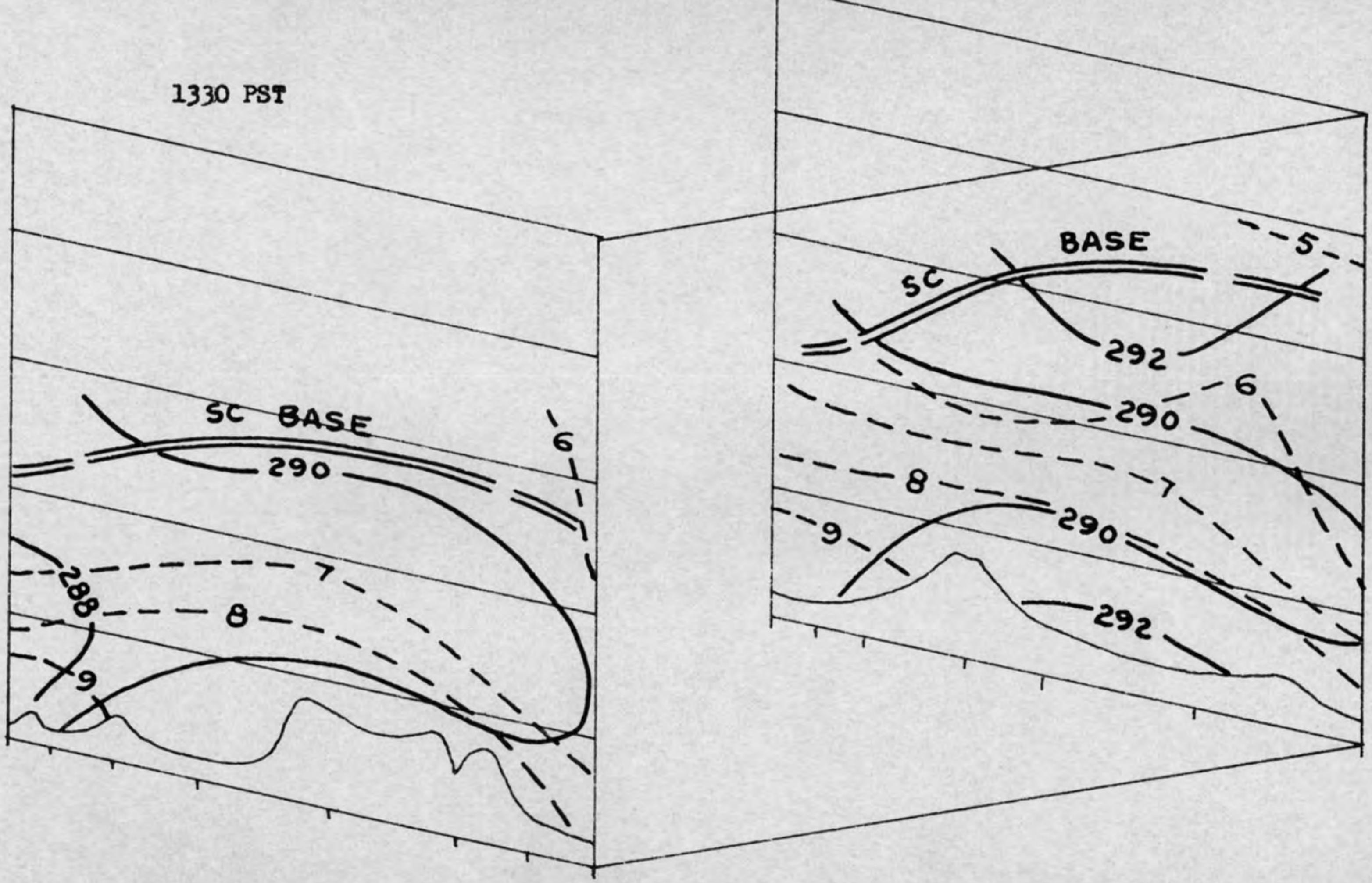
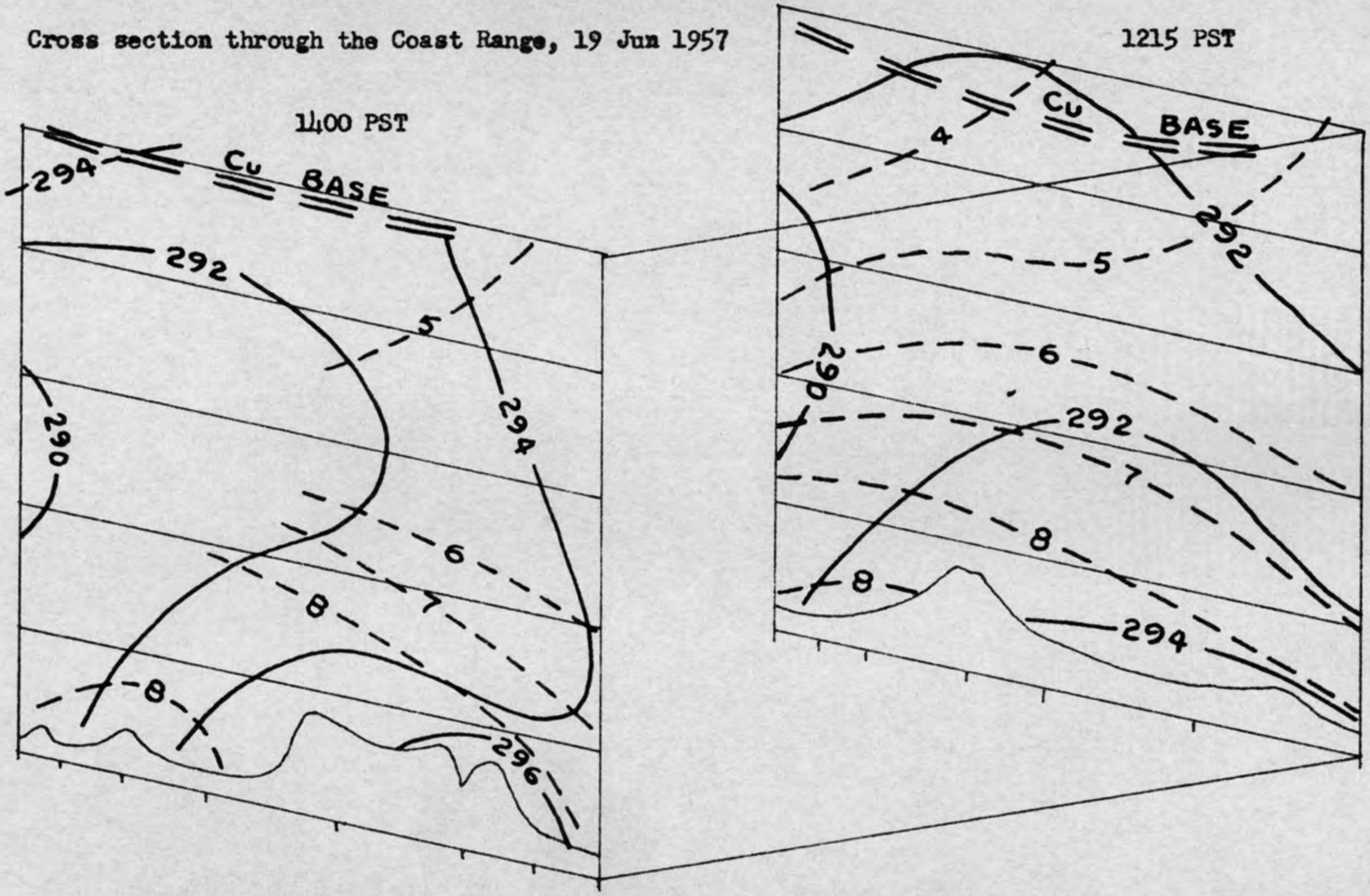


FIGURE B 6

Cross section through the Coast Range, 19 Jun 1957



Cross section through the Coast Range, 26 Jun 1957

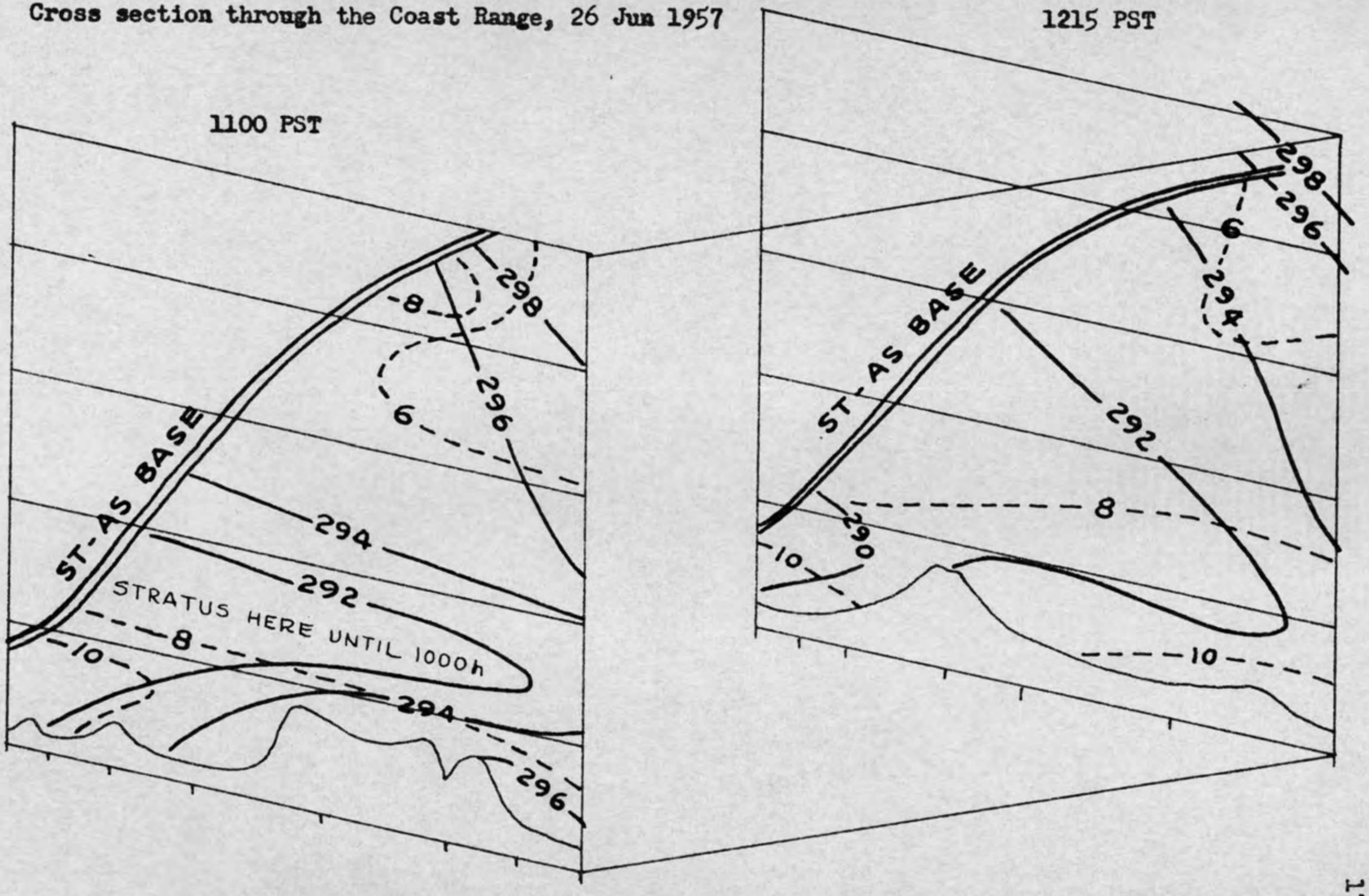


FIGURE B 7

Cross section through the Coast Range, 3 July 1957

1100 PST

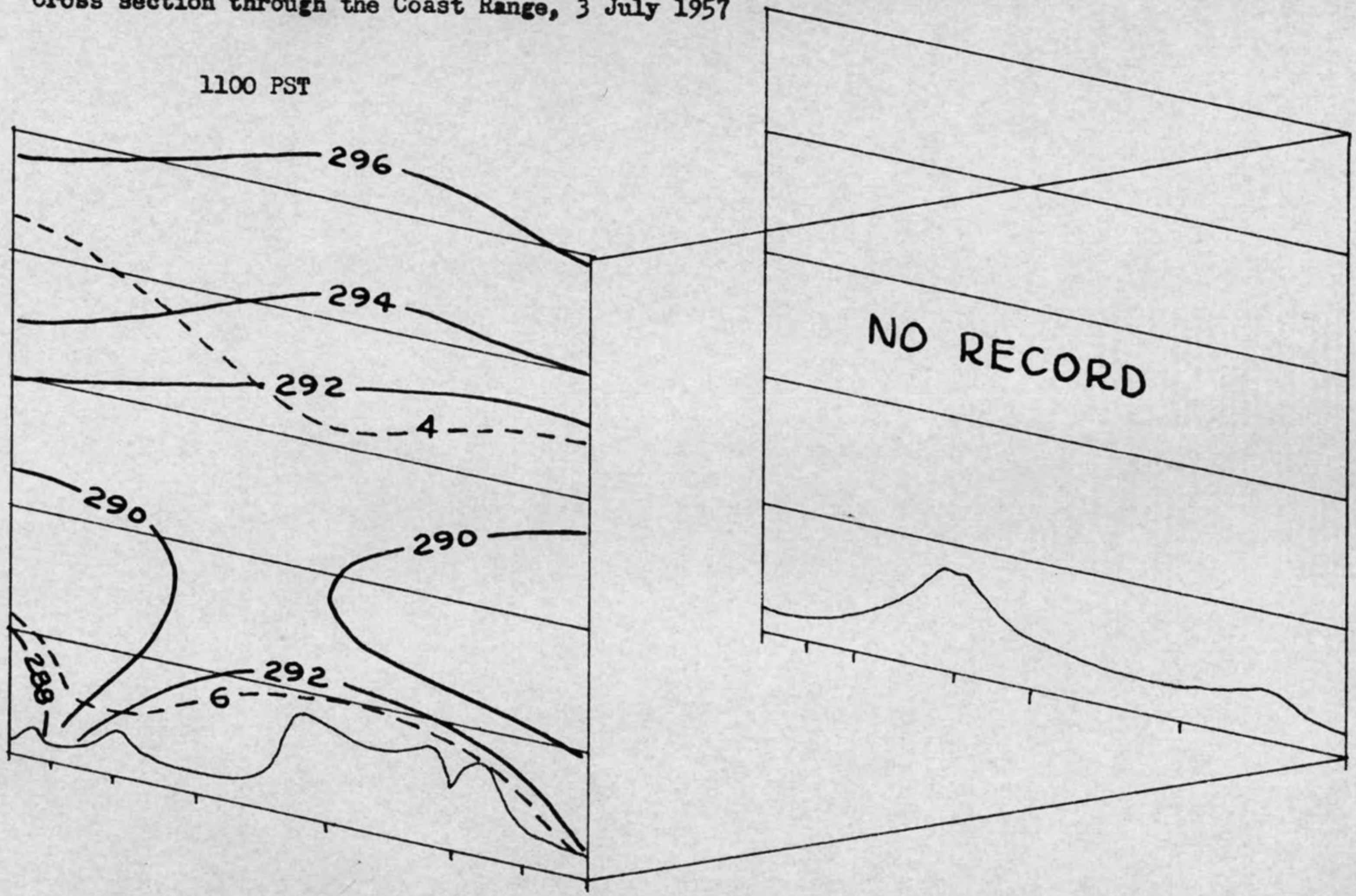


FIGURE B 8

Cross section through the Coast Range, 10 Jul 1957

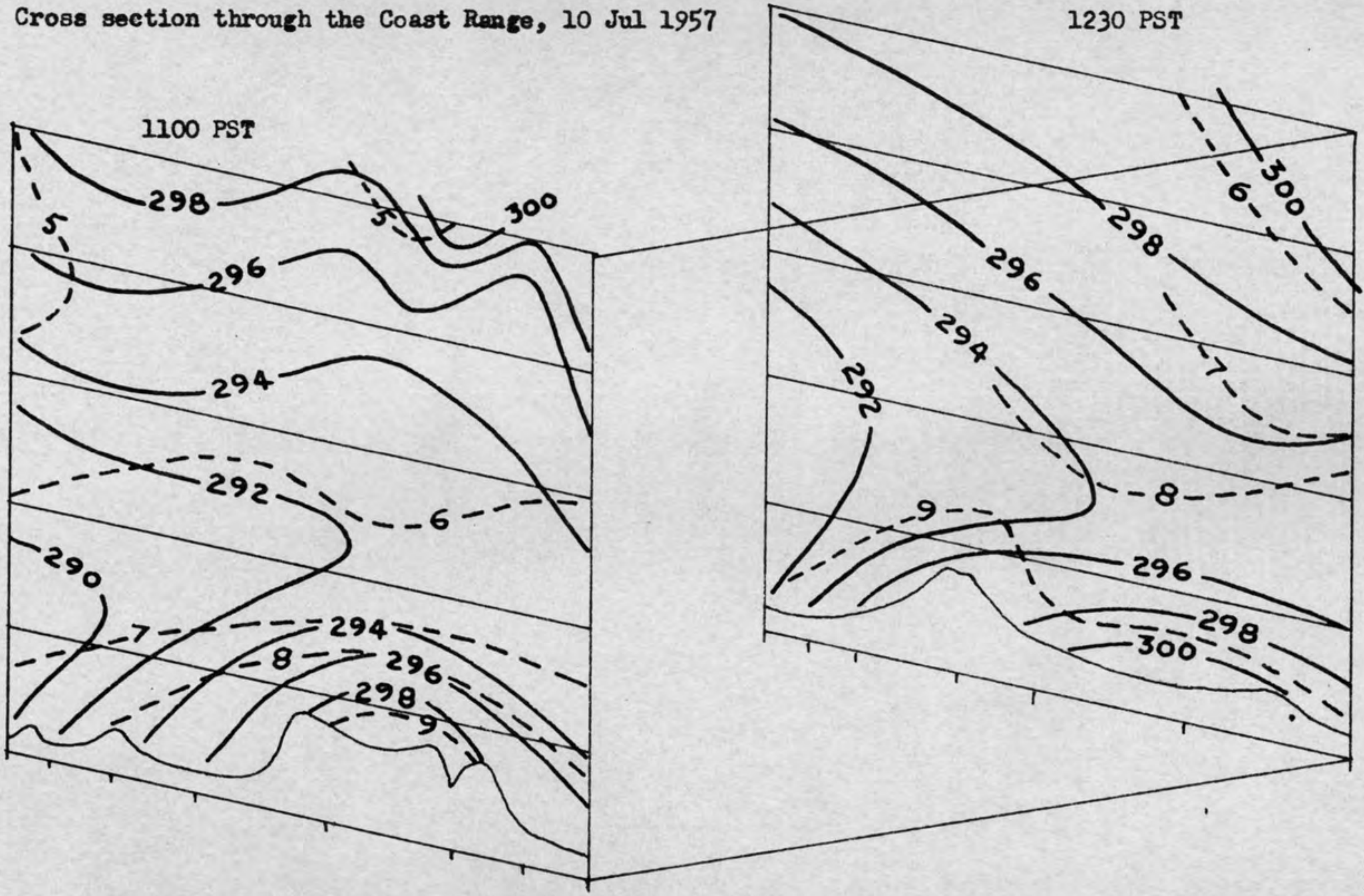


FIGURE B 9

Cross section through the Coast Range, 17 Jul 1957

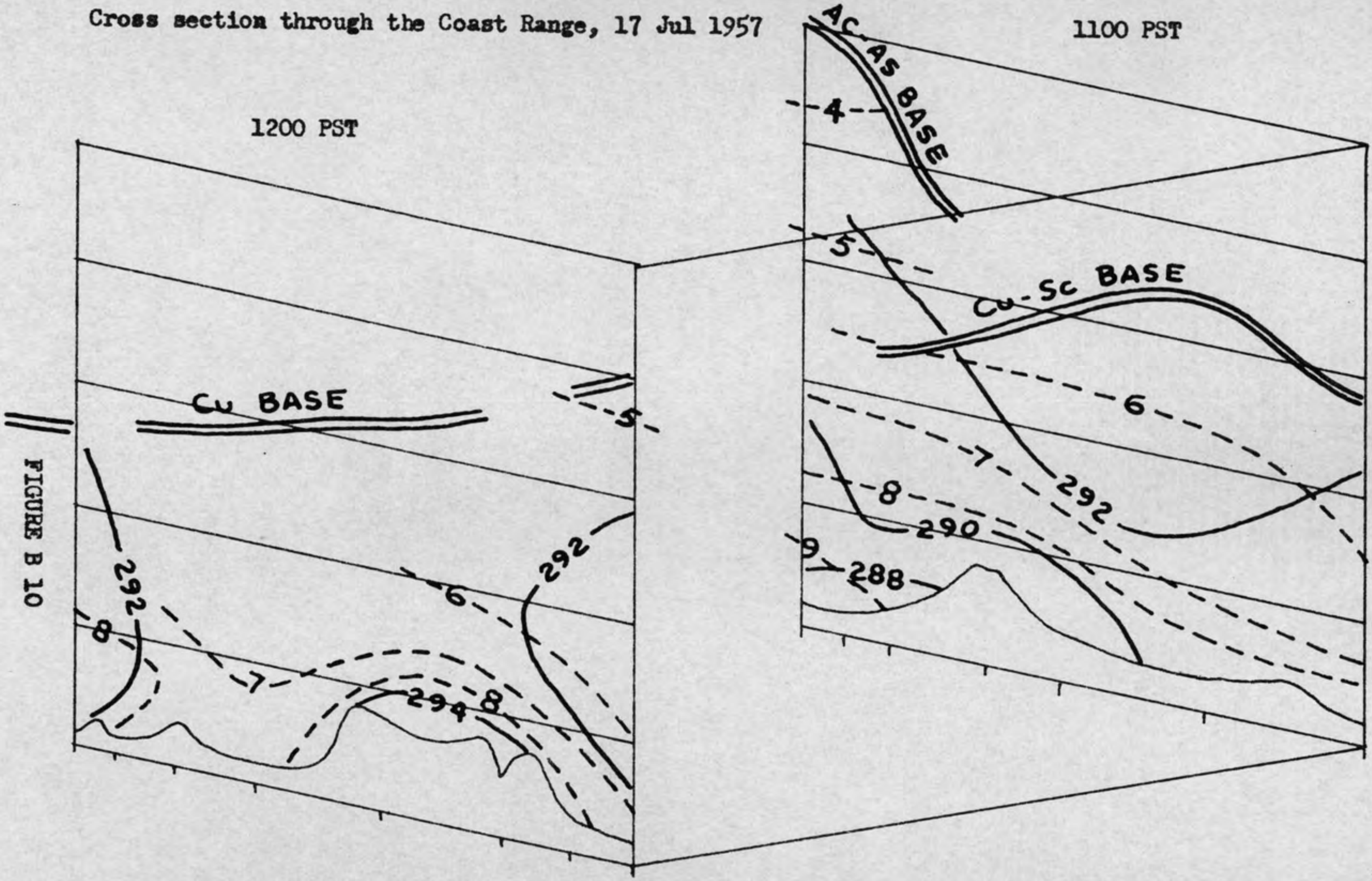
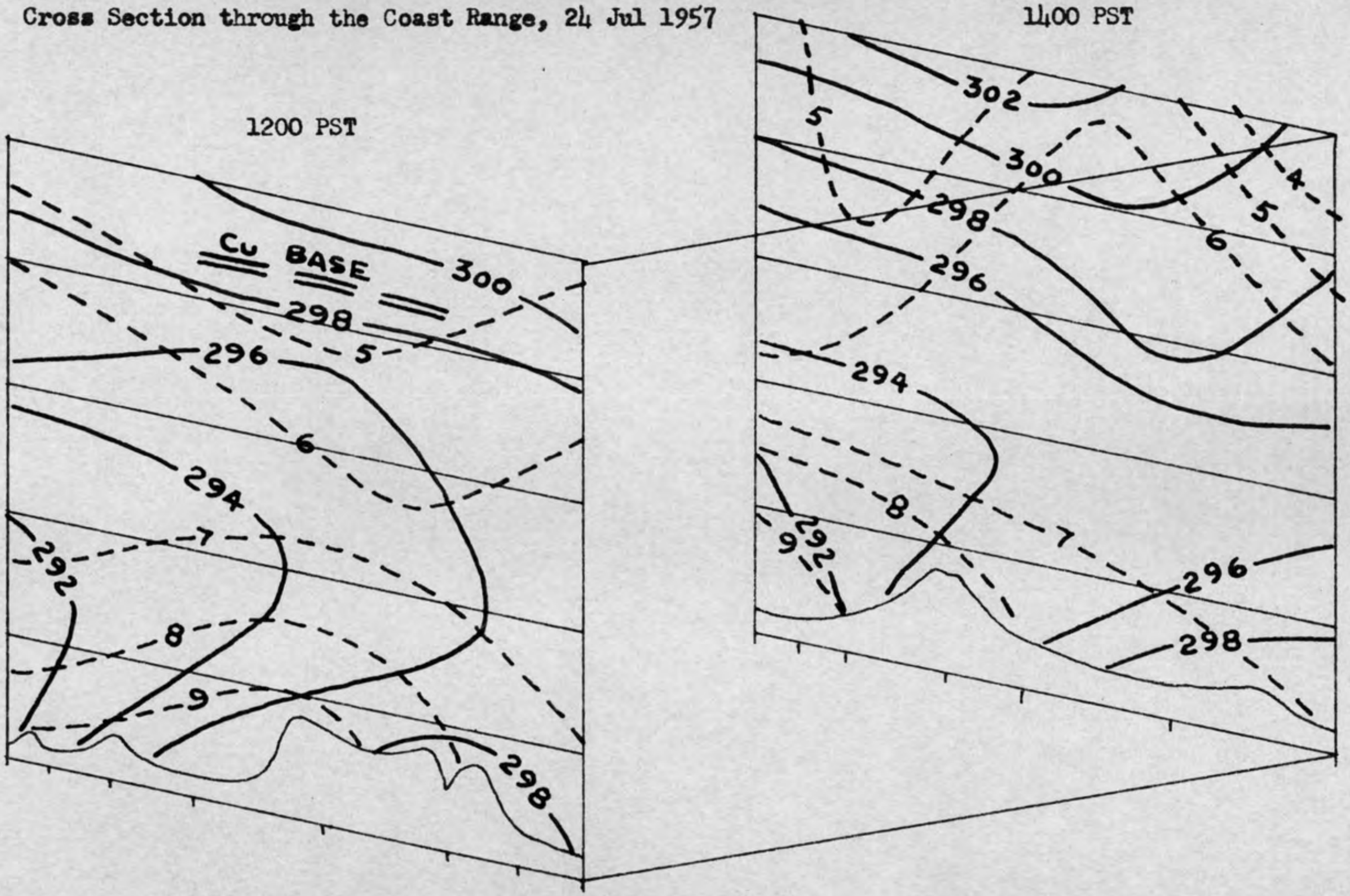


FIGURE B 10

Cross Section through the Coast Range, 24 Jul 1957



1200 PST

1400 PST

FIGURE B 11

Cross section through the Coast Range, 7 Aug 1957

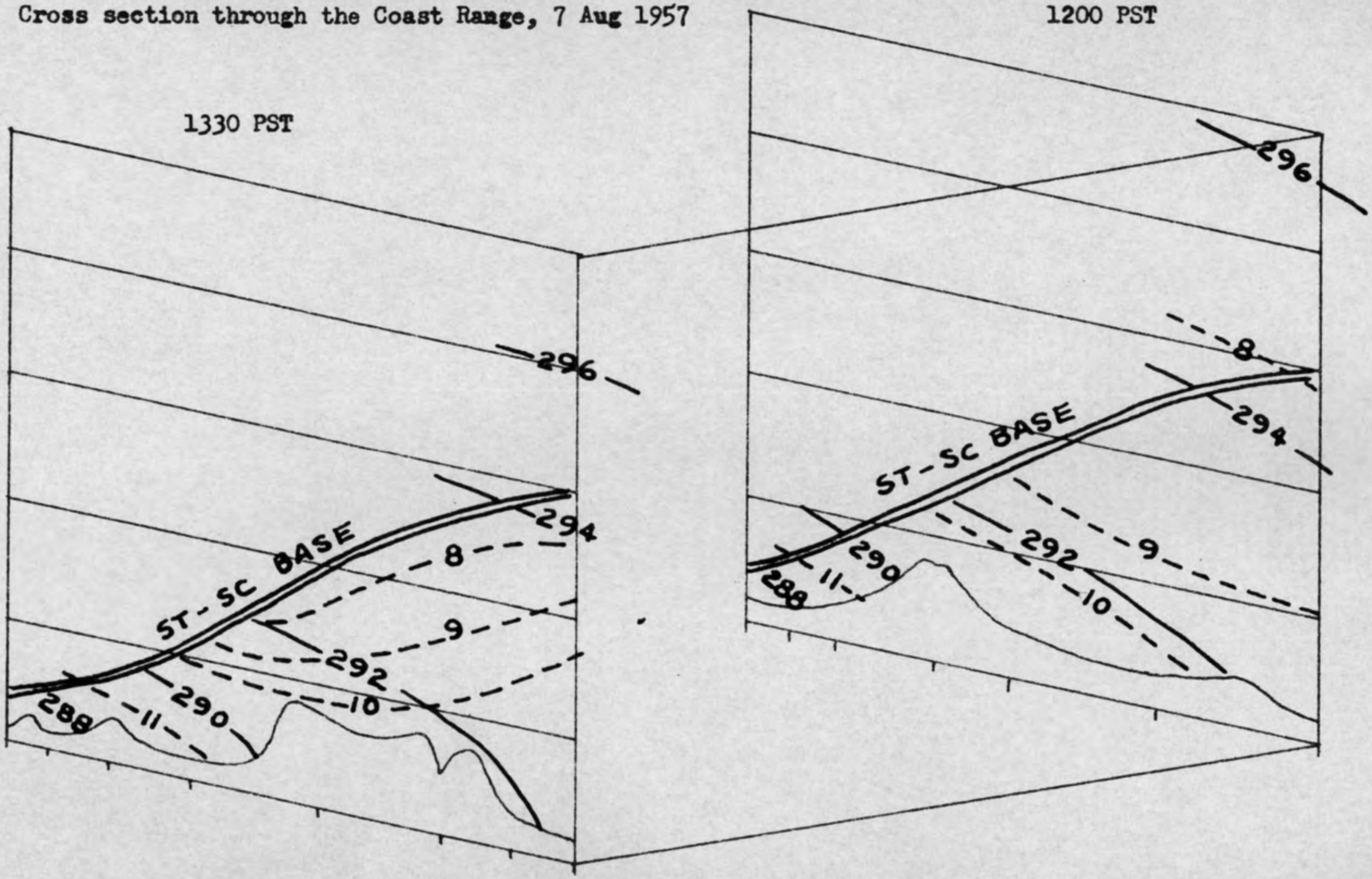


FIGURE B 12

Cross section through the Coast Range, 14 Aug 1957

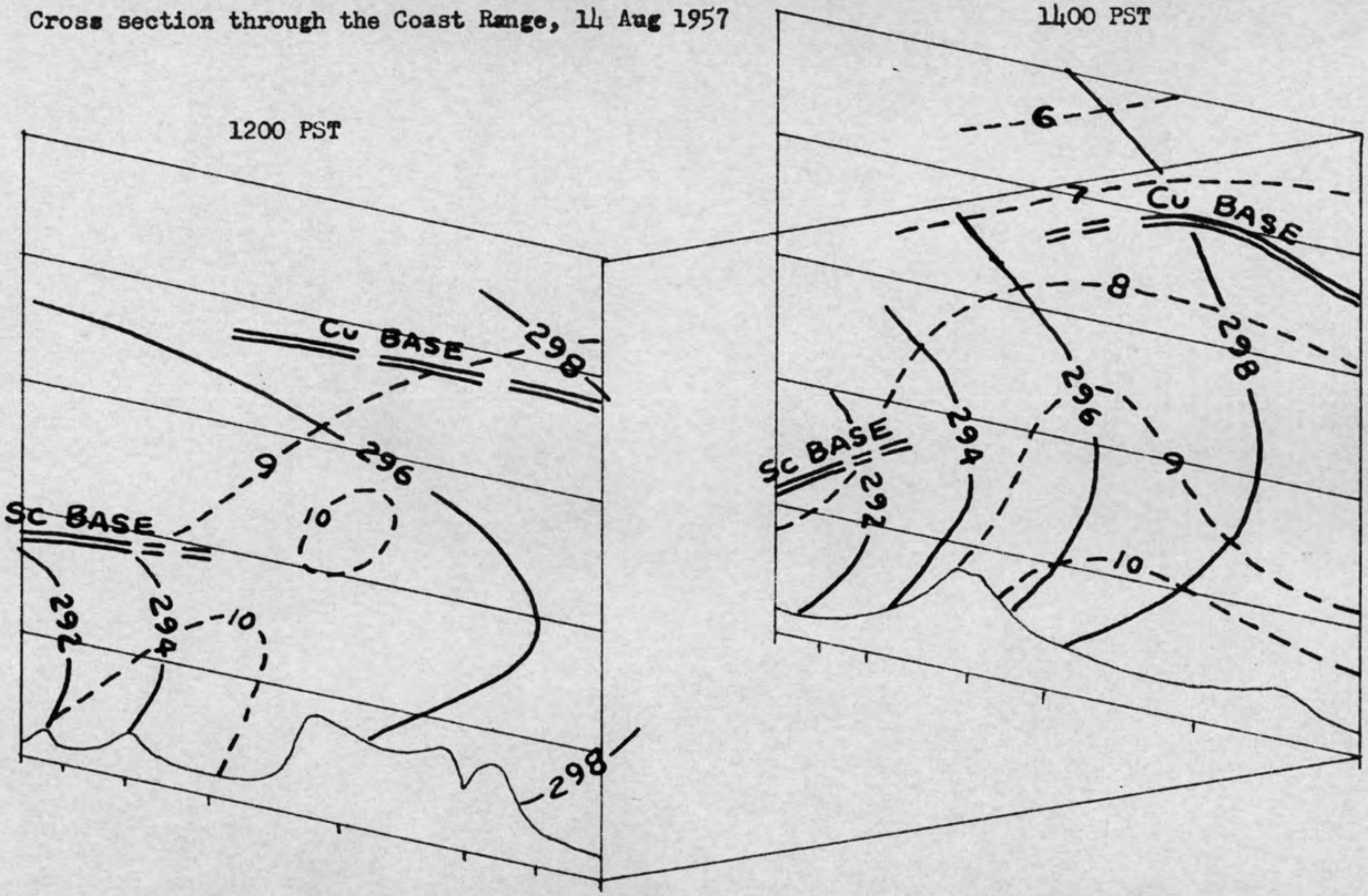


FIGURE B 13

Cross section through the Coast Range, 21 Aug 1957

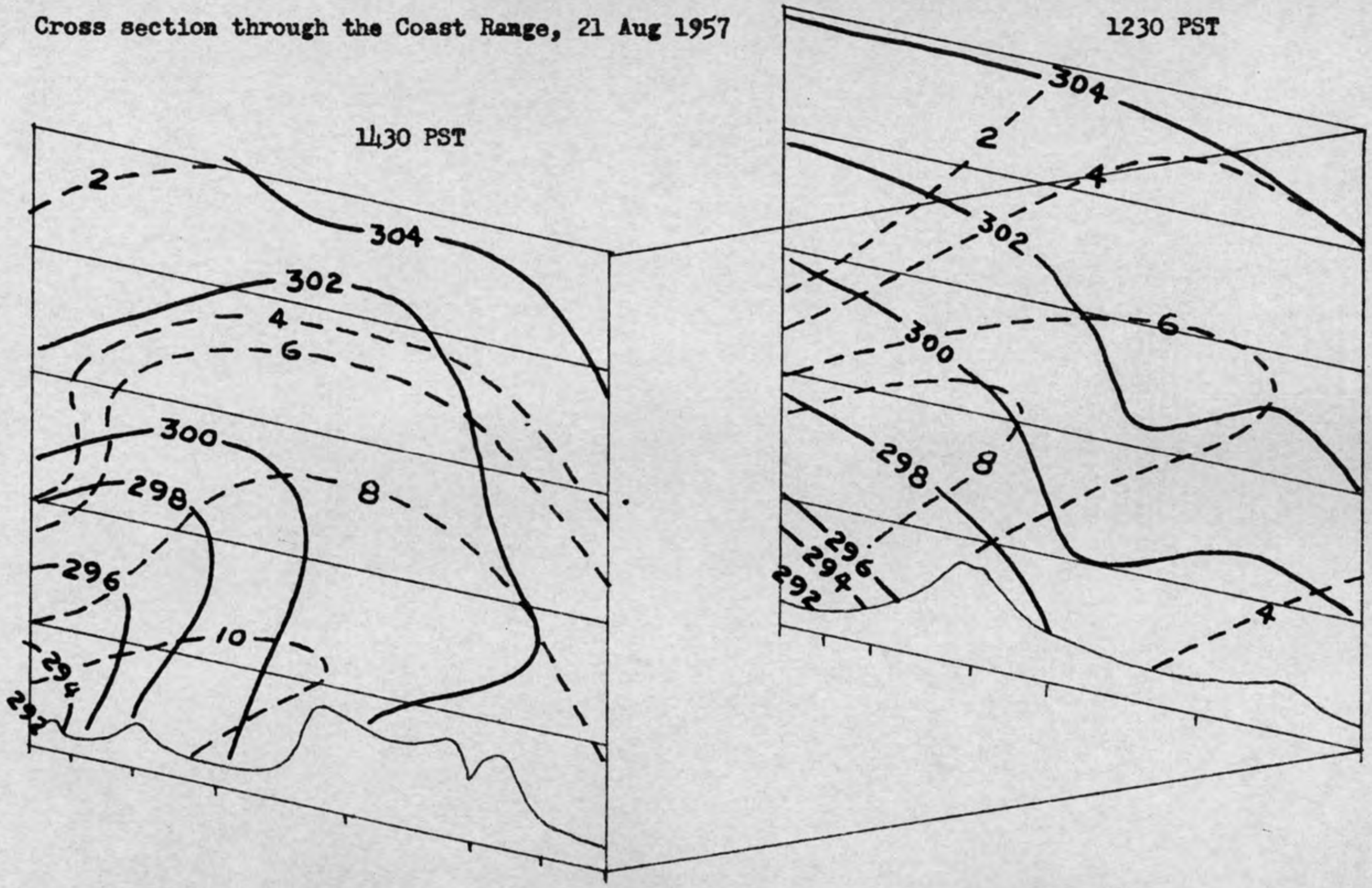
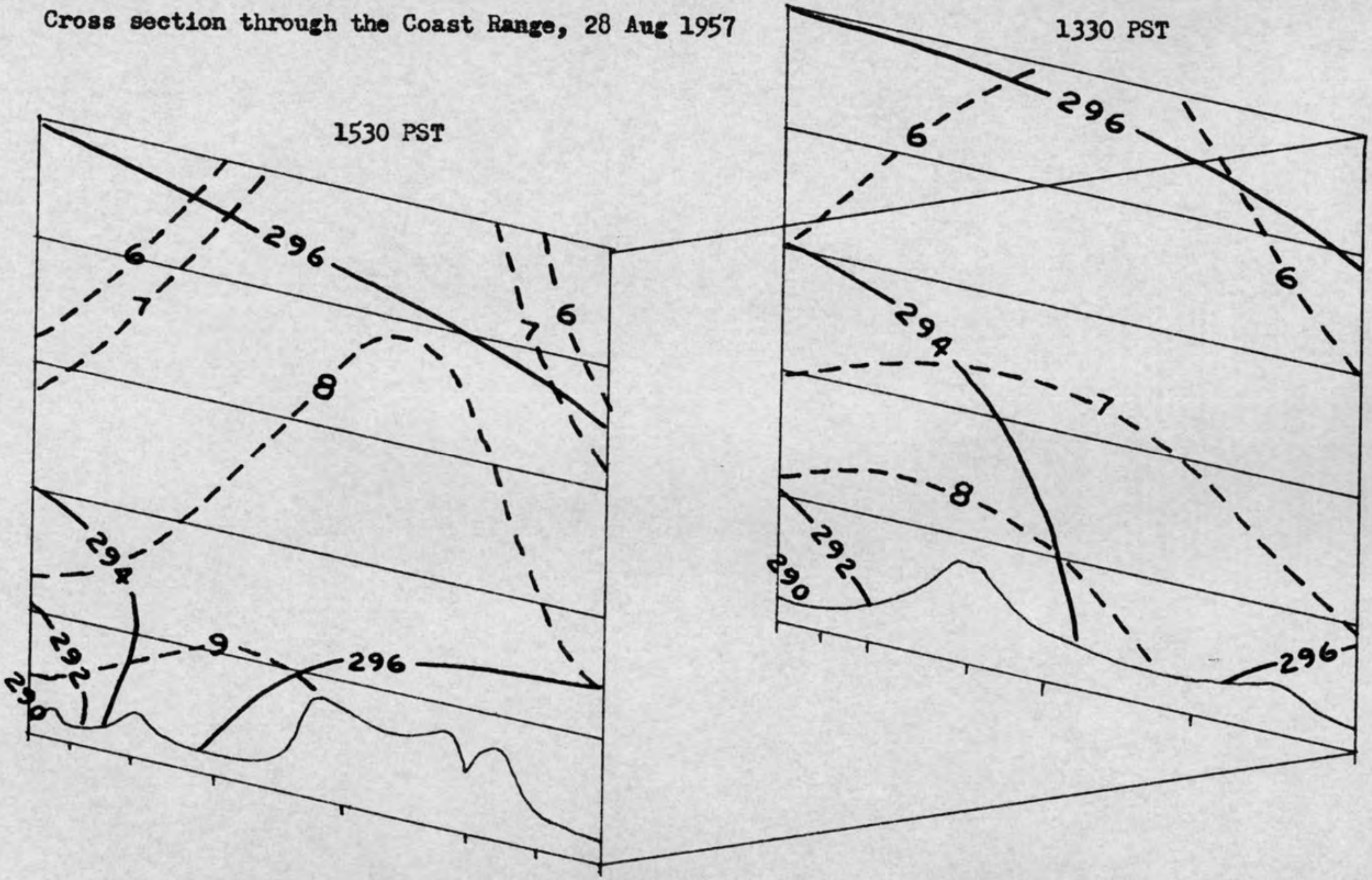


FIGURE B 14

FIGURE B 15

Cross section through the Coast Range, 28 Aug 1957



APPENDIX C

DIURNAL VARIATIONS OF TEMPERATURE AND MOISTURE AT THE SURFACE

As mentioned and described on page 74, the following ten figures present in two special groupings the same data appearing in Figures 12a through 12d and in Appendix D. The data are hourly mean values of temperature, "black box" temperature difference, relative humidity and mixing ratio based on a sample of five days each of the two types of sea breeze days considered. The first group of figures presents the data so as to enable comparison of the two types of day at each station. The second group is arranged to permit comparison of the data on one type of day at all stations a similar distance from the beach. The figures and their contents are as follows:

Figure	Variable	Type of grouping
C 1a	Temperature	Two types of day, by station
C 1b	"	"
C 1c	"Black Box" difference	"
C 1d	Relative humidity	"
C 1e	Mixing ratio	"
C 2a	Temperature	One type of day, by geographical area
C 2b	"	"
C 2c	"Black Box" difference	"
C 2d	Relative humidity	"
C 2e	Mixing ratio	"

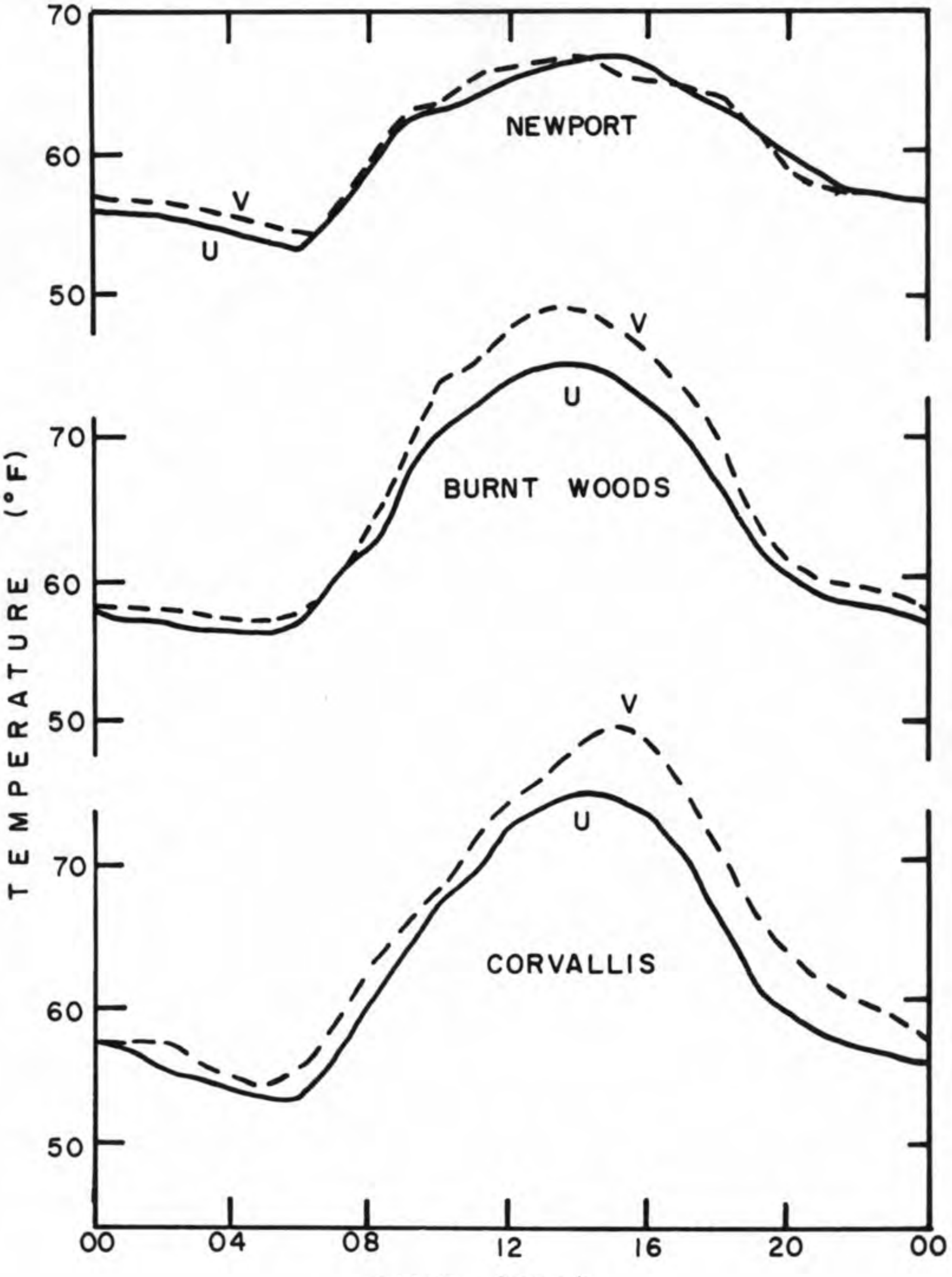

NEWPORT
BURNT WOODS
CORVALLIS
V
U
V
U
V
U
70
60
50
70
60
50
70
60
50
TEMPERATURE (°F)
00
04
08
12
16
20
00
TIME (PST)

FIGURE C 1a

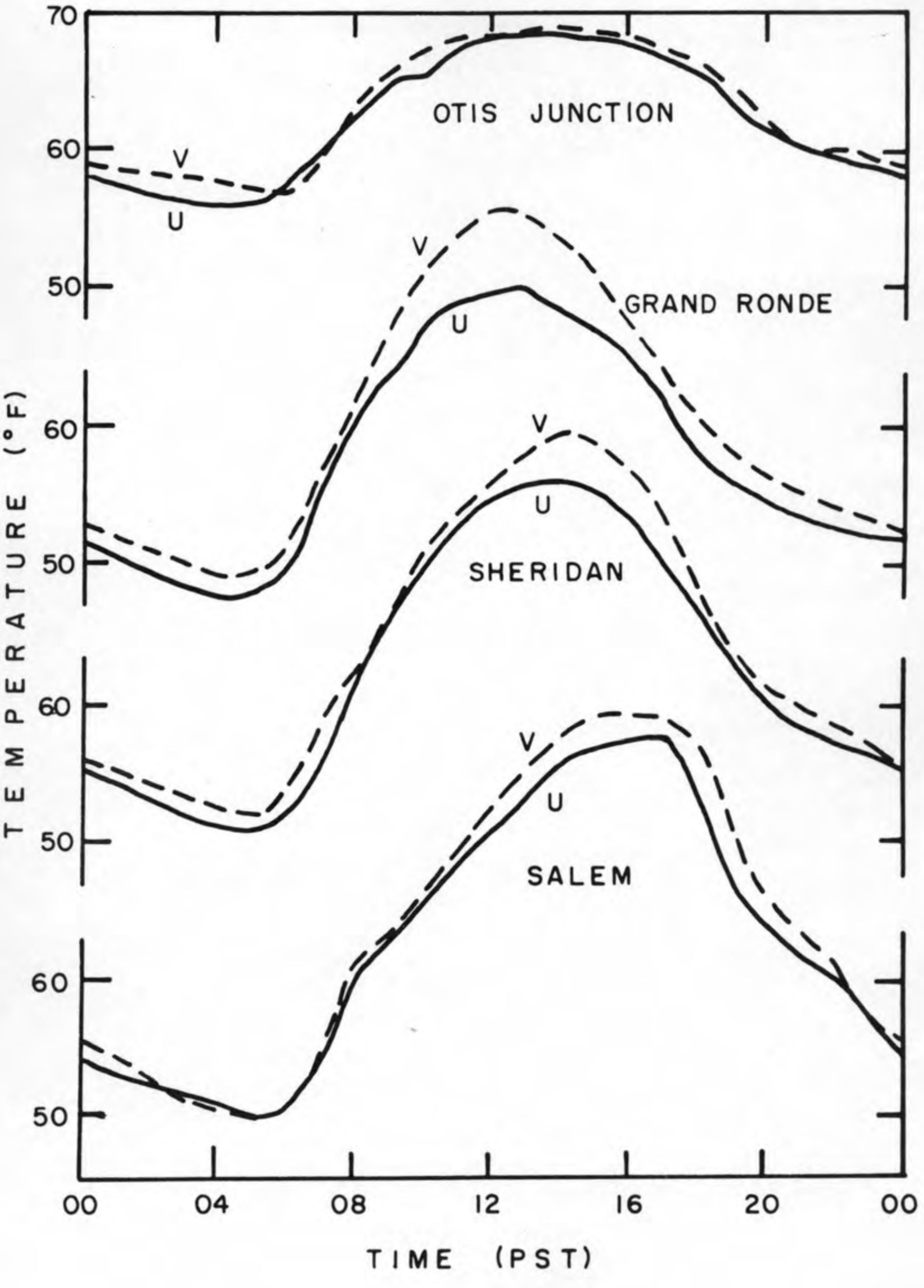

OTIS JUNCTION
GRAND RONDE
SHERIDAN
SALEM
V
U
70
60
50
TEMPERATURE (°F)
00
04
08
12
16
20
TIME (PST)

FIGURE C 1b

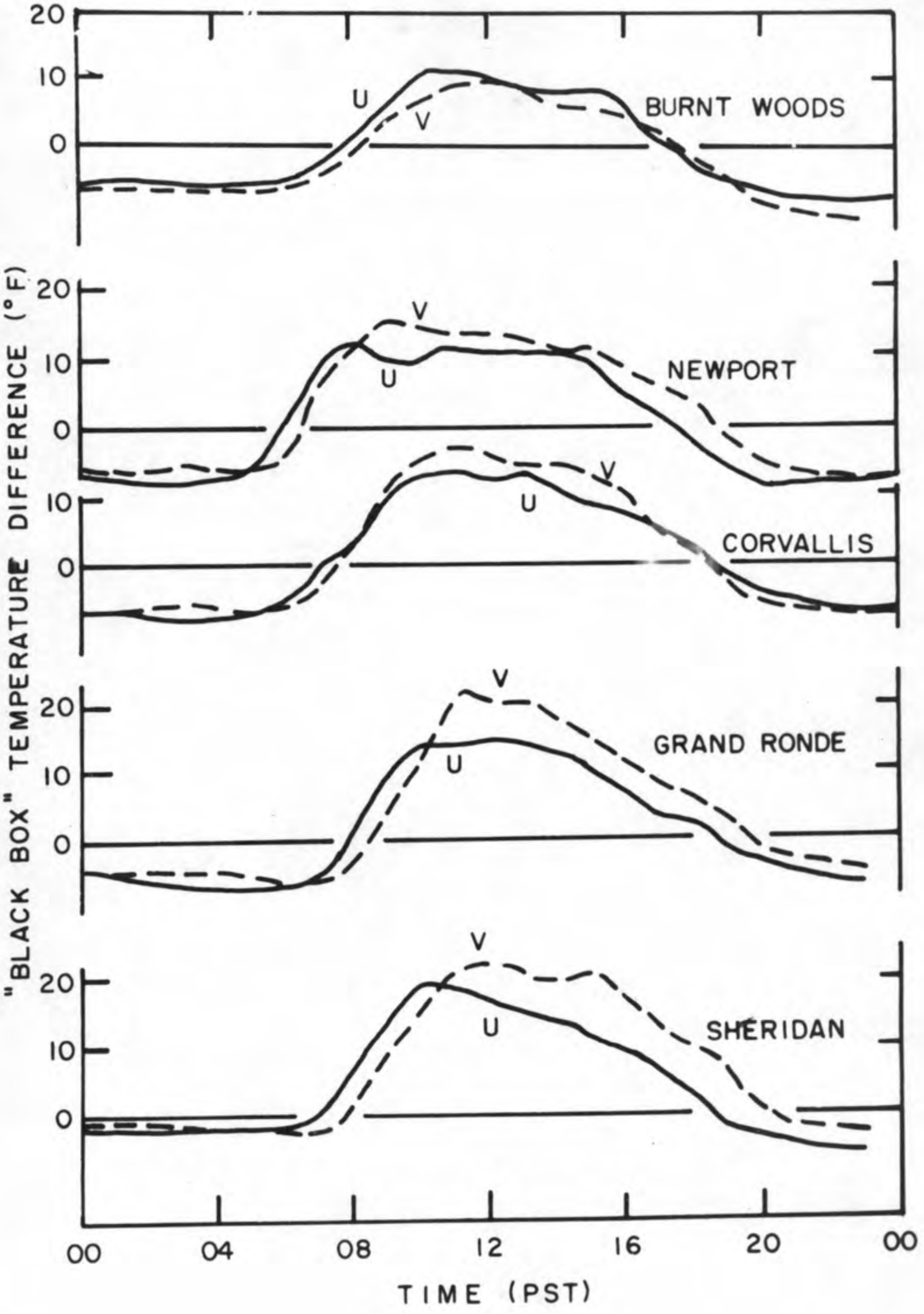

"BLACK BOX" TEMPERATURE DIFFERENCE (°F)
20
10
0
U
V
BURNT WOODS
20
10
0
V
U
NEWPORT
10
0
V
U
CORVALLIS
20
10
0
V
U
GRAND RONDE
V
20
10
0
U
SHERIDAN
00
04
08
12
16
20
00
TIME (PST)

FIGURE C 1c

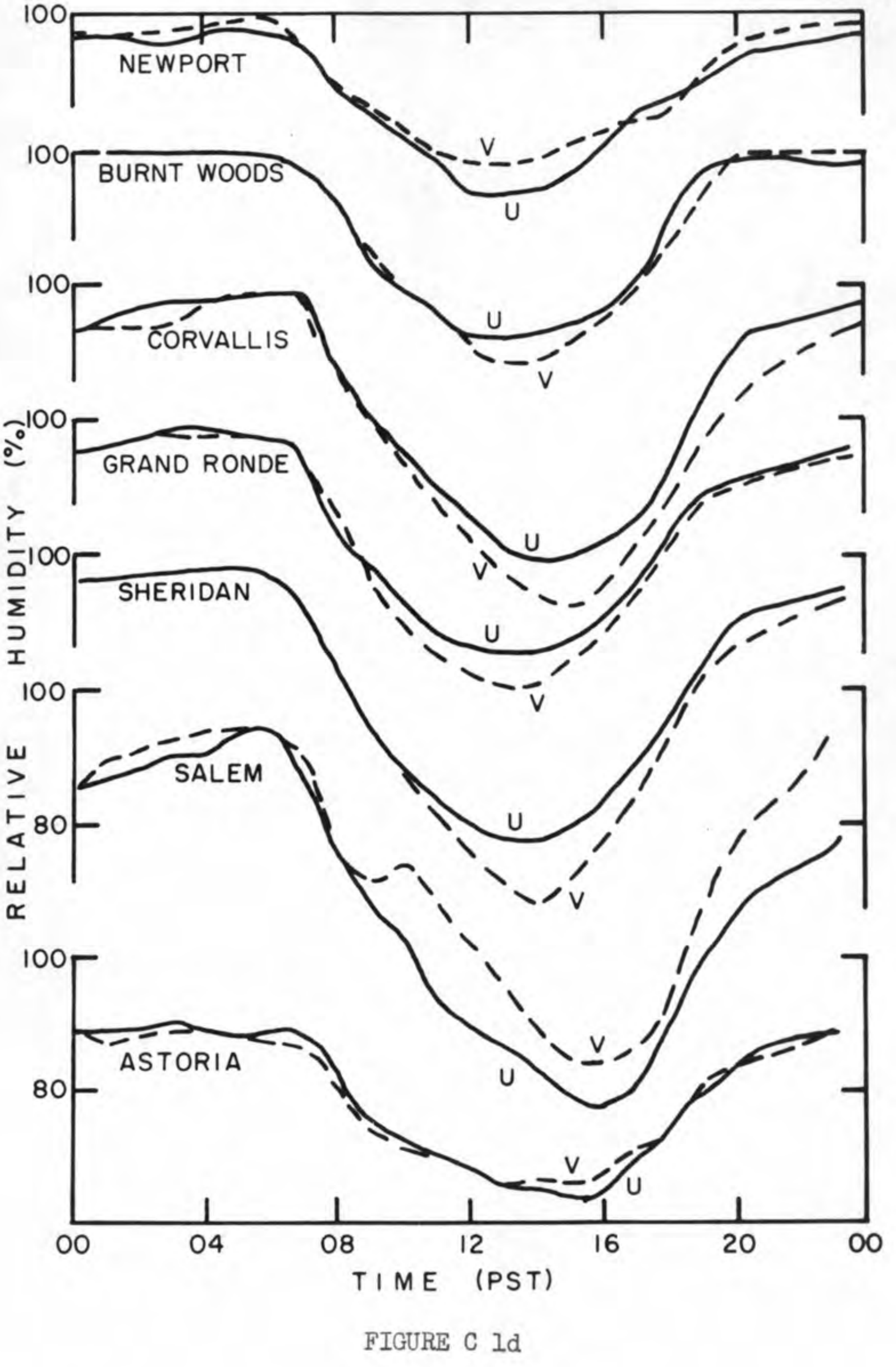

100
NEWPORT
V
100
BURNT WOODS
U
100
U
CORVALLIS
V
100
GRAND RONDE
U
V
100
SHERIDAN
U
V
100
SALEM
80
U
V
100
V
ASTORIA
U
80
V
U
RELATIVE HUMIDITY (%)
00
04
08
12
16
20
00
TIME (PST)

FIGURE C 1d

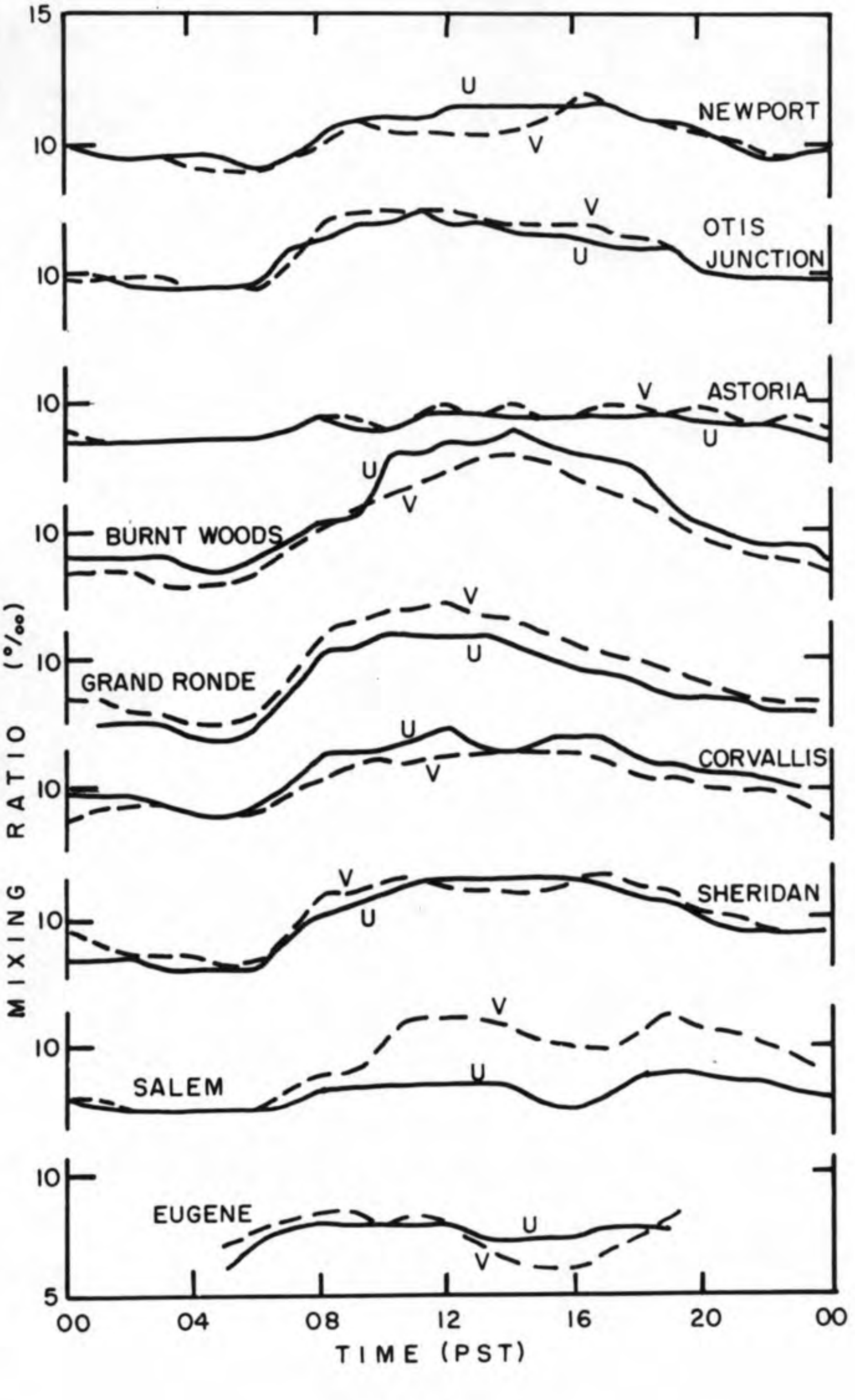

15
10
5
U
V
NEWPORT
OTIS JUNCTION
ASTORIA
BURNT WOODS
GRAND RONDE
CORVALLIS
SHERIDAN
SALEM
EUGENE
MIXING RATIO (°/oo)
00
04
08
12
16
20
00
TIME (PST)

FIGURE C 1e

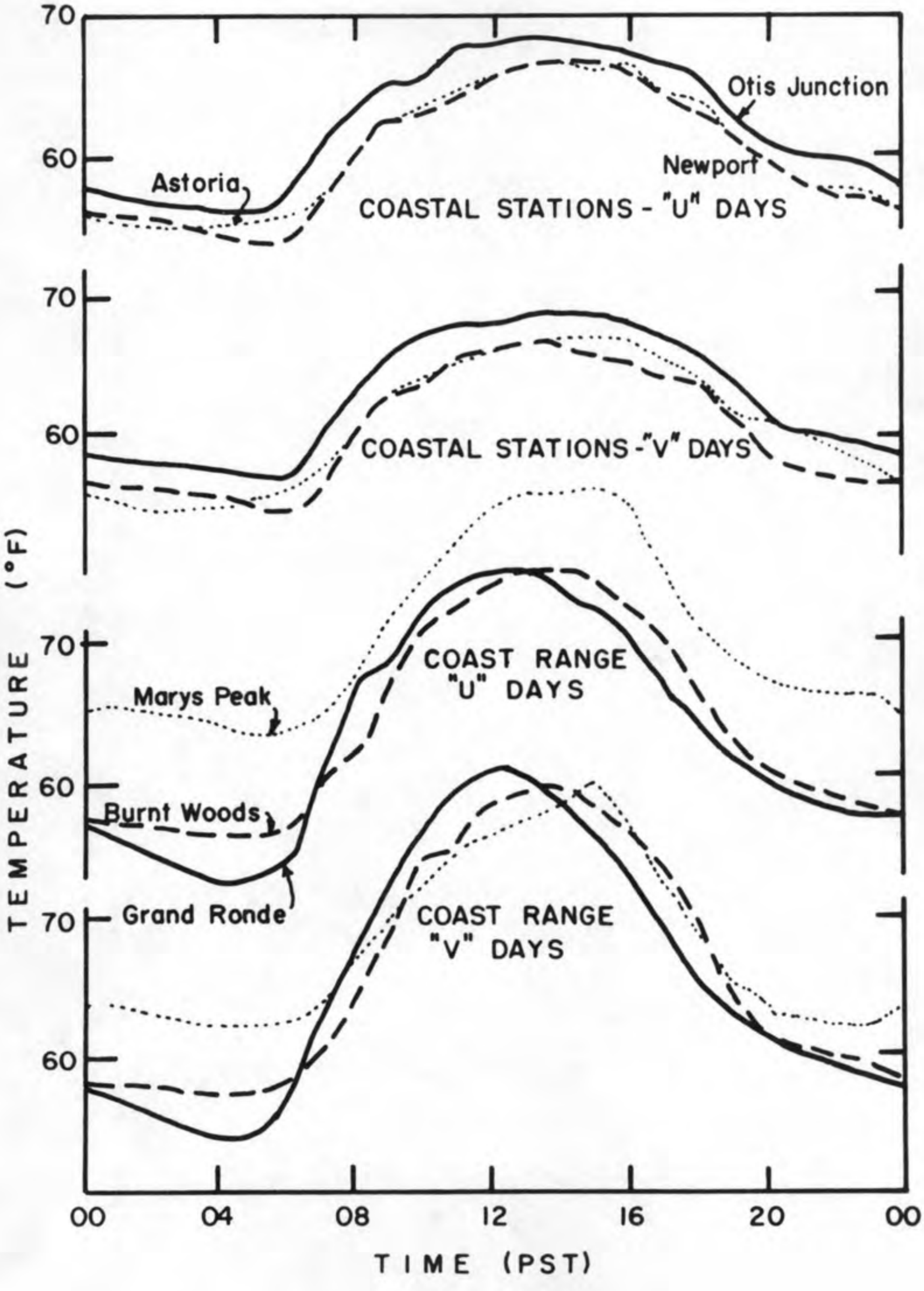

70
60
Otis Junction
Newport
Astoria
COASTAL STATIONS - "U" DAYS
70
60
COASTAL STATIONS - "V" DAYS
TEMPERATURE (°F)
70
COAST RANGE
"U" DAYS
Marys Peak
60
Burnt Woods
Grand Ronde
70
COAST RANGE
"V" DAYS
60
00
04
08
12
16
20
00
TIME (PST)

FIGURE C 2a

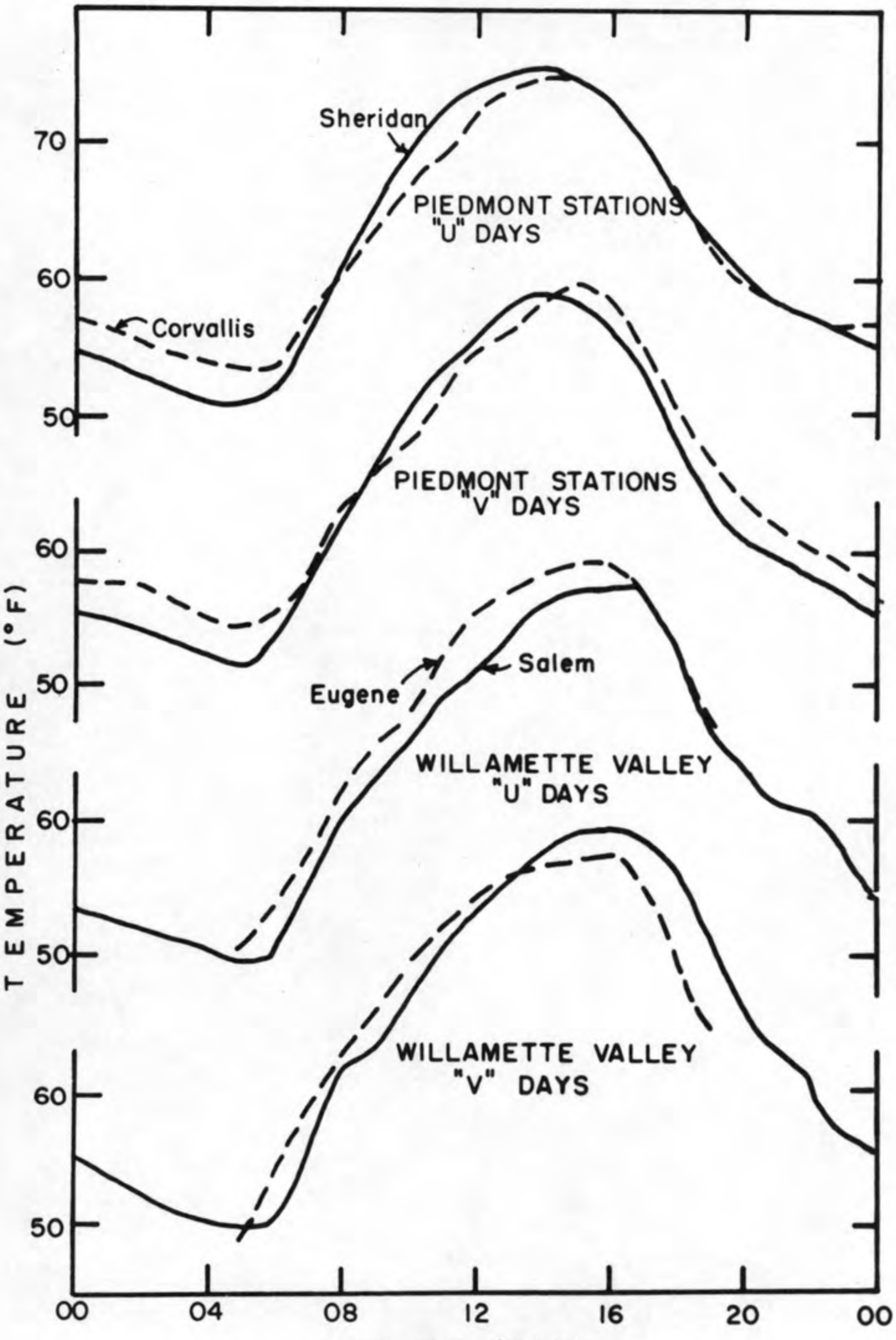
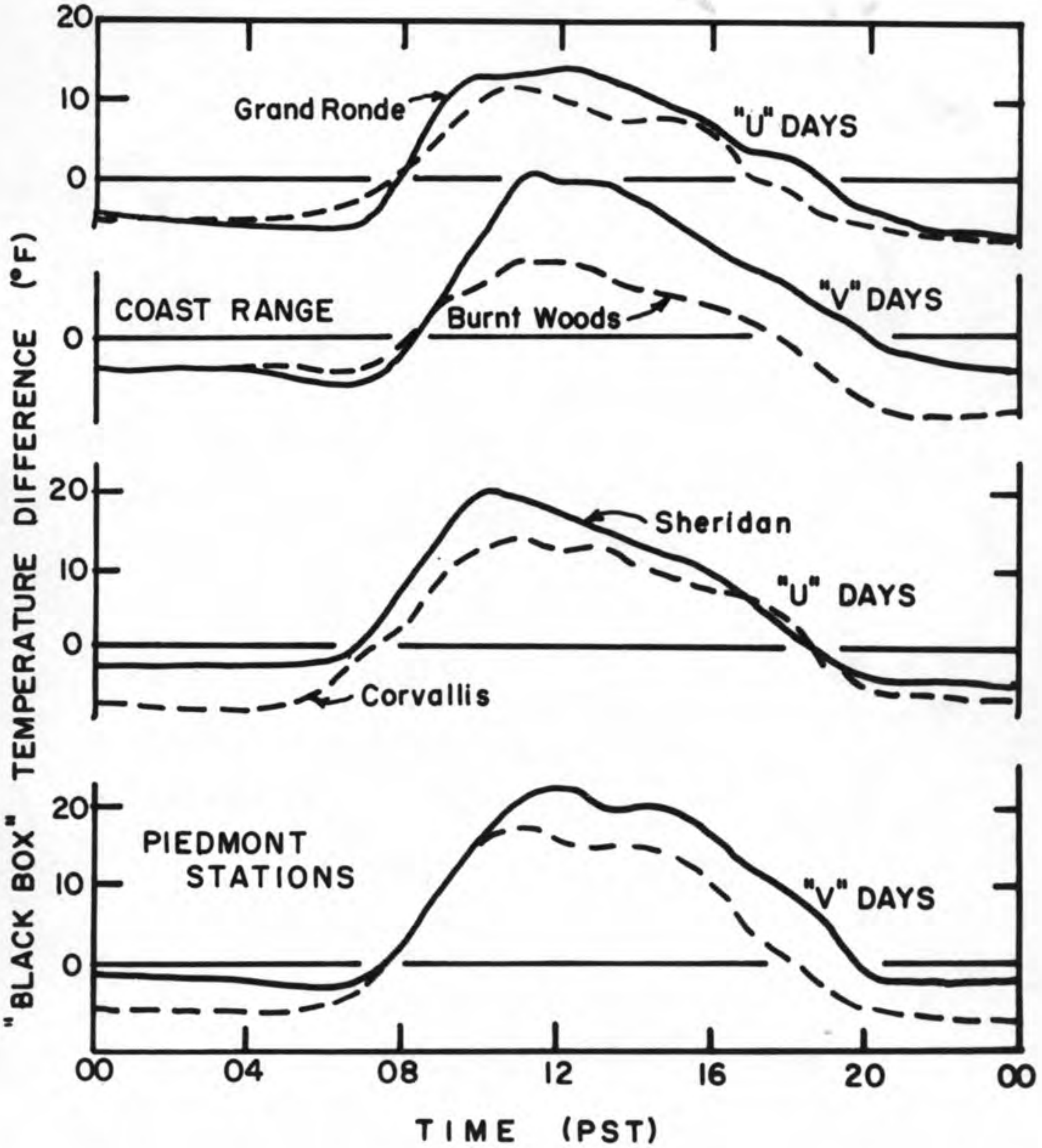

Sheridan
Corvallis
PIEDMONT STATIONS "U" DAYS
PIEDMONT STATIONS "V" DAYS
Eugene
Salem
WILLAMETTE VALLEY "U" DAYS
WILLAMETTE VALLEY "V" DAYS
TEMPERATURE (°F)
70
60
50
60
50
60
50
60
50
00
04
08
12
16
20
00
TIME (PST)

FIGURE C 2b



20
10
0
Grand Ronde
"U" DAYS
COAST RANGE
0
Burnt Woods
"V" DAYS
20
10
0
Sheridan
"U" DAYS
Corvallis
20
10
0
PIEDMONT
STATIONS
"V" DAYS
"BLACK BOX" TEMPERATURE DIFFERENCE (°F)
00
04
08
12
16
20
00
TIME (PST)

FIGURE C 2c

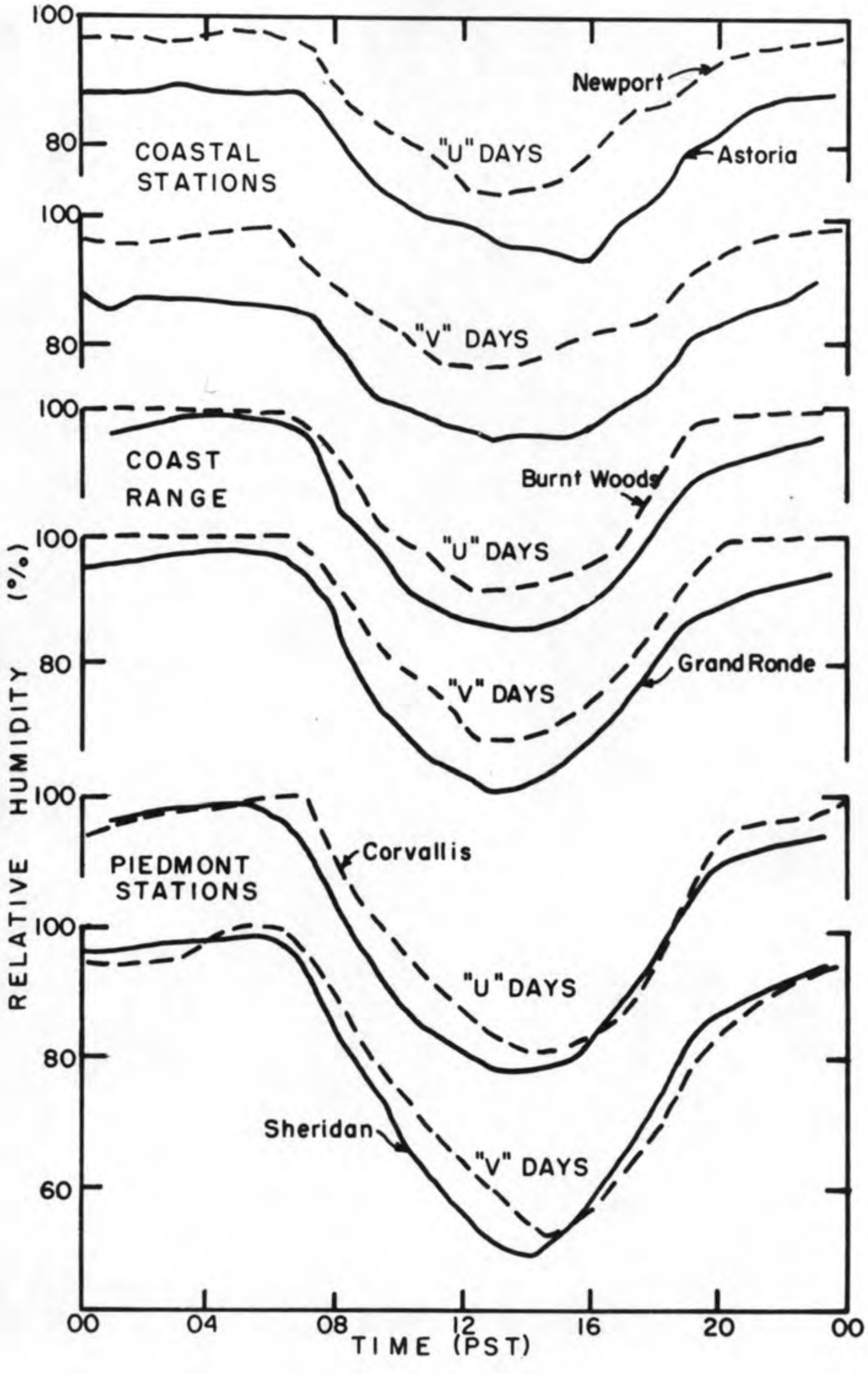

100
80
COASTAL STATIONS
"U" DAYS
Newport
Astoria
100
80
"V" DAYS
100
COAST RANGE
Burnt Woods
"U" DAYS
100
80
"V" DAYS
Grand Ronde
100
PIEDMONT STATIONS
Corvallis
100
"U" DAYS
80
Sheridan
"V" DAYS
60
RELATIVE HUMIDITY (%)
00
04
08
12
16
20
00
TIME (PST)

FIGURE C 2d

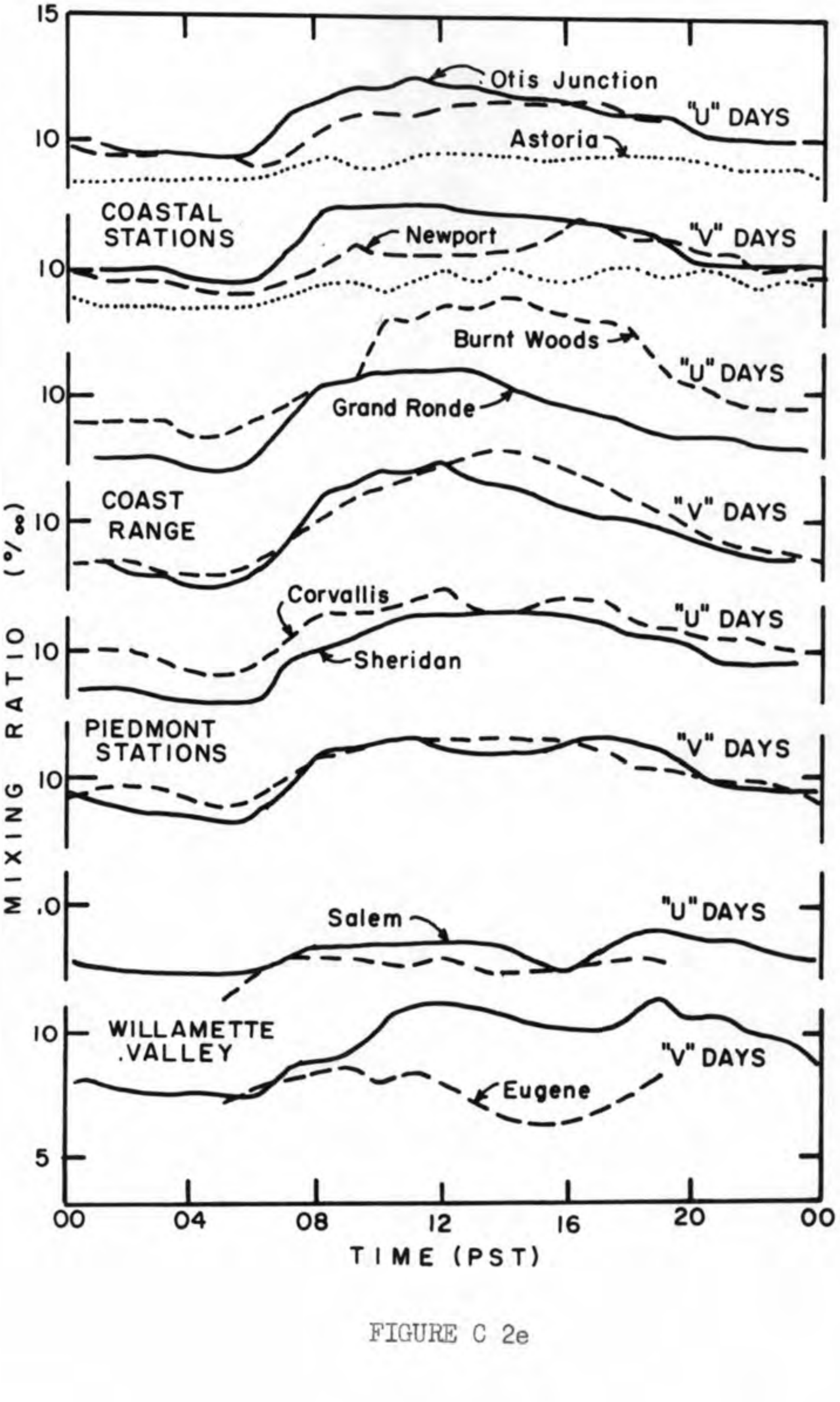

15
10
5
Otis Junction
"U" DAYS
Astoria
COASTAL STATIONS
Newport
"V" DAYS
Burnt Woods
"U" DAYS
Grand Ronde
COAST RANGE
"V" DAYS
Corvallis
Sheridan
"U" DAYS
PIEDMONT STATIONS
"V" DAYS
Salem
"U" DAYS
WILLAMETTE VALLEY
Eugene
"V" DAYS
MIXING RATIO (°/∞)
00
04
08
12
16
20
00
TIME (PST)

FIGURE C 2e

APPENDIX D

MEAN HOURLY VALUES OF TEMPERATURE, "BLACK BOX" TEMPERATURE DIFFERENCE, RELATIVE HUMIDITY, AND MIXING RATIO FOR TEN STATIONS AND FOR 5-DAY SAMPLES OF TWO KINDS OF SEA BREEZE DAY: "U" AND "V"

Variable	Type	Hour	Station									
			CORVALLIS	BURNT WOODS	NEWPORT	OTIS JUNCTION	GRAND RONDE	SHERIDAN	SALEM	ASTORIA	MARYS PEAK	EUGENE
Temperature	"U"	00	57.8	52.8	56.0	58.2	51.8	54.8	54.0	55.8	59.0	
		01	56.8	52.0	55.6	57.4	50.6	53.8	52.6	55.4	59.0	
		02	55.4	52.0	55.6	56.8	49.4	53.0	51.8	55.4	58.4	
		03	54.6	51.4	55.2	56.6	48.8	51.8	51.2	55.0	57.8	
		04	54.4	51.4	54.4	56.4	47.8	51.0	50.8	55.5	57.8	
		05	53.4	51.4	54.0	56.2	47.8	50.6	49.4	55.2	57.4	48.6
		06	53.4	52.0	53.4	57.0	50.0	51.6	50.2	55.4	57.4	53.8
		07	56.0	55.4	55.8	60.4	55.4	56.0	54.8	56.8	59.0	58.6
		08	60.6	58.8	59.6	62.6	61.8	61.2	60.2	59.2	61.4	62.0
		09	63.8	62.2	62.4	65.0	64.0	66.0	63.0	62.2	65.0	65.6
		10	67.6	65.8	63.0	65.4	67.6	69.8	65.2	63.4	67.4	69.4
		11	69.2	67.6	64.0	67.6	69.0	72.4	69.4	64.4	70.0	72.2
		12	72.8	69.8	65.4	68.2	69.8	74.2	71.2	65.4	70.8	74.4
		13	74.0	70.6	66.4	68.6	70.2	75.2	73.4	66.4	72.0	76.0
		14	75.0	70.4	66.6	68.2	68.6	75.8	76.2	66.8	73.0	76.4
		15	75.0	69.6	66.8	68.0	67.0	75.0	76.8	66.0	74.6	77.0
		16	73.6	67.8	66.2	67.4	65.0	73.0	77.0	66.4	72.0	77.0
		17	70.4	65.4	64.2	66.4	61.8	70.0	77.4	64.6	68.0	74.8
		18	65.8	61.4	63.2	65.6	58.6	66.0	73.6	63.8	63.4	69.2
		19	61.8	57.6	61.2	63.2	56.2	62.0	66.6	61.2	60.2	64.8
		20	59.6	55.2	59.6	60.8	54.8	59.4	63.4	59.9	58.8	
		21	58.2	54.0	58.4	59.8	53.8	58.2	61.2	57.8	57.6	
		22	57.4	53.8	57.0	59.4	52.6	57.0	60.6	57.6	57.0	
		23	56.8	53.4	57.2	58.8	52.2	56.4	58.0	57.0	57.0	

APPENDIX D (CONTINUED)

Variable	Type	Hour	Station									
			CORVALLIS	BURNT WOODS	NEWPORT	OTIS JUNCTION	GRAND RONDE	SHERIDAN	SALEM	ASTORIA	MARYS PEAK	EUGENE
Tempera- ture	"V"	00	57.6	53.2	57.0	58.8	52.8	55.6	55.2	56.0	59.8	
		01	57.4	53.0	56.6	58.4	52.4	54.8	53.8	55.2	60.2	
		02	57.2	53.0	56.6	58.2	51.0	53.8	52.2	54.6	59.8	
		03	56.2	52.6	56.0	58.0	50.2	53.2	51.2	54.6	59.6	
		04	55.0	52.2	55.8	57.6	49.0	52.2	50.6	54.8	58.8	
		05	54.0	52.2	55.0	57.0	49.4	51.6	49.8	55.2	58.0	50.4
		06	55.6	52.8	54.4	57.0	51.6	52.8	50.2	55.8	58.2	54.0
		07	58.6	55.0	56.0	60.2	56.6	57.4	54.6	57.4	59.4	57.3
		08	63.0	59.0	60.0	63.6	62.2	63.0	61.2	60.0	62.6	62.2
		09	65.6	63.8	63.2	66.0	68.0	66.6	63.0	62.8	66.6	65.6
		10	68.2	69.2	63.8	67.2	71.8	70.8	66.4	63.8	69.6	67.5
		11	72.0	70.0	65.8	68.0	74.2	73.8	69.6	65.2	72.4	72.4
		12	74.8	73.2	66.4	68.2	76.0	75.8	72.6	65.8	74.2	75.8
		13	76.0	74.2	66.8	68.6	75.0	78.0	75.6	66.4	75.6	76.8
		14	78.4	74.4	67.0	68.8	73.2	79.4	77.6	66.8	74.8	78.2
		15	79.8	73.0	65.8	68.2	71.0	78.0	79.4	66.8	75.8	79.2
		16	78.6	71.0	65.4	68.0	67.8	76.4	79.0	66.4	75.2	79.0
		17	75.0	68.8	64.6	66.8	64.2	73.2	78.8	65.0	70.8	77.2
		18	70.4	65.2	64.0	65.6	60.6	68.2	76.6	64.0	66.4	72.8
		19	66.4	59.6	61.4	63.8	57.6	63.6	71.2	61.2	63.8	67.2
		20	63.0	56.6	58.6	61.4	56.2	60.6	66.0	60.8	62.0	
		21	61.6	55.4	57.6	60.0	55.0	59.4	63.4	59.6	61.0	
		22	60.2	54.8	57.2	59.8	54.4	58.2	61.6	58.6	60.8	
		23	59.6	54.6	57.2	59.2	53.4	56.8	57.6	57.8	61.0	

APPENDIX D (CONTINUED)

Variable	Type	Hour	Station **				
			CORVALLIS	BURNT WOODS	NEWPORT	GRAND RONDE	SHERIDAN
"Black Box" Temperature	"U"	00	51.2	47.8	49.2	47.6	52.0
		01	50.0	47.4	48.4	45.8	51.0
		02	49.2	47.4	48.4	44.4	50.0
		03	47.6	46.8	48.2	43.4	49.4
		04	47.0	46.4	47.8	42.4	49.2
		05	46.8	46.6	47.8	42.0	48.2
		06	48.8	47.8	53.8	43.8	50.0
		07	55.2	53.6	65.0	50.2	56.8
		08	62.8	60.0	72.2	63.0	68.4
		09	73.4	68.4	72.2	74.4	80.0
		10	79.8	76.6	72.6	81.8	89.0
		11	83.4	79.6	75.2	83.2	92.4
		12	85.8	80.0	76.4	84.4	91.6
		13	87.2	78.8	77.4	84.2	91.6
		14	85.6	77.2	77.4	81.2	89.6
		15	84.6	77.4	75.9	77.4	87.2
		16	81.4	73.8	69.9	72.8	82.2
		17	75.6	65.8	66.7	65.8	76.0
		18	69.2	59.6	61.5	62.2	69.2
		19	60.8	51.8	54.7	56.2	61.4
		20	54.6	49.2	50.9	51.0	56.4
		21	52.0	47.8	50.1	48.6	54.4
		22	57.4	47.0	49.3	47.6	53.4
		23	49.4	46.8	49.5	46.4	52.4

** Only the first six stations listed had "black box" temperatures, and during the ten days of these samples, the Otis Junction station record was missing due to instrument failure.

APPENDIX D (CONTINUED)

Variable	Type	Hour	Station				
			CORVALLIS	BURNT WOODS	NEWPORT	GRAND RONDE	SHERIDAN
"Black Box" Temperature	"V"	00	51.4	49.8	51.0	48.6	53.6
		01	50.8	49.6	50.8	47.9	53.2
		02	51.0	49.8	50.8	46.5	52.0
		03	50.6	49.4	50.4	45.7	51.0
		04	49.2	48.8	49.6	45.0	50.2
		05	47.8	48.6	48.4	44.6	50.0
		06	49.4	49.0	50.0	45.8	49.8
		07	55.4	51.0	62.4	50.4	55.0
		08	66.4	58.4	72.0	59.4	64.0
		09	76.4	67.8	78.6	71.8	76.4
		10	83.6	76.0	78.6	84.8	86.4
		11	89.2	80.0	80.0	95.4	94.2
		12	91.2	82.6	79.8	95.8	98.2
		13	90.8	83.8	80.0	94.8	98.6
		14	93.4	81.2	78.4	91.0	97.8
		15	93.0	78.6	76.4	84.8	98.2
		16	88.6	75.8	73.8	78.8	93.2
		17	79.4	70.8	71.0	77.7	85.8
		18	72.2	64.6	67.6	67.1	78.4
		19	62.4	54.6	59.0	60.6	68.6
		20	58.0	48.0	53.6	54.7	60.0
		21	55.6	46.2	51.4	52.2	57.4
		22	54.0	45.6	50.6	50.2	56.0
		23	52.6	44.6	50.4	49.4	55.0

APPENDIX D (CONTINUED)

Variable	Type	Hour	Station							
			CORVALLIS	BURNT WOODS	NEWPORT	OTIS JUNCTION	GRAND RONDE	SHERIDAN	SALEM	ASTORIA
Relative Humidity	"U"	00	93.5	99.5	97.0	92.5			85.4	88.6
		01	95.5	99.7	97.0	92.7	96.6	96.6	87.4	88.6
		02	96.9	99.7	97.0	93.5	97.8	97.9	89.0	88.6
		03	99.0	99.7	96.8	94.1	99.0	97.6	89.8	90.4
		04	98.2	99.7	97.6	94.5	99.0	98.8	90.6	89.2
		05	99.6	99.7	98.2	94.3	98.8	98.6	94.0	88.2
		06	99.4	99.7	97.6	94.1	98.2	98.0	93.6	89.4
		07	99.9	97.1	96.0	93.3	95.0	93.0	85.6	88.6
		08	89.2	92.7	88.6	91.5	84.8	83.8	73.8	83.0
		09	81.8	83.9	84.8	87.7	79.2	74.8	67.0	74.8
		10	74.4	79.3	81.4	84.9	72.6	67.8	62.4	70.6
		11	71.0	77.7	79.2	82.5	69.2	64.0	53.4	70.0
		12	65.2	73.5	73.6	79.7	67.0	60.2	49.6	68.6
		13	61.6	73.1	73.6	77.9	65.6	57.6	46.0	65.2
		14	60.0	72.9	74.0	76.7	65.6	57.6	42.0	65.0
		15	60.8	74.1	75.6	76.1	67.6	59.0	38.4	63.8
		16	61.6	76.1	79.2	76.5	70.2	63.0	37.6	63.6
		17	65.8	80.1	85.0	77.7	75.2	68.2	40.4	69.8
		18	72.8	90.5	86.8	79.3	82.6	75.8	49.6	72.8
		19	83.4	97.7	90.0	83.5	56.2	83.0	60.6	80.0
		20	91.8	98.9	92.8	86.1	91.0	88.8	66.4	82.2
		21	94.4	98.9	95.6	87.9	92.8	91.4	71.8	86.4
		22	96.4	98.7	95.8	90.3	94.0	92.2	73.6	88.2
		23	97.4	98.7	96.0	91.5	95.4	93.4	77.4	88.4

APPENDIX D (CONTINUED)

Variable	Type	Hour	Station							
			CORVALLIS	BURNT WOODS	NEWPORT	OTIS JUNCTION	GRAND RONDE	SHERIDAN	SALEM	ASTORIA
Relative Humidity	"V"	00	94.0	99.9	97.4	91.0	96.2	95.6	84.6	90.0
		01	94.3	99.9	96.8	91.6	96.6	95.8	90.4	86.8
		02	94.3	99.9	97.0	92.4	97.4	96.8	91.0	89.0
		03	94.5	99.9	97.8	92.2	98.2	98.2	93.0	88.8
		04	97.5	99.9	98.2	92.4	98.0	98.2	94.0	88.6
		05	98.7	99.9	98.8	92.6	99.0	98.0	94.0	87.2
		06	99.1	99.9	99.2	93.0	98.6	97.6	94.4	87.2
		07	97.5	97.4	95.4	92.4	94.8	91.8	90.0	86.6
		08	89.9	93.2	89.8	91.0	87.2	84.0	75.8	81.0
		09	80.7	84.4	85.8	87.0	75.8	76.6	70.0	73.6
		10	75.1	80.0	83.4	84.6	69.4	67.4	73.2	70.8
		11	68.9	76.0	79.4	82.6	65.0	61.2	68.0	69.0
		12	63.1	70.6	77.8	80.8	62.4	56.0	61.4	68.0
		13	58.1	68.0	77.8	78.4	60.8	51.0	55.2	65.4
		14	54.3	69.4	78.0	77.6	61.4	48.8	48.4	66.2
		15	51.9	71.8	80.2	77.4	64.0	51.4	44.4	65.8
		16	54.3	74.6	81.8	77.2	68.4	57.4	44.2	66.4
		17	60.5	79.2	84.0	78.6	74.0	63.4	45.2	71.0
		18	66.9	87.2	84.8	80.2	82.4	72.0	54.0	73.6
		19	76.3	94.2	90.2	82.6	87.4	82.2	66.2	80.6
		20	82.5	99.9	95.0	85.4	89.8	86.4	75.4	82.8
		21	86.1	99.9	96.4	89.0	91.6	88.8	82.0	84.6
		22	90.5	99.9	97.4	91.2	92.6	91.0	85.8	85.8
		23	91.3	99.9	98.0	92.6	94.4	93.0	93.8	89.0

APPENDIX D (CONTINUED)

Variable	Type	Hour	CORVALLIS	BURNT WOODS	NEWPORT	OTIS JUNCTION	GRAND RONDE	SHERIDAN	SALEM	ASTORIA	EUGENE
Mixing ratio	"U"	00	9.0	8.5	10.0	10.0			8.0	8.5	
		01	9.5	8.5	9.5	10.0	7.5	8.5	7.5	8.5	
		02	9.5	8.5	9.5	9.5	7.5	8.5	7.5	8.5	
		03	9.5	8.0	9.5	9.5	7.5	8.0	7.5	8.5	
		04	9.0	8.0	9.0	9.5	7.0	8.0	7.5	8.5	
		05	9.0	8.0	9.0	9.5	7.0	8.0	7.5	8.5	6.4
		06	9.0	8.5	9.0	9.5	7.5	8.0	7.5	8.5	7.7
		07	10.0	9.5	9.5	11.0	9.0	9.5	8.0	9.0	8.0
		08	10.5	10.5	10.0	11.5	10.5	10.0	8.5	9.5	8.2
		09	11.0	11.0	11.0	12.0	10.5	10.5	8.5	9.0	7.9
		10	11.0	11.5	10.5	12.0	11.0	11.0	8.5	9.0	7.9
		11	11.0	12.0	10.5	12.5	11.0	11.5	8.5	9.5	7.6
		12	11.5	12.5	10.2	12.0	11.0	11.5	8.5	9.5	7.9
		13	11.5	13.0	10.5	12.0	11.0	11.5	8.5	9.5	7.3
		14	11.5	13.0	10.5	11.5	10.5	11.5	8.5	9.5	7.5
		15	11.5	12.5	11.0	11.5	10.0	11.5	7.5	9.2	7.6
		16	11.6	12.0	12.0	11.5	9.5	11.5	7.5	9.5	7.7
		17	11.0	11.5	11.5	11.0	9.5	11.0	8.5	9.5	8.0
		18	10.5	11.0	11.0	11.0	9.0	10.5	9.0	9.5	8.1
		19	10.5	10.5	11.0	11.0	8.5	10.5	9.0	9.5	7.9
		20	10.0	9.5	10.5	10.0	8.5	10.0	8.5	9.2	
		21	10.0	9.0	10.5	10.0	8.5	9.5	8.5	9.0	
		22	10.0	9.0	9.5	10.0	8.0	9.5	8.5	9.0	
		23	9.5	9.0	10.0	10.0	8.0	9.5	8.0	9.0	

APPENDIX D (CONTINUED)

Variable	Type	Hour	Station								
			CORVALLIS	BURNT WOODS	NEWPORT	OTIS JUNCTION	GRAND RONDE	SHERIDAN	SALEM	ASTORIA	EUGENE
Mixing ratio	"V"	00	10.0	9.0	10.0	10.0	8.5	9.5	8.0	9.0	
		01	10.0	9.0	9.5	10.0	8.5	9.0	8.0	8.5	
		02	10.0	9.0	9.5	10.0	8.0	8.5	7.5	8.5	
		03	9.5	9.0	9.5	10.0	8.0	8.5	7.5	8.5	
		04	9.0	8.5	9.5	9.5	7.5	8.5	7.5	8.5	
		05	9.0	8.5	9.5	9.5	7.5	8.0	7.5	8.5	7.1
		06	9.5	9.0	9.0	9.5	8.0	8.5	7.5	8.5	7.8
		07	10.5	9.5	9.5	10.5	9.5	9.5	8.5	9.0	8.1
		08	11.5	10.5	10.5	12.0	11.0	11.0	9.0	9.5	8.5
		09	11.5	10.5	11.0	12.5	11.5	11.0	9.0	9.5	8.7
		10	11.5	13.0	11.0	12.5	12.0	11.5	10.5	9.0	8.0
		11	12.0	13.0	11.0	12.5	12.0	11.5	11.0	9.5	8.4
		12	12.5	13.5	11.5	12.5	12.5	11.0	11.0	10.0	7.9
		13	11.5	13.5	11.5	12.0	11.5	11.0	11.0	9.5	6.9
		14	11.5	14.0	11.5	12.0	11.5	11.0	10.5	10.0	6.4
		15	12.0	13.5	11.5	12.0	11.0	11.0	10.0	9.5	6.4
		16	12.0	13.0	11.5	12.0	10.5	11.5	10.0	9.5	6.4
		17	12.0	13.0	11.5	11.5	10.0	11.5	10.0	10.0	7.0
		18	11.0	12.5	11.0	11.5	10.0	11.0	11.0	10.0	7.6
		19	11.0	10.5	10.5	11.0	9.5	11.0	11.2	9.5	8.3
		20	10.5	10.5	10.5	10.0	9.0	10.0	10.5	10.0	
		21	10.5	10.0	10.0	10.0	8.5	10.0	10.5	9.5	
		22	10.5	9.5	10.0	10.0	8.5	9.5	10.2	9.0	
		23	10.0	9.5	10.0	10.0	8.5	9.5	9.5	9.5	

APPENDIX E

1-HOUR AND 3-HOUR LOCAL CHANGES IN TEMPERATURE, RELATIVE HUMIDITY, MIXING RATIO, AND "BLACK BOX" TEMPERATURE DIFFERENCE FOLLOWING THE TIME OF RELATIVE HUMIDITY MINIMUM AT SIX SPECIAL GROUND STATIONS ON SEA BREEZE DAYS IN 1957

Station	Date	T_0	ΔT_1	ΔT_3	R_0	ΔR_1	ΔR_3	m_0	Δm_1	Δm_3	B_0	ΔB_1	ΔB_3
Newport	8 Jul	65	-3	-1	79	-1	2	11.0	-1.5	0	13	5	-1
	22	64	-1	0	77	0	-1	10.5	-1.0	-0.5			
	24	64	1	2	76	-1	-1	10.0	0.5	0.5	20	-5	-6
	28	63	1	1	88	0	0	11.5	0.5	0.5			
	14 Aug	64	0	3	90	-1	-7	12.0	0	0	22	-6	-8
	15	64	0	3	85	-2	-6	11.0	0	0.5	17	-1	-1
	19	63	-1	2	80	5	-4	10.0	0.5	0.5	8	0	7
	20	64	2	4	85	-4	-9	11.5	0	0	16	-2	-4
	22	68	1	3	86	-4	-16	13.0	0	-1.0	22	-4	-8
	23	67	0	1	84	1	2	12.5	0	0.5	17	-1	-4
	25	64	0	1	70	-2	-3	9.0	0	0.5	21	0	-6
	26	62	1	5	82	-6	-19	10.0	-0.5	-0.5	23	-2	-5
Oceanlake	8 Jul	68	0	-1	88	-1	-2	13.0	0	-0.5			
	22	64	0	0	94	-2	-5	12.5	-0.5	-0.5	13	2	4
	23	66	1	3	99	-1	-3	14.0	1.0	1.0	9	3	14
	24	65	0	2	91	-2	-6	12.5	0	0	8	7	10
	28	66	1	2	95	-2	-4	13.5	0	0	17	-1	-2
	14 Aug	68	0	1	92	-3	-6	13.5	0	0			
	15	66	1	3	94	-3	-7	13.0	0	0.5			
	19	68	1	-1	90	-4	-8	13.5	0	-1.5			
	20	65	1	5	97	-4	-9	13.0	0.5	1.0			
	22	68	1	3	90	-4	-10	13.5	0	0			
	23	70	-1	0	86	-2	-4	14.0	-1.0	-1.0			
	25	65	1	2	83	-2	-9	11.5	0	-0.5			
	28	67	-1	-1	80	-1	-1	12.0	-1.0	-1.0			

APPENDIX E (CONTINUED)

Station	Date	T_0	ΔT_1	ΔT_3	R_0	ΔR_1	ΔR_3	m_0	Δm_1	Δm_3	B_0	ΔB_1	ΔB_3
Burnt Woods	8 Jul	71	1	1	70	1	2	12.0	1.0	1.5			
	22	68	-3	-11	78	3	16	12.5	-1.0	-2.5			
	14 Aug	74	-1	-4	75	3	11	15.0	-0.5	-0.5	12	-3	-3
	15	76	-2	-6	71	2	5	15.0	-0.5	-2.0	10	-1	0
	19	74	-1	-6	69	5	11	14.0	0	-1.5	17	-2	-3
	20	77	0	-5	58	5	14	12.5	1.5	0.5	15	-3	-7
	22	83	-1	-6	59	5	6	15.5	1.0	-1.5	17	-4	-8
	23	75	0	-1	78	1	4	16.0	0	0	11	-3	-7
	25	71	-2	-3	62	3	8	11.0	0	0	12	-4	-5
	26	73	-2	-5	63	2	15	12.5	-0.5	-1.5	19	-4	-13
Grand Ronde	8 Jul	73	-3	-8	77	4	8	14.0	-0.5	-2.0	31	-6	-15
	22	69	-1	-2	82	-1	-1	13.0	-0.5	-1.0	14	-3	-10
	23	76	-2	-8	75	2	7	15.0	-1.0	-2.5	16	-9	-12
	24	77	-4	-7	70	2	8	14.0	-1.0	-1.0	20	-5	-14
	28	78	-3	-7	68	7	15	14.0	0	0	20	-6	-12
	14 Aug	77	-2	-6	62	0	6	12.5	-0.5	-1.0	22	-2	-4
	15	78	-3	-8	66	-2	2	14.0	-1.5	-2.5	17	2	-5
	19	77	-3	-8	62	-1	2	12.5	-1.0	-2.5	23	-7	-15
	20	77	-3	-8	58	1	11	12.0	-1.0	-1.0	24	-8	-14
	22	87	-6	-12	42	9	14	12.5	-0.5	-2.0			
	23	73	-4	-3	68	8	8	12.5	-0.5	-0.5			
	26	74	-1	-5	50	4	15	9.5	0.5	1.0			

APPENDIX E (CONTINUED)

Station	Date	T_0	ΔT_1	ΔT_3	R_0	ΔR_1	ΔR_3	m_0	Δm_1	Δm_3	B_0	ΔB_1	ΔB_3
Corvallis	8 Jul	81	0	-8	40	10	20	9.5	2.0	1.5	13	-7	-4
	22	73	-5	-15	62	7	25	11.5	-1.0	-2.0	7	-4	-10
	23	79	-2	-12	51	8	20	11.0	1.0	-0.5	15	-4	-14
	24	81	-3	-11	45	12	18	11.0	1.0	-0.5	16	-8	-13
	28	82	-1	-8	50	9	16	12.0	2.0	0	14	-4	-5
	14 Aug	81	-3	-11	50	7	22	12.0	0	0	17	-7	-13
	15	81	-3	-10	52	6	15	12.0	0.5	-0.5	9	-1	-8
	19	79	-3	-15	55	8	25	12.5	0.5	-2.0	16	-4	-3
	20	83	-5	-15	44	12	26	11.0	1.0	0	15	-2	-5
	22	91	-7	-17	38	16	24	12.0	2.0	0	14	-7	-20
	23	83	-2	-8	52	6	16	13.0	0.5	0.5	16	0	-14
	25	75	-2	-6	48	3	10	9.5	0	-0.5	15	-5	-16
	26	78	-3	-12	40	13	28	8.5	1.5	1.5	16	-16	-22
Sheridan	8 Jul	76	-4	-8	52	1	13	10.0	-1.0	0	16	-4	-19
	22	73	-2	-10	60	5	15	11.0	0	-1.5			
	23	76	-1	-6	55	9	12	11.0	1.5	0	24	-5	-11
	24	80	-2	-7	52	7	14	12.0	0.5	0	18	-6	-13
	28	83	-4	-9	50	6	16	12.5	0	0	19	-7	-12
	14 Aug	79	-2	-6	52	8	20	11.5	0.5	1.5	20	-6	-15
	15	83	-4	-9	50	6	18	12.5	-0.5	0.5	23	-8	-19
	19	79	-2	-8	52	6	18	12.5	-0.5	-0.5	25	-12	-21
	20	82	-3	-9	42	12	26	10.5	1.5	1.5	23	-9	-18
	22	89	-6	-15	32	18	28	9.5	3.0	1.5	25	-10	-23
	23	78	1	-1	52	8	16	11.0	2.5	3.0	23	-11	-15
	25	76	-3	-6	41	7	11	8.0	0.5	0.5	23	2	-5
	26	78	-2	-7	42	10	24	9.0	1.0	2.0	25	-9	-18
	28	77	-2	-5	46	2	11	9.5	-0.5	0.5	19	-9	-10

APPENDIX F

CALCULATION OF HEATING RATES AT THE SURFACE

ACCORDING TO EQUATION 1, PAGE 80

Date	Location*	Time	Term B	Term C				Term A
			$\partial\theta/\partial t$	$\Delta\theta$	Δx	$\Delta\theta/\Delta x$	V	$d\theta/dt$
			(deg C/hr)	(deg C)	(km)	(deg/km)	(km/hr)	(deg/hr)
15 May	1-2	0945	1.3	2	5	0.4	10	5.3
		1030	1.3	2	5	0.4	15	7.3
		1420	1.0	4	5	0.8	23	19.4
		1515	0	3	5	0.6	23	13.8
	2-3	0945	1.3	1.5	5	0.3	10	4.3
		1030	1.3	1.5	5	0.3	15	5.8
		1420	1.0	0.5	5	0.1	23	3.3
		1515	0	1.0	5	0.2	23	4.6
	4-5	0940	1.0	2.0	5	0.4	10	5.0
		1050	1.0	2.0	5	0.4	10	5.0
		1410	0.5	0.5	5	0.1	15	2.0
		1450	0.5	0.5	5	0.1	15	2.0
	6-7	0900	3.0	0	10	0	10	3.0
		1120	1.0	1.0	10	0.1	15	2.5
		1340	-1.5	1.0	10	0.1	23	0.8
		1600	-1.5	0.5	10	0.05	23	-0.4
	8-9	0915	5.5	-2.5	10	-0.25	10	3.0
		1115	0.5	0	10	0	10	0.5
		1330	-2.5	0.5	10	0.05	20	-1.5
		1515	-1.5	0	10	0	23	-1.5
	10-11	0830	2.5	0	8	0	5	2.5
		1300	0.5	0	8	0	15	0.5
	12-13	0900	2.5	0	18	0	10	2.5
		1145	2	-0.5	18	-0.03	10	1.7
		1315	0	-0.5	18	-0.03	15	-0.5
		1545	-1.5	0	18	0	23	-1.5

* Locations are given as x increments corresponding to pairs of the following points:

1 - Newport
2 - Yaquina, about 5 km east of Newport
3 - Toledo
4 - Oceanlake
5 - Otis Junction
6 - Burnt Woods
7 - 10 km east of 6
8 - Boyer
9 - Grand Ronde
10 - Philomath
11 - Corvallis
12 - Wallace Br.
13 - Perrydale

APPENDIX F (CONTINUED)

Date	Location	Time	Term B	Term C				Term A
			$\partial\theta/\partial t$ (deg C/hr)	$\Delta\theta$ (deg C)	Δx (km)	$\Delta\theta/\Delta x$ (deg/km)	V (km/hr)	$d\theta/dt$ (deg/hr)
29 May	1-2	0950	0.5	1.5	5	0.3	8	2.9
		1030	0.5	1	5	0.2	8	2.1
		1430	0	1	5	0.2	23	4.6
		1540	-0.5	0.5	5	0.1	23	1.8
	2-3	0950	0.5	0	5	0	8	0.5
		1030	0.5	0	5	0	8	0.5
		1430	0	1.5	5	0.3	23	6.9
		1540	-0.5	1	5	0.2	23	4.1
	4-5	0940	0	1	5	0.2	8	1.6
		1050	1.5	1.5	5	0.3	8	3.9
		1410	-1	1	5	0.2	23	3.6
		1450	-1	1.5	5	0.3	23	5.9
	6-7	0900	5.0	2	10	0.2	5	6.0
		1130	1	3	10	0.3	10	4.0
		1350	-1.5	3	10	0.3	15	3.0
		1620	-3.5	2	10	0.2	23	1.1
	8-9	0920	4	0	10	0	5	4.0
		1115	-2	3	10	0.3	15	2.5
		1330	0	3	10	0.3	23	6.9
		1510	-2.5	2	10	0.2	23	2.1
	10-11	0830	2	0.5	8	0.06	5	2.3
		1320	-2	0.5	8	0.06	10	-1.4
	12-13	0900	4	1	18	0.06	5	4.3
		1150	2	1.5	18	0.09	5	2.5
		1315	0	1	18	0.06	10	0.6
		1540	-1.5	2	18	0.18	15	1.5

APPENDIX F (CONTINUED)

Date	Location	Time	Term B	Term C				Term A
			$\partial\theta/\partial t$ (deg C/hr)	$\Delta\theta$ (deg C)	Δx (km)	$\Delta\theta/\Delta x$ (deg/km)	V (km/hr)	$d\theta/dt$ (deg/hr)
24 July	1-2	0950	3.0	3.0	5	0.6	23	16.8
		1040	0.5	5	5	1.0	23	23.5
		1420	-0.5	4.5	5	0.9	23	20.2
		1610	-1.0	3	5	0.6	23	12.8
	2-3	0950	2	-0.5	5	-0.1	20	0
		1040	1.5	0	5	0	20	1.5
		1420	-1	1	5	0.2	20	3.0
		1615	-1	1.5	5	0.3	20	5.0
	4-5	1000	1.5	2	5	0.4	23	10.7
		1400	-0.5	1	5	0.2	23	4.1
	8-9	0940	4	0	10	0	5	4.0
		1100	3	1	10	0.1	5	3.5
		1400	-2	2	10	0.2	23	2.6
		1500	-1	1	10	0.1	23	1.3
	10-11	0840	3	0.5	8	0.06	-10	2.4
		1150	1	-1	8	-0.12	-10	2.2
		1300	1	0.5	8	0.06	15	1.9
		1720	-3.5	0.5	8	0.06	20	-2.3
	12-13	0900	4	-0.5	18	-0.03	-5	4.2
		1140	2	1	18	0.06	0	2.0
		1330	1	-1	18	-0.06	0	1.0
		1540	-2.5	3	18	0.18	20	1.1

APPENDIX F (CONTINUED)

Date	Location	Time	Term B	Term C				Term A
			$\partial\theta/\partial t$	$\Delta\theta$	Δx	$\Delta\theta/\Delta x$	V	$d\theta/dt$
			(deg C/hr)	(deg C)	(km)	(deg/km)	(km/hr)	(deg/hr)
21 Aug	1-2	1000	1	6.5	5	1.3	5	7.5
		1030	1	6	5	1.2	5	7.0
		1500	0	6	5	1.2	20	24.0
		1600	-0.5	5	5	1.0	20	19.5
	2-3	1000	1	-0.5	5	-0.1	5	0.5
		1030	1	2	5	0.4	5	3.0
		1500	0	1	5	0.2	20	4.0
		1600	-0.5	1.5	5	0.3	20	5.5
	4-5	1020	0.5	2.5	5	0.5	5	3.0
		1440	2	3.5	5	0.7	20	16.0
	6-7	0910	3	-1	10	-0.1	5	2.5
		1130	2	-0.5	10	-0.05	5	1.7
		1400	-0.5	1	10	0.1	20	1.5
		1650	-3	2	10	0.2	23	1.6
	8-9	0950	5	-1.5	10	-0.15	-5	5.8
		1100	3	-0.5	10	-0.05	-5	3.3
		1415	-0.5	1	10	0.1	5	0
		1515	-4	1.5	10	0.15	20	-1.0
	10-11	0840	3	-0.5	8	-0.03	-5	3.2
		1150	3.5	0	8	0	-5	3.5
		1340	2	0.5	8	0.03	15	2.5
		1730	-5	0.5	8	0.03	15	-4.5
	12-13	0930	3	-1	18	-0.06	-5	3.3
		1200	3.5	0	18	0	-5	3.5
		1350	2	0.5	18	0.03	-5	1.8
		1550	-1	1	18	0.06	5	-0.7

APPENDIX F (CONTINUED)

Date	Location	Time	Term B	Term C				Term A
			$\partial\theta/\partial t$	$\Delta\theta$	Δx	$\Delta\theta/\Delta x$	V	$d\theta/dt$
			(deg C/hr)	(deg C)	(km)	(deg /km)	(km/hr)	(deg/hr)
28 Aug	1-2	0950	2	5	5	1	5	7.0
		1040	0.5	3	5	0.6	5	3.5
		1430	0	5	5	1	23	23.0
		1600	0	4	5	0.8	20	16.0
	2-3	0950	2	-0.5	5	-0.1	5	1.5
		1040	0.5	-1	5	-0.2	5	-0.5
		1430	0	0	5	0	23	0
		1600	0	1.5	5	0.3	20	6.0
	4-5	1015	-0.5	2	5	0.4	5	1.5
		1345	0	1.5	5	0.3	20	6.0
		1500	0	1	5	0.2	20	4.0
	6-7	0900	3	0.5	10	0.05	10	3.0
		1130	2	1.5	10	0.15	10	3.5
		1345	-0.5	1	10	0.10	15	1.0
		1650	-2	1	10	0.1	15	-0.5
	8-9	0945	5	0	10	0	5	5.0
		1100	3	0	10	0	10	3.0
		1320	0.5	0	10	0	15	0.5
		1540	-2	1	10	0.1	15	-0.5
	10-11	0840	4	-1.5	8	-0.2	-5	5.0
		1200	2	0.5	8	0.06	10	2.6
		1300	1.5	0	8	0	15	1.5
		1720	-3.5	0.5	8	0.06	20	-2.3
	12-13	0920	5	-0.5	18	-0.03	5	4.8
		1200	2.5	-0.5	18	-0.03	-5	2.7
		1300	1	-0.5	18	-0.03	10	0.7
		1630	-3	1	18	0.06	20	-1.8

CALCULATION OF THE SLOPE OF THE MARINE INVERSION, dH/dx, FROM DIFFERENCES IN POTENTIAL TEMPERATURE AND PRESSURE BETWEEN PAIRS OF STATIONS THROUGH TWO TRANSECTS IN THE OREGON COAST RANGE ACCORDING TO EQUATION 6: $dH/dx = \underbrace{(.0175 \times 10^4)(d\theta/dx)}_{\text{Term A}} + \underbrace{(.082 \times 10^4)\ (dp/dx)}_{\text{Term B}}$

Mean values for five clear days in the summer of 1957

Time	Stations*	dx (km)	$10^4(d\theta/dx)$	Term A	$10^4(dp/dx)$	Term B	dH/dx
0900	1 - 2	10	3.2	.056	-0.29	-.023	.033
	2 - 3	5	0.8	.014	0.23	.048	.062
	3 - 4	8	0.6	.011	0.22	.045	.056
	4 - 5	12	0.4	.007	-0.29	-.059	-.062
	5 - 6	16	-0.8	-.014	-0.07	-.015	-.029
	6 - 7	12	0.7	.012	0.39	.080	.092
1100	1 - 2		4.2	.074	0	0	.074
	2 - 3		-0.4	-.007	0	0	-.007
	3 - 4		2.3	.040	0	0	.040
	4 - 5		2.2	.039	-0.29	-.059	-.020
	5 - 6		0.3	.005	0.07	.015	.020
	6 - 7		0	0	0.10	.020	.020
1400	1 - 2		4.6	.081	-0.12	-.024	.057
	2 - 3		0.8	.014	0.23	.048	.062
	3 - 4		1.3	.023	0	0	.023
	4 - 5		2.0	.035	-0.19	-.039	-.004
	5 - 6		0.4	.007	-0.07	-.015	-.008
	6 - 7		0.7	.012	-0.34	-.070	-.058
1600	1 - 2		3.6	.063	-0.35	-.071	-.008
	2 - 3		-1.6	-.028	0	0	-.028
	3 - 4		1.8	.032	-0.29	-.060	-.028
	4 - 5		0.8	.014	-0.10	-.020	-.006
	5 - 6		0.3	.005	-0.07	-.015	-.010
	6 - 7		1.0	.018	-0.10	-.020	-.002

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* Station designations on the southern transect as follows:

1 - Newport
2 - Toledo
3 - Pioneer Summit
4 - Eddyville
5 - Burnt Woods
6 - Wren
7 - Corvallis

APPENDIX G (CONTINUED)

Mean values for five clear days in the summer of 1957

Time	Stations*	dx (km)	$10^4(d\theta/dx)$	Term A	$10^4(dp/dx)$	Term B	dH/dx
0900	8 - 9	4	3.5	.061	-0.88	-.180	-.119
	9 - 10	6	1.3	.023	0.09	.019	.042
	10 - 11	12	1.8	.032	0	0	.032
	11 - 12	9	-0.9	-.016	0.13	.026	.010
	12 - 13	9	-0.7	-.012	0.13	.026	.014
	13 - 14	16	0	0	0.07	.015	.015
1100	8 - 9		4.0	.070	-1.16	-.238	-.168
	9 - 10		2.3	.040	1.16	.238	.278
	10-- 11		2.7	.047	-0.19	-.039	.008
	11 - 12		1.1	.019	0	0	.019
	12 - 13		0	0	0	0	0
	13 - 14		-0.1	-.002	0.07	.015	.013
1400	8 - 9		2.0	.035	0.16	.033	.068
	9 - 10		3.0	.053	-0.19	-.039	.014
	10 - 11		2.3	.040	0	0	.040
	11 - 12		2.0	.035	-0.13	-.026	.009
	12 - 13		0.7	.012	-0.45	-.093	-.071
	13 - 14		-0.3	-.005	0.15	.030	.025
1600	8 - 9		3.5	.061	0.16	.033	.094
	9 - 10		2.0	.035	0.19	.039	.074
	10 - 11		1.8	.032	-0.19	-.039	-.007
	11 - 12		1.6	.028	0	0	.028
	12 - 13		0.9	.016	-0.13	-.026	-.010
	13 - 14		0.6	.011	-0.21	-.044	-.033

* Station designations on the northern transect as follows:

8 - Oceanlake
9 - Otis Junction
10 - Rose Lodge
11 - Boyer
12 - Grand Ronde
13 - Wallace Bridge
14 - Perrydale

APPENDIX G (CONTINUED)

Values for 24 July 1957

Time	Stations	dx (km)	$10^4(d\theta/dx)$	Term A	$10^4(dp/dx)$	Term B	dH/dx
0900	1 - 2	10	4.0	.070	-0.12	-.024	.046
	2 - 3	5	-2.0	-.035	0.23	.048	.013
	3 - 4	8	0	0	0.22	.045	.045
	4 - 5	12	1.7	.030	-0.34	-.070	-.040
	5 - 6	16	-1.3	-.023	-0.03	-.007	-.030
	6 - 7	12	1.7	.030	0.43	.089	.119
1100	1 - 2		5.0	.088	-0.23	-.048	.040
	2 - 3		0	0	-0.35	-.071	-.071
	3 - 4		1.3	.023	0.37	.075	.098
	4 - 5		0.8	.014	-0.29	-.060	-.046
	5 - 6		-0.6	-.011	-0.07	-.015	-.026
	6 - 7		0.8	.014	0.19	.039	.053
1400	1 - 2		5.0	.088	0.12	.024	.064
	2 - 3		-2.0	-.035	0	0	-.035
	3 - 4		2.5	.044	0.15	.030	.074
	4 - 5		2.5	.044	-0.39	-.080	-.036
	5 - 6		0	0	0.03	.007	.007
	6 - 7		0	0	0.34	.070	.070
1600	1 - 2		3.0	.053	-0.35	-.071	-.018
	2 - 3		-2.0	-.035	0	0	-.035
	3 - 4		2.5	.044	0.15	.030	.074
	4 - 5		0.8	.014	-0.39	-.080	-.066
	5 - 6		-0.6	-.011	-0.07	-.015	-.026
	6 - 7		0.8	.014	-0.10	-.020	-.006

APPENDIX G (CONTINUED)

Values for 24 July 1957

Time	Stations	dx (km)	$10^4(d\theta/dx)$	Term A	$10^4(dp/dx)$	Term B	dH/dx
0900	8 - 9	4	0	0	0.15	.031	.031
	9 - 10	6	1.7	.030	0.10	.020	.050
	10 - 11	12	0.8	.014	-0.10	-.020	-.066
	11 - 12	9	0	0	-0.51	-.106	-.106
	12 - 13	9	-1.1	-.019	0.85	.173	.154
	13 - 14	16	0	0	-0.11	-.023	-.023
1100	8 - 9		2.5	.044	0.15	.031	.075
	9 - 10		1.7	.030	0.10	.020	.050
	10 - 11		1.7	.030	-0.10	-.020	.010
	11 - 12		2.2	.039	0.13	.026	.065
	12 - 13		-1.1	-.019	-0.13	-.026	-.045
	13 - 14		0.6	.011	-0.29	-.060	-.049
1400	8 - 9		0	0	0.15	.031	.031
	9 - 10		1.7	.030	0.29	.060	.090
	10 - 11		2.5	.044	0.10	.020	.064
	11 - 12		3.3	.058	-0.26	-.053	.005
	12 - 13		-1.1	-.019	-0.45	-.092	-.111
	13 - 14		-0.6	-.011	-0.25	-.052	-.063
1600	8 - 9		0	0	0.15	.031	.031
	9 - 10		1.7	.030	0.29	.060	.090
	10 - 11		2.5	.044	-0.19	-.039	.005
	11 - 12		2.2	.039	-0.19	-.039	0
	12 - 13		0	0	-0.45	-.092	-.092
	13 - 14		1.9	.033	-0.29	-.060	-.027

APPENDIX H

A QUESTIONNAIRE ON THE INFLUENCE OF SEA BREEZE ON FORESTRY OPERATIONS*

THE SEA BREEZE OF NORTHWEST OREGON: The sea breeze is the wind blowing inland from the coast on the sunny, warm days of summer. In the Willamette Valley it is felt less frequently than on the coast, but when it does reach inland it arrives in the later afternoon at about mid-valley. A series of sea breeze days will usually have low clouds during the late night and early morning hours with clearing in the afternoon at inland points. Nearer the coast, the low clouds form in the afternoon. At all points the relative humidity usually rises soon after the sea breeze begins. PLEASE INDICATE YOUR ANSWERS TO THE FOLLOWING QUESTIONS ABOUT THE RELATIONSHIP OF THE SEA BREEZE TO YOUR WORK by circling the appropriate answers.

1. Based on the above description, would you say you have noticed the sea breeze at your operation or place of business?
YES NO

2. If you have noticed the sea breeze there, how often would you say it occurs in summer? SELDOM FREQUENTLY ALMOST DAILY

3. If you have circled "Frequently" or "Almost daily", please indicate the approximate time your experience tells you the sea breeze generally begins. 6 AM 8AM 10AM NOON 2PM 4PM 6PM LATER

4. If you recognize the sea breeze as part of the summer climate, please describe any ways in which it affects the conduct of your operation.

5. If the occurrence does affect the conduct of your operation, please indicate briefly any adjustments you make in your activities according to whether or not the sea breeze occurs on a particular day.

6. If the occurrence of the sea breeze affects your activities, do you have any records or accounts which indicate the effect and which you would be willing to make available IN YOUR OFFICE to a staff member of the Oregon Forest Research Center? YES NO

Your name	Your address	Nature of your business

Name of the location you had in mind when answering the questions above.

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* This appendix includes the exact text of the questionnaire, though not its form. Typed lines providing space for answers to questions 4 through 6 were provided on the original.