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U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Environmental Research Laboratories

Relative Dispersion Within the Los Angeles Basin as Estimated From Tetroon Triads

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SILVER SPRING,
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ENVIRONMENTAL RESEARCH LABORATORIES

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DEPARTMENT OF COMMERCE * UNITED STATES OF AMERICA *

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UNITED STATES
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Frederick B. Dent, Secretary

NATIONAL OCEANIC AND
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Robert M. White, Administrator

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Wilmot N. Hess, Director

PREFACE

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ABSTRACT

The Los Angeles Reactive Pollutant Project (LARPP) in the autumn of 1973 involved helicopter sampling of a volume of air "tagged" by means of three constant volume balloons (tetroons) released simultaneously from the same point on the ground. Based on radar tracking of 35 tetroon triads at a mean height 350 meters above sea level, this paper considers the variation of lateral and longitudinal standard deviation of tetroon position with travel time and distance. In the average, the median lateral standard deviation varies from 90 meters after 15 minutes to 800 meters after 120 minutes, and from 140 meters at 2 km to 1000 meters at 20 km, but there is more than a factor of two difference associated with gross divisions according to time of day, atmospheric stability, and turbulence intensity. As expected, interaction with the sea breeze front increases the dispersion by at least a factor of two, but there is evidence of horizontal convergence prior to the sea breeze reversal. The derived relative dispersion in the Los Angeles Basin is compared with results obtained by other investigators in other locales, and it is shown that the dispersion rate within the Basin is frequently anomalously small, particularly with respect to travel time.

1. INTRODUCTION

The Los Angeles Reactive Pollutant Project (LARPP) was carried out in September, October, and November of 1973. The main purpose of the experiment was to measure the change in pollutant concentration following a given volume of air (Lagrangian approach) rather than at a fixed point (Eulerian approach), as done previously. Towards this end, triads of constant volume balloons (tetroons) were released simultaneously in order to "tag" a particular volume of air. The tetroons, flying at a mean height of about 350 meters MSL, were followed by helicopters which did the air sampling.

This paper considers only the tetroon aspect of the experiment, and in particular, the estimate of relative dispersion obtained from the spreading of the three tetroons making up each triad. The rate of dispersion is compared with that obtained from bulk tracer experiments in other locations, and is also considered as a function of time of day, atmospheric stability, and turbulence intensity. So far as is known, this experiment represents the first direct estimate of relative dispersion within the Los Angeles Basin over relatively large space and time intervals.

2. PROCEDURES

The tetroons, with transponders attached, were tracked by an M-33 radar from the Air Resources Laboratories Field Research Office, National Reactor Testing Station (NRTS), Idaho Falls, Idaho. A second M-33 radar from the NRTS was used to track and vector the helicopters engaged in air sampling. The transponder frequencies for each tetroon triad were set at approximately 403 megahertz, with enough frequency separation to permit positive balloon identification. Tetroon positions were obtained every three minutes. A computer in the radar served to translate (in real time) the range and azimuth and elevation angles of the tetroons into east-west and north-south grid coordinates, as well as height, for the purpose of vectoring the helicopters.

The two M-33 radars were positioned on Flint Peak (elevation 580 m) 3 km west of the Pasadena Rose Bowl. From this elevated site the radar could track tetroons all the way from Santa Monica in the west to San Bernardino in the east, the latter city being nearly as far as the radar could position because of the pulse repetition rate (limiting tracking range 100 km). Frequently, however, the tetroons were lost to radar view in the region of the Puente Hills, and these hills also served as very efficient tetroon snatchers. Only occasionally did a tetroon triad successfully pass over these hills into the San Gabriel Valley to the east.

Some compromise was required with respect to the choice of tetroon float level. It was desirable that the tetroons be as close to the ground as possible without snagging power lines, etc., and if the flights had been confined to the Los Angeles Basin itself, a mean float level near 200 m MSL would have been satisfactory. However, since an important aspect of LARPP was the question of the source of air reaching the Riverside-San Bernardino area (height approximately 300 m MSL) during the afternoon, the tetroons were set to float about 350 m above sea level. Table 1 gives the date and time of the experiments under consideration as well as the mean MSL height of the three tetroons making up each triad. The wind speed is an average based on the speeds derived from the three tetroons of the triad.

Table 1. Experiment listing for tetroon-triads tracked for at least 1 hour during the autumn of 1973. "Downtown" refers to downtown Los Angeles.

Experiment	Date	Launch Site	Launch Time (local)	Tracking duration (hours)	Wind Speed (ms^{-1})	Tetroon MSL heights (meters)
1	9-4	Redondo	1200	2½	4.0	480, 470, 440
5	9-18	Downtown	1030	2	1.4	390, 370, 390
8	9-24	Downey	0900	4½	1.9	480, 450, 460
9	9-25	Long Beach	10000	4	2.1	560, 440, 410
10	9-27	Downtown	0900	2½	2.5	170, 260, 250
11	9-28	Downtown	0830	4	2.8	250, 250, 240
12	10-1	Downey	0830	4½	1.5	370, 410, 490
13	10-2	Pomona	1400	1½	3.2	720, 850, 790
14	10-4	Downtown	1930	2½	1.1	300, 310, 340
15	10-5	Downey	1200	2	2.6	350, 300, 280
16	10-10	Downey	0830	1	1.7	280, 250, 260
17	10-11	Downtown	0800	4½	2.3	420, 290, 390
18	10-12	Downtown	0930	3½	2.4	510, 390, 420
19	10-15	Downey	0930	3½	1.4	390, 350, 380
20A	10-16	Downtown	0930	2	3.2	440, 460, 450
20B	10-16	Downtown	1300	1	1.9	420, 280, 290
21	10-17	Downtown	0930	4½	2.6	390, 360, 360
22A	10-18	Downey	0900	2½	2.9	320, 260, 360
22B	10-18	Downey	1130	2	2.0	290, 280, 340
23	10-24	Downey	0900	2½	0.8	360, 260, 290
24	10-25	Downtown	0830	4	1.4	370, 300, 280
25	10-26	Downtown	1000	6	1.9	340, 390, 320
26	10-27	Downtown	0900	3	2.7	360, 360, 370
27	10-28	Downey	1100	2½	2.8	550, 380, 400
28	10-29	Downey	0830	2	2.1	190, 220, 230
29	10-30	Downey	0830	2½	1.5	250, 250, 260
30	10-31	Downtown	0830	1½	3.1	310, 350, 350
31A	11-1	Downtown	0730	2½	2.8	270, 270, 280
31B	11-1	Downtown	1130	1½	3.0	400, 390, 530
32	11-2	Downey	1200	1½	5.1	360, 360, 350
33	11-5	Downey	0700	6	1.0	310, 340, 310
34A	11-6	Downtown	0730	3	1.9	280, 280, 270
34B	11-6	Downtown	1100	2	2.1	390, 450, 410
35	11-7	Downtown	0830	2½	1.2	280, 290, 330

3. TRAJECTORIES OF TETROON TRIADS

Figure 1 represents the trajectories of tetroon triads for those cases when the transition from land to sea breeze resulted in a quite abrupt change in trajectory direction toward the north. In this, and subsequent diagrams, the triangle vertices indicate the locations of the three simultaneously released tetroons at one-half hour intervals, while the numbers along the trajectories indicate the time after release in hours (triads tracked for less than one hour are not included). The dashed line represents a subjective estimate of the mean path of the triad. The "downtown" launch site was located at 7th and Alameda, or just east of the high-rise section of downtown Los Angeles.

It can be seen from figure 1 that the tetroon dispersion was greatly increased by encounter with the sea breeze from the west. In experiment 11 the increase was noted mainly in the lateral (cross-stream) direction whereas in experiment 24 it was noted mainly in the longitudinal (along-stream) direction. On experiments 12 and 18 both components exhibited a sharp increase. The effect of the sea breeze on dispersion will be considered quantitatively in section 6. In experiment 34A the tetroons were again located near the downtown launch site seven hours after release, but a continuous track was not possible because of new tetroon launches.

The top diagram of figure 2 shows that on experiment 11 the tetroon height doubled due to the ascending motion associated with the sea breeze convergence zone. At this time and in this general area there was a temperature inversion between the surface and a height of 500 m. A similar tetroon height change was noted on experiment 17. The second diagram from the top in figure 2 shows the pronounced vertical tetroon oscillations

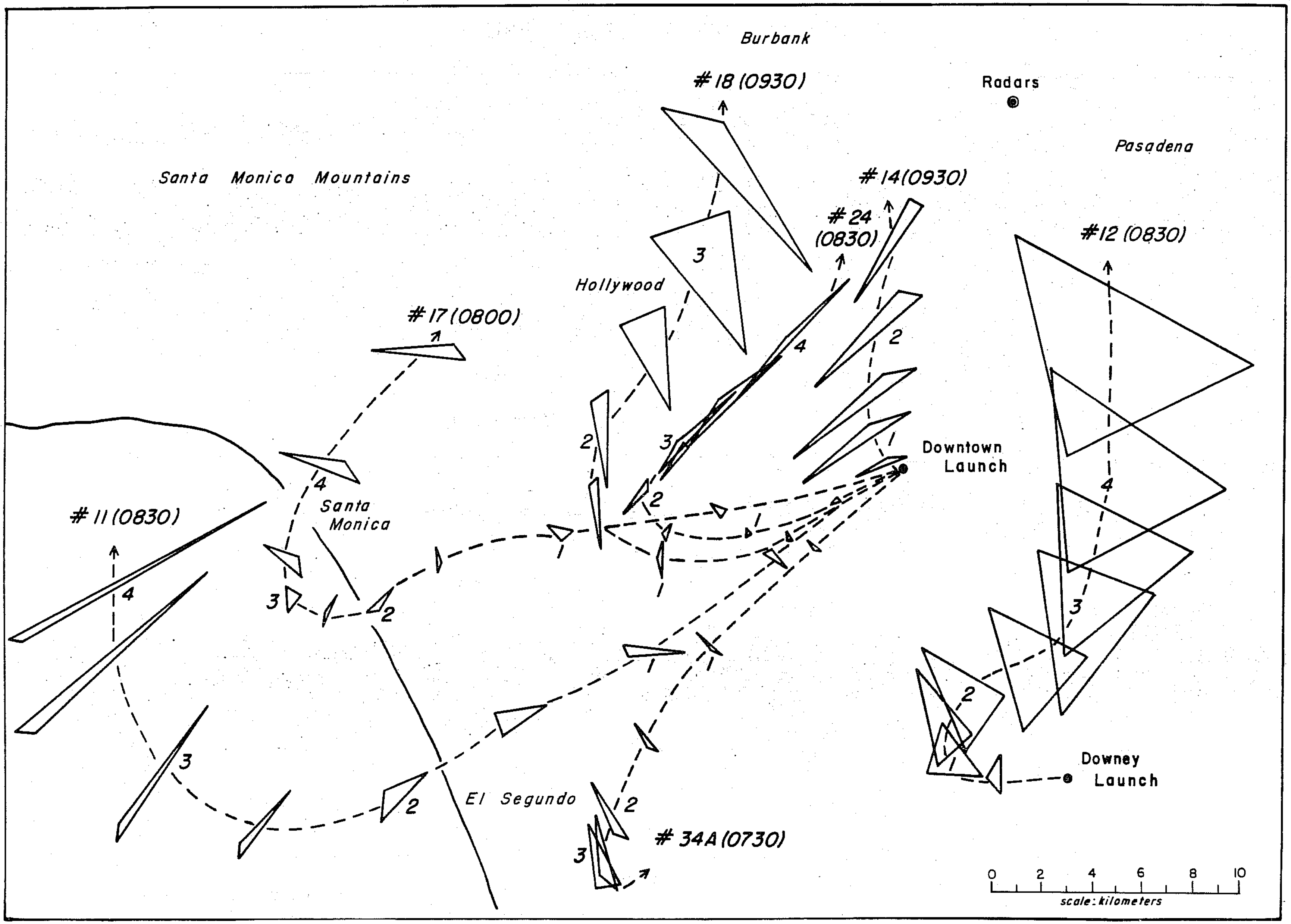

Figure 1. Dispersion of tetroon triads within the Los Angeles Basin in cases of trajectory turnings toward the north associated with the transistion from land breeze to sea breeze. The triangle vertices indicate the location of the three simultaneously released tetroons at one-half hour intervals, with the numbers along the trajectory signifying the hours since release.

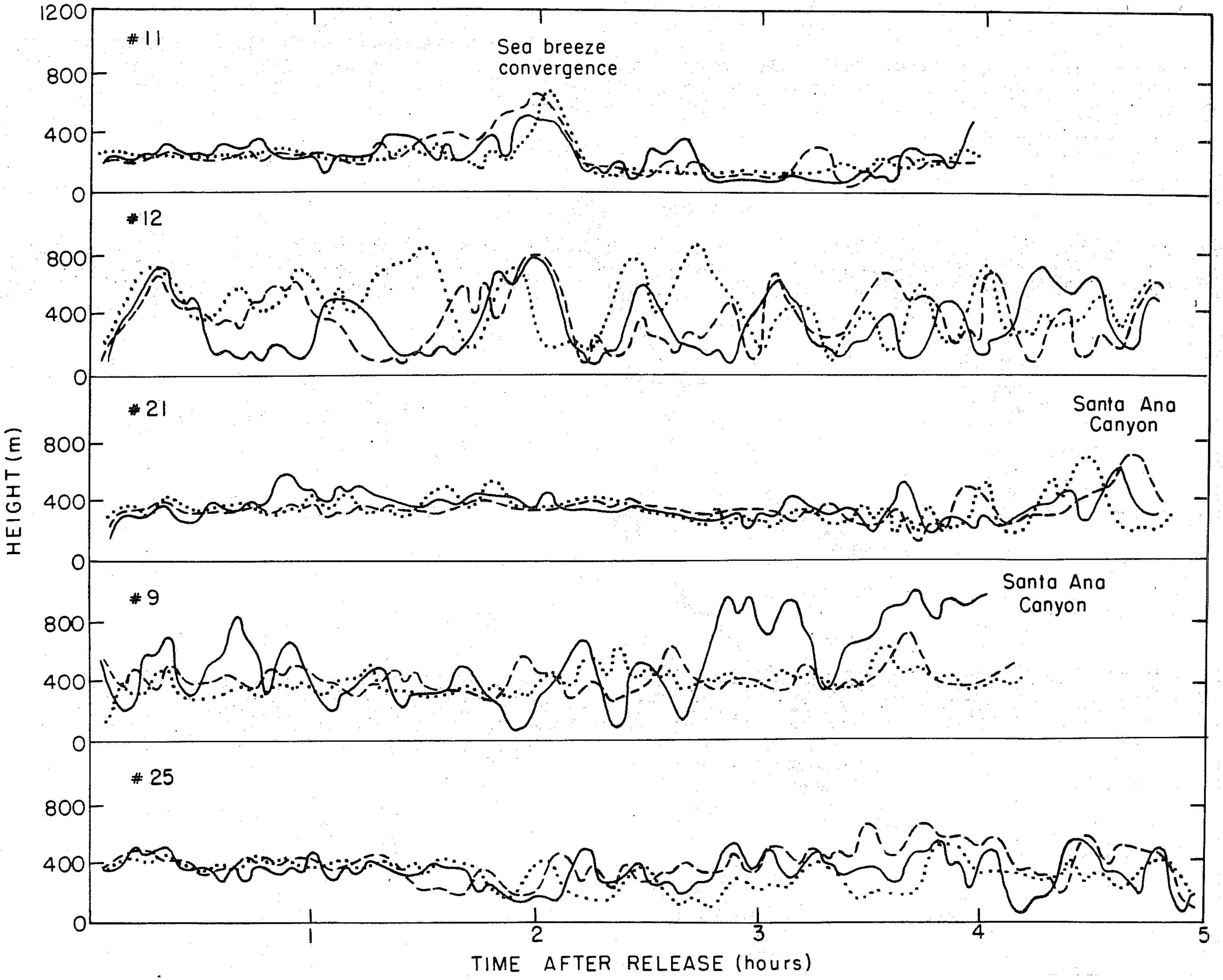

Figure 2. Tetroon-triad height (above sea level) traces for experiments 9, 11, 12, 21, and 25.

associated with the large dispersion on experiment 12, where there was nearly a dry adiabatic lapse rate between the surface and 500 m.

Figure 3 presents examples of tetroon triads in cases of trajectory turnings toward the east. The increase in tetroon dispersion at the time of these sea breeze reversals is not nearly so pronounced as in figure 1, perhpas because most of the reversals occurred further to the east where the sea breeze "front" is not so strong. In this connection, the middle diagram of figure 2 shows that there was no appreciable change in tetroon height, i.e., no appreciable vertical air motion, at the time (two hours after release) of trajectory turning toward the east on experiment 21.

In experiment 21 the triad was lost to radar view while passing eastward through Santa Ana Canyon (east of Anaheim) at a speed of about 5 ms^{-1} (there is a 540 m peak just to the north of the canyon). While the tetroons were never again picked up, if this speed were maintained the tetroons would have been in the Riverside-San Bernardino area (40-50 km east-northeast of Anaheim) in two to three hours, or between 1600 and 1700 local time. It is believed this is one avenue by which pollutants from downtown Los Angeles may reach the Riverside-San Bernardino area during the same day, particularly in stable conditions when the air is funneled rapidly through the canyon. It is thus of interest that the two surviving tetroons of experiment 10 also moved into Santa Ana Canyon, and that in experiment 22A, while the triad had to be abandoned because of new tetroon launchings, the triad was later picked up moving northeastward in the region between Santa Ana and Anaheim, suggesting that also these tetroons may have passed eastward through Santa Ana Canyon. This whole matter will be considered in detail in another paper.

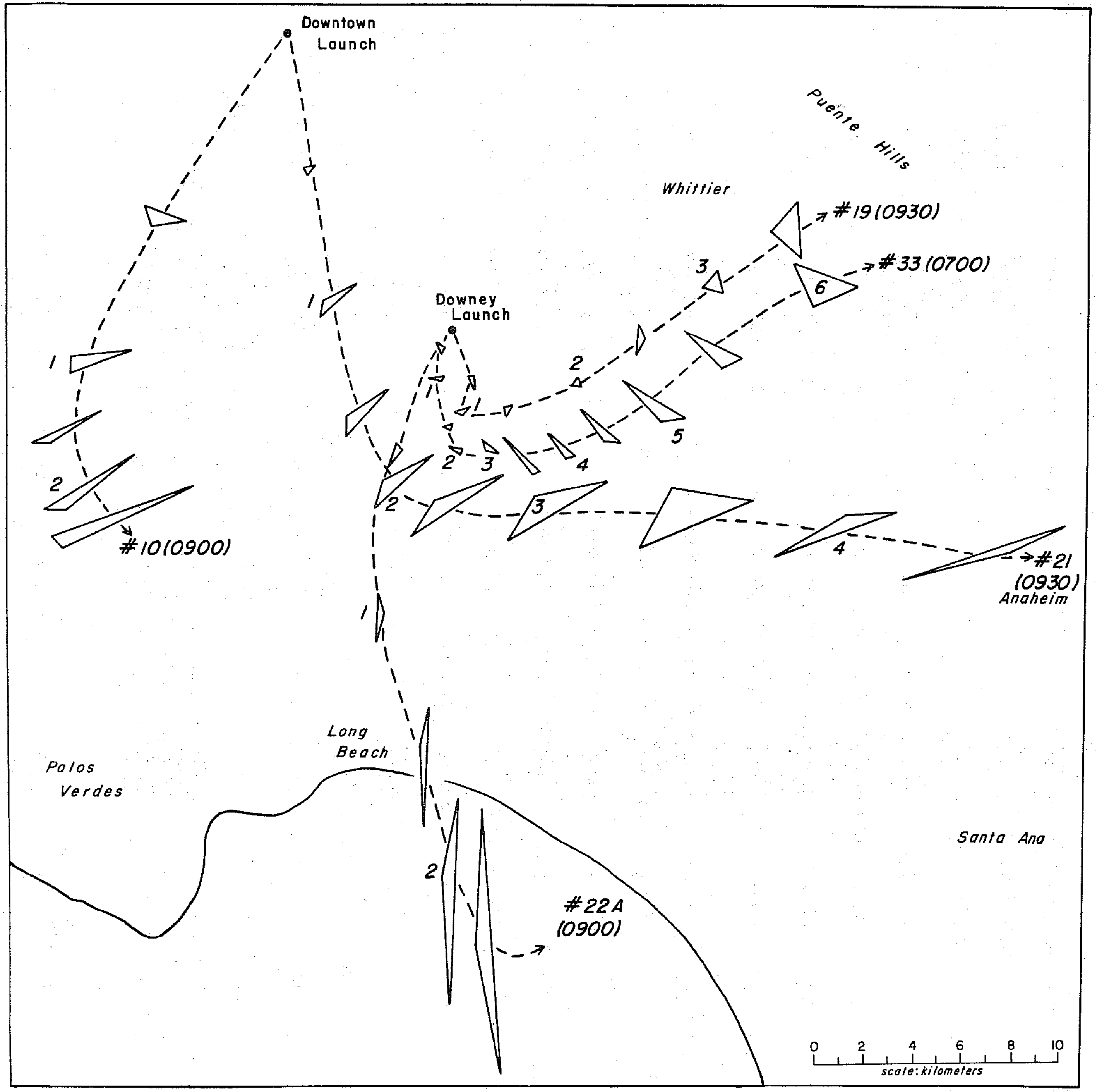

Figure 3. Dispersion of tetroon triads in cases of trajectory turnings toward the east associated with the transition from land breeze to sea breeze. Otherwise, see figure 1 legend.

Experiment 22A is also of interest in showing how the sea breeze turning extended seaward in time, the northernmost tetroon undergoing a turn toward the east considerably before the southernmost tetroon. Thus, at least in this case (and perhaps in general in this area), one cannot speak of an advancing sea breeze front, but rather the heating of the south-facing mountain slopes induces air further and further to the south to move northeastward.

Figure 4 illustrates the dispersion of tetroon triads under conditions of relatively straight flow (in this figure, and particularly in fig. 5, the triangles have occasionally been exaggerated in size in order that they be visible). It is seen that, in the absence of an appreciable gradient flow, late morning releases generally move northward due to the heating of the south-facing mountain slopes, and it is this northward transport of polluted air that brings about the severe smog in places such as Pasadena and Glendale. By afternoon, the westerly sea breeze generally becomes dominant, as shown by the eastward movement of the tetroons in experiment 1. The tetroon dispersion is much greater in the latter case than in the case of northward flow, suggesting the greater dispersion associated with the sea breeze regime.

Figure 5 presents a potpourri of those tetroon triads with relatively straight paths not considered previously. Note the extremely small dispersion on experiments 29 and 30, and the decrease in triad size at one and one-half hours on experiment 27. We shall see in section 6 that there frequently is a decrease in triad size also before a sea breeze reversal. The triad released from Pomona in the afternoon moved east-northeastward toward Cajon Pass (north of San Bernardino), but was lost to radar view

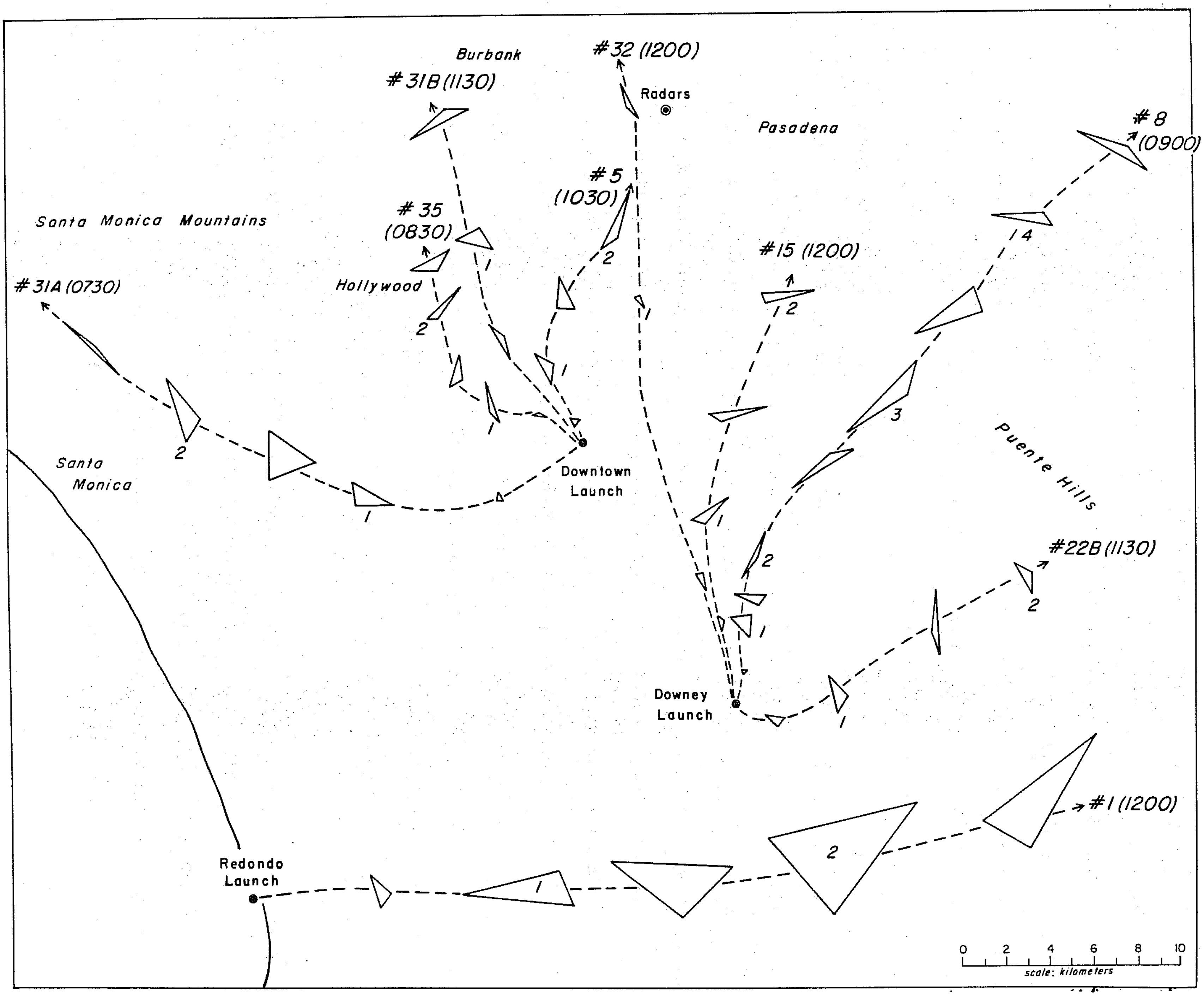

Figure 4. Dispersion of tetroon triads under conditions of relatively straight upslope flow in the late morning. Otherwise, see figure 1 legend.

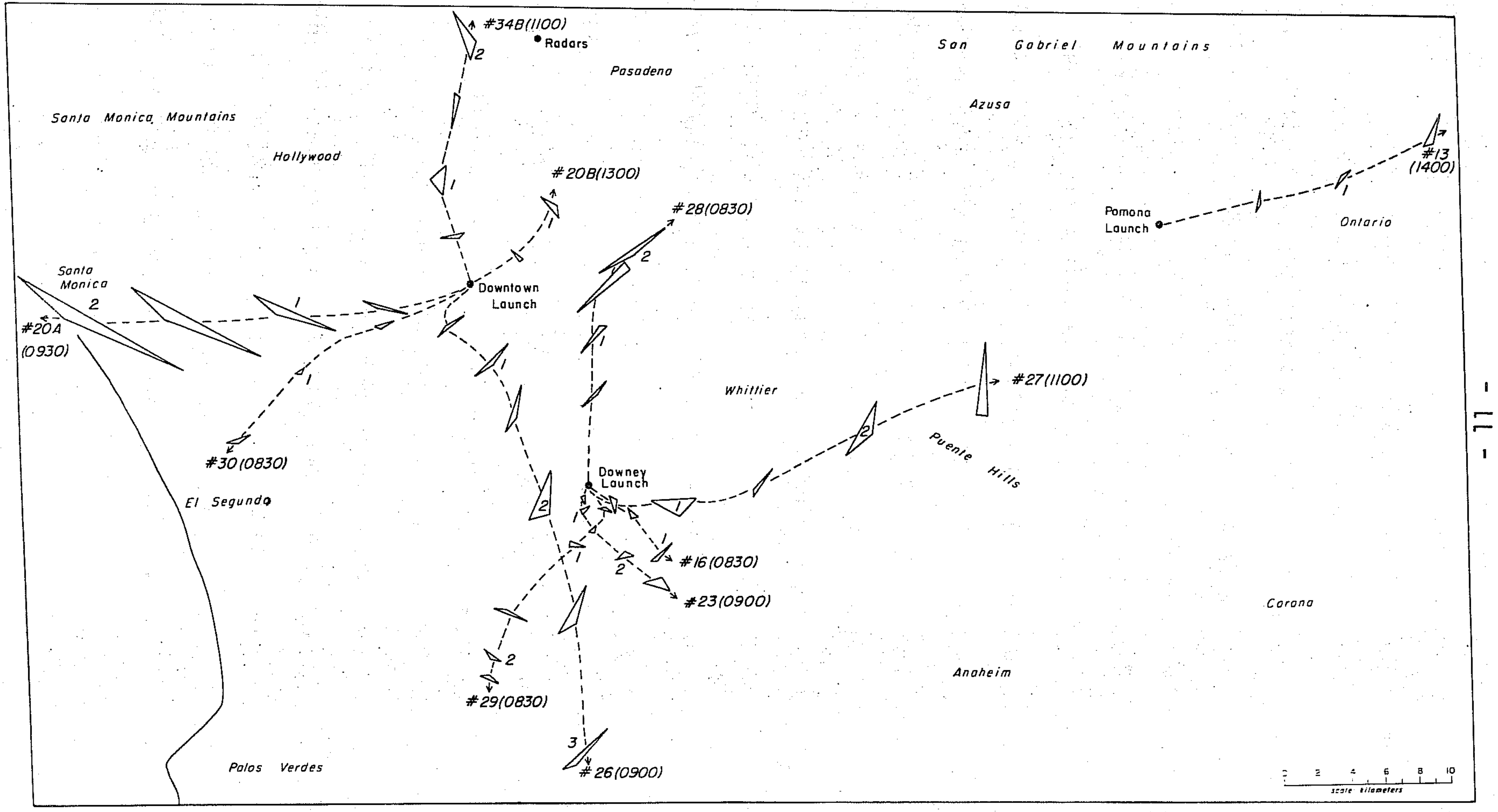

Figure 5. More examples of the dispersion of tetroon triads under conditions of relatively straight flow. Otherwise, see figure 1 legend.

behind mountains to the northeast of Ontario. Becasue of the northward trend, it does not appear likely that polluted air from downtown Los Angeles reaches the Riverside-San Bernardino area by this avenue.

The above diagrams show that in the great majority of cases the simultaneously released tetroons remain relatively close together, i.e., any one of the tetroon trajectories would have sufficed to give a good estimate of the actual air trajectory. On two experiments this was not so, as shown in figure 6. In experiment 25 one of the tetroons did not turn to the northeast nearly as quickly as the other two, and thus the triad approached the Puente Hills on a broad front. The trajectory difference is more spectacular in experiment 9, where two of the tetroons moved southeastward along the coast while the other tetroons moved eastward into Santa Ana Canyon.

The two bottom diagrams of figure 2 illustrate the three tetroon heights on each of these experiments. On experiment 9 the solid line represents the height of the "anomalous" tetroon which passed eastward through Santa Ana Canyon. There is no doubt that during the first hour after release, when the separation was becoming appreciable, the height of the Santa Ana flight was about 100 m greater than that of the other two (though this was not so later on), and with more evidence of convection. Thus, it may be that this flight passed through a weak inversion into a more unstable layer of slightly different wind direction. The greater height of this tetroon towards the end of the flight is the result of its passage through Santa Ana Canyon.

On experiment 25 the dotted line represents the "anomalous" tetroon which remained further south. At the time of most rapid separation (about

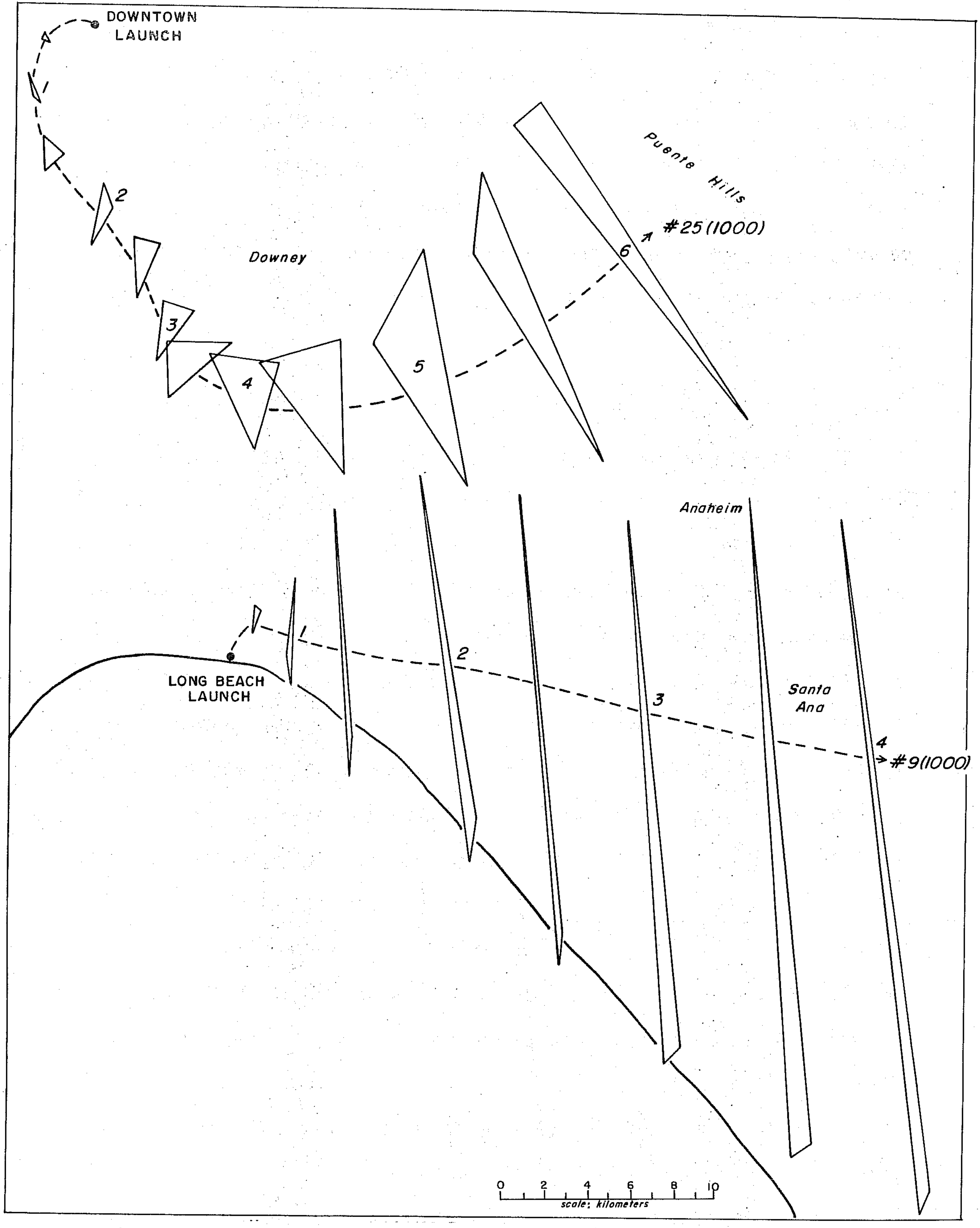

Figure 6. The two tetroon triads exhibiting the greatest dispersion. Otherwise, see figure 1 legend.

four hours after release) there is little evidence of a mean difference in tetroon height, although earlier this tetroon was flying about 100 m lower than the other two. Thus, we probably have here an example of the difficulties that can occur in attempting to specify trajectories, in that air parcels close together may, on occasion, end up far apart. For purposes of the subsequent statistical analysis, neither of the above experiments has been eliminated from the sample.

4. LATERAL AND LONGITUDINAL DISPERSION OF TETROON TRIADS

The lateral and longitudinal standard deviation of tetroon position for each triad was determined at 15 minute intervals by drawing perpendiculars from the balloon locations to the straight line joining the triad centroid one-half hour earlier and one-half hour later (thereby obtaining, by the usual root mean square calculations, the longitudinal standard deviation of position), and by drawing of perpendiculars from the balloon locations to a line normal to this connecting line (thereby obtaining the lateral standard deviation of position). Because of the limited accuracy of radar positioning, calculations of standard deviation were made only to the nearest 10 m. Accordingly, the basic data for the subsequent analysis consist of lateral and longitudinal standard deviations of position at 15-minute intervals for the 35 experiments for which the tetroon triad was positioned at least 30 minutes. Of course, due to loss of balloon members of the triad, the number of experiments decreases with increase in travel time beyond 30 minutes.

Before discussion of the relative dispersion values obtained, possible sources of bias in the technique should be considered. First of all, while the tetroons were released simultaneously only a few meters apart on the ground, by the time they reached float altitude (typically 250-300 m above ground) they frequently were an appreciable distance apart due to varying ascent rates and the effect of varying wind shear between surface and float level. Thus, at float level we are not really starting with a point source, and the subsequent standard deviations are somewhat too large because of this. A more serious bias arises from the fact that the tetroons cannot be placed at exactly the same height, and thus the derived relative dispersion is increased because of the effect of wind shear in the vertical (see table 1 for mean tetroon height differences). These effects are counterbalanced to an unknown extent because of the tendency for the tetroon to return to an equilibrium float level, almost ensuring that the vertical oscillations of the tetroon are smaller than that of the surrounding air. In general, one would anticipate that the actual dispersion is usually being overestimated through use of the tetroons, but less so in unstable than in stable conditions. This may partly explain why the variation of relative dispersion with stability (section 5) is perhaps not as pronounced as expected.

Figure 7 shows the cumulative percentage of cases for which the lateral standard deviation of position (left) and longitudinal standard deviation of position (right) was less than the abscissa value for given travel times (top) and travel distances (bottom). Since in this paper we are dealing with the real world, all 35 experiments are included in the statistics, including the two "maverick" experiments of figure 6. The intersection of the curves in the four diagrams with horizontal lines at cumulative percentages of 16, 50 and 84% yields the median value and the one standard deviation (1σ) value. Subsequent diagrams are based on these

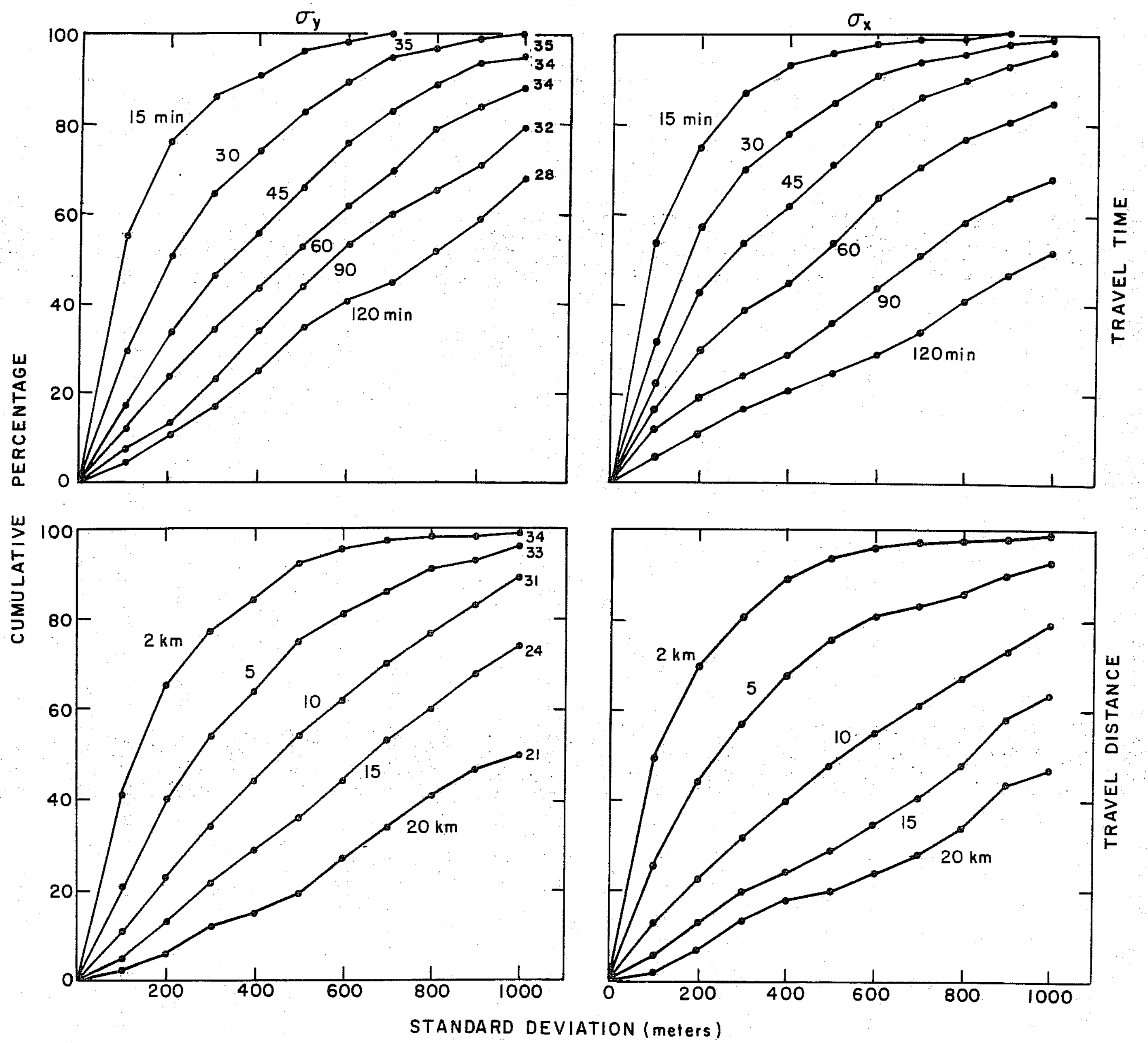

Figure 7. Cumulative percentage frequency of lateral (left) and longitudinal (right) standard deviations of position less than the abscissa value for given tetroon-triad travel times (top) and travel distances (bottom). The number of tetroon triads on which the statistics are based is indicated at center.

values values obtained in a similar manner. Note that because of the few, very large dispersion values (fig. 6), the median is probably a more representative estimate of central tendency than the average.

The left hand diagram of figure 8 shows the derived variation of lateral (dots) and longitudinal (circles) standard deviation with travel time. The vertical bars embrace 68% of the observations. Given the manner in which we have defined lateral and longitudinal, there is little difference between the two, i.e., the diffusion is horizontally isotropic. Both standard deviations increase approximately as the 1.1 power of time. Before too much importance is attached to the finding of a power greater than one, it should be remembered that the longest tetroon flights are those that involve a sea-breeze reversal, and we have already seen that the dispersion on these flights is anomalously large. The horizontal diffusivity K, obtained from the expression $\sigma^2=2Kt$, increases with travel time from a value of $5x10^4cm^2s^{-1}$ at 15 minutes to nearly $10^6cm^2s^{-1}$ at two hours.

The right hand diagram of figure 8 presents the comparison between the variation of median lateral standard deviation (and 1σ limits) with travel time in the Los Angeles Basin, and the mean (HM) and upper (HU) and lower (HL) bounds of lateral dispersion estimated by Hage (1964) from a variety of experiments. Heffter's (1965) synthesis yielded results similar to those of Hage, and Bauer (1974) has summarized these and more recent findings using Hage's apparently representative estimates as a basis for comparison. Some caution is required when comparing with these other results because the tetroon dispersion is obtained at a height 100-300 meters above the ground, while most other relative diffusion experiments are carried out

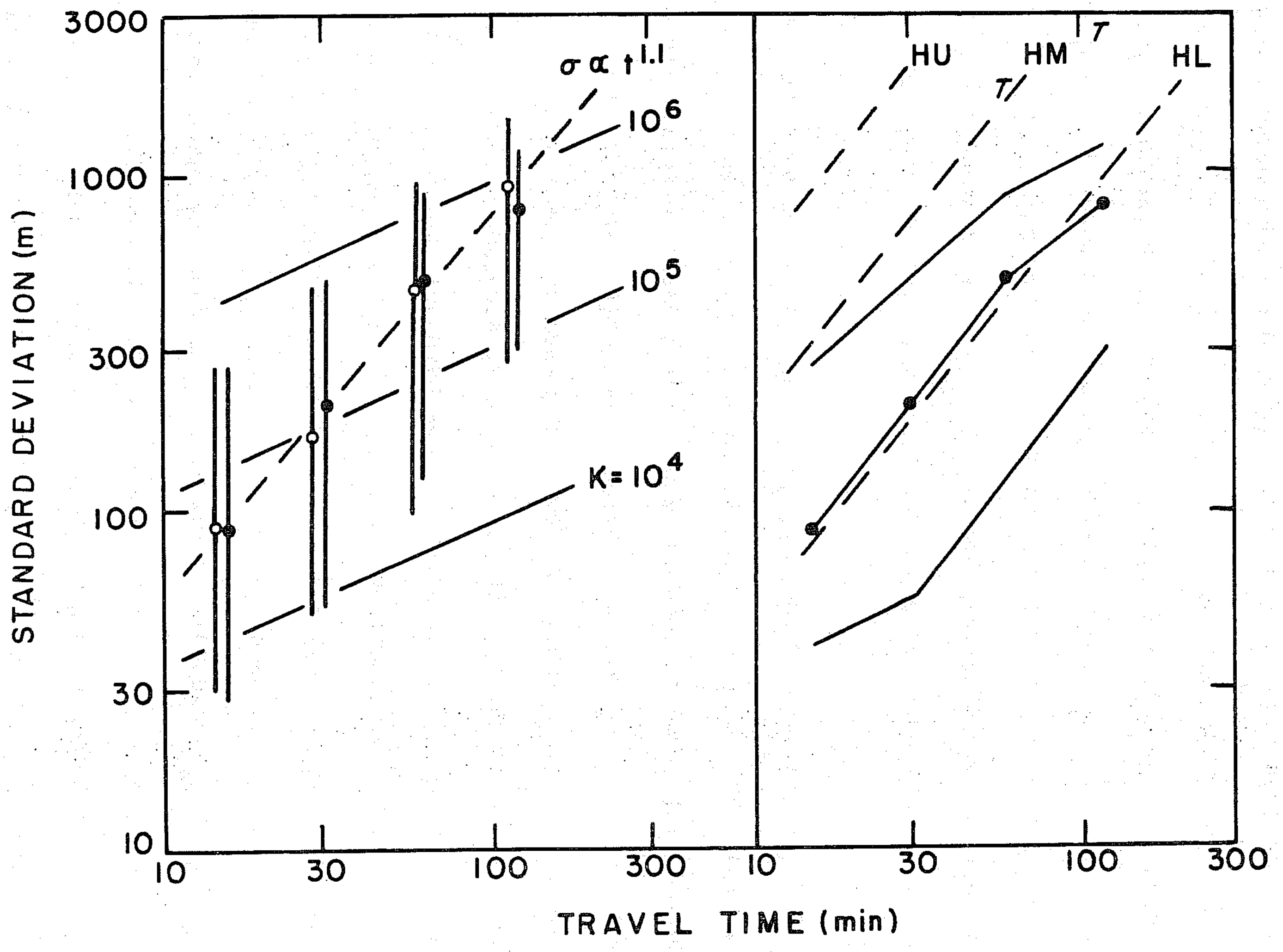

Figure 8. Median value of lateral (dots) and longitudinal (circles) standard deviation of position as a function of travel time, where the vertical bars embrace 68% of the observations and the horizontal diffusivity K (cm^2s^{-1}) has been estimated from the relation $\sigma^2=2Kt$. At right is shown the median and 16% limiting values of lateral standard deviation (solid lines) in comparison with the mean (HM) and upper (HU) and lower (HL) bounds of Hage, as well as results obtained from tetroon triads at Las Vegas, Nevada (T).

at a somewhat lower level. The median value within the Los Angeles Basin falls very nearly along Hage's lower bound, suggesting that within the basin, at these heights, the dispersion with respect to travel time is considerably less than found in most other experiments. That this difference is not merely a function of the measurement technique is shown by the factor of four difference between the results at Los Angeles and the results obtained from the release of triads of tetroons (T) for flight at a height of 3000 m MSL at Las Vegas, Nevada (Angell et al, 1971).

Figure 9 is similar to figure 8, but with travel distance rather than travel time as the independent variable. In Los Angeles, the lateral and longitudinal standard deviations increase as about the 0.9 power of distance, a result generally in agreement with that found by others. The right hand diagram shows the comparison of the median lateral standard deviation (and 1σ limits) at Los Angeles with the results from bulk tracer dispersion experiments, as summarized by Slade (1968) in "Meteorology and Atomic Energy." The median values at Los Angeles nearly coincide with the neutral-unstable results obtained at Idaho Falls (I) and Edwards Air Force Base (S) but the dispersion at Point Arguello (P) is considerably greater under both stable and unstable conditions, presumably because of the hilly terrain in the latter area. In about 10% of the cases the relative dispersion in Los Angeles is less than that measured by Högström (1964) at a height near 50 m in stable conditions (dot-dash line labeled H). The Los Angeles dispersion is more obviously reduced, when compared with other data, when viewed with respect to travel time than travel distance, the result of the light winds in the Los Angeles Basin (Table 1).

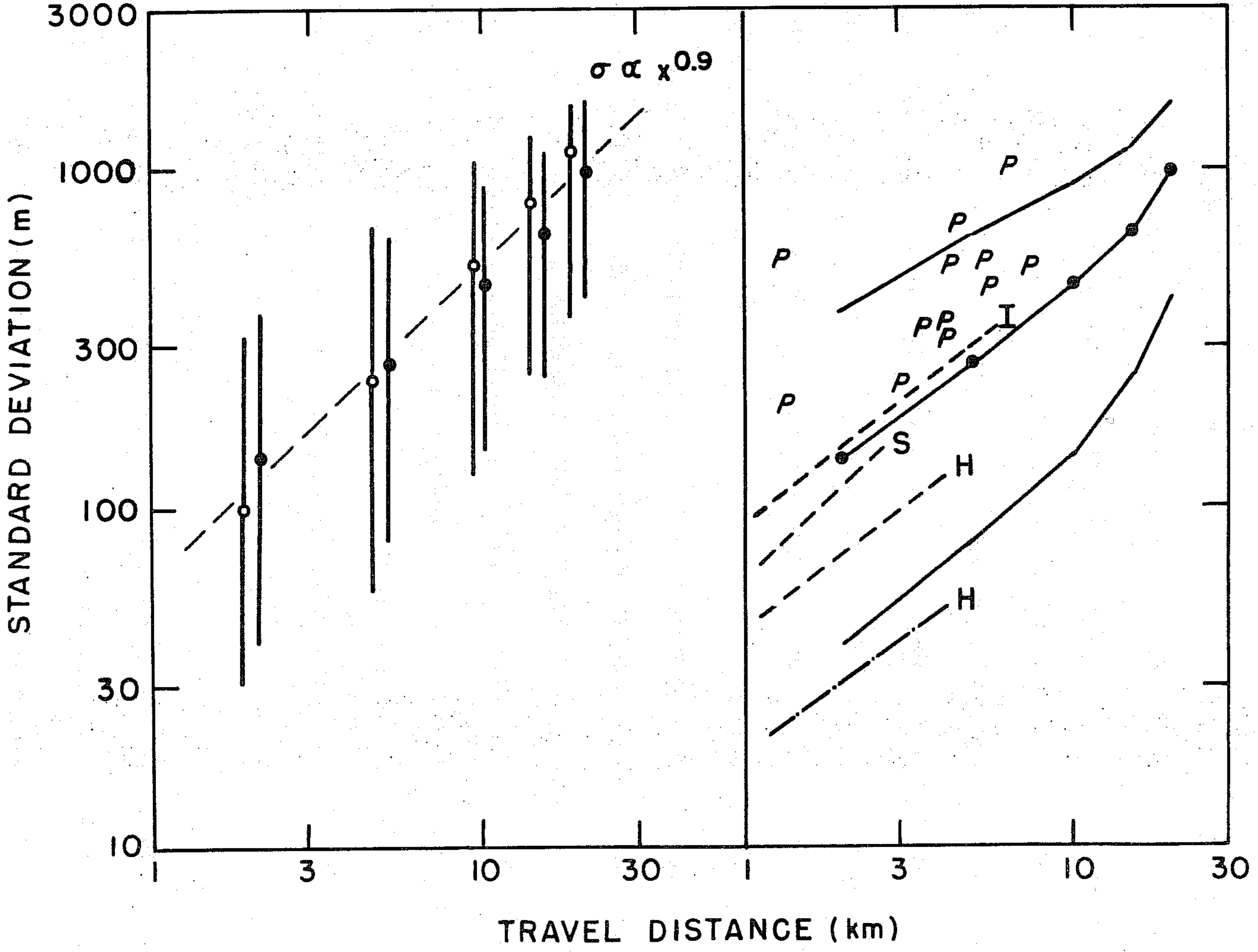

Figure 9. Median value of lateral (dots) and longitudinal (circles) standard deviation of position as a function of travel distance. At right is shown the median value of lateral standard deviation and the 16% limiting values (solid lines) in comparison with results obtained by Högström (H) under stable conditions (dot-dash line), and at Idaho Falls (I), Edward Air Force Base (S) and by Högström (H) under neutral or unstable conditions (dashed lines). P represents results obtained at hilly Point Arguello under both stable and unstable conditions.

5. VARIATION OF LATERAL STANDARD DEVIATION WITH TIME OF DAY, STABILITY AND TURBULENCE INTENSITY

Up until now we have treated all 35 tetroon dispersion experiments in toto without regard for variations in meteorological parameters such as atmospheric stability. In this section the relation between relative dispersion and such parameters will be examined. Because of the relatively few tetroon-triad experiments, and the complications introduced into the dispersion statistics by the sea breeze and by hilly terrain, we shall look at the relation in only a gross way, i.e., by division of the total sample into two samples of equal size based on the value of the parameter under consideration, and application of the procedure of figure 7 to determine the median and 1σ values. This yields the sense of the parameter effect on relative dispersion, but does not indicate the exact relation between parameter and dispersion.

Hereafter only the lateral standard deviation of position will be considered, in part because this is the component of greater interest and also because the longitudinal standard deviation appears to behave in a similar manner. Figure 10 shows the median value of lateral standard deviation (and 1σ limits) as a function of travel time and distance, for the 18 tetroon triads released between 0700 and 0900 and the 17 triads released between 0900 and 1400 local time. It is seen that the lateral dispersion is smaller in the morning than near midday. Thus, for a travel time of 100 minutes, 16% of the time the lateral standard deviation was less than 170 m in the morning, but only less than 350 m near midday. The difference in median value increases uniformly with travel time, but not with travel distance, and in general, the difference in the case of travel distance is not so impressive.

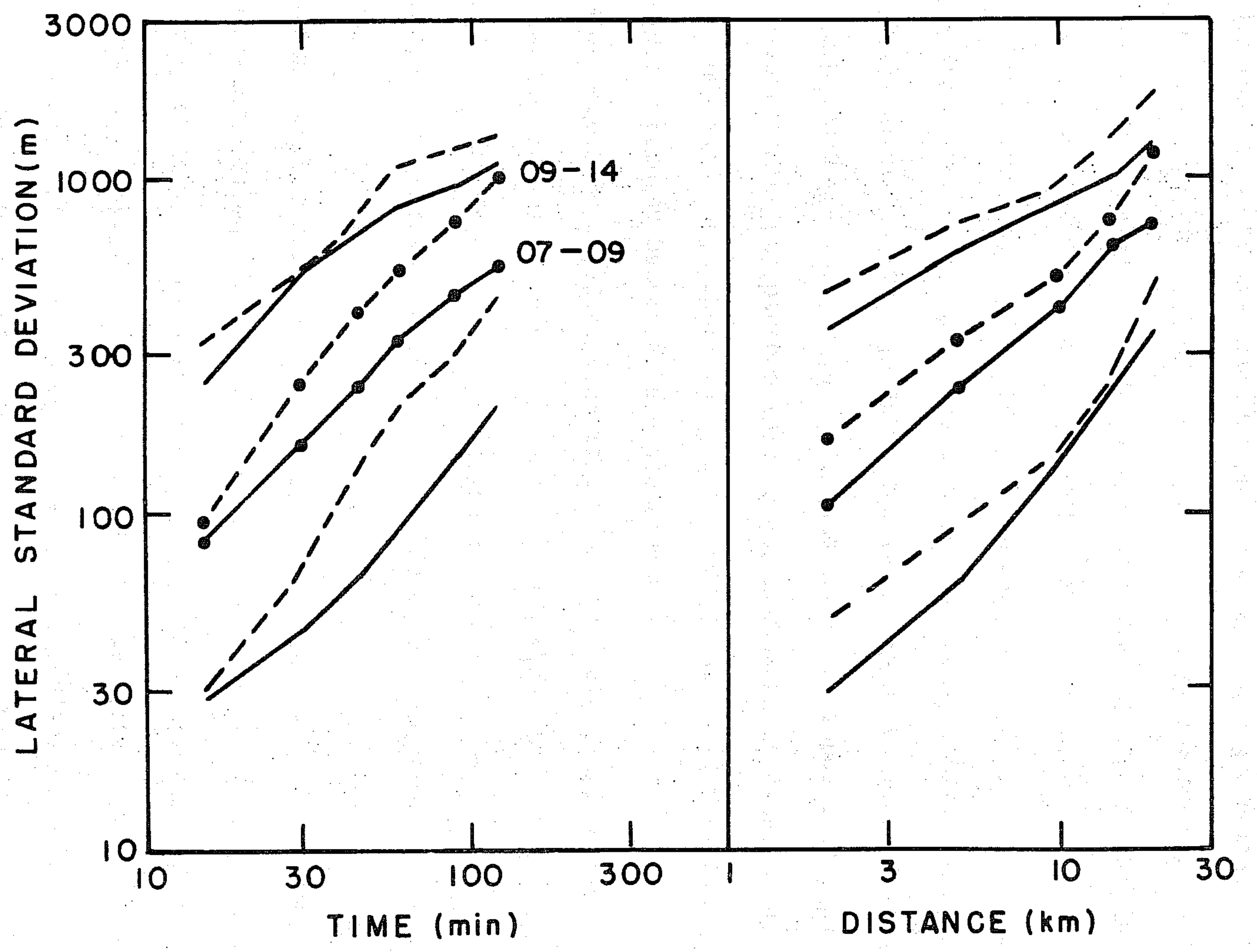

Figure 10. Median and 16% limiting values of lateral standard deviation as a function of travel time (left) and distance (right) for tetroon triads released between 0700 and 0900 (solid lines) and between 0900 and 1400 (dashed lines).

The variation of lateral dispersion with time of day suggest that atmospheric stability plays an important role in dispersion magnitude. Accordingly, the mean lapse rate between 1000 and 950 mb (approximately the lowest 500 m of the atmosphere) was evaluated at the EMSU station at Los Angeles International Airport, just north of El Segundo (Fig. 1), and at El Monte, about 10 km north of Whittier (Fig. 3), during the days of tetroon experiments. At about 0600 local time the average lapse rate at El Monte and Los Angeles Airport was -0.68 and -0.33°C/100 m, respectively, while at about 1200 the respective average lapse rates were 0.82 and 0.10°C/100 m, illustrating the much smaller diurnal variation in stability near the coast.

It is, of course, difficult to estimate the mean lapse rate along tetroon trajectories from only two sounding stations. We have attempted to do so by first interpolating at both stations with respect to time, and then interpolating in space. Figure 11 shows the comparison between the lapse rate so estimated and the average root mean square vertical velocity (σw) of the tetroons making up the triad. The correlation of 0.65 between the two suggests that the derived lapse rates have some validity. Of perhaps more interest is the evidence for an abrupt "break" in the value of σw at the position of the vertical dashed line, or at a lapse rate of about 0.3°C/100 m (coincidentally, this line also divides the data sample in half). There is the suggestion here that σw remains relatively small until a critical lapse rate is reached, at which point it may become relatively large. We somewhat arbitrarily denote these two stability classes as "neutral" and "stable".

The left hand diagram of figure 12 shows the lateral standard deviation of position as a function of travel time for these "neutral"

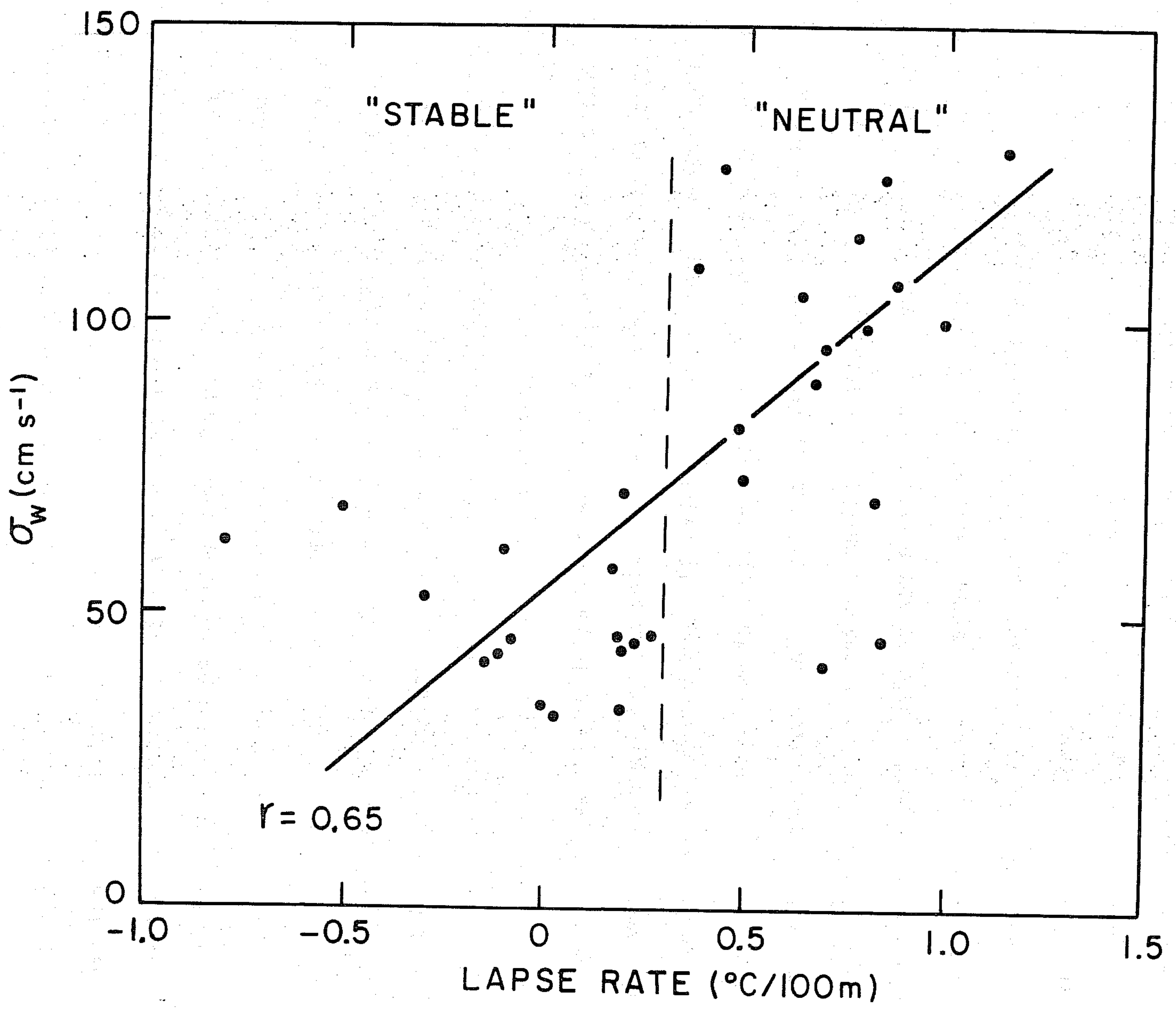

Figure 11. Comparison between the lapse rate (surface to 500 meters) estimated along tetroon-triad paths, and the average root mean square vertical velocity of the tetroons making up the triad. The solid line is the regression line, while the vertical dashed line shows the stability division into "neutral" and "stable".

and "stable" cases. The standard deviation is about twice as large in "neutral" as in "stable" conditions. After a travel time of 60 minutes, in 16% of the cases the lateral standard deviation is less than 80 m under "stable" conditions but is bounded by the much larger value of 220 m under "neutral" conditions. The letters U, N, and VS in the right hand diagram (lateral standard deviation as a function of travel distance) indicate the lateral standard deviations under unstable, neutral and very stable conditions suggested for use by "Meteorology and Atomic Energy, 1968." The suggested values appear conservative (small), the Los Angeles "stable" values corresponding with the suggested neutral, and the Los Angeles "neutral" values corresponding with the suggested unstable. Recall, however, that because of the light wind in the basin, in comparison with other data the Los Angeles dispersions are not so obviously small with respect totravel distance as with respect to travel time. In any event, about 16% of the time in "stable" conditions the Los Angeles lateral standard deviation is less than that suggested for very stable conditions in "Meteorology and Atomic Energy."

To help place these dispersion values in context, the dotted line labeled F in the right hand diagram of figure 12 represents the Pasquill-Gifford moderately-stable category for a <u>continuous</u> point source release, as taken from "Meteorology and Atomic Energy, 1968." Because of meandering, a continuous points ource should, of course, yield a larger lateral standard deviation than an instantaneous point source (IPS), and since this F line corresponds closely with the IPS median value under "stable" conditions, the relative dispersion with respect to travel distance is <u>not</u> anomalously small in the Los Angeles Basin. Finally, the letter H in

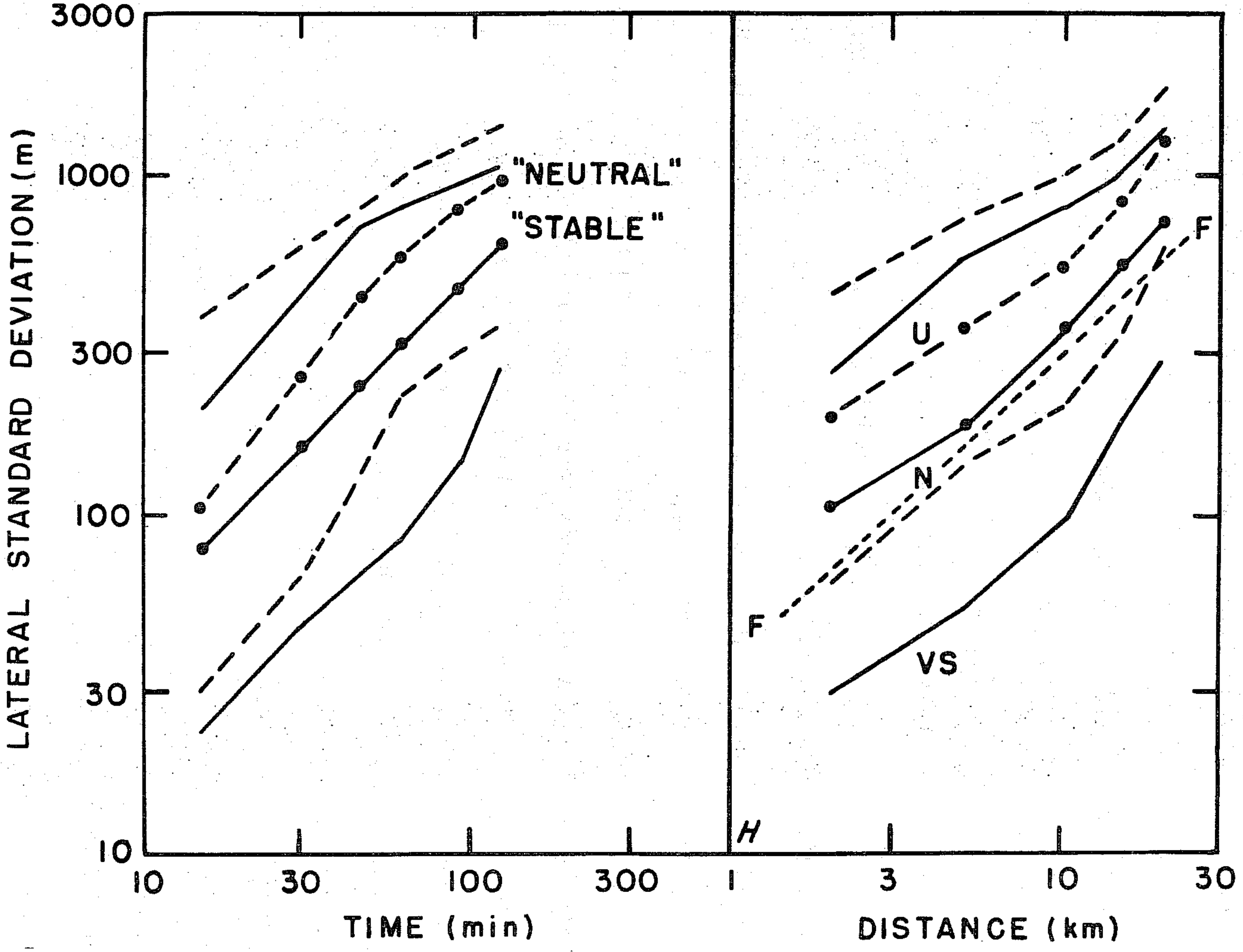

Figure 12. Median and 16% limiting values of lateral standard deviation as a function of travel time (left) and distance (right) under "stable" (solid lines) and "neutral" (dashed lines) conditions (see fig. 11). The letters U, N and VS at right represent "suggested estimates" (Meteorology and Atomic Energy, 1968) under unstable, neutral and very stable conditions, while the dotted line labeled F represents the Pasquill-Gifford moderately-stable estimate for a continuous point source. H indicates the smallest lateral dispersion measured by Högström.

the lower left corner of the right diagram represents the smallest lateral dispersion obtained by Högström (1964) under very stable conditions.

One would expect the lateral standard deviation of position to be proportional to lateral turbulence intensity, or perhaps even the square of lateral turbulence intensity (Pasquill, 1963). Unfortunately, the root mean square lateral velocity was not evaluated in the computer program because of the complexities introduced by trajectory turnings, and hence the lateral turbulence intensity is unknown. However, since lateral and vertical turbulence intensity tend to be proportional, it appeared worthwhile to examine the lateral standard deviation of position in terms of the vertical turbulence intensity. Figure 13 shows the result, as a function of travel distance only, for vertical intensities exceeding or less than 0.3. Overall, there is again about a factor of two difference, although at a travel distance of 10 km, 16% of the time the lateral standard deviation is less than 280 m when the vertical turbulence intensity is greater than 0.3, but less than 80 m when the turbulence intensity is less than 0.3, a factor of nearly four.

In order to determine whether the lateral standard deviation of position is more likely proportional to turbulence intensity or the square of turbulence intensity, the correlation among these parameters was determined as a function of travel distance. Figure 14 shows that the correlation is consistently higher in the case of turbulence intensity itself. Because of the use of vertical rather than lateral turbulence intensity, one hesitates to draw any hard and fast conclusions, but what evidence there is suggests the greater usefulness of the linear relationship.

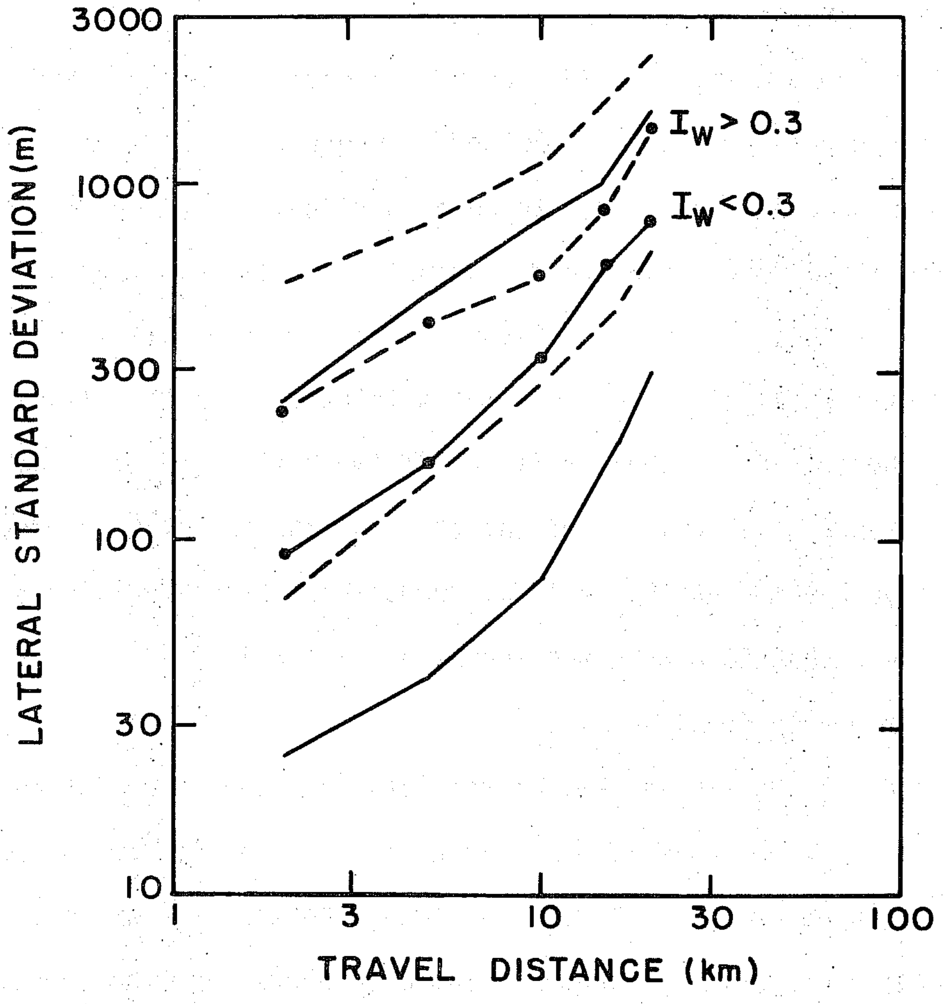

Figure 13. Median and 16% limiting values of lateral standard deviation as a function of travel distance when the vertical turbulence intensity was less than 0.3 (solid lines) and exceeded 0.3 (dashed lines).

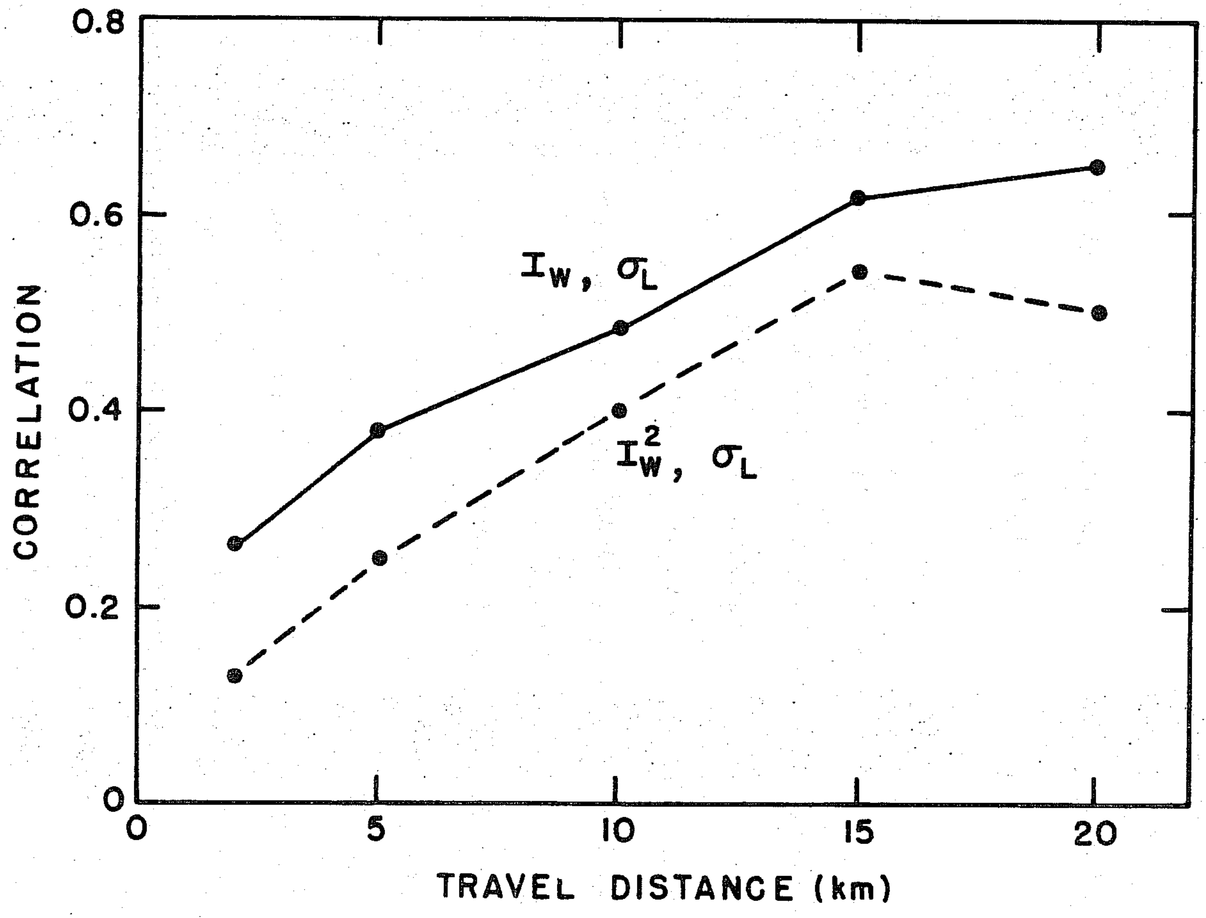

Figure 14. Correlation between vertical turbulence intensity and lateral standard deviation, and between the square of vertical turbulence intensity and lateral standard deviation, as a function of travel distance.

6. INFLUENCE OF THE SEA BREEZE ON LATERAL DISPERSION

In this section an attempt is made to quantify the sea breeze effect on atmospheric dispersion. The seven experiments in figure 1 have been divided according to whether the sea breeze reversal occurred about one-half hour after tetroon launch (experiments 12, 14, 18, 24) or more nearly one and one half hours after tetroon launch (experiments 11, 19, 34A). Figure 15 shows the mean lateral standard deviation of position as a function of travel time for these triads (dashed lines), as well as the mean value for the 28 remaining triads (solid line). In general, interaction with the sea breeze appears to increase the lateral dispersion by at least a factor of two. An interesting feature, however, is the evidence on three of the experiments for a <u>decrease</u> in lateral standard deviation prior to contact with the sea breeze front, as if strong lateral convergences existed ahead of this "front". Obviously, the statistics on lateral dispersion presented in this paper are, to some extent, dependent on the number of experiments involving sea breeze reversals, and a more extensive field experiment will be required to really pin down the values of relative dispersion under given atmospheric conditions within the Los Angeles Basin.

7. CONCLUSION

These measurements of tetroon dispersion probably represent the first direct estimates of relative diffusion within the Los Angeles Basin over appreciable space and time intervals. The usefulness of the measurements should be considerable, with the caveat that they were obtained at an MSL height of 350 m (100-300 m above ground), not near the surface. In unstable conditions this should make little difference, but in stable conditions the tetroons may be underestimating the diffusion existing close to the ground.

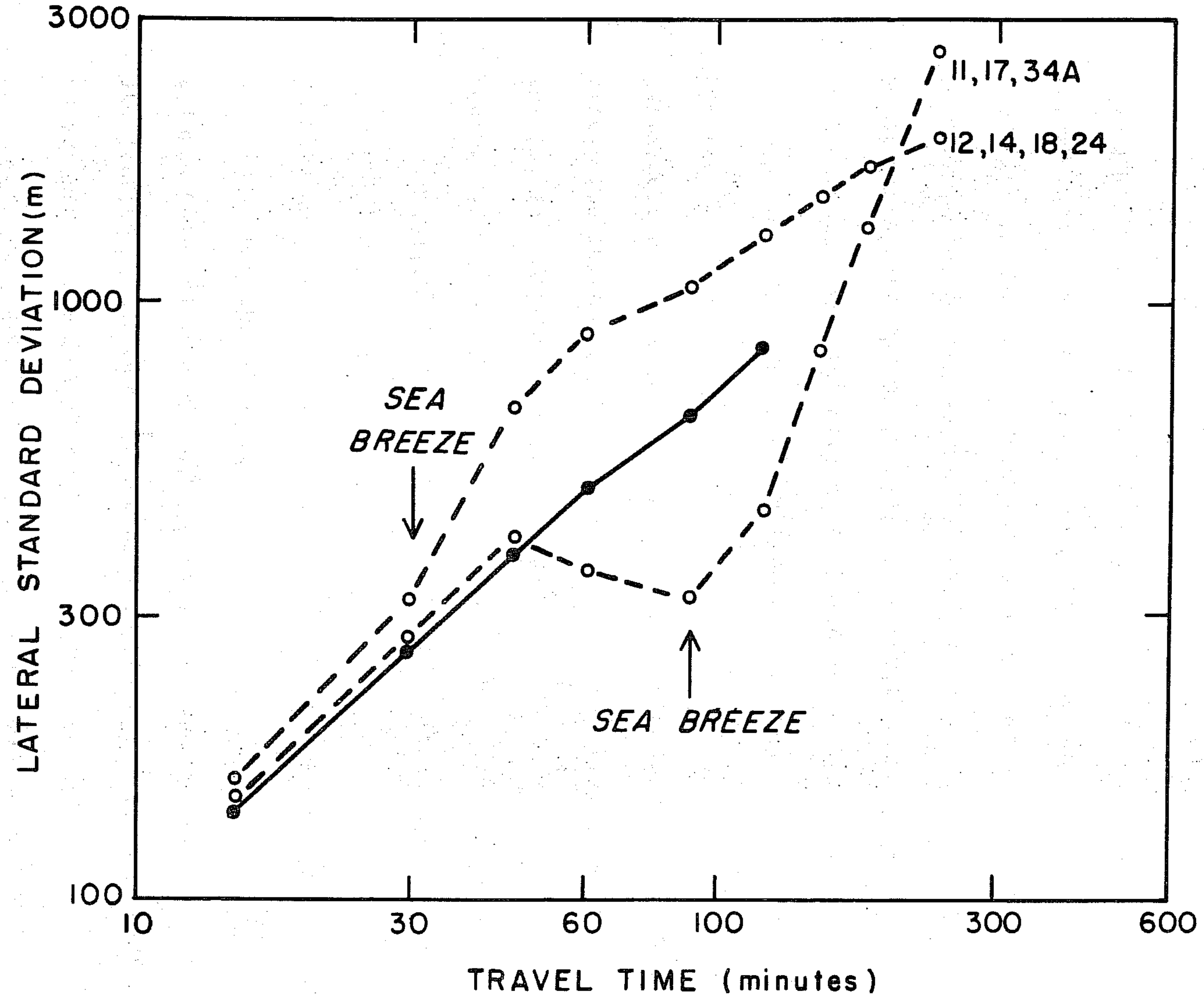

Figure 15. Comparison between the mean lateral standard deviation determined from the triads of figure 1 (divided according to whether the sea breeze was encountered about one-half hour or one and one-half hours after release) and the mean value determined from the remainder of the triads (solid line).

To no one's surprise, the lateral dispersion within the basin is frequently very small, particularly with respect to travel time. Especially in stable conditions, the actual dispersion may be even smaller than indicated because the tetroons do not originate as a point source and often are located at somewhat different mean heights. In any event, tetroon flights were not made at night when the dispersion may be a minimum. It has been shown that the effect of the sea breeze is not only to bring in fresh unpolluted air, but also to greatly enhance the diffusion of the air originally within the basin.

A corollary of LARPP is that in most cases a single tetroon trajectory represents a good estimate of the air trajectory, since in only two out of the thirty-five experiments was there a wide diversity of trajectories within the tetroon triad. Thus, the controversial question of the representativeness of a single tetroon trajectory now seems to be satisfactorily, and favorably, resolved.

The tetroon-transponder system should have considerable application in future work dealing with urban pollution, both because the tetroon undoubtedly yields the best possible estimate of air trajectory, and also because triads of tetroons give useful estimates of relative diffusion along the trajectory. Their use in the Los Angeles Basin to "tag" a given volume of air was completely successful, and points the way to further experiments using this technique.

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The tetroon and helicopter-vectoring aspect of LARPP owes its success to many individuals. We particularly want to express our thanks to F. White, who kept the two M-33 radars in top condition and did most of the helicopter tracking, D. Forsyth, who did most of the tetroon tracking and assisted in radar maintenance, and N. Ricks and J. Sagendorf, who undertook the tedious job of vectoring the helicopters to the proper locations, all of the Air Resources Laboratories Field Research Office, Idaho Falls. G. Start and H. Boen of the above group were responsible for the data reduction by computer. J. Edinger, Jr. was of great assistance in tetroon tracking. Assisting in tetroon launching, and also taking soundings, were R. Soller and J. Smith of the Air Resources Laboratories Meteorology Laboratory, Raleigh. M. Hodges calculated the standard deviations of tetroon position and did the drafting.

Finally, in the overall context of LARPP we wish to express our appreciation to the experiment director, W. Perkins, for his unfailing support and able direction, as well as to the helicopter crews, ground crews and all others who helped make this experiment a milestone in the study of urban pollution.

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