METEOROLOGICAL FACTORS INFLUENCING AIR POLLUTION IN THE LOS ANGELES AREA

Charles G. P. Beer and Luna B. Leopold

Abstract.--The Los Angeles area is faced with the problem of planning the mitigation of air pollution. The meteorological factors which determine the distribution of the pollution and the intensity of the nuisance are the height of the prevailing summer subsidence inversion and the local sea-land breeze regime. Data on details of the wind structure and visibility are presented. These, with the time variations of the inversion, are discussed in relation to the pollution problem.

Introduction--In common with many other expanding metropolitan areas, Los Angeles has encountered the problem of increasing nuisance from smoke and other types of air pollution. The recent war period led to an acceleration of industrial growth, and the air pollution is now recognized as a definite problem. Not only is the City of Los Angeles affected, but many of the surrounding suburbs become acutely aware of the problem at times when weather conditions bring the pollution into their vicinity.

The most serious complaint has been smarting or irritation of the eyes noticed by many people in the affected areas on a few days each year. There is also the presence of smoke in some amount, although this is not as serious a problem as it would be in a region where coal is used as a common fuel. However, the reduction in the amount of light caused by passing through a widespread layer of smoke is a noticeable loss in a community where outdoor living and sunshine are such valuable assets. Although the complete abatement of smoke may prove uneconomical in any city, it can be shown that proper consideration of meteorological features in city planning would do much to reduce the nuisance.

The problem of air pollution around Los Angeles involves not only the location of the sources and measurement of amounts of impurities, but also the effect of certain climatic and weather features of the area. Among these are the prevalent low stratus cloudiness of summer, the possible presence of quantities of condensation nuclei derived from the nearby ocean (see Fig. 1), and the sea breeze, a daily occurrence of great regularity most of the year. It will be the primary aim of this paper to point out some of the controls which weather conditions exert on the distribution of air pollution, both horizontally and vertically.

Even if the pollution were entirely prevented, the Los Angeles area would experience a large percentage of low cloudiness and fog in the summer season. This is associated with the position of Southern California in relation to the semipermanent high-pressure cells over the Atlantic and Pacific Oceans and the ocean currents along the coast. A similar climate prevails in other parts of the world situated in analogous positions; namely, the areas around Casablanca, North Africa; Cape Town, South Africa; and Valparaiso, Chile. The frequent occurrence of fog and clouds in such areas is to be distinguished from what may be termed "air pollution." In this sense the term "air pollution" correctly implies materials which would not be found in the air in the absence of human activities.

Because the smoke pall so often occurs in combination with the summer fog and stratus, and at times even looks like a fog bank, it has sometimes been called "smog." This has unfortunately created some confusion as to the nature of the nuisance. The presence of smoke probably causes the formation of slightly more fog than would otherwise occur, but this has not yet been demonstrated from the available climatological records.

Meteorological aspects of the pollution problem

The effects of air pollution in Los Angeles are especially aggravated by two climatic features of the area. These are the temperature inversion and the local winds. As will be shown later, the local winds determine the horizontal distribution of the smoke by carrying it along in the air stream, that is, by advection. The vertical distribution of the pollution is limited by the persistent temperature inversion, beneath which the air is continually stirred by vertical convection and frictional turbulence. As suggested independently by Fletcher and Smith [see "References" at end of
the distribution of air pollution may be regarded as a combination of two processes, advection and convection.

Winds experienced in the Los Angeles basin are influenced by two factors. First, there is the local alternation between a sea breeze blowing toward the land and up the mountain valleys during the day, and a land breeze or down-valley wind during the night. These local winds will be discussed in more detail later. Second, there is the effect of the prevailing westerly winds of the temperate latitudes.

In summer the Los Angeles area is in the southerly fringe of the belt of prevailing westerlies, which, though they are rather light at this latitude, are still persistent enough to be called prevailing. The pressure gradient responsible for these winds tends to reinforce the sea breeze each day and to oppose the land breeze at night. A net transport of air from west to east results. Nevertheless, there are many times during the summer when this flow is reversed, especially at levels somewhat above the surface of the ground. Such reversals tend to aggravate the accumulation of impurities, since they do not allow them to be carried away in the general drift toward the east.

In winter the belt of westerlies shifts southward and brings the Los Angeles area under strong west winds for a larger part of the time. The temperature inversion is usually absent or quite high under these conditions. The smoke is then rapidly mixed through a deep layer of atmosphere, and advection carries it away in a relatively short time.

This general winter condition is frequently interrupted when a high-pressure center develops over North America and especially over the Great Basin. The prevailing westerlies may then be displaced at the surface by northeast winds and the inversion sinks to the surface and disappears. In such situations the smoke will be carried seaward at the surface.
METEOROLOGICAL FACTORS INFLUENCING AIR POLLUTION

These two conditions, either the prevailing westerlies or the east winds from a continental high, characterize much of the Southern California winter. It will be noted that under both conditions deep vertical mixing is possible because convection and turbulence are not limited by an inversion. This, in combination with the stronger winds, greatly reduces the effects of air pollution in winter. Summer is probably the season suffering the greatest overall nuisance, but spring and fall may bring a few days of acute conditions. These are due to the combination of a very stable summer-type inversion held to a low level by a winter-type circulation.

The temperature inversion

The characteristic summer temperature inversion is illustrated in Figure 2, a diagrammatic sounding showing the change of temperature with height through the lower atmosphere above Los Angeles in summer. The inversion is the layer through which the temperature increases with height. It is characterized by much greater stability (resistance to vertical motion or stirring) than the layers in which the temperature decreases with height. It thus tends to limit the height to which impurities are lifted from the surface.

Fig. 2--Diagrammatic sounding

The point at which the temperature begins to increase with height is called the inversion base. It varies considerably in height during any one day and from day to day, and may even disappear entirely for a short time at the higher stations. Thus the thickness through which the pollution may be distributed is quite variable, giving rise to considerable variation in its concentration.

The point above the inversion base at which the temperature again begins to decrease with height is called the inversion top. Its height also varies considerably with time.

The layer of air beneath the inversion base may be called the marine stratum. It is unstable most of the time, resulting in continuous stirring which tends to produce a homogeneous mixture of water vapor, air, and any smoke or other impurities present. The air of the marine stratum has usually undergone recent travel over the ocean and its water-vapor content is therefore high, as shown in Figure 2 by a mixing ratio of ten g per kg at both the surface and the inversion base.

Air above the inversion top is characterized chiefly by its dryness. Although it may originally have been a maritime air mass, large-scale subsidence occurring in the subtropical belt of high pressure usually causes a change in its characteristics. It is preferable to refer to the air above.
the inversion as "superior" air, since this term is more descriptive of what happens when the inversion sinks low enough to allow the upper air mass to descend upon cities of the basin. This usually takes place several times each summer and is accompanied by a period of hot dry weather or "foehn." In the process of change from stratus or foggy weather to foehn conditions, contaminated air may be brought into areas normally free of pollution.

The mean height of the inversion base in the Los Angeles area is about 2000 feet msl but varies somewhat with distance inland. Some idea of the shape of the inversion surface can be obtained from Figure 3, which shows the average contours for the month of September, 1944. This figure is taken from a previous report in which the shape and oscillations of the inversion have been discussed in greater detail [NEIBURGER, BEER, and LEOPOLD, 1945]. It can be seen that a slight trough in the inversion is present, roughly parallel to the coast and slightly offshore. The upward slope toward the land is caused at least in part by the higher surface temperatures attained inland as compared with coastal stations. The slope is important in that it allows a greater depth through which the pollution can be distributed in the eastern portion of the basin, toward which the pollution is blown by the mean wind flow.

![Fig. 3--Average contours of inversion base, September 1944](image)

In summer the inversion is often wiped out in the eastern part of the basin and adjacent to the mountains by heating of the surface to a temperature considerably greater than that of the inversion top. When this occurs the pollution near the surface may be rapidly alleviated by convection through a thicker layer of air.

Figure 4 shows the change in height of the inversion base above Pasadena between August 31 and September 7, 1944. Both the diurnal and the long-period variations are apparent. The long-period changes are associated with convergence and divergence under the influence of moving troughs and wedges in the pressure patterns aloft [UNITED STATES ARMY AIR FORCES, WEATHER DIVISION HEADQUARTERS, 1945 a].
It can be seen from Figure 4 that during most of the 5th, 6th, and 7th of September, 1944, Pasadena was in the "superior" air mass rather than the marine stratum. The example is one of fairly rapid change from cloudy to foehn conditions, culminating in a temperature of 103°F on September 8, 1944. In other cases, when the inversion remains at elevations such as those on the 4th, the effects of air pollution may become quite noticeable at Pasadena. The impurities are then concentrated in a thin layer near the ground and may be associated with surface fog, as differentiated from stratus clouds or "high fog."

The diurnal variations in height of the inversion which can also be seen in Figure 4 result from the daily changes in solar insolation and the concomitant convergence in the sea breeze regime. The time of maximum height varies slightly from the coast inland [NEIBURGER, BEER, and LEOPOLD, 1945]. Stations near the coast such as Orange County Airport or UCLA experience maximum height at about 06h00m PWT, and minimum at about 18h00m PWT. Inland stations such as Pasadena have the maximum height near 14h00m, again the effect of greater surface temperatures. These diurnal variations in the inversion height are responsible for corresponding changes in the severity of any pollution nuisance.

Land and sea breezes

Wind advection is the other factor which exerts a strong influence on the distribution of air pollution. The effect of the prevailing pressure gradient has been discussed. It was noted that this gradient is small in the seasons of worst pollution nuisance. A complete evaluation of wind advection must therefore include knowledge of the diurnal wind variations. All stations in the Los Angeles basin are influenced to some extent by the sea-land breeze regime characteristic of coastal areas. In general, they experience a southwesterly sea breeze beginning in the late afternoon and ending about sunset. During the night a lighter land wind from the northeasterly quadrant is the rule. The regime at each station is also influenced by local topographic features, but the alternation between day and night winds is apparent in all cases. Since it is sometimes difficult to determine whether a local wind is caused by the temperature difference between land and sea or that between mountain and valley, the terms "sea-valley" or "land-mountain" breeze will be applied to questionable cases.

Surface winds--The surface-wind pattern for each station is summarized in Figure 5, giving the average time of beginning and end of the prevailing wind directions in August 1944. Space limitations required the use of call letters to identify the observation stations. These are listed together with the station elevations in Table 1.

The daytime wind regime is indicated by the solid arrows in Figure 5. Wind directions characteristic of the late afternoon are shown with heavier lines. These represent the flow near the time of maximum sea breeze. It is immediately apparent from the overall picture of the afternoon sea breeze that the flow of air comes onshore approximately perpendicular to the local coast line, but is guided up the main valleys toward the passes. The flow splits into two streams, one stream flowing northwestward into the San Fernando Valley, the other eastward toward San
Gorgonio Pass. The sea-valley wind regime is felt at Palm Springs (DPZ) east of the San Gorgonio Pass and some 80 miles inland from the coast, and slightly affects the winds at San Clemente Island (NGA), 80 miles out to sea. San Nicolas Island (NCB), 80 miles from the coast, apparently is not subject to the diurnal shifts of the land-sea breeze regime.

Table 1 -- Call letters and station elevations

<table>
<thead>
<tr>
<th>Station</th>
<th>Call letters</th>
<th>Elevation (ft msl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beaumont</td>
<td>TUT</td>
<td>3892</td>
</tr>
<tr>
<td>Burbank (Lockheed Air Terminal)</td>
<td>BU</td>
<td>725</td>
</tr>
<tr>
<td>El Toro (Marine Corps Air Station)</td>
<td>DGX</td>
<td>332</td>
</tr>
<tr>
<td>Glendale (Grand Central Terminal)</td>
<td>DLF</td>
<td>106</td>
</tr>
<tr>
<td>Lomita Flight Strip</td>
<td>HB</td>
<td>40</td>
</tr>
<tr>
<td>Long Beach (Army Air Field)</td>
<td>LA</td>
<td>96</td>
</tr>
<tr>
<td>Los Angeles Airport (Mines Field)</td>
<td>DPZ</td>
<td>512</td>
</tr>
<tr>
<td>Los Angeles (Weather Bureau City Office)</td>
<td>NH</td>
<td>1190</td>
</tr>
<tr>
<td>Newhall</td>
<td>OC</td>
<td>10</td>
</tr>
<tr>
<td>Oceanside (Army Air Field)</td>
<td>DOI</td>
<td>920</td>
</tr>
<tr>
<td>Orange County Air Field</td>
<td>DSW</td>
<td>52</td>
</tr>
<tr>
<td>Oxnard Flight Strip</td>
<td>DOC</td>
<td>62</td>
</tr>
<tr>
<td>Palm Springs (Army Air Field)</td>
<td>DLF</td>
<td>420</td>
</tr>
<tr>
<td>Pasadena (Calif. Institute of Tech., CIT)</td>
<td>DUA</td>
<td>758</td>
</tr>
<tr>
<td>Riverside (March Field)</td>
<td>RV</td>
<td>1528</td>
</tr>
<tr>
<td>San Bernardino (Army Air Field)</td>
<td>D JL</td>
<td>1088</td>
</tr>
<tr>
<td>San Clemente Island (Naval Air Station)</td>
<td>NGA</td>
<td>906</td>
</tr>
<tr>
<td>San Nicolas Island (Naval Air Field)</td>
<td>NCX</td>
<td>505</td>
</tr>
<tr>
<td>San Pedro (Naval Air Station)</td>
<td>NCU</td>
<td>10</td>
</tr>
<tr>
<td>Santa Maria (Army Air Field)</td>
<td>TZM</td>
<td>229</td>
</tr>
<tr>
<td>University of California at Los Angeles (UCLA)</td>
<td>PUC</td>
<td>505</td>
</tr>
<tr>
<td>Van Nuys (Metropolitan Airport)</td>
<td>DVN</td>
<td>797</td>
</tr>
</tbody>
</table>

It will be noted that the night winds shown in dotted arrows are present at nearly all stations as far inland as March Field (RV) and seaward as far as San Clemente Island. These night winds are, however, weaker than the sea breeze at all stations. Their general pattern of flow is in the opposite direction to that of the sea breeze.

The details of the diurnal regimes at various stations are more complicated than the general picture just described. At some stations a westerly wind begins two or three hours after sunrise but comes from a direction slightly different from that of the maximum sea breeze. This early wind can usually be interpreted as a valley wind which commences earlier than the true sea breeze. Analysis of the diurnal changes at Orange County Airport (DSW) is typical of the reasoning which may be applied to many other stations. The sea-valley breeze begins at about 09h30m PWT from the west-southwest and backs gradually to southwest by 14h30m. This change of direction is opposite that which would be expected as a true sea breeze approaches balanced flow. During the progress of the day the Coriolis force should tend to produce veering of wind at coastal stations. The west-southwest wind at the time of onset may be regarded, therefore, as the vector sum of a southwest sea breeze perpendicular to the coast and a west wind blowing into the valley east of Orange County Airport. The sea breeze effect increases as the day progresses, becoming dominant by 14h30m and continuing until two hours after sunset.

In general, the speed attained by the sea-valley breeze appears to be nearly the same at all stations. Since a true sea breeze should diminish in speed farther inland it is apparent that a merging of the sea breeze into the valley wind takes place. Noticeable increases in speed at a few stations (for example, DOI, NH, RV) are probably the result of channelization of the flow by topography rather than thermal effects.

It will also be noted that the onset of the sea-valley breeze at inland stations such as Newhall (NH) and March Field (RV) occurs only one or two hours later than at the coastal stations. This is insufficient time for the air which crossed the coast at the onset of the sea breeze there to have reached the inland stations. Moisture content of the air is, therefore, not a characteristic of the
sea-valley breeze as defined in this paper. Fresh moisture will, of course, be carried inland by the sea breeze later in the day, but the change of wind direction may occur several hours before the arrival of new moisture at the inland stations.

The land breeze, being of smaller speed, is affected even more by the local topography. After the sea breeze dies down, a period of variable wind or calm usually ensues, followed by a drainage or mountain wind, later reinforced by the general easterly land breeze. For example, at Orange County Airport (DSW) the period of calms or variable wind lasts until midnight, when a definite east wind begins, continuing until the sea breeze starts at 09h30m. The cooling mountain slopes modify any tendency for a land breeze perpendicular to the shoreline.

The night-time current flowing southward out of the San Fernando Valley joins a broader easterly flow which crosses the coast along Santa Monica Bay. Cold air from the San Fernando Valley may account for the northeasterly beginning of the land breeze at Mines Field (LA), the wind veering gradually to east as the flow from the Santa Ana River basin increases.

Beaumont (TUT, 2592 feet), which lies in the mouth of San Gorgonio Pass, shows a diurnal wind regime quite different from the other stations. The predominant wind is not the sea-valley breeze but a lighter northwest wind which takes over as the sea-valley breeze diminishes around 22h00m. This northwest wind remains very steady throughout the night, but at 08h00m begins to back slowly, reaching west-southwest by 11h30m. At this time the full effect of the sea-valley breeze has presumably reached the station. Although the summit of the Pass is near Beaumont the surrounding ridges continue to rise for another 14 miles to the east. This favors the continuation of the afternoon westerly wind through the pass in spite of the descending valley floor, an effect sometimes termed a "Malobja wind." Narrowing of the valley toward the east end probably accounts for the high speeds of the wind reaching Palm Springs (DPZ).

These observations combined with pibals (pilot-balloon observations of upper winds) at DJL and RV indicate that the night-time layer of easterlies must become thinner toward the Pass, allowing a constant flow of the higher level westerlies through the Pass. At the eastern outlet of the Pass this westerly flow disappears by mixing into a southeasterly flow over Palm Springs.

Upper winds-The pilot-balloon observations taken at regular weather stations are not sufficient in number each day to allow analysis of the details of diurnal change. To collect data for such an analysis, a large number of slow ascent pibals were taken at the Army Research Weather Station, UCLA, under the direction of the authors in the summer of 1944. The balloons were inflated for a rate of ascent of about six feet per second and readings were taken at vertical intervals of 150 feet. The periods of observation were August 15 - November 20, 1944, during which 570 ascents were observed, and January 8 - 31, 1945, with 149 ascents.

The diurnal wind regime at UCLA studied in detail by these special observations is similar to that at most stations in the area, consisting of a sea breeze from the southwest during the afternoon and an easterly off-land wind during the night.

To illustrate this regime Figure 6 presents a time-height section of the winds observed at UCLA on September 1, 1944. Though no individual day shows all the features of the average picture, this day demonstrates some of the prevalent characteristics of the régime. During the period from midnight to noon the winds at the surface and in the lowest 2000 feet were east or southeast at small speeds, typical of the off-land night-time wind. At noon the surface wind veered to south, the characteristic harbinger of the sea breeze. The southwest sea breeze was well developed by 13h30m PWT below 2000 feet, while the easterlies persisted in a layer aloft. The sea breeze disappeared at the surface at 20h30m while still blowing aloft. By shortly after midnight the wind in the layer from 1000 to 2000 feet backed to southeast.

During the entire day the winds from 5000 to 10,000 feet were steadily from the northwest quadrant, thus emphasizing the reality of the easterly wind in the lowest levels. Though occurring on many days, a layer of east winds persisting during the entire day, as in the case of September 1, 1944, is by no means invariable. The time section has been analysed to show the separation of the easterly from the southwesterly winds in the lower levels, and the northwesterlies aloft.

The delineation of a sea breeze and a land breeze is not always easy, inasmuch as there is a transition zone between the sea breeze, land breeze, and upper flow, characterized by a gradual turning of wind with height. As an example, at 15h00m PWT September 1, 1944 (see Fig. 6), the east-southeast winds at 2000 feet backed gradually to northwest at 8000 feet. It is clear that the easterly winds represented the land breeze while the northwest or west-northwest winds predominating aloft throughout the day were part of the general circulation.
The wind direction in the transition layer can be considered the vector resultant of an easterly component, the land-breeze effect, and a northwest wind vector representing upper flow. The increase of the northwest effect with height and the decrease of easterly component would produce the observed backing with height.

For the purposes of the wind-time sections in this paper the division lines between land wind and upper flow have been drawn to include winds from south-southeast to north-northeast in the...
land breeze zone, and north winds in the upper flow. This is equivalent to saying that the vector component of upper flow is considered to predominate over the easterly component when the wind has backed to north.

The sea breeze, which is ordinarily southwest, often veers into a northwest flow at higher levels in the same manner that the easterly winds back through north to northwest. In the present analysis of time sections, the solid lines defining the sea breeze at UCLA include winds from west to south-southwest. Where the transition was not distinct or where data were insufficient to place it with accuracy, dashed lines have been used.

In order to demonstrate the variety of patterns experienced, Figures 7a and 7b provide a time section for 24 consecutive days at UCLA. A relatively small number of wind arrows are plotted on these diagrams, but they have been chosen to represent the general condition of flow at that level and time. On most days the number of pibals available for the construction of the Figures was comparable to that shown in Figure 6.

The patterns in Figures 7a and 7b demonstrate a number of facts. Easterly winds representing the land breeze occur on every day except in unusual instances of very strong north or north-west winds. On some days the land wind persists aloft over the sea breeze during the whole day.

In some cases the sea breeze begins in the level just above the ground before it is discernible at the surface. This is presumably the result of friction, and has been noted in other regions [NAVAL METEOROLOGICAL BRANCH (BRITISH), HYDROGRAPHIC DEPARTMENT, 1944]. In very few cases does the land breeze begin aloft before it is seen at the surface. This results from the drainage mountain wind, which begins somewhat sooner than the more general land breeze and merges indistinguishably with it.

Also, in nearly every case, the sea breeze persists aloft above the land breeze. Not as often, but in many cases, the land wind persists aloft for a time after the sea breeze has begun at the surface.

From a study of these wind observations in conjunction with the corresponding weather charts, it appears that there are three layers of wind patterns below the general upper flow. The lowest and most local is the valley-mountain wind regime, controlled by the details of topography. The next is the sea-land breeze pattern, also characterized by a diurnal cycle, activated by the differential heating of air over land and sea. This regime is confined to the coastal plain and the ocean area immediately adjacent to the coast. Just above the sea-land breeze is the third wind pattern, controlled by the thermal low pressure over the southwestern deserts, and not confined to the coastal plain. On particular days the thermal low is definitely in evidence at 5000 feet not only during the daytime but for a portion of the night. It has a diurnal cycle of changing intensity, but at times exists at 5000 feet for a period of more than one day. The diurnal wind regime produced has been called a continent-ocean wind [UNITED STATES ARMY AIR FORCES, WEATHER DIVISION HEADQUARTERS, 1945b]. At those times during which a low-pressure area over the land persists, the on-shore flow in the layer just above the sea breeze approaches the character of a true monsoon.

The general circulation aloft, which is little affected by the local heating of the coast line or the desert thermal low, prevails above the monsoonal winds.

There is ordinarily a gradual merging of each of these patterns into the one above it, but on certain days the effect of each layer can be definitely seen. If the inversion is wiped out along the mountain slopes by surface heating, resulting convection on such days may produce two or more layers of smoke over the Los Angeles basin.

Average diurnal wind regime at UCLA---In order to integrate the surface- and upper-air observations the average diurnal wind regime in height and time has been represented in Figure 8 for three periods, roughly representing summer, fall, and winter seasons. These diagrams have been constructed to show the predominant wind direction and force for each 500-foot level and for as many individual hours during the day as the data allowed.

A 45-degree sector of direction containing the largest number of cases determined the predominant direction and is represented by the arrow. Each wind arrow is labeled to show the total number of observations at that time and level, and the number of observations in which the wind was from the direction shown by the arrow. When another direction was also noted in a large number of observations, a secondary dotted arrow is shown and labeled with the number of cases.
Fig. 7a--Wind-time section, UCLA, August 18-29, 1944
Fig. 7b—Wind-time section, UCLA, August 30 - September 10, 1944
Fig. 8--Predominant daily winds at UCLA
The average time sections have been analyzed in the same manner described previously. On the basis of the analysis comparisons between seasons may be drawn.

The three seasons have several characteristics in common. In the lowest 2000 feet there is a cyclic change from southwest in the afternoon to easterly in the evening and early morning. The southwest sea breeze had the longest duration in summer and the shortest in winter. The height of the sea breeze apparently exceeds 5000 feet in summer, appears to be about 5000 feet in the fall, and 3500 feet in the winter.

The easterlies constitute a greater duration of time in the lower layers than does the sea breeze and apparently extend to greater height than the sea breeze.

Inasmuch as the average height of the base of the temperature inversion at UCLA was about 1800 feet msl, the average wind time sections indicate that the height of the diurnal wind fluctuation is not limited by the inversion. It has been suggested [UNITED STATES ARMY AIR FORCES, WEATHER DIVISION HEADQUARTERS, 1948] that "an inversion of temperature and a decrease of relative humidity characterize the vertical extent of the land breeze," In the Los Angeles basin the diurnal wind changes attributed to the sea-land breeze regime definitely occur considerably above the prominent subsidence inversion.

The maximum velocities of the sea breeze occurred at 1000 to 1500 feet msl at UCLA, the elevation of which is 500 feet.

As noted from the time sections for individual days, the averages show that the land breeze is still blowing aloft at the time the sea breeze begins in the lower layers. The persistence of the sea breeze above the initial land wind is, however, much less distinct.

Areal wind patterns on an individual day--On September 5-6, 1944, the authors enlisted the cooperation of six Army weather stations in the Los Angeles area to observe slow ascent pibals at time intervals of 1-1/2 hours for a 24-hour period. The day chosen was at the end of a stratus cycle and the beginning of a foehn condition caused by the development of high pressures above the Great Basin (see Fig. 4). There were no fronts in the western United States during the period. At 10,000 feet the winds over the area were controlled by the high center in Idaho. At 1500 PWT, September 5, 1944, the thermal low present over the Mojave Desert was well marked at 5000 feet but the resulting west winds at that level were overcome by east winds of the anticyclone at about 0900 PWT on the 6th.

To provide an easier synthesis of the geographic picture of the development of the local wind pattern, the cross-section of Figure 9 is presented. It represents a profile from the coast inland; each station is shown approximately at its perpendicular distance from the coast. Van Nuys (DVN) lies in the San Fernando Valley, which experiences a sea breeze flowing in from the passes to the southeast as explained in the discussion of Figure 5. The distance along the trajectory of the sea breeze was used to place DVN and RV on the profile.

At 1800 PWT on September 5, 1944, all stations shown on the profile were experiencing westerly sea breeze. The upper portion of Figure 9 shows the development of the land wind from 1900 PWT to 0100 PWT. At 1900 PWT the land wind shows only as a shallow layer of easterly winds near the surface at UCLA, DVN, and DUA. At 2100 PWT easterlies occur from the surface up to 1500 feet at UCLA, DVN, and DUA, but westerlies are still occurring at Mines Field (LA) and at DOI. The development eastward of the land wind at the surface as shown by the profiles was checked with the surface winds at stations lying near the cross-section line.

The lower set of profiles in Figure 9 shows a uniformly developing layer of easterly winds, represented by the area below the profile lines of 0300 PWT and 0600 PWT. It will be noted that the land wind began near the coast and worked inland, increasing in depth fastest over the inland stations. The first pibal showing any land wind above Mines Field (LA) was at 0300 PWT. This late beginning of the east winds at LA is typical of the average surface wind regime shown in Figure 5.

At 0900 PWT the land wind is developed at all stations, but LA shows a sea breeze up to 1100 feet and a layer of easterlies between 1100 and 2700 feet. By 1300 PWT westerly sea wind occurs at all stations except the most inland, TUT. Due to the foehn conditions the usual westerly flow through San Gorgonio Pass has been reversed. A thin layer of east winds can be seen at this hour 1500 feet above LA and UCLA and at 3000 feet above DVN, while a considerable thickness of easterlies is still present at DUA (2000 to 4200 feet), and DOI (3500 to above 5000 feet). The fact that the sea breeze at 1300 PWT is thicker at DVN than at DUA is probably explained by the fact that the two stations are not so close together geographically as the profile indicates.
Fig. 9--Profiles of land and sea winds at various hours, Los Angeles basin, September 5-6, 1944
Air pollution and visibility

Visibility is the regularly observed meteorological element most indicative of the amount of air pollution, though it is by no means a perfect index. It will be shown in this section how a knowledge of advection and convection processes can be applied to explain some of the variations of visibility and air pollution over Southern California stations.

Visibility, as determined in the hourly weather observations during the daylight hours, is the maximum distance at which a bulky dark object, such as a water tank, can be seen against a sky background. Night visibility references are usually lights selected to give visibility observations equivalent to those of daytime under the same atmospheric conditions. It is commonly noted that a dark object against a sky background in daytime does not disappear with distance by being blotted out with a darkening screen of intervening atmosphere. Instead, the disappearance is due to progressive brightening of the dark object from black to gray until it finally blends into the distant sky brightness. The paramount control of visibility is thus seen to be the amount of light scattered into the line of sight by small particles in the air, rather than the absorption of light from the object. Some absorption does occur, especially if many of the intervening particles are opaque solids, but this effect is ordinarily negligible in comparison with the glare produced by scattering of the sky light.

Particles which limit the visibility include all types of air pollution as well as naturally-occurring impurities and the air molecules themselves. For the purposes of this paper, all the particles may be classified as follows: (1) Air molecules--nitrogen, oxygen, argon, water vapor, carbon dioxide, and minor gases; (2) hygroscopic nuclei--including both natural materials such as sea salt, and artificial combustion products; and (3) non-hygroscopic particles--including artificial combustion products and natural dust.

The restrictions to visibility recognized in ordinary weather observations are fog, smoke, and haze. "Haze" is a particularly inclusive term. At most weather stations it is used to describe conditions of low visibility which do not appear to fall under the more easily identified conditions of fog or smoke [UNITED STATES DEPARTMENT OF COMMERCE, WEATHER BUREAU, 1941]. Being so vaguely defined, the word haze has been avoided in this paper.

"Smoke" is another word of somewhat variable meaning. British meteorologists apply it only to the non-hygroscopic combustion products. This is not in agreement with the definitions of the United States Weather Bureau, which include odor as a means of identification. Non-hygroscopic smoke particles are usually quite large and when present have pronounced effects on the visibility.

At most stations, however, the chief source of variation in the visibility lies in the hygroscopic nuclei. Thus by studying the visibility changes some insight into the number and characteristics of hygroscopic nuclei present may be obtained. Variation of the visibility is not necessarily associated with changes in the number of nuclei. Hygroscopic nuclei have the property of increasing in size as the relative humidity of the air increases toward 100 per cent. If the relative humidity reaches a certain degree of super-saturation (that is, over 100 per cent) the particles grow rapidly to the size of fog or cloud droplets. Until that critical relative humidity is reached the reduction of visibility is gradual, but it may nevertheless be appreciable.

Observed visibility-relative humidity relations--Figure 10 shows the marked difference between Santa Maria and the Los Angeles basic stations in the visibility-relative humidity relation. The Figure was prepared by determining the mean visibility for five per cent ranges of relative humidity increases below 85 per cent. Further studies to determine the effects of hygroscopic nuclei alone might eliminate such variations due to the presence of non-hygroscopic smoke or dust particles.

Diurnal variations--By comparing the diurnal changes in visibility and relative humidity at different stations the relative importance of air impurities and changes in their distribution become apparent. Figure 11a presents the average diurnal variation of visibility and relative
humidity for August 1944 at Santa Maria, UCLA, and Long Beach. While the diurnal change of relative humidity is much the same at all three stations, the variations of visibility show pronounced differences. Most of these may be explained by analysis of the factors acting at the different stations.

At Santa Maria there is a nearly inverse relation between the visibility and relative humidity, as can be seen in the Figure. The surface sea breeze ends at 22h00m PWT and a period of calms or light variable winds ensues, continuing through the night. The relative humidity increases slowly from 22h00m to 01h30m, and remains fairly constant thereafter until sunrise. The visibility, however, decreases rather rapidly from 22h00m to 01h30m. This is probably caused by a combination of the rising relative humidity and the cessation of smoke-free advection of the sea breeze, although it cannot be said from these data to what extent each contributes. From 01h30m
to sunrise the visibility also continues to decrease gradually, and since the relative humidity is essentially constant, this decrease may be due to the gradual accumulation of smoke.

At sunrise the relative humidity begins to drop and convection is initiated, but the visibility does not increase for another hour. Because the wind is calm, this lag may also be explained by accumulation of small amounts of smoke. The only effect of the onset of the sea breeze at 10h00m PWT seems to be a reduction in the rate of increase of visibility and in the rate of decrease of relative humidity.

Thus Santa Maria experiences a sea breeze of long duration each day and no appreciable land breeze at night. The diurnal variation of visibility is almost entirely explained by the diurnal change of relative humidity, although there is evidence of minor smoke accumulation during the calm portion of the night and early morning, which is later blown away by the sea breeze.

At UCLA a northerly land breeze begins at 22h00m PWT (see Fig. 5) and continues until 06h00m. During this time the relative humidity is nearly constant and the visibility drops, slowly until 03h30m, then rapidly. The decrease in visibility must be due to smoke brought in on the land breeze. Because of the lack of smoke sources to the north of UCLA, the northerly mountain wind during the night cannot account for this smoke advection. However, at the foot of the slope the north wind merges into a broad easterly current flowing toward the ocean. Since UCLA is located in the northwestern part of the city, these general east winds of the lower basin tend to cover visibility reference marks south of the station with smoke from the industrial section. The station itself may remain in relatively clear air of the northerly mountain breeze.
The land breeze stops at sunrise and the relative humidity falls rapidly. Calms or very light south-southeast winds are observed until 10h00m PWT. The visibility does not improve, however. The conclusion is that smoke or other impurities must be present and persist until 10h00m. These particles tend to accumulate in the lowest valleys during the night. In the calm period after sunrise convection currents continue to reduce the visibility by stirring the dense smoke of the lower terrain up to the elevation of the station.

This effect of convection is also shown in Figure 11b, prepared from hourly observations taken during January 1945. The visibility was observed separately in each of the six sectors indicated in the Figure. The nearby Santa Monica Mountains dominate the northwesterly half of the horizon and are practically free of smoke sources. The southeasterly sectors encompass the major smoke sources and low valleys into which smoke tends to settle at night. It is evident that the decrease in visibility shortly after sunrise is more pronounced in the direction of the low valleys. Some of this is, of course, the effect of smoke sources which operate only during the normal business hours each day, but convection is the primary factor in lifting the smoke to the station elevation.

After convection has lifted the smoke to the level of UCLA, continuation of the process tends to mix the smoke particles through a thicker layer. The mixture is thus diluted and the visibility tends to increase. Between 08h00m and 10h00m this effect, combined with the falling relative humidity, stops the fall of visibility.

At 10h00m PWT the sea breeze begins. The rate of decrease of relative humidity is diminished and the visibility begins to rise. This indicates that the primary effect of onset of the sea breeze is to raise the visibility by carrying away the impurities brought in by the land breeze during the night.

In summary, then, UCLA experiences a pronounced sea- and land-breeze regime. The diurnal variation of visibility is thrown out of its usual relationship with the relative humidity by the presence of appreciable amounts of impurities advected by the land breeze, and also by the diurnal change of convection which affects the stratification of the pollution.

A detailed analysis of the visibility regime at Long Beach (HB) will not be made. From an inspection of the Figure it is apparent that HB has a regime between that of TCM and UCLA. The presence of large amounts of smoke reduces the dependence of visibility on the relative humidity. The low elevation of the station, however, reduces the effect of stratification of the air, since the station is less often completely above the smoke layer. Irregular sources of the impurities advected over the station are indicated by the frequent breaks in the visibility curve.

Conclusions--Certain variations in the visibilities recorded at weather stations in the Los Angeles area indicate the presence of air pollution and its vertical and horizontal distribution. Special observations, supplementing the regular weather records, show the important part played by the changing height of the temperature inversion and by the diurnal wind structure in distributing the contaminated air. It is concluded that a considerable amount of information regarding the type and distribution of air pollution over the city may be obtained by a thorough study of available climatological records, possibly supplemented by a few additional observations of the controlling features. Such studies can yield long-range estimates of the vulnerability of certain locations in the city to low visibility or smoke nuisance. These are of special interest in planning airports and zoning ordinances, and should be considered in all phases of community planning.

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California State Bridge Department (C. G. P. B.),
Los Angeles, California

Pineapple Research Institute of Hawaii (L. B. L.),
Honolulu, Territory of Hawaii

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