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Average characteristics of subsidence inversions associated with the Pacific High have only been documented for areas along the U. S. West Coast and over the tropical eastern North Pacific Ocean. This study, which is based on 3414 upper-air soundings for June through September of 1964 and 1965, shows the average summer season characteristics of the inversion from Tatoosh Island, Washington northward along the coast of the Gulf of Alaska. A comparison is also made with the subsidence inversion found over the eastern North Pacific Ocean from Johnston Island (17°N, 168.5°W) to Ocean Station PAPA (50°N, 145°W). Some of the more notable findings are: (a) a diurnal oscillation of the height of the inversion base exists, except in the regions of Yakutat and Anchorage, Alaska; (b) the height of the inversion increases with increasing latitude from Tatoosh Island to Anchorage; (c) the inversion thickness decreases from Tatoosh Island to Anchorage; (d) subsidence inversions are most pronounced over the California coast compared to any other location between Johnston Island and Anchorage.

Characteristics of the Subsidence Inversion
Over the Eastern North Pacific Ocean
North of the 48th Parallel

by

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CHARACTERISTICS OF THE SUBSIDENCE INVERSION OVER THE EASTERN NORTH PACIFIC OCEAN NORTH OF THE 48th PARALLEL

I. INTRODUCTION

Normally, the temperature in the troposphere decreases with height, but many times increases in temperature with altitude through a layer or layers of air are observed. These are called temperature inversions. Because of the stability of the air in an inversion layer, the stratum acts as an effective lid in suppressing the upward and downward mixing of air through the inversion, often preventing the dispersion of atmospheric pollutants. It is the intent of this study to examine the general characteristics of a special type of inversion - the subsidence inversion - associated with anticyclones along the coast of the Gulf of Alaska and over the water itself and to compare these features with those of the subsidence inversion found along the U. S. West Coast and over the tropical eastern North Pacific Ocean.

Characteristics of subsidence inversions associated with anticyclones over the Atlantic and the eastern Pacific Ocean (south of 50°N) have been well documented by Neiburger et al. (1945, 1960, 1961), Petterssen et al. (1947), Bell (1958), Boyden (1964), and Haraguchi (1968). However, the subsidence inversion characteristics north of 50°N over the eastern North Pacific Ocean have not been documented to the writer's knowledge. The results contained in this study are based on 3414 upper-air soundings taken during June through September of 1964 and 1965 at latitudes between 48°N and 61°N.

II. AREA OF STUDY AND METHODOLOGY

Geographical Area and Upper-Air Stations

Figure 1 shows the area of consideration for this study. Data from the following stations, which make rawinsonde observations at 0000 GMT and 1200 GMT each day, were used in this report:

Station	Latitude	Longitude	Elevation (meters)	Station Designator
Tatoosh Island (U. S.)	48°23'N	124°44'W	31	TAT
Ship PAPA (Canada)	50°00'N	145°00'W	5	P
Port Hardy (Canada)	50°41'N	127°22'W	23	PH
Annette (U. S.)	55°02'N	131°34'W	37	ANN
Kodiak (U. S.)	57°45'N	152°31'W	4	KOD
Yakutat (U. S.)	59°31'N	139°40'W	12	YAK
Anchorage (U. S.)	61°10'N	150°01'W	45	ANC

It had originally been intended to use additional radiosonde data from ships of the Cooperative Ship Upper-Air Program and the Continental Air Defense System to broaden the coverage over the Gulf of Alaska. The first program (Kornmann 1968) began in 1955 and ended in 1972 used radiosonde equipped merchant ships for taking atmospheric soundings during their regular schedule of operations. The second program, now also discontinued, used military radar picket vessels stationed off the west coasts of the United States and Canada. The fact that these data might be available primarily determined the years selected for this study. It appeared from the series of

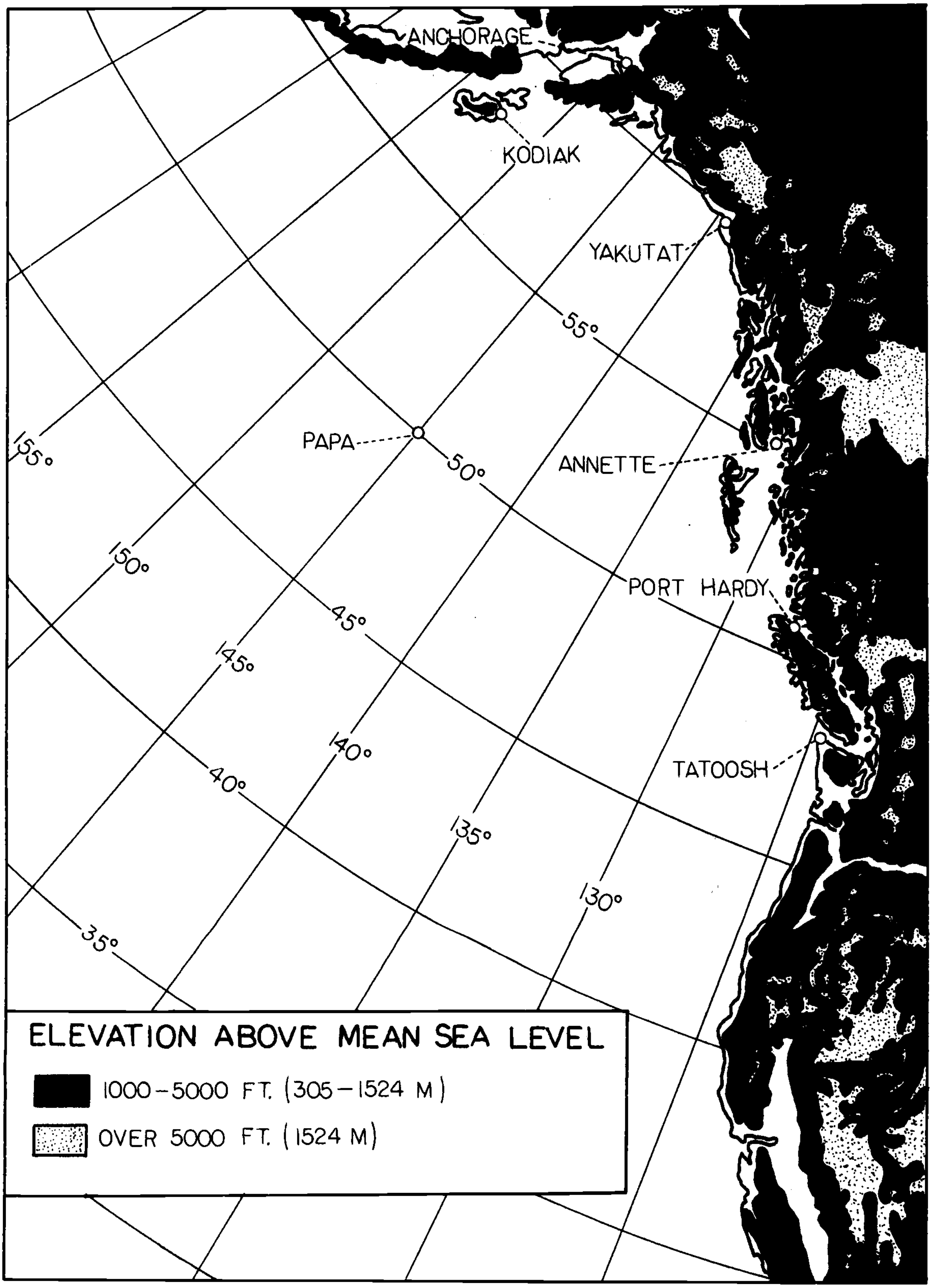


Figure 1. Map of upper-air stations and topography.

atlases, Daily Series Synoptic Weather Maps, Part 1, Northern Hemisphere Sea Level Charts and 500 Millibar Charts, that these years had the most soundings from these ships. Unfortunately, the computer tapes of upper-air data for these sources furnished by the Environmental Data Service of the National Oceanic and Atmospheric Administration contained only the mandatory levels (fixed pressure levels: 1000, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10, 7, 5, 3, 2, and 1 mb), which are not sufficient for studying inversions. Approximately 528 soundings in the area of study are available, but most of them are taken at varying locations, which is not very useful for determining average parameters of the inversion over specific points. On a case by case study, however, copies of the original sounding records could be obtained to examine the complete radiosonde runs. Thus, the study is limited to the six land stations along the coast and Ocean Station Vessel PAPA (50°N, 145°W).

Data Collection and Literature Search

Rawinsonde data for all the stations used in this study, except Kodiak, were made available on magnetic tape by the Environmental Data Service, Asheville, North Carolina. The tapes contained both the mandatory levels and the significant levels (intervening levels, including ground level, at which important changes occur in temperature and/or relative humidity). Kodiak data were not available on magnetic tape and consisted of rolls of microfilmed records of the original pseudoadiabatic charts plotted from the balloon ascent data. The microfilmed records had the usual upper-air sounding information written to one side of the chart for each mandatory and significant level. This greatly facilitated the extraction of information for the computer program. In addition, the microfilmed records showed the current weather, cloud amount, and cloud type for each balloon release. Only the summer months of June through September are considered.

Neiburger (1961) made a detailed study of the subsidence inversion over and along the U. S. West Coast for these months. Bell (1958) also limited his study of the California inversion to some of the summer months. Using only months of the summer season, especially in higher latitudes, is justified because of the frequent transit of depressions and troughs across the Northeast Pacific during the other seasons. Figure 2 shows the average pressure patterns observed over the eastern Pacific Ocean during these months. Compare these charts with the conditions shown in Figure 3 for the months of December and March. It is very apparent that high pressure is more prevalent in summer in the Gulf of Alaska than at any other season. In addition to the rawinsonde data, a literature search was made using the following sources:

<u>Cummulated Bibliography and Index to Meteorological and Geoastrophysical Abstracts.</u>

<u>Meteorological and Geoastrophysical Abstracts.</u>

<u>Royal Meteorological Society Bibliography of Meteorological Literature.</u>

<u>International Catalogue of Scientific Literature: Part F, Meteorology.</u>

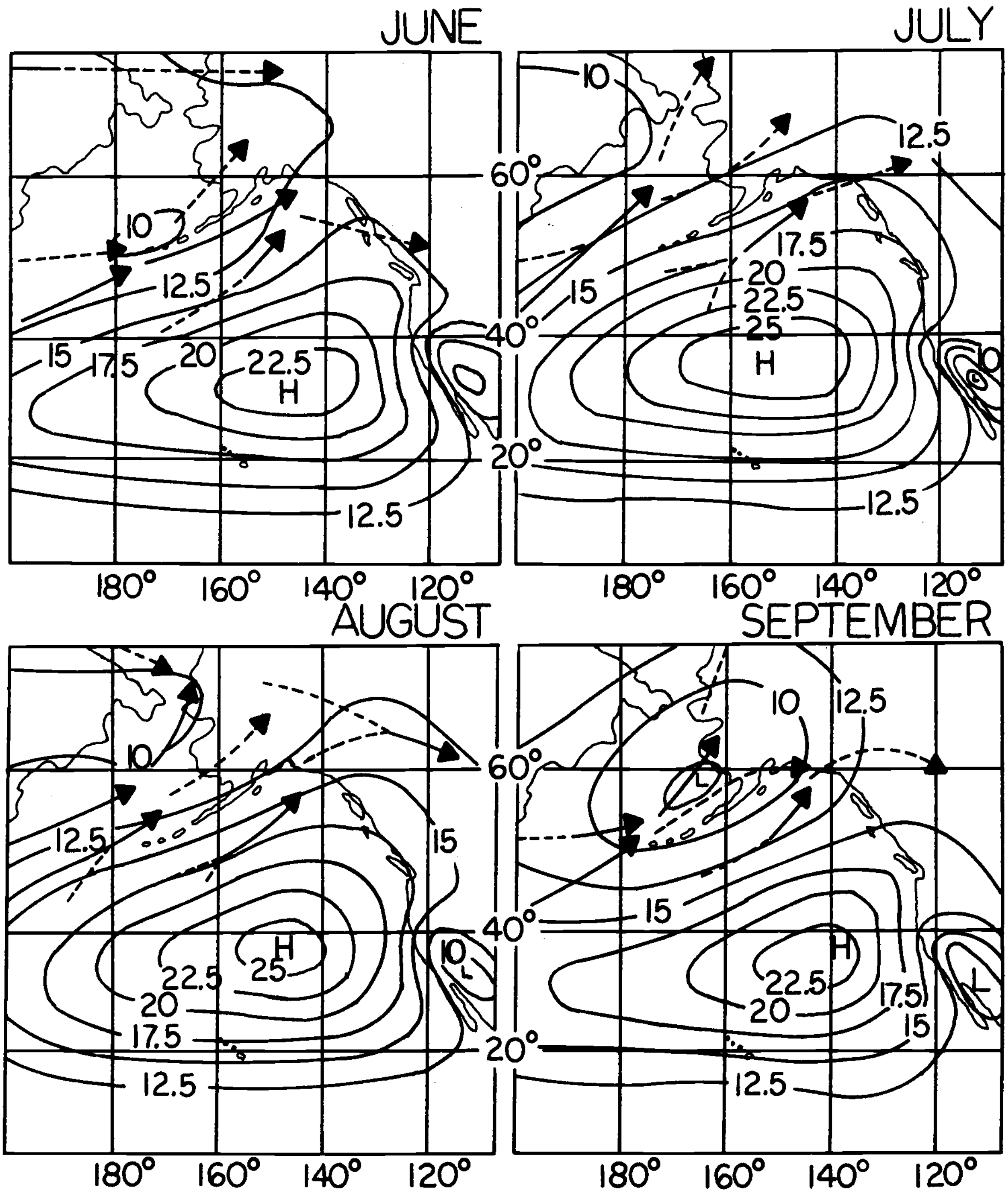


Figure 2. Average sea level pressure patterns for summer months. Solid arrows denote major storm tracks. Dashed arrows are secondary storm tracks (after U. S. Navy, 1956).

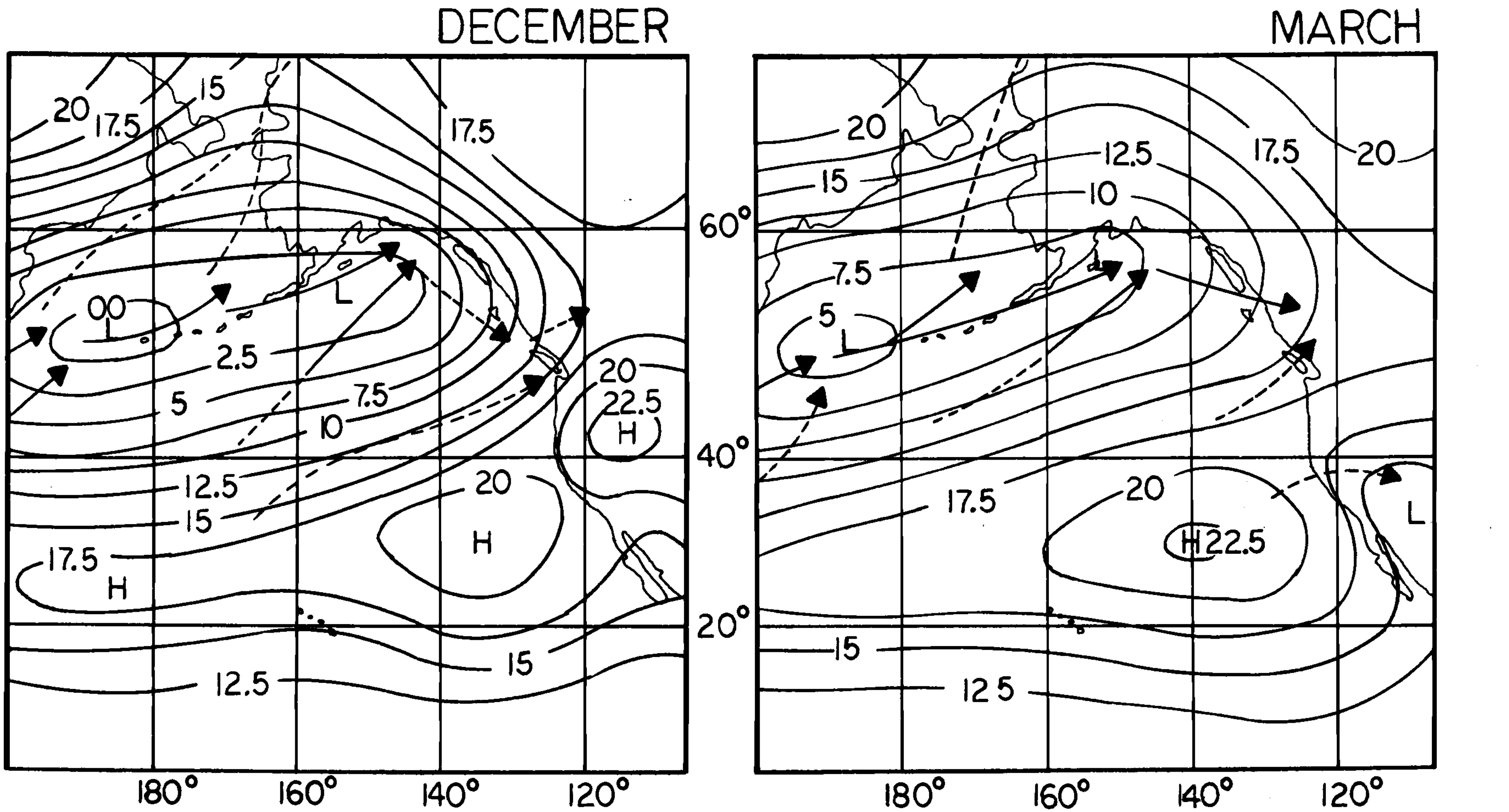


Figure 3. Average sea level pressure patterns for December and March. Solid arrows denote major storm tracks. Dashed arrows are secondary storm tracks (after U. S. Navy, 1956).

U. S. Weather Bureau Technical Papers.

Publications in Geography, University of California.

Data Reduction and Accuracy

A computer program was written, verified using test sounding data, and applied to the Environmental Data Service magnetic tapes and the Kodiak card deck of data extracted manually from the microfilms. From the ground to 400 mb, these items were determined: pressure, geopotential height, temperature, relative humidity, wind direction, wind speed, potential temperature, mixing ratio, geometric height (above mean sea level), successive layer thicknesses, temperature lapse rates, and potential temperature lapse rates. A discussion of the well-known basic equations will not be given, but it is interesting to note some of the accuracies associated with the Rawin Set AN/GMD-2 used at U. S. upper-air stations (Leviton et al., 1970).

Temperatures are measured to a standard error of 0.7°C with a slightly larger error at higher levels. Relative humidity errors of 5% to 10% can be expected, especially at low atmospheric relative humidities. An accuracy of 3 to 4 millibars at the surface and 1.5 to 2.0 millibars at about 100,000 feet or the 10 millibar level can be expected from pressure measurements. These errors, when combined, produce a height error of about ± 0.4% according to Leviton et al. (1970). The inversion height computations made in this study are thus only accurate to about ± 4 meters for every 1,000 meters of elevation. Similarly, although temperatures are computed to the nearest 0.1 degree, they may vary up to $\pm$ 0.7 degree. Finally, relative humidity values may be in error by about 10%.

Types of Inversions, Causes, and Characteristics

According to Saucier (1955), there are six types of inversions, which are caused by: (a) radiation cooling, (b) contact cooling, (c) differential horizontal advection, (d) differential radiation, (e) differential mixing, (f) differential vertical motion.

Radiation cooling produces inversions at the earh's surface, most notably under stagnant air conditions during winter time. As the ground heats up in the morning, the inversion is often destroyed in the air layers next to the ground. An inversion caused by this process alone will show no sharp discontinuity in the specific humidity or mixing ratio at the top of the inversion although there is likely to be some decrease in these parameters. During the summer months, a radiation inversion will be destroyed by the afternoon unless there is subsidence aloft to maintain the inversion near the ground.

Contact cooling inversions exhibit similar characteristics to radiation cooling inversions, but are principally caused by warm air flowing over cold surfaces in which the lower layers are cooled. In the free atmosphere, consideration must be given to the remaining four inversion types.

A frontal inversion is an example of the type of inversion caused by differential horizontal advection. Warmer air overriding cool air, as in a warm front, and colder air undercutting warm air, as in a cold front, are the most common types. These inversions are characterized by increasing specific humidities or mixing ratios through the inversion layer along with increases in relative humidities with height. These conditions are accentuated by the cloudiness accompanying most fronts.

Similar to radiational cooling at the earth's surface, differential radiation cooling occurs from cloud tops, haze layers, and moisture discontinuities. Namias (1936) and Neiburger et al. (1945) show that radiational cooling is much greater from the tops of clouds than from the tops of haze or moisture layers since clouds effectively act as black body radiators. Stratus or altostratus clouds are often found below subsidence inversions, which results in these inversions being more intense due to the radiational cooling from the cloud tops. If only a haze or moisture layer exists below the inversion, the layer actually gains more heat than it loses, which in turn weakens the inversion. Turbulence can also produce inversions.

Differential mixing or turbulence occurs when the ground warms during the day causing the air to mix in the lower layers up to about 1,000 meters. The effect this can have on the environmental lapse rate is shown in Figure 4. Curve ABCD is the original environmental lapse rate prior to sunrise in which the potential temperature, θ, is such that $\theta(A) < \theta(B) < \theta(C) < \theta(D)$. As the day

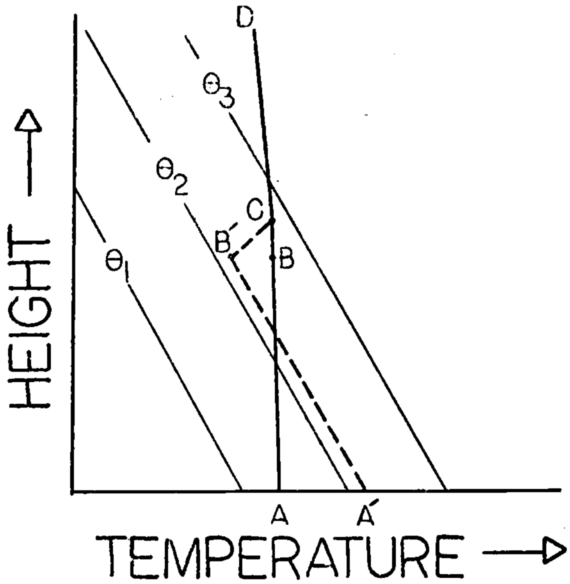


Figure 4. Turbulence inversion.

warms up, mixing occurs in the lower atmosphere, establishing a dry adiabatic lapse rate as shown by A'B'. The layer separating B' from the undisturbed air above C is the inversion layer. This process depends on the initial atmospheric stability and the strength of the turbulence. Petterssen (1940) points out that the specific humidity does not decrease from the bottom to the top of the inversion. Any of the inversion processes mentioned so far can be strengthened due to differential vertical motion, namely, subsidence.

As the name implies, subsidence is the sinking motion of air in which air parcels from higher levels are heated adiabatically by compression. To visualize the general dynamic mechanism, refer to Figure 5. The arrows indicate the flow of air. Air flowing into a column produces vertical stretching of the column since mass is conserved. In the case of divergence with air flowing out near the base of the column, the thickness must decrease.

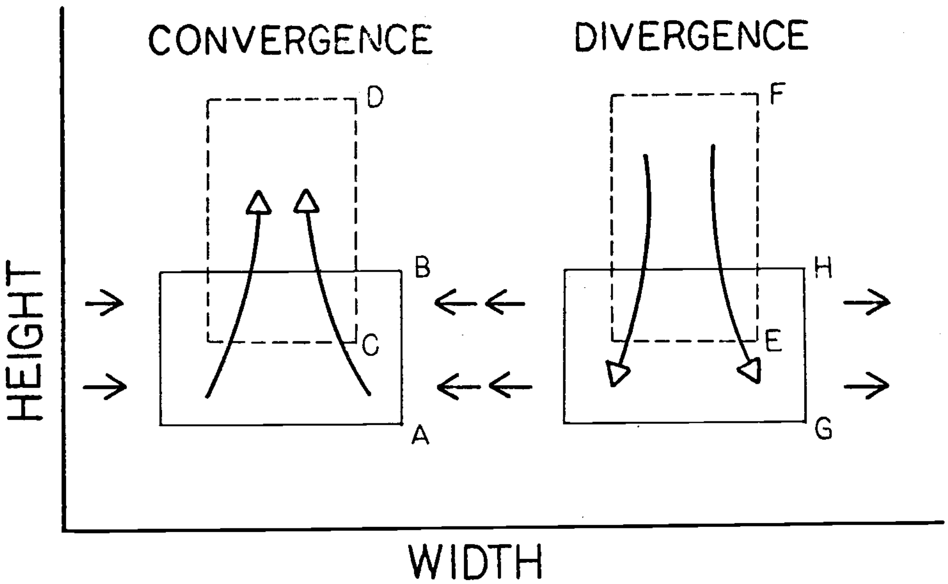


Figure 5. Convergence and divergence effects on air columns (after Haltiner et al., 1957).

Consider the effects of divergence using the equation of continuity.

$$\frac{\partial \rho}{\partial t} = - \vec{V} \cdot \nabla \rho - \rho \nabla \cdot \vec{V}$$

where:

ρ = density

t = time

V = velocity vector $(u\hat{i} + v\hat{j} + w\hat{k})$

Transposing $-\vec{V} \cdot \nabla \rho$ to the left side and using the equation for the total change of a quantity:

$$\frac{df}{dt} = \frac{\partial f}{\partial t} + \vec{c} \cdot \nabla f$$

where:

f = function of x, y, z, t

$\vec{c}$ = velocity

t = time

gives the following result when the definition of specific volume, $\alpha = 1/\rho$, is used,

$$-\frac{1}{\rho}\frac{d\rho}{dt} = \nabla\cdot\vec{V} = \frac{1}{\alpha}\frac{d\alpha}{dt} \tag{1}$$

Now consider a moving parcel of air of constant mass, M, cross-sectional area, A, vertical thickness, h, and density, ρ. Hence, $M = \rho Ah$. After some manipulation of terms and assuming the conservation of mass,

$$0 = \frac{dM}{dt} = \frac{d(\rho Ah)}{dt} = \frac{1}{h}\frac{dh}{dt} + \frac{1}{A}\frac{dA}{dt} + \frac{1}{\rho}\frac{d\rho}{dt}$$

and,

$$-\frac{1}{\rho}\frac{d\rho}{dt} = \frac{1}{h}\frac{dh}{dt} + \frac{1}{A}\frac{dA}{dt} \tag{2}$$

Substituting (2) into (1),

$$\nabla\cdot\vec{V} = \frac{1}{h}\frac{dh}{dt} + \frac{1}{A}\frac{dA}{dt}$$

and,

$$\nabla_h\cdot\vec{V} + \frac{\partial w}{\partial z} = \frac{1}{A}\frac{dA}{dt} + \frac{1}{h}\frac{dh}{dt}$$

If only the horizontal velocity is considered,

$$\nabla_h\cdot\vec{V} = \frac{1}{A}\frac{dA}{dt}$$

Consideration of only the vertical velocity results in,

$$\frac{\partial w}{\partial z} = \frac{1}{h}\frac{dh}{dt}$$

Thus, horizontal divergence may be interpreted as the fractional rate of areal expansion, and vertical divergence is the fractional rate of thickness expansion. In an anticyclone where subsidence is occurring, both motions take place. The effects divergence and convergence have on the environmental lapse rate are illustrated in Figure 6.

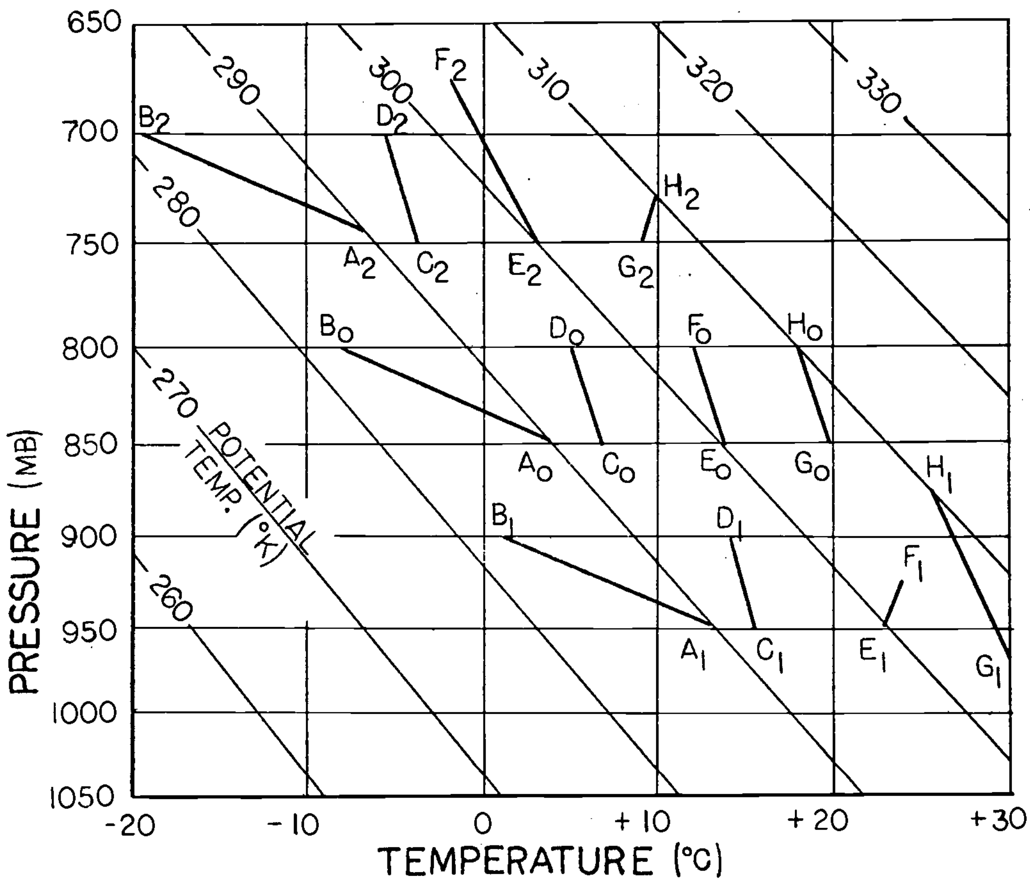


Figure 6. Effects of vertical motion on lapse rates on a pseudoadiabatic chart.

Entire layers of air may be displaced vertically caused by such effects as surface topography forcing air upward, divergence, and convergence. Lapse rates in the affected layers usually change when these motions occur. Consideration will be given only to dry adiabatic motions.

Without loss or gain of mass within the layer of air, lifting causes the lapse rate to approach the dry adiabatic lapse rate, and sinking causes the lapse rate to depart even further from the dry adiabatic lapse rate. For example, unstable layers tend to become even more unstable on descent, but more stable on ascent as shown by the initial lapse rate in a layer, A_0B_0 descending to A_1B_1, and ascending to A_2B_2. The difference in potential temperature between the top and bottom of the layer, A_0B_0, remains constant in the dry adiabatic process, but the lapse rate changes due to the geometric distance between the 50 mb thick layer on descent becoming less than the distance for the same pressure thickness on ascent. Similarly, a stable lapse rate, as shown by C_0D_0, tends to become more stable in sinking to position C_1D_1 and becomes more unstable when ascending to C_2D_2. Note in these first two examples that the movement of the top and bottom of the layer located at 800 to 850 mb has been over the same pressure difference, namely, 100 mb.

Consider the effects of divergence on the same stable lapse rate, E_0F_0. If the air is sinking in a column which is undergoing divergence in the lower layer, the top of the original layer will sink further than the bottom layer. The result is a dramatic increase in the stability of the layer upon reaching E_1F_1. If there is divergence aloft and the layer is forced upward, it is stretched to position E_2F_2 and becomes more unstable. Consider another case in which $G_0H_0 = E_0F_0$. If this layer descends in a column which is undergoing convergence (a very unlikely occurrence), the layer is stretched, causing the lapse rate to steepen as shown by $G_1 H_1$. Finally, if $G_0 H_0$ ascends into a converging region, the layer is compressed, and the new lapse rate, $G_2 H_2$, is more stable.

The formation and maintenance of subsidence inversions is a complicated process and not simply dependent on the horizontal divergence of the air. It has been shown by Neiburger et al. (1961) that considerable horizontal advection of layers of subsiding air can take place. Both Namias (1934) and Neiburger et al. (1945, 1961) list a number of factors entering into the formation and maintenance of subsidence inversions. The primary cause, of course, is divergence of air from regions of high pressure in a moving or quasi-stationary anticyclone. Only the more salient features of these factors will be discussed here.

Once subsidence has occurred, the intensification of the inversion, that is, the increase in stability of the layer, depends not only on changes in vertical air motions but on: (a) radiational cooling or heating at the inversion base; (b) turbulent mixing; (c) advection of warmer air aloft and/or cooler air below; (d) local sea breeze and terrain induced changes in the air flow pattern. A brief discussion of each of these factors will be given. However, the intent of this study is to focus on the characteristics of subsidence inversions over the Gulf of Alaska and compare them with the well-known features of subsidence inversions along the U. S. West Coast and over the tropical Pacific Ocean. Further studies might do well to consider these causitive and supportive factors in detail, perhaps on a case by case basis.

Radiational cooling in an air layer occurs when outgoing long-wave radiation exceeds heating due to incoming radiation. In his 1934 study, Namias proposed that a haze layer or moisture discontinuity at the base of a subsidence inversion layer would act as a strong emitter of long wave radiation and would cause the base layer of the inversion to cool. However, Neiburger (1945) showed that although this is the case for soundings not having an inversion immediately above the haze or moisture layer, it is not the case for subsidence inversions in which the inversion is already established. In fact, the discontinuity layer actually warms at a rate of the order of $+0.5^{o}C/3$ hours. The reason for this is that the discontinuity layer does not yet emit as a black body and being located at the coolest point on the sounding (at the inversion base) is warmed from the adjacent warmer layers above and below. However, once a cloud deck forms at and below the inversion base, cooling does occur since the cloud acts as a black body emitter. It is characteristic of the air above the subsidence inversion to be much drier than the average conditions. This facilitates the loss of long wave radiation from cloud tops. The cooling from the top of a stratus cloud layer in the marine layer at the inversion base was calculated by Neiburger to be of the order of $-3^{o}C/3$ hours, although it was not observed due to turbulent mixing in the layer beneath the inversion.

Turbulent mixing in the air below the inversion greatly affects the height of the inversion base and the intensity of the inversion itself. Since most of the inversions in this study occurred below 2,000 meters, turbulence undoubtedly played a substantial role in the formation and maintenance of the inversions. Again, referring to Figure 1 (Chapter II), the high terrain near each of the stations, except PAPA, can be seen. It is beyond the scope of this paper to consider each station and the specific effects the terrain had on the air flow. Neiburger et al. (1945) discussed the general features to consider in determining whether or not turbulent transfer of heat in the layer beneath the inversion is occurring upward or downward. The primary factors to consider are wind speed, terrain, and the lapse rate in this lower layer. If the observed lapse rate is more than the adiabatic lapse rate, the layer is unstable and subject to convective mixing. If the lapse rate is less than the adiabatic lapse rate, the layer is more stable, and limited mixing occurs only if induced by strong winds. Well developed subsidence is a dry adiabatic process.

Advection of warmer air aloft and cooler air below may occur and maintain a stronger subsidence inversion than would otherwise occur. Unfortunately, especially in the friction layer, simple calculations of this effect are difficult. The wind flow is not geostrophic as it is greatly influenced by terrain. Again, Neiburger et al. (1945) considered advection in their cases using the thermal wind equation and an expression for the temperature change due to advection. The conclusion was that advection played only a minor role in intensifying subsidence inversions. Wind speeds and temperature gradients are generally small in anticyclones.

Although the vertical motion of the air associated with divergence is the primary cause for the formation and maintenance of subsidence inversions on the synoptic scale, there may be local vertical motion fields caused by the effects of terrain. Neiburger et al. (1945) observed that the potential temperature is almost constant in time and space at the inversion base, but is slightly higher during the afternoon than at night. This small variation in potential temperature would be expected since the vertical motions are nearly adiabatic. However, the sea-land breeze should be considered in any study involving an explanation of the reasons why the height of the subsidence inversion changes during the day. Along the coast of California, the inland mountain ranges nearly parallel the coastline causing the wind some distance offshore to blow parallel to the terrain. Near the coast and over the coastal plain, an onshore component is normally observed, augmented by an onshore sea breeze during the day. Neiburger reasoned that this results in a thinner marine layer beneath the inversion since the undisturbed air currents further to sea do not replenish the coastal air at the same rate it is flowing away. Consequently, the inversion base height gradually lowers during the day. After sunset, the reverse process occurs with a slight offshore wind component developing. This, in turn, results in convergence along the coast resulting in a rise in the inversion base height, which reaches a maximum sometime shortly after sunrise.

The greater the difference in temperature between land and sea, the greater the sea breeze effects should be. This writer is not aware of any studies done on this phenomenon for the stations used in this study. Suffice it to say that a detailed accounting of the factors affecting the subsidence inversion over the Gulf of Alaska should examine this possibility.

According to Namias (1934), subsidence inversions are more likely to occur with pressure rises. However, a study by Petterssen et al. (1947) of subsidence inversions over England associated with anticyclones revealed that the occurrence was about equally distributed between rising and falling sea level barometric pressures. This writer made a test using the rise and fall of the 700 mb height contours instead of the sea level pressures. This eliminates some of the local effects on sea level pressure, such as diurnal variation in pressure due to temperature changes and is further justified because subsidence results from upper air motions. Table I shows the results of the investigation in which the preceding 12 hour change in 700 mb height for each inversion case was examined. Rising 12 hour 700 mb heights are denoted by a plus sign and falling heights by a minus sign. The table makes no distinction between the 0000 GMT and 1200 GMT inversion events. The results show there is a definite preference for subsidence inversions to occur during upper level height rises. This is not surprising since the vertical motion of the air is generally downward ahead of a ridge or high pressure system.

TABLE I. MONTHLY OCCURRENCE OF SUBSIDENCE INVERSIONS COMPARED TO PRECEDING 12 HOUR 700 MILLIBAR HEIGHT CHANGES

	JUNE			JULY			AUGUST			SEPT.			TOTAL		
	No. Cases			No. Cases			No. Cases			No. Cases			No. Cases		
Station	+	-	0	+	-	0	+	-	0	+	-	0	+	-	0
Tatoosh	18	10	1	15	11	0	16	6	1	22	8	0	71	35	2
PAPA	29	14	0	29	16	0	23	13	2	22	26	2	103	69	4
Port Hardy	12	8	0	24	14	0	15	15	0	21	14	0	72	51	0
Annette	14	3	0	13	9	0	20	6	0	17	15	0	64	33	0
Kodiak	17	2	0	16	12	0	13	3	0	20	11	2	66	28	2
Yakutat	14	6	0	9	8	0	12	4	1	28	17	0	63	35	1
Anchorage	8	3	0	6	6	0	8	11	0	18	12	1	40	32	1

Petterssen *et al*. (1947) also showed that anticyclonically curved sea level isobars existed in 60% of the cases of subsidence inversions he examined. Correspondingly, anticyclonic vorticity existed 79% and 82% of the cases at the 750 mb and 500 mb levels, respectively. Cyclonic vorticity occurred in 4% of the cases at these same levels. As would be expected, subsidence inversions are associated with high surface pressures and were shown to occur 92% of the time at pressures equal to and greater than 1010 mb.

III. RESULTS OF INVESTIGATION

Selecting Subsidence Inversion Cases

The single greatest difficulty in studying subsidence inversions is determining whether or not the inversion is, in fact, a result of subsidence. It is not feasible to consider every single case on the basis of synoptic map analyses from which vertical velocities can be calculated, especially when a fairly large number of cases are being examined. None of the studies by other researchers (see Chapter I) examines the vertical air velocities for each inversion case before including it in the data set. However, Neiburger *et al*. (1960, 1961) discussed vertical motions associated with divergence in the region along the coast of California and the adjacent ocean areas using *Normal Weather Charts for the Northern Hemisphere* from the National Weather Service. It is therefore necessary to establish criteria for determining which inversions are caused by subsidence and use the distinctive characteristics of these cases in selecting other examples. Fortunately, in the subtropical regions of the eastern North Pacific Ocean, the Pacific High is a year-round feature, especially during the summer and fall months, and has been extensively studied. Using characteristics found with known subsidence inversions, it was possible to select cases for this study.

Referring again to Figure 2 (Chapter II), it can be seen that even during the summer, storm tracks still cross the northern part of the Gulf of Alaska. Therefore, not only was it necessary to consider the subsidence characteristics as found with the more southerly inversions, but to try to eliminate inversions associated with frontal systems. The following criteria were used in selecting subsidence inversion cases for this study:

1. Temperature lapse rate $\leq 0^{\circ}C/100$ m.
2. Mixing ratio at top of inversion less than at base of inversion.
3. Relative humidity at top of inversion less than at base of inversion.
4. Height of 700 mb surface $>$ observed monthly average 700 mb height.
5. Surface pressure $>$ observed monthly average surface pressure.
6. Criteria (4) and (5) must occur simultaneously for a period of at least four consecutive soundings.

By using criteria (4), (5), and (6), only those inversions associated with quasi-stationary anticyclones would be included. Average monthly observed surface pressures and 700 mb heights were determined for each station and are shown in Table II. Figure 7 illustrates that the method used for selecting subsidence inversions is a reasonable approach. For the three stations shown in the example, note that the inversion cases selected occur during periods when the sea level pressures and 700 mb heights are higher than average. To further illustrate the effectiveness of this method, the weather and cloud conditions at each balloon release were available for Kodiak on the microfilm records. Common types of clouds associated with

TABLE II. OBSERVED AVERAGE MONTHLY SEA LEVEL PRESSURE (MILLIBARS) AND 700 MILLIBAR SURFACE HEIGHT (GEOPOTENTIAL METERS)

Station	JUNE		JULY		AUGUST		SEPTEMBER	
	1964	1965	1964	1965	1964	1965	1964	1965
Tatoosh	1013	1014	1013	1015	1013	(1) 1013	1014	1014
	3040	(1) 3068	3076	3113	3080	(1) 3098	3075	3089
PAPA	1012	1015	1014	1018	1016	(2) 1020	1016	1025
	2983	3006	3025	3069	3067	(2) 3085	3055	3172
Port Hardy	1014	1017	1014	1017	1014	1015	1015	1017
	3030	3059	3052	3105	3061	3100	3059	3102
Annette	1011	1014	1011	1015	1011	1014	1012	1017
	3019	3029	(1) 3028	3085	3031	3093	3032	3103
Kodiak	1012	(2) 1009	(4) 1011	(3) 1016	(4) 1008	(1) 1017	(3) 1010	(4) 1015
	(2) 2984	(3) 2917	(4) 2938	(4) 3023	(5) 2920	(6) 3043	(3) 2989	(4) 3040
Yakutat	1014	1014	1012	1016	1012	1016	1014	1020
	(1) 3017	2976	3012	(1) 3050	3006	3044	3010	3063
Anchorage	1007	1007	1006	1012	1005	1011	1007	1011
	(1) 2990	2954	3001	3042	2986	3036	2988	3032

Note: Numbers in parentheses indicate number of estimated values.

Number of soundings per month are 60 in June and September and 62 in July and August.

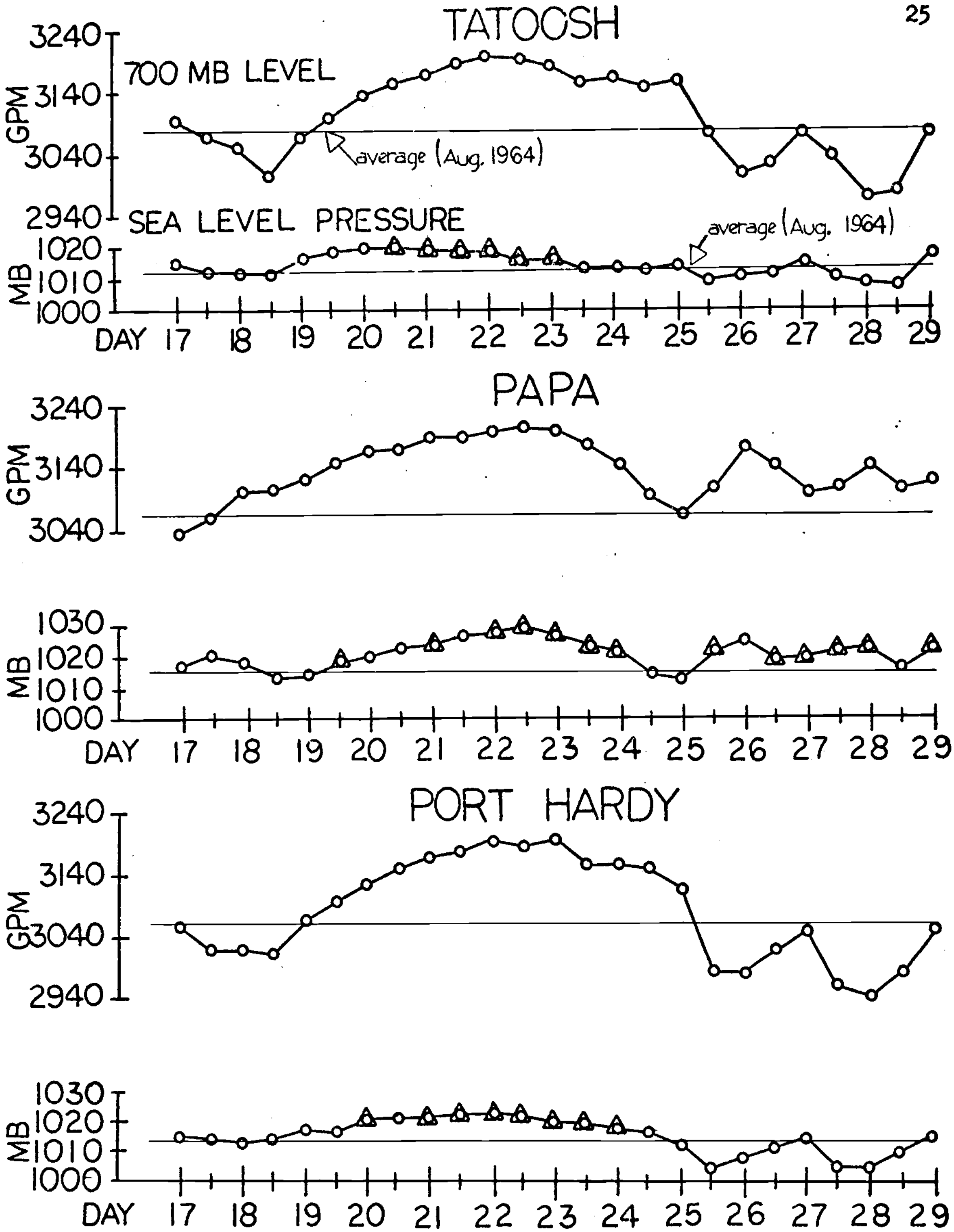
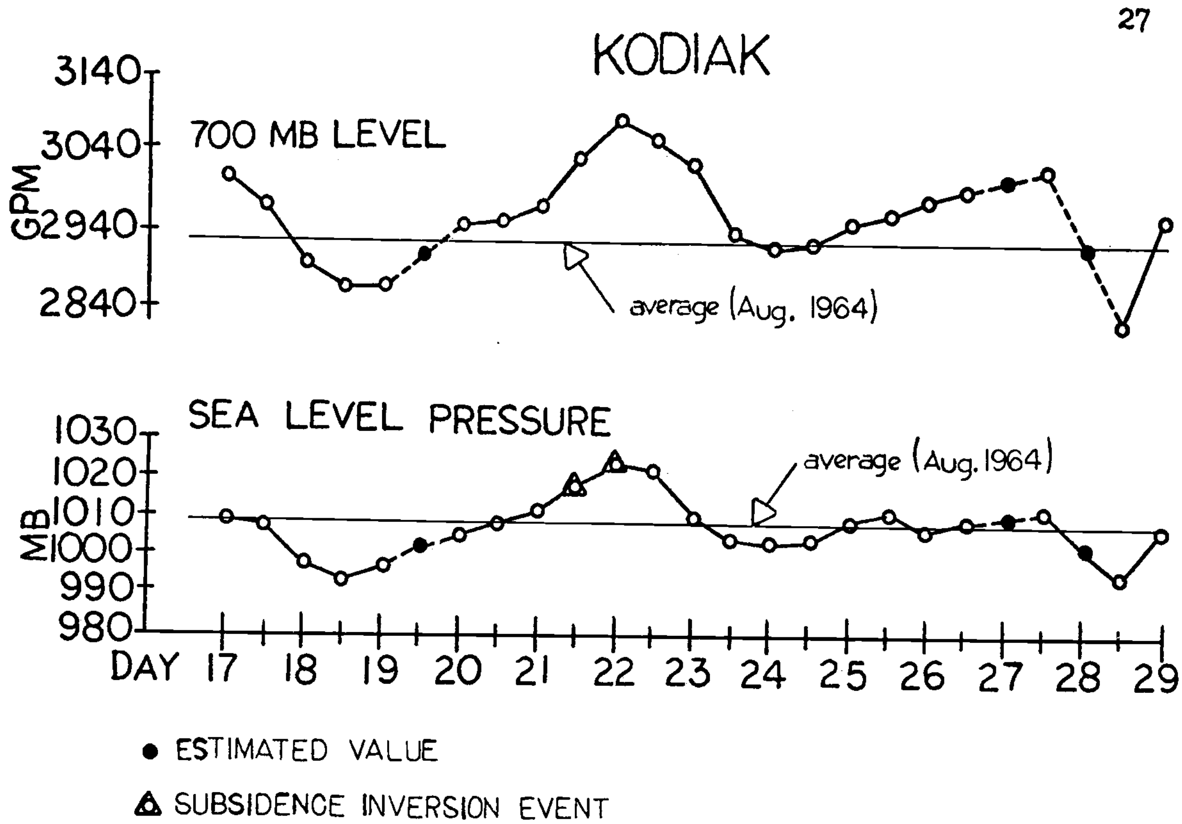


Figure 7. Selecting subsidence inversion cases using 700 mb height and sea level pressure graphs for 17-29 August 1964. Subsidence inversion event indicated by a triangle.

subsidence inversions are fog, stratus, stratocumulus, altostratus, altocumulus, and cirrus. Light drizzle may occur, but rain is unlikely due to the inversion "capping" the vertical development of clouds, preventing the formation of nimbostratus or towering cumulus. Petterssen _et_ _al_. (1947) obtained statistics on the types of clouds observed with well-developed subsidence inversions over England and showed that stratocumulus clouds were observed in 64% of the cases. Fog occurred 2% of the time, cumulus 17%, and no clouds 17%. Altostratus was observed 9% of the time with altocumulus or cirrocumulus 32% of the time. No medium or high clouds were observed during subsidence inversion events in 59% of the cases. Namias (1934) showed that altocumulus clouds were the most common type beneath higher level subsidence inversions and stratocumulus and fog being commonly found beneath lower level inversions. Figure 8, which uses the same time period as Figure 7, shows the subsidence inversion events at Kodiak along with the associated cloud amounts and types.

Each individual sounding, as printed out by the computer, was examined for the above six criteria and the following data recorded on special forms for each inversion case selected:

1. Day and hour (GMT) of sounding.
2. Sea level pressure.
3. Height of 700 mb surface.
4. Geometric height of base and top of inversion above mean sea level.
5. Temperature at base and top of inversion.



GMT Date/Time	Weather and Clouds
17/0000	⦶ .4Ac
17/1200	⊕ .8As .7Cs
18/0000	⊕ R-- 1.0St
18/1200	⊗ L- F 1.0F
19/0000	⦷ .2Sc .4Sc .1Ac
19/1200	⦷ .1Sc .2Ac .3Ci
20/0000	⦶ .3Cu .1Ac
20/1200	⦷ .5Sc .3Ac
21/0000	⦷ .6Sc
21/1200 △	⦶ .2Cu
22/0000 △	⦷ .2Cu .1Sc .5Ci
22/1200	⊕ R-- .8Sc .2As
23/0000	⊕ R 1.0St
23/1200	⦷ .2St .5Sc .1Ci
24/0000	⊕ 1.0Sc
24/1200	⦶ .1Ac
25/0000	⦶ .4Sc .1Ac
25/1200	○ Clear
26/0000	⦷ .7As .2Cs
26/1200	missing data
27/0000	○ Clear
27/1200	⊕ 1.0Cs
28/0000	missing data
28/1200	⊕ R-- 1.0Sc
29/0000	⦶ .4Sc

Figure 8. Clouds and weather associated with Kodiak subsidence inversions of 17-29 August 1964.

6. Potential temperature at base and top of inversion.

7. Mixing ratio at top and bottom of inversion.

8. Relative humidity at base and top of inversion.

There were insufficient wind data at the base and top of the inversions to be included. The two daily soundings occur at 0000 GMT and 1200 GMT, the first being an afternoon sounding, and the latter being an early morning sounding for the area studied. Results obtained from these two times should indicate the general makeup of the subsidence inversion near the maximum warming and cooling periods of the day. The next three sections will deal with the average summer season characteristics of subsidence inversions in the study area and will compare the inversions with those found at lower latitudes.

Average Diurnal Characteristics of Inversion During Summer Season

The number of monthly inversion cases for each observation time is rather small over a two-year period as can be seen in Table III.

TABLE III. NUMBER OF CASES OF SUBSIDENCE INVERSIONS FOR 1964 AND 1965 COMBINED

	JUNE		JULY		AUGUST		SEPTEMBER	
Station	00 GMT	12 GMT	00 GMT	12 GMT	00 GMT	12 GMT	00 GMT	12 GMT
Tatoosh	15	14	15	11	13	10	16	16
PAPA	23	20	22	23	20	18	26	24
Port Hardy	9	11	18	20	15	15	18	17
Annette	10	7	12	10	13	13	17	15
Kodiak	12	8	16	14	10	10	18	16
Yakutat	10	10	10	7	10	7	25	21
Anchorage	8	3	6	6	7	12	18	13

It was felt that more meaningful results could be obtained for the season rather than each month individually. However, it is of interest to note how the months compared to average months based on climatology to see if the seasons were unusual. Table IV shows the climatic averages of sea level pressure and 700 mb height for each station, and Table V shows whether the observed average height of the 700 mb surface is above (A) or below (B) the climatic average. Climatic averages are based on the National Weather Service publication, Technical Paper No. 21, Normal Weather Charts for the Northern Hemisphere. Also given in Table V is the frequency of inversion occurrence as a percent of the total number of monthly soundings.

TABLE IV. CLIMATIC AVERAGE SEA LEVEL PRESSURE (MB) AND 700 MILLIBAR SURFACE HEIGHT (GPM)

Station	JUNE	JULY	AUGUST	SEPTEMBER
Tatoosh	1016.1 3054	1018.3 3098	1017.8 3099	1016.7 3072
PAPA	1015.1 2999	1020.0 3078	1020.0 3106	1015.8 3060
Port Hardy	1016.5 3042	1018.1 3077	1017.8 3088	1016.3 3058
Annette	1015.0 3023	1016.9 3048	1016.8 3067	1014.4 3030
Kodiak	1012.2 2961	1016.8 3018	1013.3 3018	1009.3 2957
Yakutat	1013.3 2999	1015.0 3031	1014.5 3032	1011.4 2980
Anchorage	1012.1 2982	1013.1 3018	1012.3 3008	1009.3 2948

TABLE V. COMPARISON OF OBSERVED AVERAGE MONTHLY 700 MILLIBAR HEIGHT WITH CLIMATIC AVERAGE AND PERCENT OCCURRENCE OF SUBSIDENCE INVERSION EVENTS FOR EACH SUMMER MONTH 1964 AND 1965

	JUNE		JULY		AUGUST		SEPTEMBER	
Station	1964 %	1965 %	1964 %	1965 %	1964 %	1965 %	1964 %	1965 %
Tatoosh	B 30	A 18	B 24	A 18	B 24	B 13	A 27	A 27
PAPA	B 45	A 27	B 31	B 42	B 26	B 35	B 27	A 57
Port Hardy	B 20	A 13	B 29	A 32	B 18	A 31	A 28	A 30
Annette	B 8	A 20	B 13	A 23	B 23	A 19	A 22	A 32
Kodiak	A 20	B 13	B 31	A 18	B 13	A 19	A 25	A 32
Yakutat	B 17	B 17	B 5	A 23	B 6	A 21	A 40	A 37
Anchorage	A 5	B 13	B 8	A 11	B 10	A 21	A 25	A 27

A--above average
B--below average

The summer of 1964 was generally below average except for September, and 1965 was mostly above average. There does appear to be a tendency for a higher percent of subsidence inversions to occur in above average months than in below average months. That this is not always the case indicates that the terrain and air flow patterns greatly influence subsidence inversion formation. If subsidence is causing the inversion, it is likely that the inversion exists about an equal number of times during the afternoon as in the morning. Table VI shows the ratio of the number of 0000 GMT inversions compared to the number of 1200 GMT subsidence inversions. The closer the ratio is to 1.00, the less the tendency for the inversion to occur at a preferred time.

TABLE VI. MONTHLY RATIO OF 0000 GMT SUBSIDENCE INVERSION EVENTS TO 1200 GMT EVENTS (1964 AND 1965 COMBINED)

Station	JUNE	JULY	AUGUST	SEPTEMBER
Tatoosh	1.07	1.36	1.30	1.00
PAPA	1.15	0.96	1.11	1.08
Port Hardy	0.82	0.90	1.00	1.06
Annette	1.43	1.20	1.00	1.13
Kodiak	1.50	1.14	1.00	1.13
Yakutat	1.00	1.43	1.43	1.19
Anchorage	2.67	1.00	0.58	1.40

Table VII indicates the frequency of subsidence inversion occurrences as a percentage of the total number of soundings for each month over the two-year period. The percentages shown in this table should not be interpreted as the expected frequency of occurrence since the data include only those cases in which stationary or quasi-stationary anticyclones exist. It is very likely that subsidence inversions occur more frequently than shown. Because of the relatively small number of cases for each observation time during individual months, it was felt that combining the months into a seasonal description would be more valid. Therefore, only the seasonal characteristics will be graphically displayed and used for comparative purposes.

TABLE VII. MONTHLY PERCENTAGE FREQUENCY OF SUBSIDENCE INVERSION OCCURRENCE (1964 AND 1965 COMBINED)

Station	JUNE	JULY	AUGUST	SEPTEMBER
Tatoosh	24	21	19	27
PAPA	36	37	31	42
Port Hardy	17	31	25	29
Annette	14	18	21	27
Kodiak	17	25	16	29
Yakutat	17	14	14	39
Anchorage	9	10	16	26

The tables and figures to follow deal with the average characteristics of the subsidence inversion at 0000 GMT and 1200 GMT for the combined months of June, July, August, and September of the combined years, 1964 and 1965. Table VIII shows the number of cases included in this study for the combined seasons.

TABLE VIII. NUMBER OF SUBSIDENCE INVERSION CASES FOR 1964 AND 1965 COMBINED SUMMER SEASONS

Station	0000 GMT	1200 GMT
Tatoosh	59	51
PAPA	91	85
Port Hardy	60	63
Annette	52	45
Kodiak	56	48
Yakutat	55	45
Anchorage	39	34

In order to see if there was a preference for more subsidence inversions to occur in the afternoon than in the morning, a preference ratio was determined using the ratio of the number of 0000 GMT inversions to 1200 GMT inversions. The results are in Table IX.

TABLE IX. PREFERENCE RATIO FOR 1964 AND 1965 COMBINED SUMMER SEASONS

Station	Preference Ratio
Tatoosh	1.16
PAPA	1.07
Port Hardy	0.95
Annette	1.16
Kodiak	1.17
Yakutat	1.22
Anchorage	1.15

Except for Port Hardy, there appears to be a 7% to 22% preference for subsidence inversions to occur in the afternoon rather than early morning. Figures 9, 10, 11, and 12 illustrate the average characteristics of the subsidence inversion for the summer season for each observation time.

As can be seen in Figure 9(a), the inversion is generally at minimum height during the afternoon and maximum height early in the morning except at Yakutat and Anchorage. In addition, there is a definite tendency for the base height to increase with latitude (the stations are plotted according to increasing latitude) since the base height at Tatoosh is about 530 meters and is 2300 meters at Anchorage. It was observed in Chapter II that the sea-land breeze

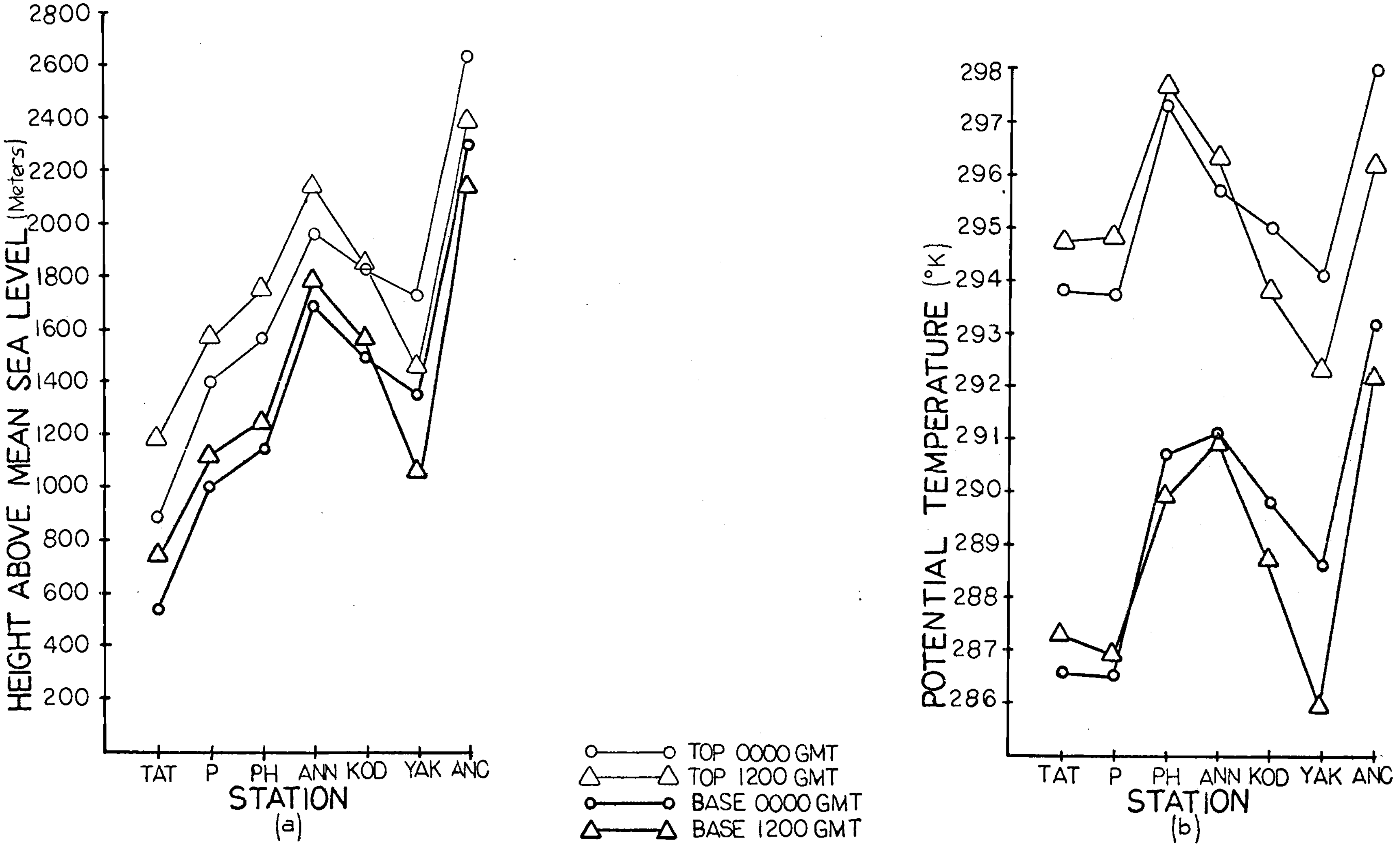


Figure 9. (a) Average heights of inversion base and top at 0000 and 1200 GMT for summer season.
(b) Average potential temperatures of inversion base and top at 0000 and 1200 GMT.

effect causes a diurnal variation in the inversion height along the U. S. West Coast. That this same effect causes the variation even far out to sea, such as at PAPA, has been proposed by Neiburger et al. (1961). The sea-land breeze does not appear to affect Yakutat and Anchorage.

Figure 9(b) indicates that the subsidence process is essentially adiabatic because the differences between morning and afternoon potential temperatures are small. Note that the base potential temperatures are slightly higher in the afternoon than in the morning, but that the reverse is true at the tops of the inversion for Tatoosh, PAPA, Port Hardy, and Annette. The fact that they are warmer at the base during afternoon is likely to be the result of diabatic heating in the moister air below the inversion. The greater the influence of the land, the greater this difference should be. Comparison of Figure 9(a) with Figure 9(b) reveals that the height curves for the inversion tops have almost the same shapes as the potential temperature curves. Note that the potential temperature is higher when the top is higher and lower when the top is lower except at Kodiak.

As would be expected, there is a general decrease in actual air temperature with increasing latitude as illustrated in Figure 10(a). It is generally cooler at 1200 GMT than at 0000 GMT. Figure 10(b) shows that the mixing ratios at the tops and bases vary only slightly between morning and afternoon, but generally show a decrease with increasing latitude. Since the values are dependent on pressure and air temperature, it would be expected that the ratios vary

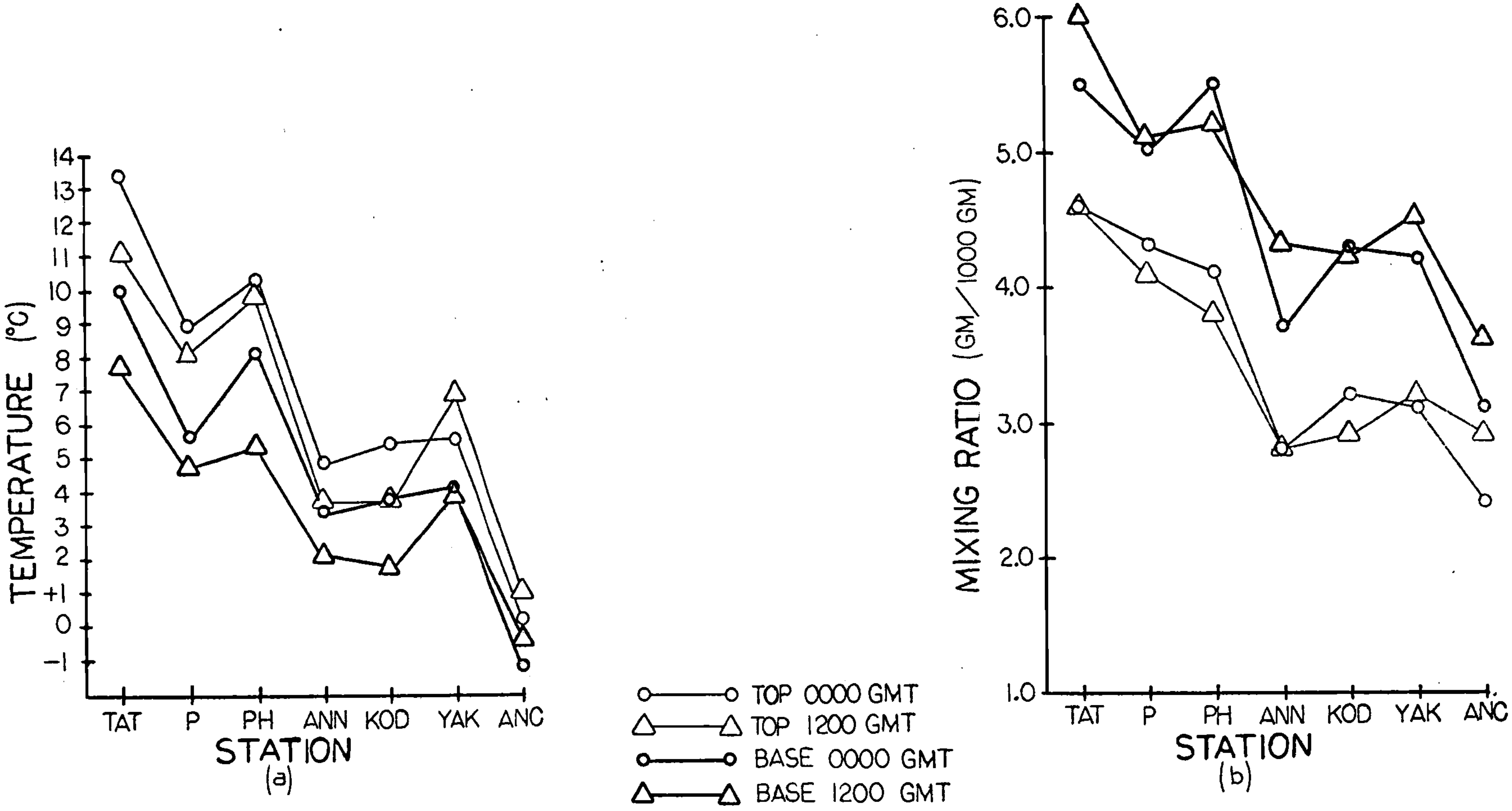


Figure 10. (a) Average temperatures of inversion base and top at 0000 and 1200 GMT for summer season.
(b) Average mixing ratios of inversion base and top at 0000 and 1200 GMT for summer season.

according to the heights and temperatures. Note the similarities between the curves in Figures 10(a) and 10(b) and that the mixing ratio curves are almost exactly the opposite of the height curves in Figure 9(a).

Figure 11 shows the effects the layer of air beneath the inversion have on the relative humidities at the base. Mixing of the air beneath the inversion during the day generally decreases the relative humidity by the afternoon, but the relative humidities show less variation during the day at the top of the inversion. The mixing ratios also showed less variability at the inversion top than at the base. It is of interest to note some differences between the base and top parameters through the inversion layer.

The top curves in Figure 12(a) indicate that the inversion is thickest in the morning at all stations except Kodiak and Anchorage, and that the thickest inversion layer occurs over Port Hardy, where it is about 510 meters in the morning and 420 meters in the afternoon. The inversion is thinnest at Annette, Kodiak, and Anchorage. The bottom curves of Figure 12(a) indicate that the potential temperature differences between top and bottom is lower in the afternoon than in the morning except at Anchorage. The top curves of Figure 12(b) show that the potential temperature lapse rate decreases almost linearly from Tatoosh to Anchorage during the afternoon, being -20 deg K/1000 m at Tatoosh and -15 deg K/1000 m at Anchorage. During the morning, however, the lapse rate is more nearly constant, for it is -17 deg K/1000 m at Tatoosh and -16 deg K/1000 m at Anchorage. It

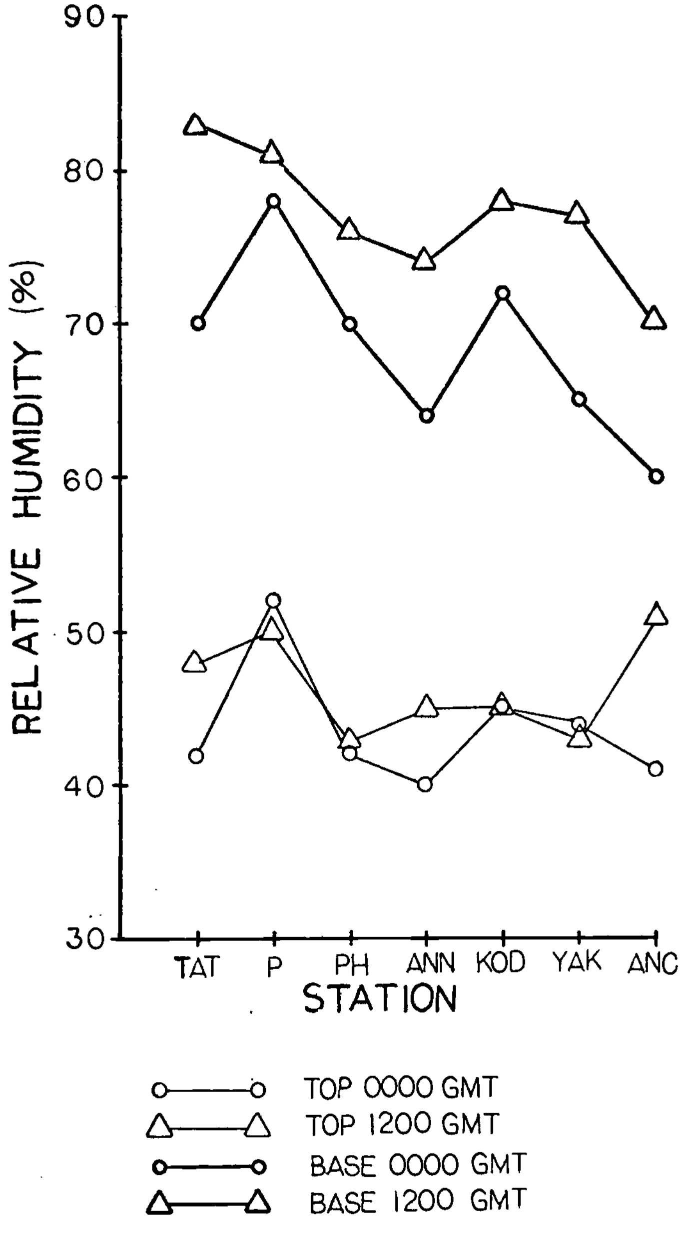


Figure 11. Average relative humidities at inversion base and top at 0000 and 1200 GMT during summer season.

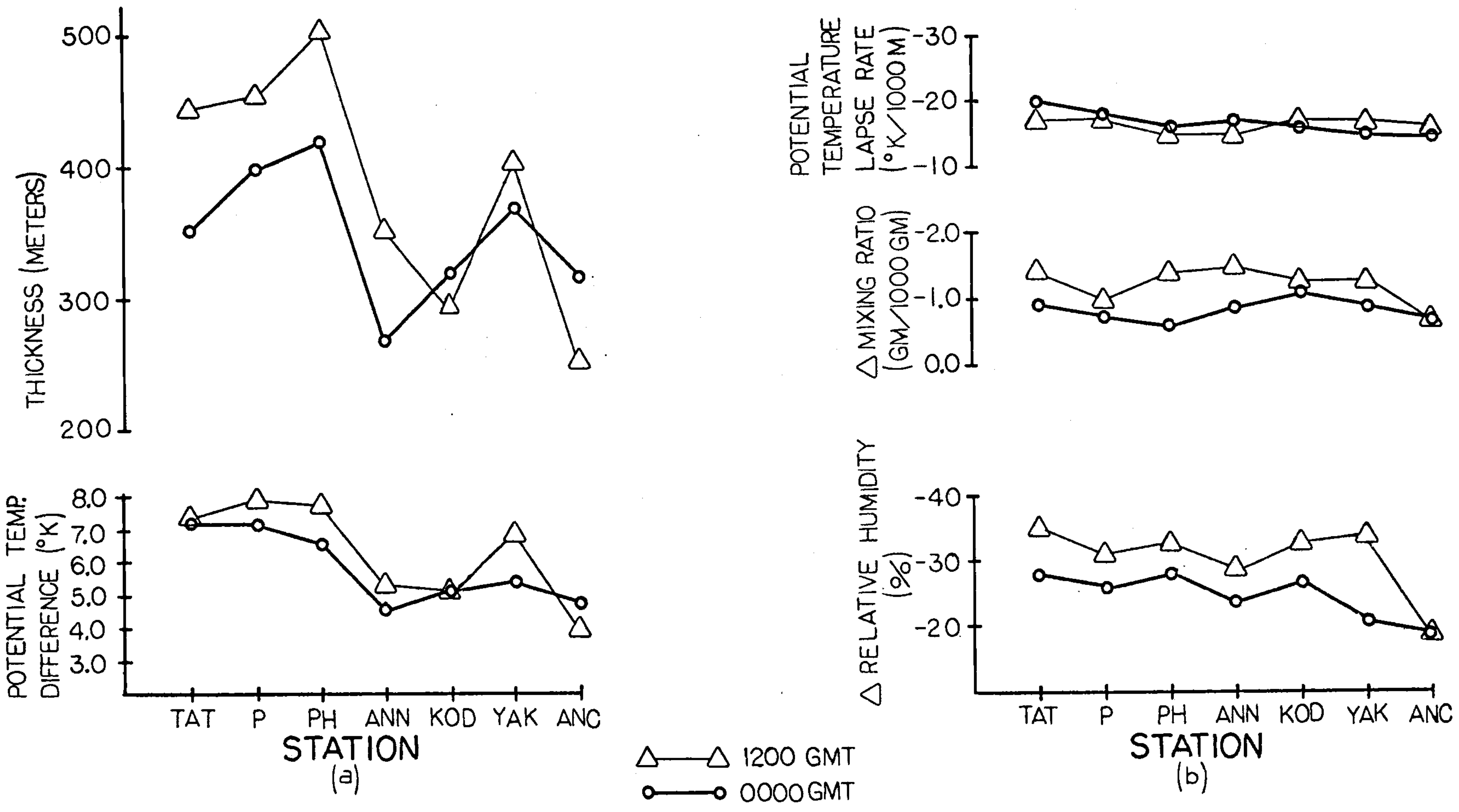


Figure 12. (a) Average inversion thicknesses and potential temperature differences through inversion layers at 0000 and 1200 GMT for summer season.
(b) Average potential temperature lapse rates, changes in mixing ratio, and changes in relative humidity through inversion layers at 0000 and 1200 GMT for summer season.

appears that the inversion intensifies more during the daytime at lower latitudes.

The middle set of curves in Figure 12(b) shows the change in mixing ratios through the inversion layers with the largest differences occurring during morning. Similarly, the bottom set of curves in the same figure shows the differences in relative humidity are greatest in the morning. In the next section, the 0000 GMT and 1200 GMT inversion cases for the two seasons are combined into daily values to determine the average daily values of the various parameters.

Summer Season Average Characteristics of Inversion

This section deals with the average daily characteristics of the subsidence inversion by combining the 0000 GMT and 1200 GMT parameters for the summer seasons of 1964 and 1965. The number of inversion cases included in this section are shown in Table X along with the percentage of soundings containing subsidence inversions selected using the criteria listed in Chapter III.

TABLE X. TOTAL NUMBER OF INVERSION CASES AND FREQUENCY OF OCCURRENCE FOR COMBINED SUMMER SEASONS 1964 AND 1965

Station	Number of Cases (0000 and 1200 GMT)	Frequency of Occurrence (%)
Tatoosh	110	23
PAPA	176	36
Port Hardy	123	25
Annette	97	20
Kodiak	104	21
Yakutat	100	21
Anchorage	73	15

As before, the frequency of occurrence is likely to be too low because of the method used in selecting the cases to be studied, but it can be concluded that subsidence inversions are rare over Anchorage.

Figure 13(a) indicates that the inversion base is lowest at Tatoosh (630 m) and highest at Anchorage (2220 m) with a secondary peak at Annette (1730 m) and a secondary minimum at Yakutat (1215 m). This same trend also appeared in Figure 9(a).

The potential temperature at the base shown in Figure 13(b) has a curve very similar to Figure 13(a) with minimum values at Tatoosh,

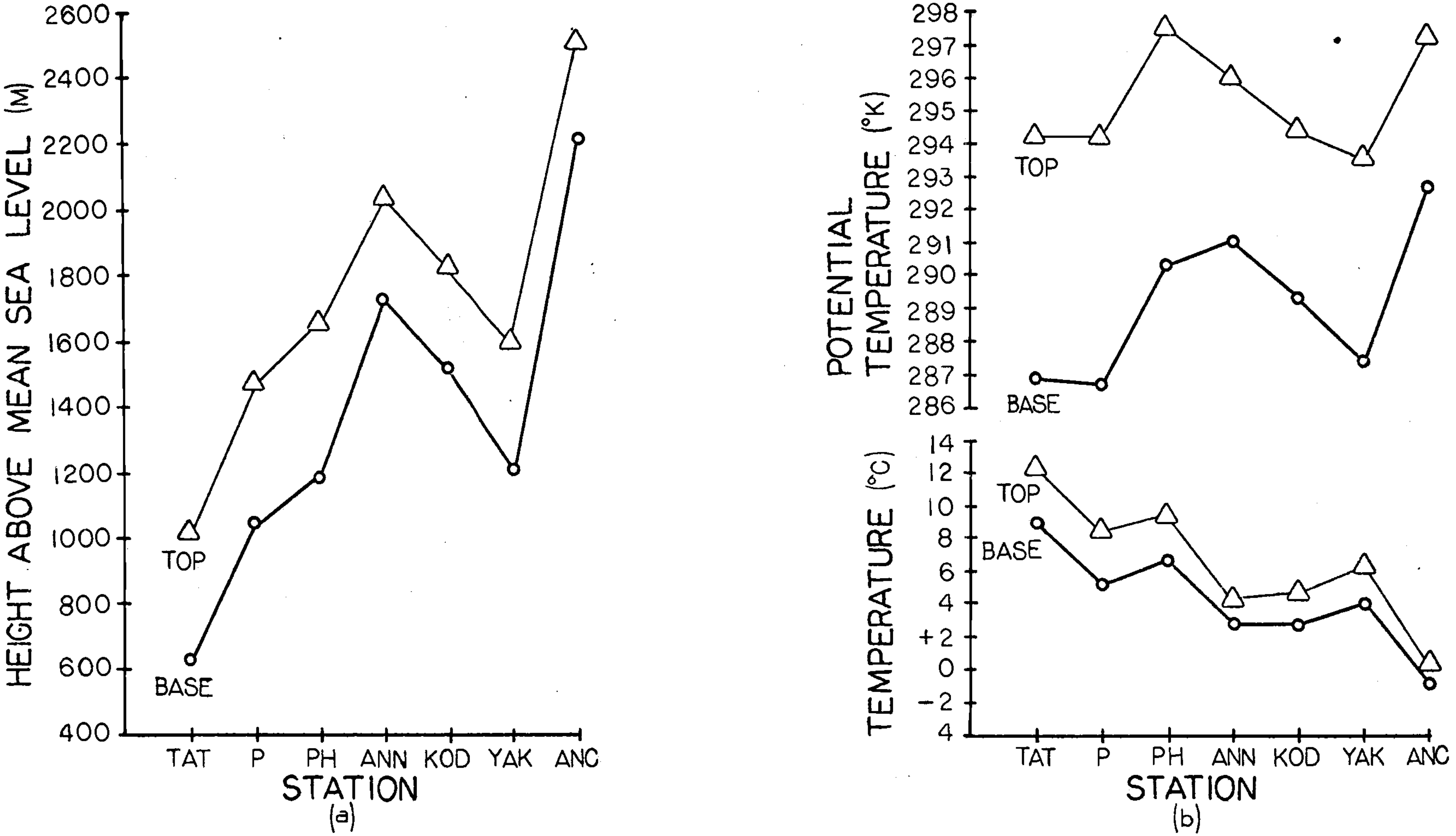


Figure 13. (a) Average heights of inversion base and top for summer season.
(b) Average potential temperatures and actual temperatures of inversion base and top for summer season.

Port Hardy, and Yakutat. Maximum values occur at Annette and Anchorage. There is evidence that this also is the case at both the afternoon and morning soundings as in Figure 9(b). Actual air temperatures, however, show a general decrease with latitude as depicted in Figure 13(b), being 8.9°C at Tatoosh and -0.8°C at Anchorage for the inversion base. Much of this is due, of course, to the greater elevations of the inversion at higher latitudes.

Because of the higher temperatures and lower base heights at Tatoosh, the mixing ratio is fairly high with a value of about 5.7 gm/1000 gm as illustrated in Figure 14(a). The lowest value is at Anchorage, where it is 3.3 gm/1000 gm. Similar results exist for values found at the top of the inversion.

The bottom set of curves in Figure 14(a) shows that the relative humidities are highest at Tatoosh, PAPA, and Kodiak, and are lowest at Annette and Anchorage at the inversion base. However, Figure 14(b) indicates that the atmosphere is more uniformly moist at Anchorage than at any of the other stations. Note that the average change in mixing ratio and relative humidity through the inversion layer is smallest at Anchorage.

Figure 15(a) shows that the thickest inversion occurs over Port Hardy (465 m), and the potential temperature difference through the inversion is 7.2°K. The thinnest inversion is at Anchorage (290 m), and the potential temperature difference is 4.5°K. The potential temperature lapse rates are -15 deg K/1000 m at both locations as shown in Figure 15(b). Interestingly, the potential temperature

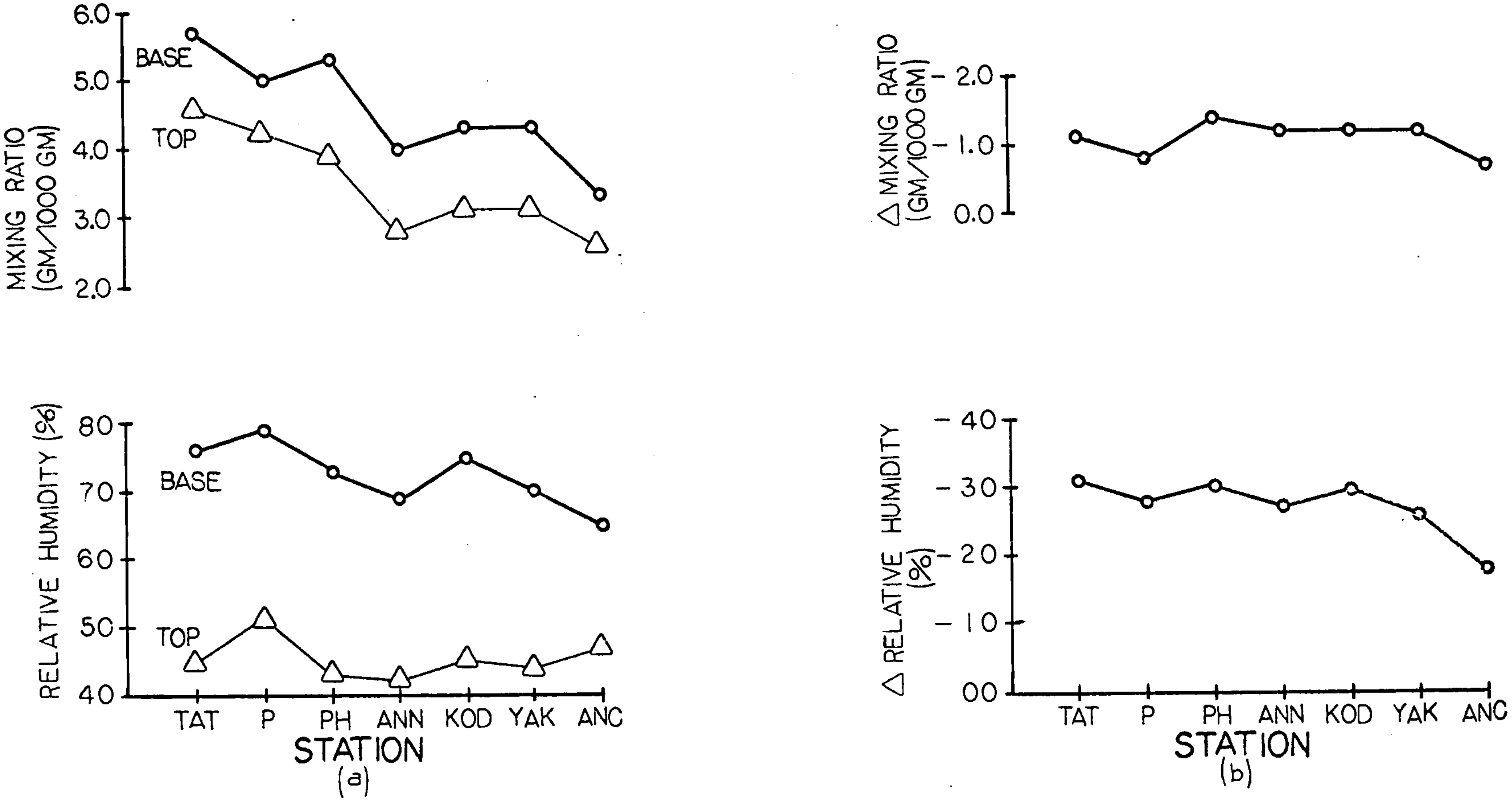


Figure 14. (a) Average mixing ratios and relative humidities of inversion base and top for summer season.
(b) Average change in mixing ratios and relative humidities through inversion for summer season.

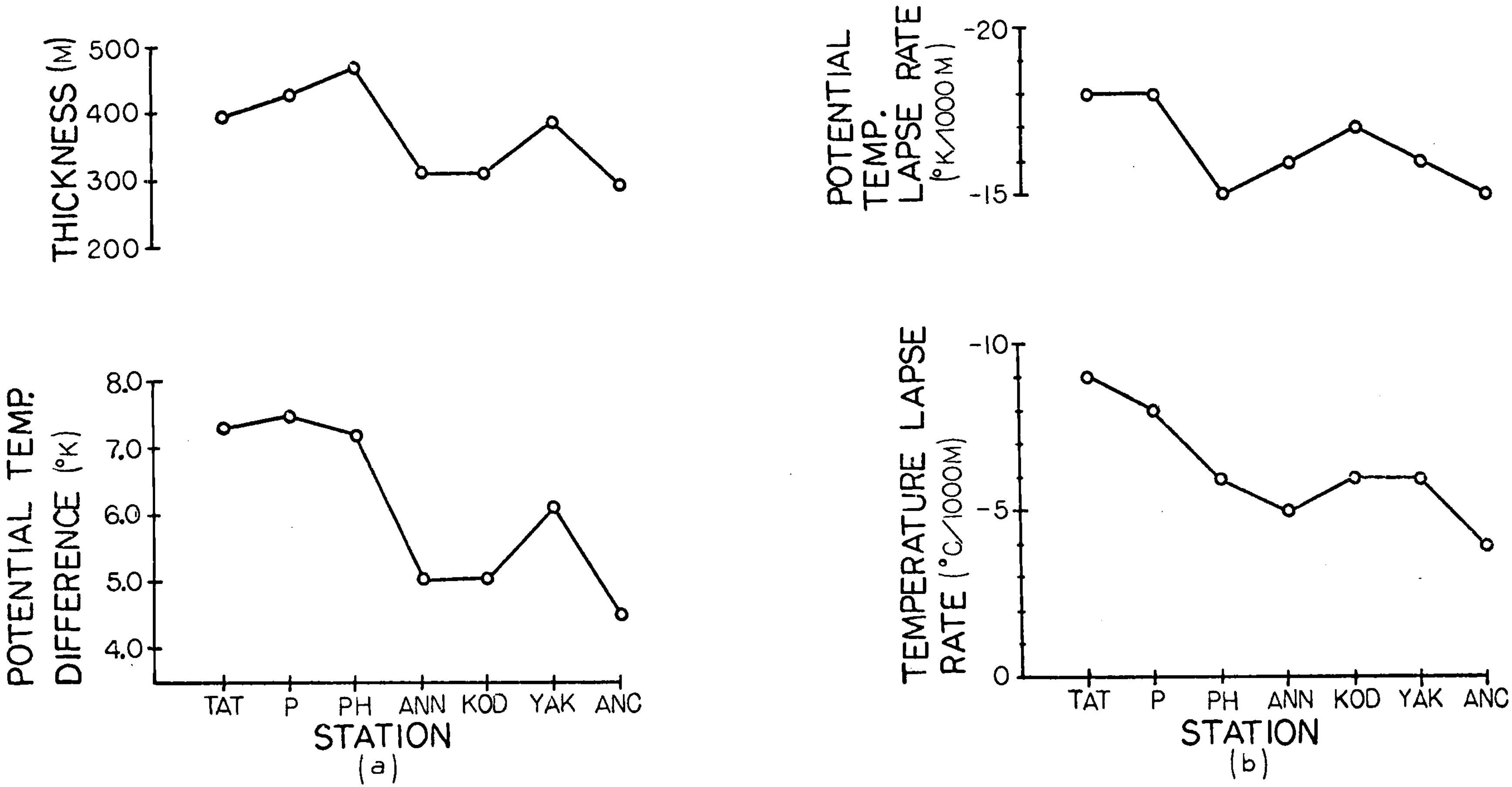


Figure 15. (a) Average inversion thicknesses and potential temperature differences through the inversion for summer season.
(b) Average potential temperature lapse rates and temperature lapse rates through the inversion for summer season.

difference curve at the bottom of Figure 15(a) has essentially the same shape as the average thickness curve shown at the top of Figure 15(a). It would be expected that the greater the thickness, the greater the potential temperature difference. The bottom curve of Figure 15(b) illustrates that the temperature lapse rate increases with increasing latitude, being -9.0 deg C/1000 m at Tatoosh and -4.0 deg C/1000 m at Anchorage. The next section will compare the Gulf of Alaska subsidence inversion with the inversion as it is found at more southerly latitudes.

Comparison of Inversion North of 48° North with Inversion at Lower Latitudes

A comparison of the more notable features of the subsidence inversion north of 48°N latitude will be made with the inversion as it exists along the U. S. West Coast and southwestward over the Pacific Ocean to Johnston Island. Using all the available data they could obtain, Neiburger *et al*. (1961) determined the average characteristics of the subsidence inversion south of 50°N for the combined months of June, July, August, and September by averaging the atmospheric parameters of the inversion using upper-air soundings at 0000 GMT and 1200 GMT. The previous section of the present study encompasses the same months and observation times, but not the same years. A shorter study by Bell (1958) was made for the California coast for the months of May, July, September, and October of 1950 and 1951. Because it does not contain data for June and August, the comparison will be made only with Neiburger's results.

The subsidence inversion, of course, is not an event that can be found at any one time existing simultaneously all the way from Johnston Island to Anchorage. Over the Gulf of Alaska, the inversion is very intermittent, existing a few days at a time from place to place. However, it is interesting to note the average characteristics of the subsidence inversions as they exist over this great range of latitudes and to appreciate the fact that they are so widely spread.

The stations from Neiburger's study used for this comparison are listed below in order of increasing latitude. The numbers in parentheses indicate the number of soundings examined.

	Station	Latitude (N)	Longitude (W)	No.	Station Designator
1.	Johnston Island	17°00'	168°30'	(555)	J
2.	Pearl Harbor, Hawaii	21°18'	157°51'	(998)	PHH
3.	Midway Island	28°13'	177°21'	(687)	MID
4.	Ship	30°00'	140°00'	(912)	SHIP
5.	San Diego, Calif.	32°44'	117°10'	(1303)	SD
6.	Long Beach, Calif.	33°49'	118°10'	(848)	LB
7.	Santa Maria, Calif.	34°54'	120°27'	(1824)	SM
8.	Oakland, Calif.	37°44'	122°12'	(2362)	OAK
9.	Tongue Pt., Ore.	46°06'	124°00'	(381)	TP
10.	Tatoosh Is., Wash.	48°23'	124°44'	(1888)	TAT
11.	PAPA	50°00'	145°00'	(142)	P

In the current study, the stations used are listed at the beginning of Chapter II. Tatoosh, PAPA, Port Hardy, Annette, and

Yakutat had 488 upper-air soundings examined for each station. Kodiak and Anchorage each had 487 soundings. The two studies overlap at Tatoosh and PAPA. Figures 16 through 20 show the results of the comparison with the results by Neiburger et al. (1961) shown by circles and solid lines, and the current study by triangles and dashed lines.

Examination of Figure 16 reveals that the subsidence inversion is definitely lowest and thickest along the California coast than at any other location. The base height decreases with latitude, reaching a minimum in the region near Santa Maria (410 m). This location is also in agreement with Bell (1958). As the latitude increases, so does the base height, reaching one maximum over Annette (1730 m) and another over Anchorage (2220 m). As one moves southwestward toward Hawaii from California, the inversion height increases again with a maximum at Johnston Island (2085 m). Note that the results of the present study almost exactly match Neiburger's results at Tatoosh Island. That the results do not match those from PAPA is probably due to the small number of soundings Neiburger used at that station. The inversion is greatly influenced by the Intertropical Convergence Zone in the latitudes nearest the equator, and, as a result, is found at much higher elevations. The effects of the sea-land breeze have been discussed previously, but it should again be mentioned that it has an effect on lowering the inversion base most notably along the California coast. More important, however, is that the average divergence of the air has a maximum over the California coast due to

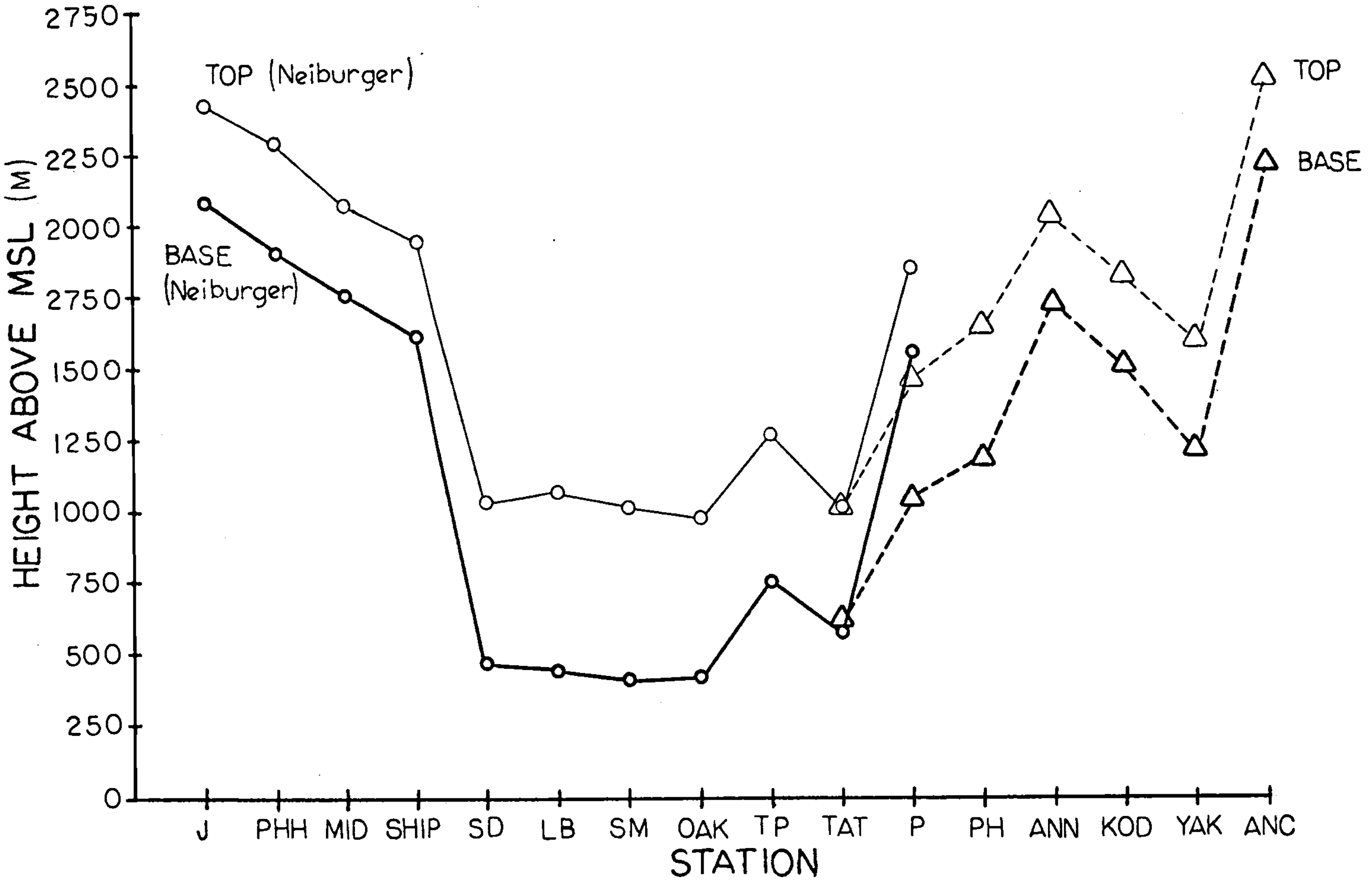


Figure 16. Average height of inversion from Johnston Island to Anchorage in summer season.

the persistent divergence of the streamlines over the area. This feature is most prevalent on the eastern side of anticyclones. Further north, and especially over the Gulf of Alaska, the inversions result from anticyclones and ridges having many varied orientations to the station, which means that the station is not necessarily in the region of maximum divergence. Another factor to consider is that the persistence of anticyclones over the Gulf of Alaska is not nearly as great as that of the Pacific High off the coast of California. Thus, subsidence inversions, though well developed on occasion, are generally transitory in behavior and do not have time to subside to lower altitudes.

Figure 17 illustrates the fact that the potential temperature is highest over the tropical waters with a generally decreasing trend as the latitude increases. However, some of the lowest potential temperatures are found over the Santa Maria area due to the inversion being lowest near this station. Once again, note the close agreement between the two studies at Tatoosh.

In Figure 18, the actual air temperatures at the inversion base are generally greater than $9^{o}C$ at all locations south of Tatoosh Island with maximum values over the California coast. Increases in latitude and the increase in base heights results in a steady decrease in temperature. Anchorage has the minimum value of $-0.8^{o}C$.

The data tabulations in Neiburger's study did not contain mixing ratio values, but did have relative humidity values. Figure 19 shows that the relative humidity is highest at the inversion base over

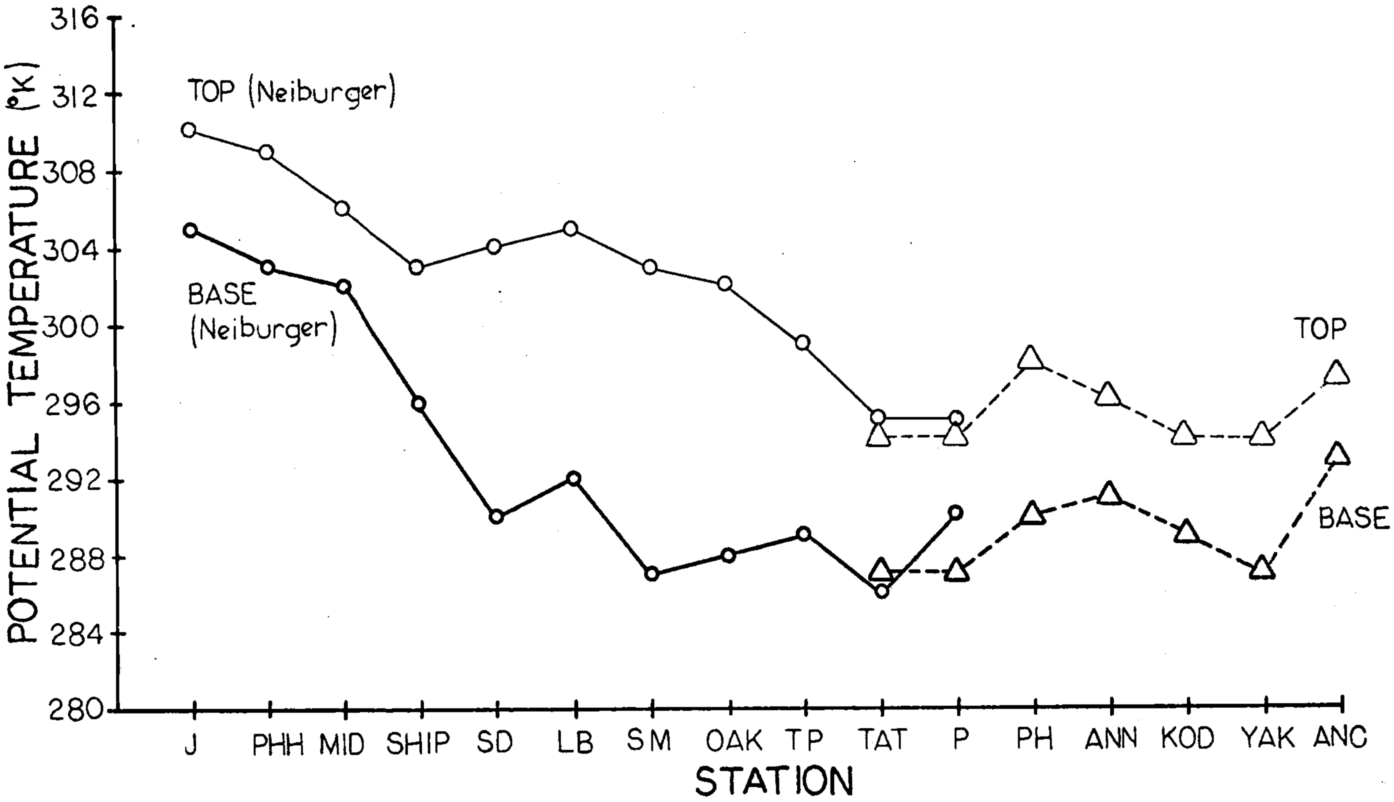


Figure 17. Average potential temperature of inversion from Johnston Island to Anchorage in summer season.

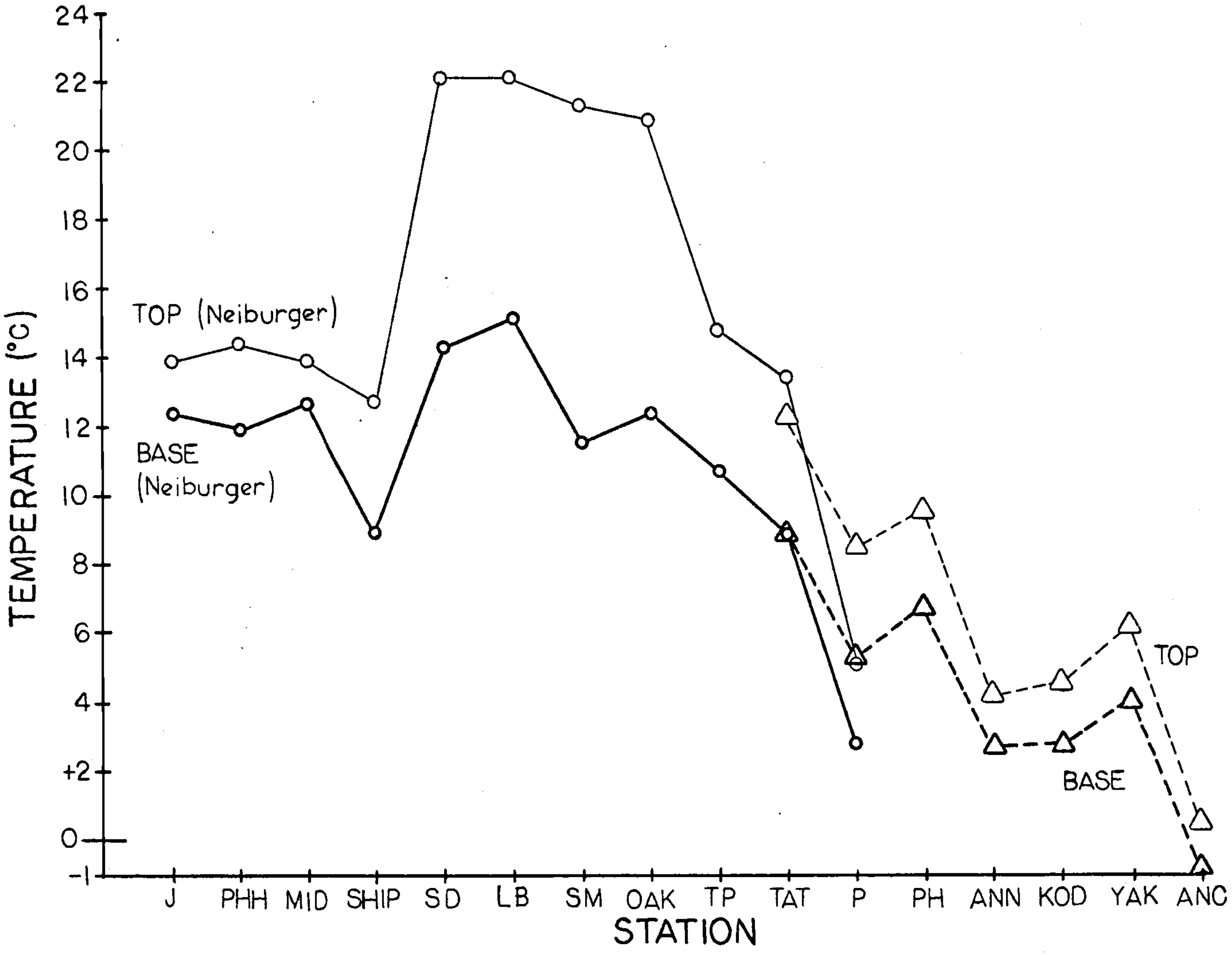


Figure 18. Average temperature of inversion from Johnston Island to Anchorage in summer.

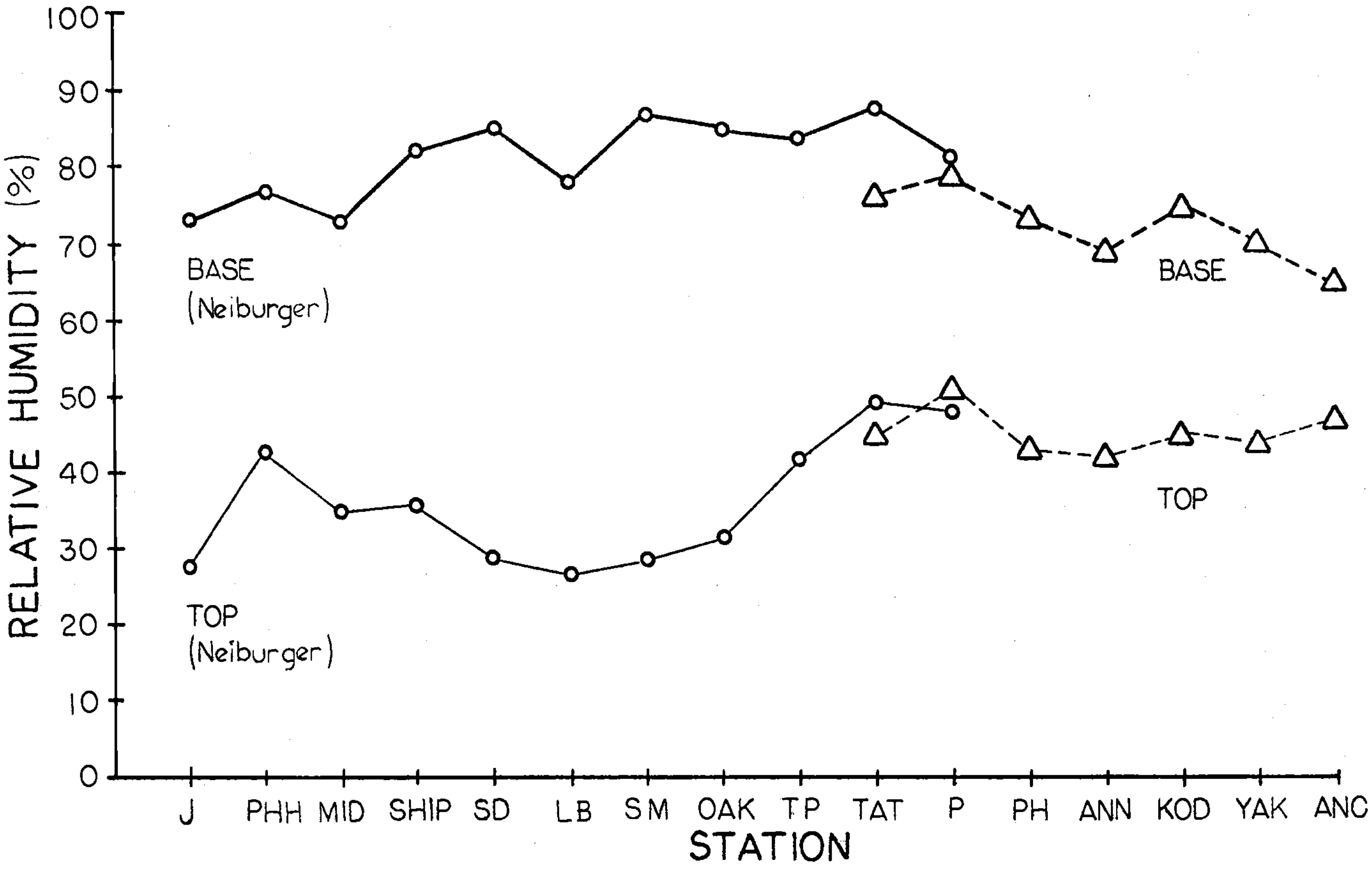


Figure 19. Average relative humidity of inversion from Johnston Island to Anchorage in summer season.

California and lowest at the top over the same area.

Finally, in Figure 20, the percent of observations containing subsidence inversions is shown. The results obtained by Neiburger contain inversions not necessarily associated with quasi-stationary anticyclones as was done in this study. The percentages shown by him for latitudes north of California are likely to be higher than obtained by this writer. Note the great disparity at Tatoosh. Since the difference was so great, a check was made on the Tatoosh computer printouts in which all inversions exhibiting subsidence characteristics regardless of surface pressure or 700 mb heights were counted. Two hundred sixty-two inversions were counted, giving 54% of the observations with inversions, which compares more favorably with the 63% determined by Neiburger. The percentages shown in the graph by this writer should be regarded in light of the very selective method used in selecting subsidence inversion cases in the first place. However, even if the percentages from the current study were to be tripled, the frequency of occurrence definitely decreases with increasing latitude. This is not unusual considering the transitory nature of the pressure systems in the more northerly latitudes.

Summary and Conclusions

The method employed in this study for selecting subsidence inversion cases appears to be adequate since the averages determined for Tatoosh Island are consistent with those obtained by Neiburger *et al.* (1961). Use of computer printouts of the upper-air sounding

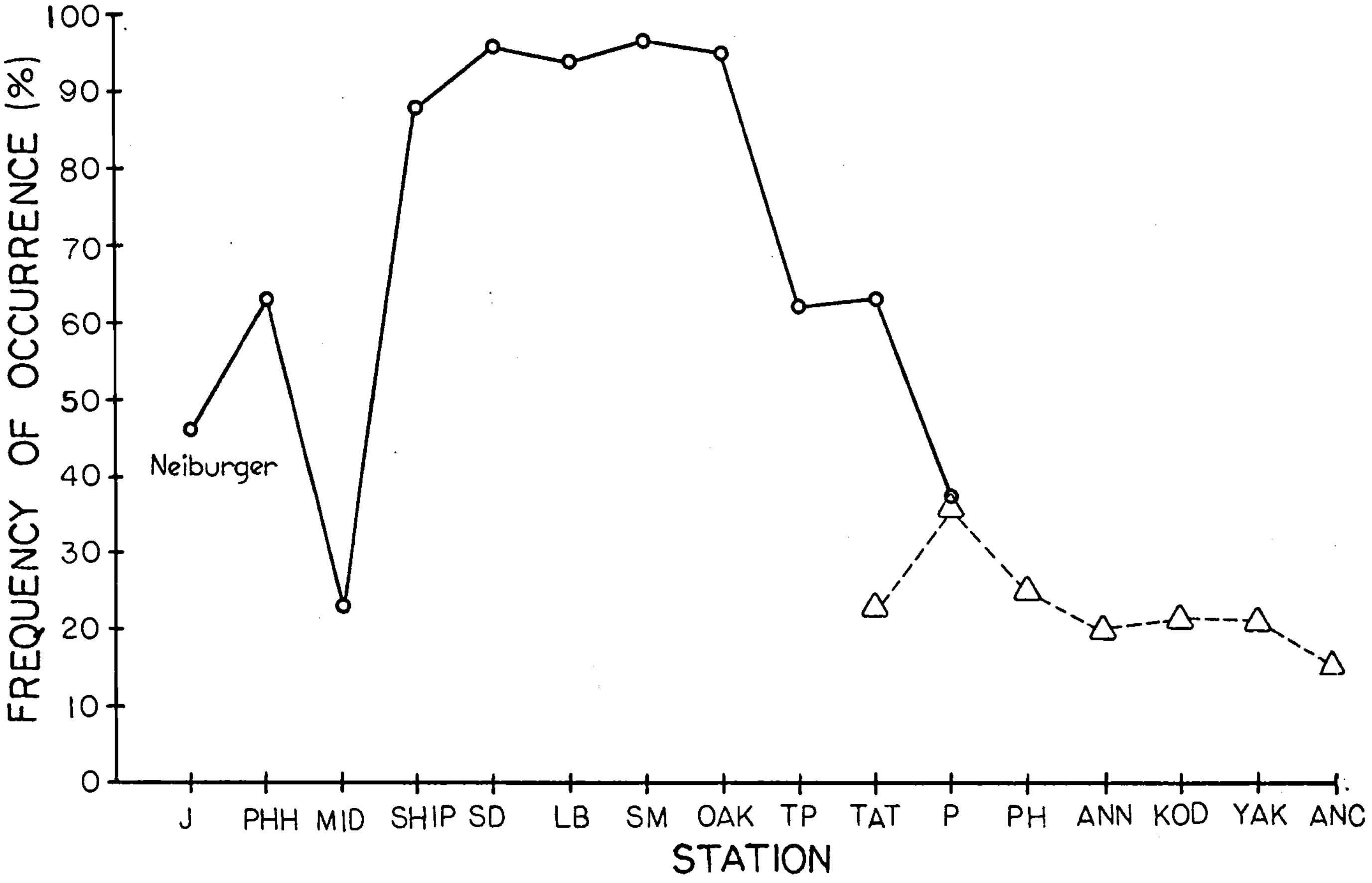


Figure 20. Frequency of inversion occurrence from Johnston Island to Anchorage as a percentage of the total number of soundings for the summer season.

data greatly facilitated the manual extraction of inversion parameters; use of pseudoadiabatic charts would have been much more tedious. In the author's opinion, anticyclonic type subsidence inversions above 50°N are not too important, except in isolated individual events, in the prevention of air pollution dispersal. Their frequency of occurrence is small, and the average heights of their bases are much greater than those found over the coast of California.

Major findings of this study reveal:

1. A diurnal oscillation of the height of the inversion base exists, except in the Yakutat and Anchorage regions.
2. The height of the inversion shows a general increase with increasing latitude.
3. The potential temperature at the base of the inversion is generally lower early in the morning than in the afternoon except in the region of Tatoosh Island.
4. Air temperatures and mixing ratios at both the bases and tops decrease with increasing latitude.
5. Lapse rates increase with increasing latitude.
6. The inversion thickness decreases with increasing latitude, but the potential temperature of the base generally increases with higher latitudes.
7. Subsidence inversions are most pronounced over the California coast compared to any other location between Anchorage and Johnston Island.

The average values obtained in this study are only based on two daily soundings. It is unlikely that the extreme daily values of the various parameters are averaged. More frequent soundings would be required to determine the "exact" time that the parameters, such as the inversion base height, reach their extreme values for the day. To determine the actual dynamical factors creating the subsidence inversions over the study area could well be the subject of a future research project. And finally, the seasonal averages obtained over the two year period should be considered preliminary, to be revised as more data become available.

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