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LOS ALAMOS SCIENTIFIC LABORATORY

OF THE UNIVERSITY OF CALIFORNIA ○ LOS ALAMOS NEW MEXICO

THE WIND VARIABILITY OF FALL-OUT PATTERNS

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EFFECTS OF ATOMIC WEAPONS

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THE WIND VARIABILITY OF FALL-OUT PATTERNS

by

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Abstract

On the basis of winds from four Pacific shot days, that part of the variability of the computed fall-out intensity patterns due to the variability of the winds is investigated. An extreme case from Operation Sandstone is also considered. The following tentative operational conclusions are drawn: (1) Low level winds are quite likely to be the critical ones for cases of rapid marked changes in fall-out intensities; furthermore, such potential extreme cases ought to be recognizable. This importance of the lower winds may influence choice of level for the weather reconnaissance flights. (2) Single-point wind runs, while probably adequate for medium range fall-out computations, are inadequate for ranges of the order of the Eniwetok-Bikini distance. A map with respect to the expected hot line is presented, giving a best estimate of the 3-hour variability due to winds in fall-out intensity. Such a variability represents the error of a 3-hour persistence forecast from the last wind run prior to shot time -- this should be an upper limit to the actual forecast error.

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1. Introduction

During weapon tests, weather forecasts are made at various intervals. An early planning forecast may be made 24 or 48 hours before shot time. However, it is general practice that repeated wind measurements be made throughout the period just preceding the shot, and the final shoot or no-shoot decision is generally made on the basis of a balloon released 2 or 3 hours before shot time. This is the case because it takes the order of an hour or more for the balloon to go up and for the results to be transmitted, because some time is involved in making the decision, and because the shot is delayed some minimum period after it has been "put on." In fact, then, a forecast of the order of 3 hours has been the key one -- the one which is used for the ultimate decision. It is of interest to examine the reliability of such forecasts. Actually, of course, longer forecasts are really involved. The fall-out occurs over a period of some hours. The winds must be satisfactory not only at shot time but also for a time thereafter. The effects of space-time variability upon the forecast will be included, at least semiquantitatively, in the forecasts for Redwing. The accuracies of these longer range forecasts are not considered here.

Crowson[1] made a study of the wind variability in the Eniwetok Island area. He used a set of 25 wind runs taken during a 30-hour period of Operation Sandstone as a basis for his study. He concerned himself primarily with the effect of this wind variability on such matters as aircraft operations. It is obviously of interest to people concerned with fall-out forecasting to repeat such a study, interpreting the variability of the wind in terms of the resulting variability of the fall-out patterns.

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A first look at Crowson's data turned up an alarming result, illustrated in Fig. 1. In that figure at the top, the height-time lattice for the 1400 Bikini time wind run is shown; at the bottom is the corresponding lattice for the wind run made 1 hour later. These two were chosen not because the discovered result was anticipated; rather, they were simply the first two of a set of three consecutive 1-hour runs from his data chosen for a preliminary look. It will be noted that due almost entirely to a shift in the winds in the lower levels (below 13,000 to 15,000 feet), the situation changes from one in which the pollution lies concentrated along a radial line from shot point, yielding a very narrow, high intensity fall-out pattern, to one in which the pollution is spread out over fairly large areas. The activity falling in corresponding boxes of the lattices is the same for a given device; the changes in area and/or overlappings of such lattice boxes during the 1-hour period imply marked changes in the intensities of the depositions which would have occurred.

The moment this potentially tremendous variability in the fall-out pattern over 1 hour was discovered, preliminary qualitative investigation of Crowson's data was dropped, and an immediate decision was made to make a quantitative investigation of the wind variability of fall-out patterns. It turned out, unfortunately, that Sandstone data in suitable form were not available. In Crowson's paper the winds are shown graphically and can be picked off from his small scale figure only with great difficulty and a loss in accuracy. Furthermore, the precise date is omitted from his article, and it has been impossible to verify the highly probable fact that his investigation was concerned with a shot day. Obviously, we are not interested in the general variability of the winds in the Marshall

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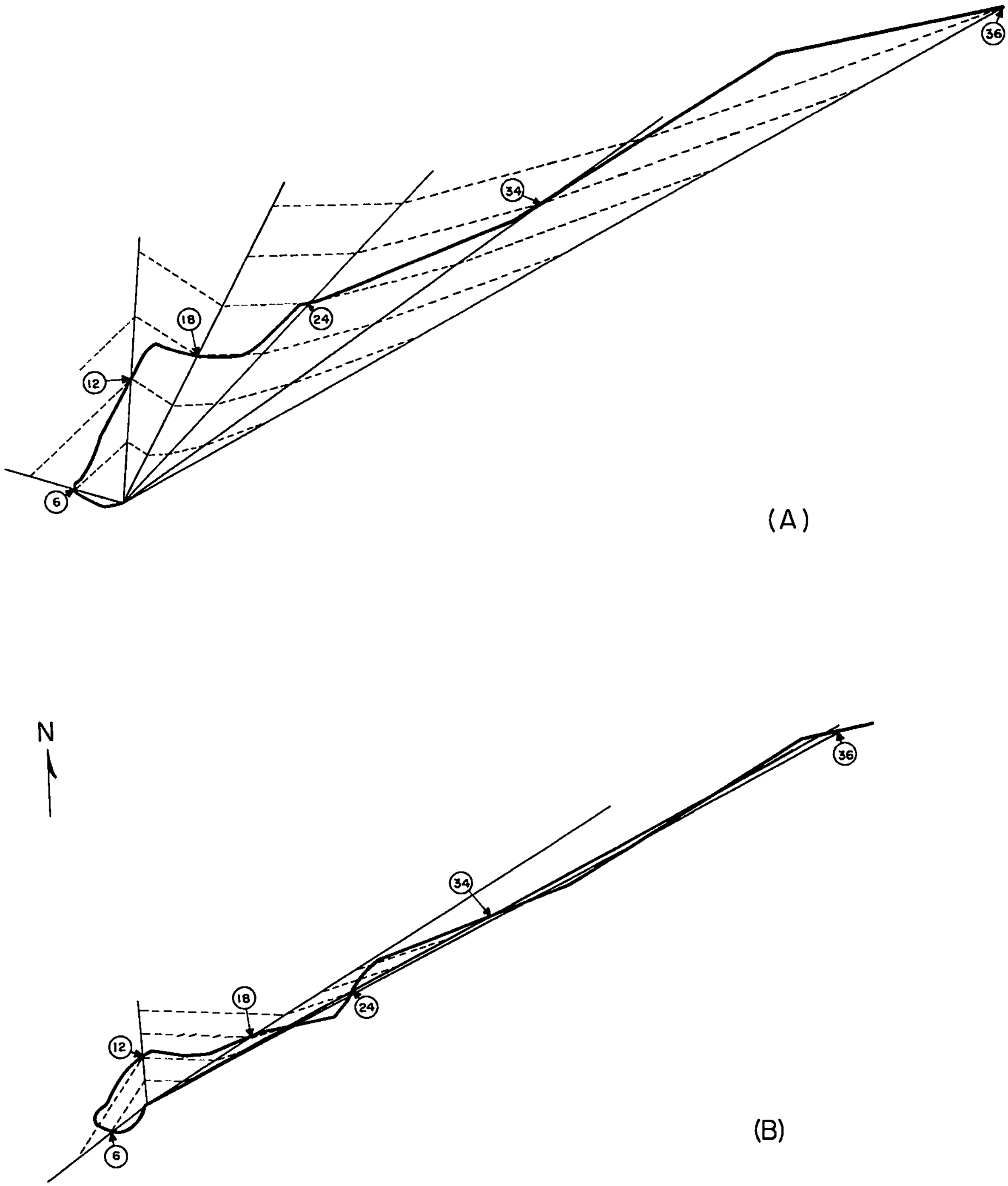

Fig. 1 Hodographs (heavy solid line) and height-time lattices (light solid and broken lines) for Marshall Island winds during a day in April: (A) at 1400 local time, (B) at 1500 local time.

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Islands area but, rather, in the variabilities during "shot" weather. Accordingly, it was decided to use available wind runs from shot days.

In the sections below, the results of computations of fall-out patterns from such wind runs are presented. The intent is to determine the variability over a typical 3-hour period on a shot day. The assumption is that the weather forecasters can do as well or better in their forecasting than a 3-hour persistence forecast. Such a forecast for the last 3 hours would have an error measured by the wind variability we shall discuss. Accordingly, this variability will be an upper limit to the wind forecast error. The results are presented below largely in terms of standard deviations. The odds are that the standard deviation will be exceeded one time in three and will in turn exceed the error two times in three. Should decisions be desired on a higher confidence level than two out of three, it is a simple matter to translate these results -- one uses appropriate multiplying factors on the standard deviations.

One other question can be readily studied in terms of the computational results obtained. That is the question of the suitability of the use of one-point winds for fall-out forecasting. In Fig. 2, a map of the shot day for Bravo is shown. This is a map of winds at the 10,000-foot level prepared at the Oahu Research Center[2]. It will be noted that these winds at Bikini and at Eniwetok are radically different both in direction and speed. It may very well be that such space variations of the winds in a given map level are illusory for our purposes. We are interested in a sort of weighted wind throughout the atmosphere, and it is certainly probable that such vertically-meaned winds will be much simpler in their spatial variability than will be the winds at any particular level. Indeed, it may

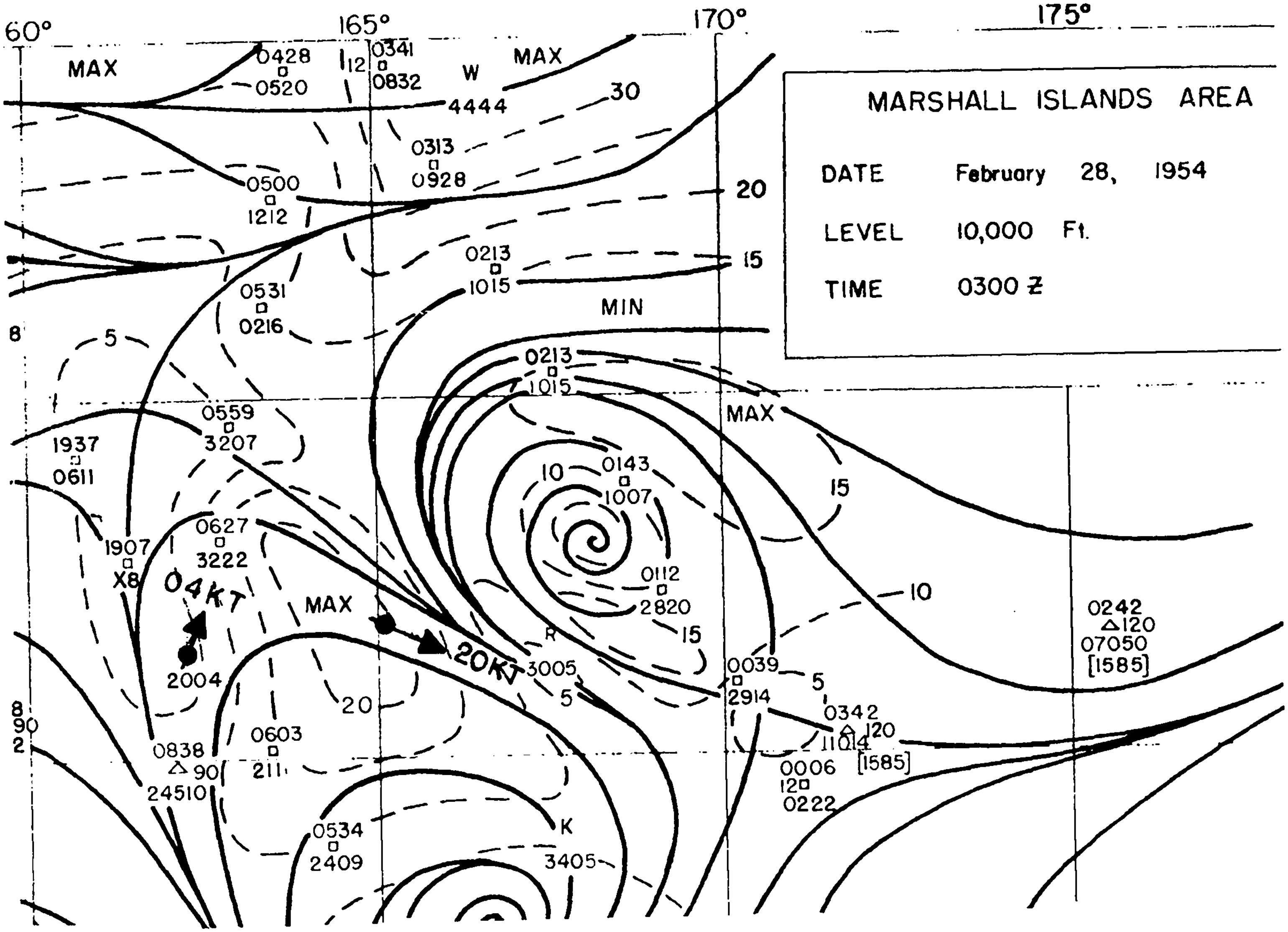

Fig. 2 Map of winds on Bravo shot day.

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well be that such weighted mean winds through layers should be the mapped and forecast quantities for fall-out purposes. More to the point of issue here, it may well be that such maps would not show very great variability over comparatively short distances; so that the results from, say, Bikini and Eniwetok, some 200 miles apart, would be essentially the same. This has been implicitly assumed in most fall-out work to date, in which fall-out forecasts for ranges of 200 miles have been based upon one-point winds. We shall discuss this assumption.

2. The Computations

The Pacific Operations data available included from three to five wind runs to 50,000 feet at 3-hour intervals centered on each of several shot times, with added runs at 6-hour intervals for times extending to $\pm$ 9 hours. Accordingly, this level has been chosen as the top of a synthetic atomic cloud for which the fall-out pattern has been repeatedly computed and its variability due to the wind variations determined. This represents a cloud which reaches through most of the troposphere -- a level of 55,000 feet, being fairly typical for the tropopause. In what follows, although we may refer to these things, for example, as the "pattern for Bravo", it must be emphasized that we here just mean the pattern based upon winds to 50,000 feet taken on the day of Bravo. This pattern, for a cloud which reaches only 50,000 feet, will correspond roughly to one for an explosion in the kiloton range and is clearly much different from the actual Bravo event; so, too, for the other patterns obtained. Thus, in no case is it valid to compare our patterns to the actual fall-out which occurred.

For this work we are interested in measuring that part of the variability of the fall-out patterns which result from the variability of the winds.

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In order to do this, some fairly realistic fall-out model is necessary -- it is not necessary that this be a precisely correct one. So long as it is a good approximation and is used consistently, the variability resulting will be a reasonable measure of that variability due to the winds. Because of convenience, we have used the card deck representing the IBM 701 electronic computer procedure for getting the fall-out used during Operation Teapot. This is a little obsolescent in terms of the latest agreement on activity distribution, etc.; however, as has been noted, these slight departures from more recent practice are not significant for our purpose here.

For each chosen wind run, a machine forecast was made whose output was fall-out intensity at each point of an array of points at the intersections of 15 radial lines spaced 8° apart, and a set of parallel lines spaced 10 miles apart and orthogonal to the central one of the chosen radii. As mentioned above, a bomb cloud which reaches 50,000 feet corresponds to one resulting from an explosion in the kiloton range. The fall-out intensities of the patterns computed are to be interpreted roughly as follows: One unit corresponds to 13 roentgens at meter level, infinite dose. Coincidentally, one unit intensity occurred 10 miles out from ground zero along the hot line for the Bravo H-hour winds. For purposes of scaling to other weapons, perhaps this unit might be more convenient. In any event, it will certainly be more convenient to assume a fission yield of 50 kt so that our intensity unit is 10 r infinite dose.

Standard deviations of the fall-out intensities for each of four shots were computed. We shall call these events 1, 2, 3 and 4. In particular, event 1 was the Bravo shot. Computations for two other shot day winds were not completed since bad initial choices were made for the central line of

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the computational grid and time was not available for a recomputation.

The computation scheme involves a guess at a good choice for the central ray of the grid. It happens that this guess was rather badly made by the author for several of the clouds. In particular the event 4 fall-out pattern computed was so far off to one side of the array that it was felt worth while to repeat the computation with a second, more intelligent, choice for the central line of the array. The two results were in general agreement but were somewhat different. This provides a measure of the differences which ensue simply because the intensities are computed at different grid points. That is to say, the differences are entirely computational and not due to wind variabilities or any change in model. The comparison between the two results is shown in Fig. 3. It will be noted that the standard deviations of the fall-out intensities for the event 4 shot were in the range of 0.2 to 0.25 unit and that the differences in the two computations (with different central lines) were about 0.10 unit over about one-third the area of computation. It may be added that the event 4 standard

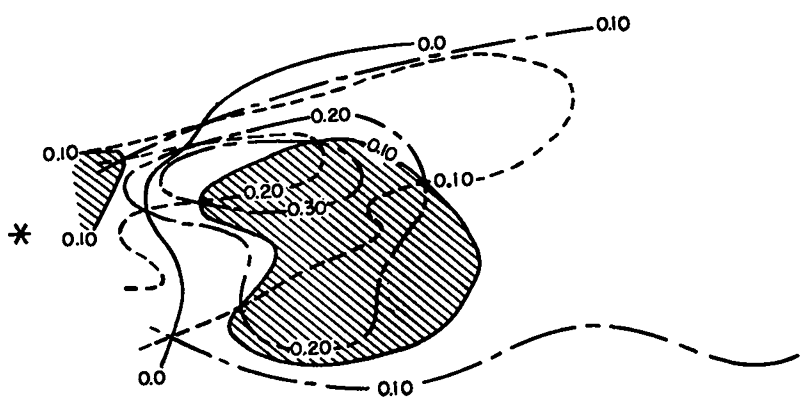

Fig. 3 A comparison of the results obtained computing the event 4 fall-out with an 075° center line (dotted) and with a 105° center line (dot-dash).

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deviations were, in general, smaller than those computed for the other shots. The difference between these two computations for the event 4 is a measure of computational accuracy of the scheme; this is probably not percentually so great in general. We can take 0.10 as a fair guess at the absolute computational uncertainty.

Standard deviations of the fall-out intensities were estimated at each point within the first 40-mile range for which data were available. The standard deviations were estimated as being the square root of the sums of the squares of the differences between consecutive fall-out intensity values computed for the particular grid points. This estimate of the standard deviation for values in sequences is justified by statisticians[3]. The work was done with winds from the Eniwetok area -- the records there were much more complete -- in every case except for the H-hour situation; for that case computations were also made with Bikini wind data in order to settle the question of the validity of one-point wind fall-out computations. The results are presented in the next section.

3. Results

The Bravo situation was the first worked with and was the one most completely handled. In Fig. 4 are shown the 0.10 unit intensity lines for the fall-out at each of four times, 3 hours apart. This is a rough picture of the sort of variability to be expected. Whether there is anything systematic there or not is left for the reader to judge. In any event, if there is, presumably the forecaster would detect it and take it into account. We have said that the forecaster should do as well or better than simple persistence forecasting. We here take the blind persistence forecast as our limiting one in estimating forecast error; hence, this variability

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over 3-hour periods shown in Fig. 4 is the sort of thing we may regard as a limit to the accuracy of 3-hour forecast fall-out patterns so far as wind effects are involved.

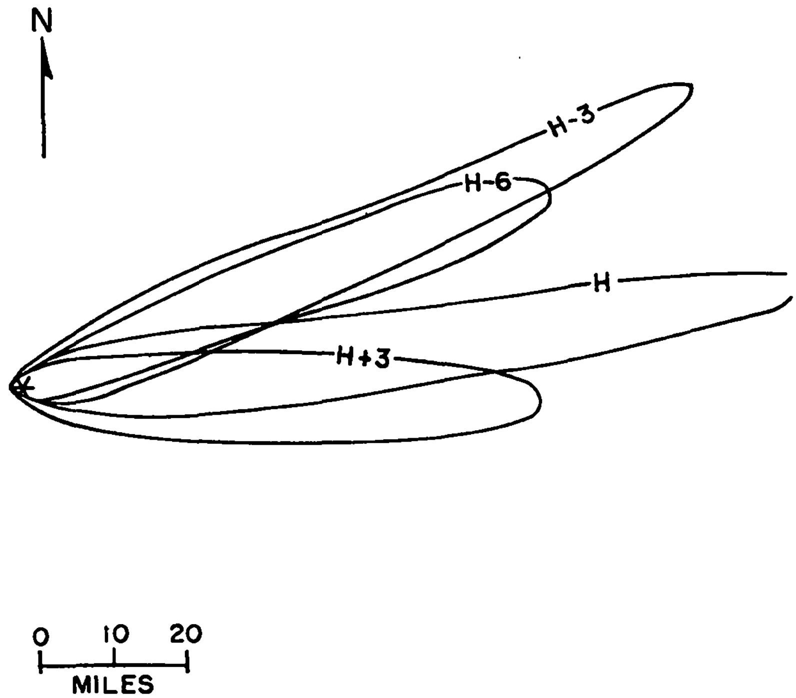

Fig. 4 The 0.10-unit lines for the fall-out patterns at the indicated times of Bravo day.

A more quantitative picture is given in Fig. 5. For the preparation of that figure, fall-out patterns were computed for each of the times shown in Fig. 4 and the three pairs of wind runs separated by 3-hour intervals were used as the basis of an estimate of the variability of the pattern at each grid point. The resulting map of the standard deviations is shown in Fig. 5. On the basis of the (H+9, H+3), (H+3, H-3), (H, H-6) wind pairs, a corresponding map of the standard deviation over 6-hour periods was prepared using the Bravo Eniwetok area winds. This is presented in Fig. 6.

Both maps of the standard deviation of fall-out intensity have a shape typical of all that were prepared for this investigation. This shape

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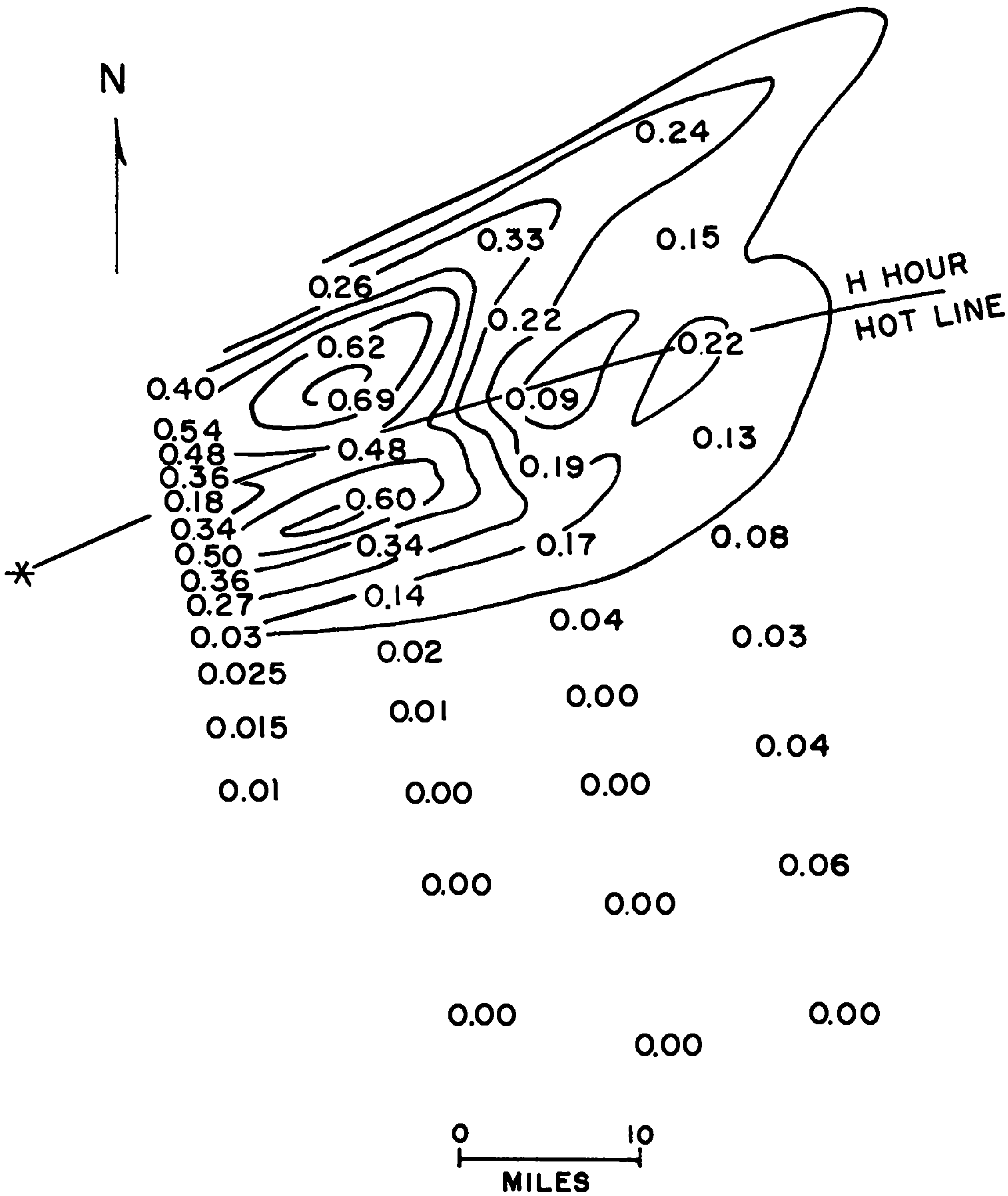

Fig. 5 Three-hour standard deviations of the fall-out intensity for the Bravo winds.

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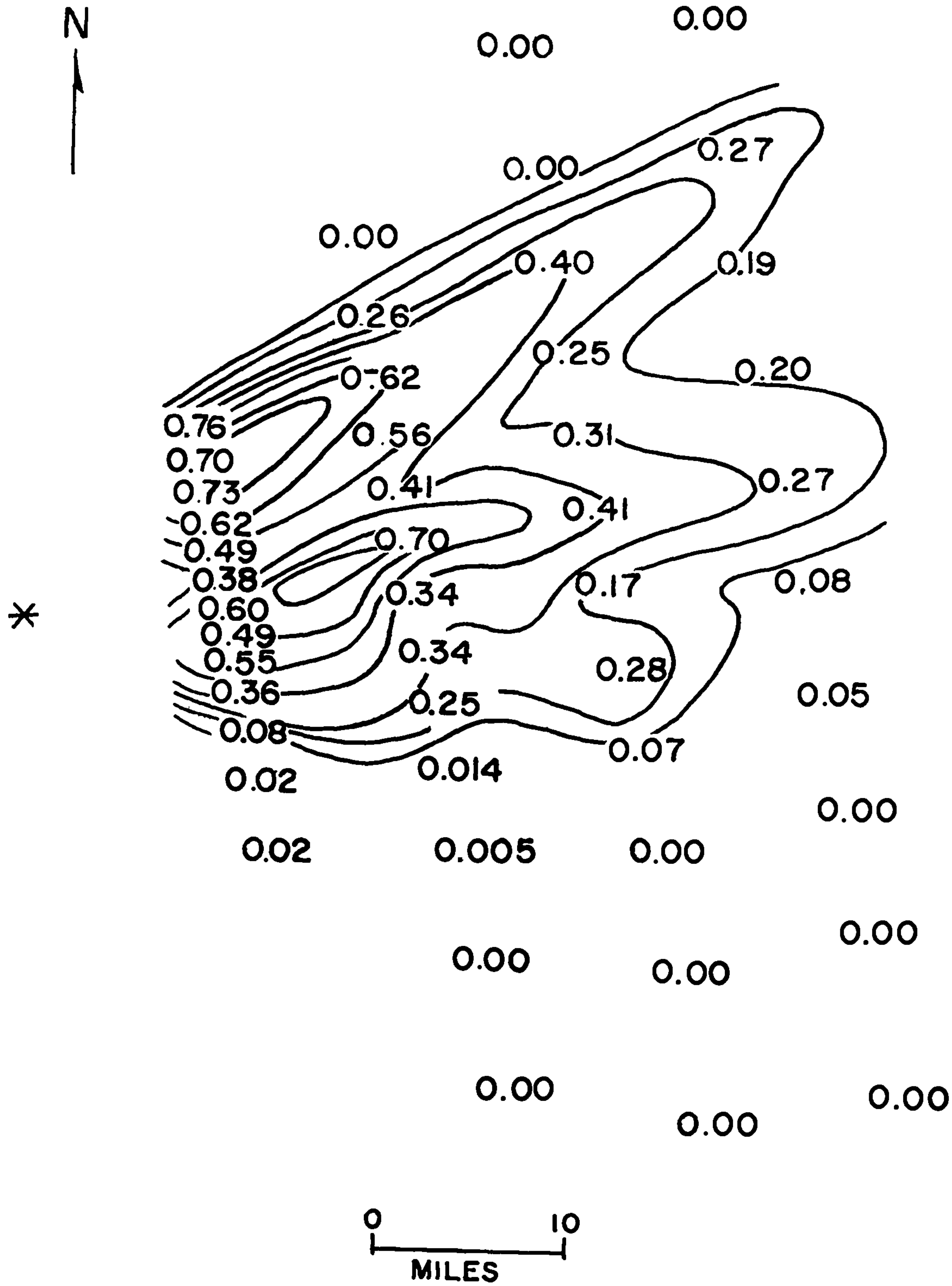

Fig. 6 Six-hour standard deviations of fall-out intensity for the Bravo winds.

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is one which is quite reasonable. It is bi-modal, there being a maximum of variability on either side of the basic fall-out pattern. Thus, should the fall-out pattern shift a bit to the north, there would be a region of maximum change at the northern edge where there have been increases, and a second region of maximum change at the southern edge where there have been decreases. There is a general relative minimum of variability just along the hot line of the basic pattern.

Surprisingly enough, the magnitudes of the standard deviations of both the 3-hour and the 6-hour standard deviations were found to be about the same. This was not anticipated but will be of use to us below. In both instances, variabilities of the winds resulted in standard deviations of the order of 60 to 70 percent of the fall-out intensity at 10 miles out on the hot line. In terms of our bomb model, this corresponds to 60 to 70 percent of a 10-r infinite dose (for a 50,000-foot, 50 kt fission yield cloud). The interpretation, then, is that we can assume the odds are two to one that the 3-hour variability and, therefore, the wind forecast error, will not exceed this 6 to 7 r and that the greatest variabilities will occur 10 to 20 miles out from ground zero and 5 to 10 miles on either side of the hot line. More detailed interpretations of these patterns (in Figs. 5 and 6) are not warranted, since a more reliable estimate of the standard deviation of fall-out intensities will be given and discussed in Fig. 8. That figure, discussed in the section on conclusions, represents a mean of the 3-hour standard deviations computed for all four shots. Each was computed as was the Bravo one, and the results were combined in terms of coincidence of the minimum between the bi-modal maxima (that is to say, in terms of coincidence of the mean hot lines).

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In order to get at the question of the reliability of the use of a one-point wind run for the forecast over great distances (say 200 miles), the H-hour Bikini and Eniwetok fall-out patterns were plotted separately for each of the four wind cases. The results are shown in Fig. 7. In each case, the 0.10-unit isolines have been drawn, together with isolines at multiples of 0.25 unit. The 0.10 and 0.50 isolines have been extended around the shot point. This extension was done simply by eye, there being no data computed closer than 10 miles from shot point. The patterns for the Bikini winds are in all cases shown as the solid lines; those for the Eniwetok winds in all cases are shown as the dotted lines.

It will be seen that in the case of the Bravo shot the wind difference, mentioned in the discussion of Fig. 2 in Sec. 1, was indeed not significant for fall-out purposes. It turns out that the mean winds through 50,000 feet on that day were essentially the same so far as the sort of fall-out patterns to which they led for both Bikini And Eniwetok. However, in the case of event 2 the generally wide pattern discovered on the basis of the Eniwetok winds narrows and, hence, intensifies when computed from the Bikini winds. This difference could well be a significant one. In the cases of events 3 and 4, the wind patterns computed are fairly similar in both size and intensity but are oriented along sufficiently different azimuths as to result in significant error were one used for the other location. It seems obvious that with three of the four cases unsatisfactory (all but Bravo), the use of one-point winds for fall-out estimates at places so widely separate as Bikini and Eniwetok is highly questionable.

It is true that this practice has seemingly worked in the past, but let us consider whether or not this is valid reasoning for the future.

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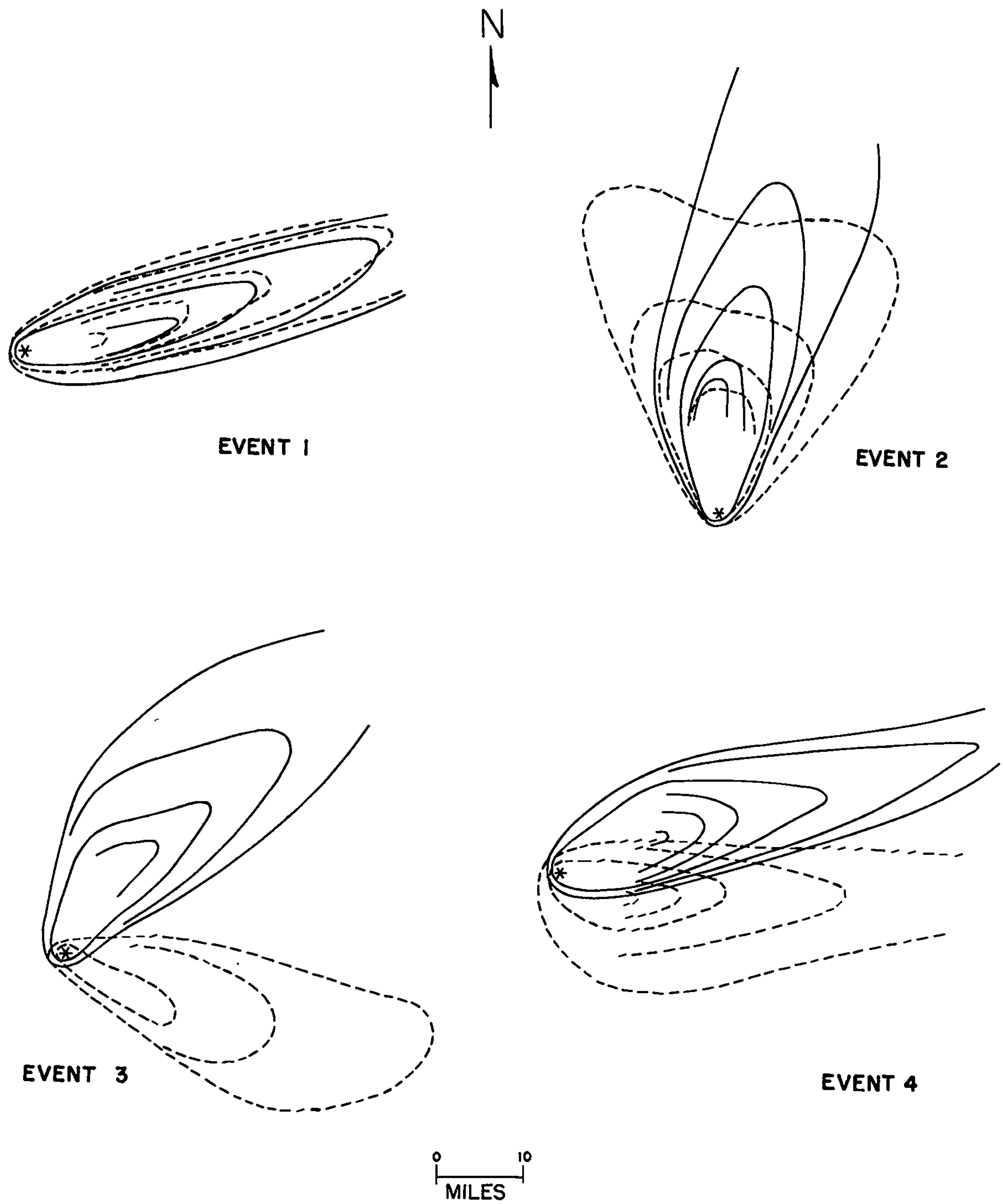

Fig. 7 H-hour fall-out patterns for Bikini (solid lines) and Eniwetok (dashed lines) winds. Infinite dose lines are drawn for 0.25 unit intervals; in addition, the 0.10 line is shown. The 0.10 and 0.50 lines have been carried around ground zero.

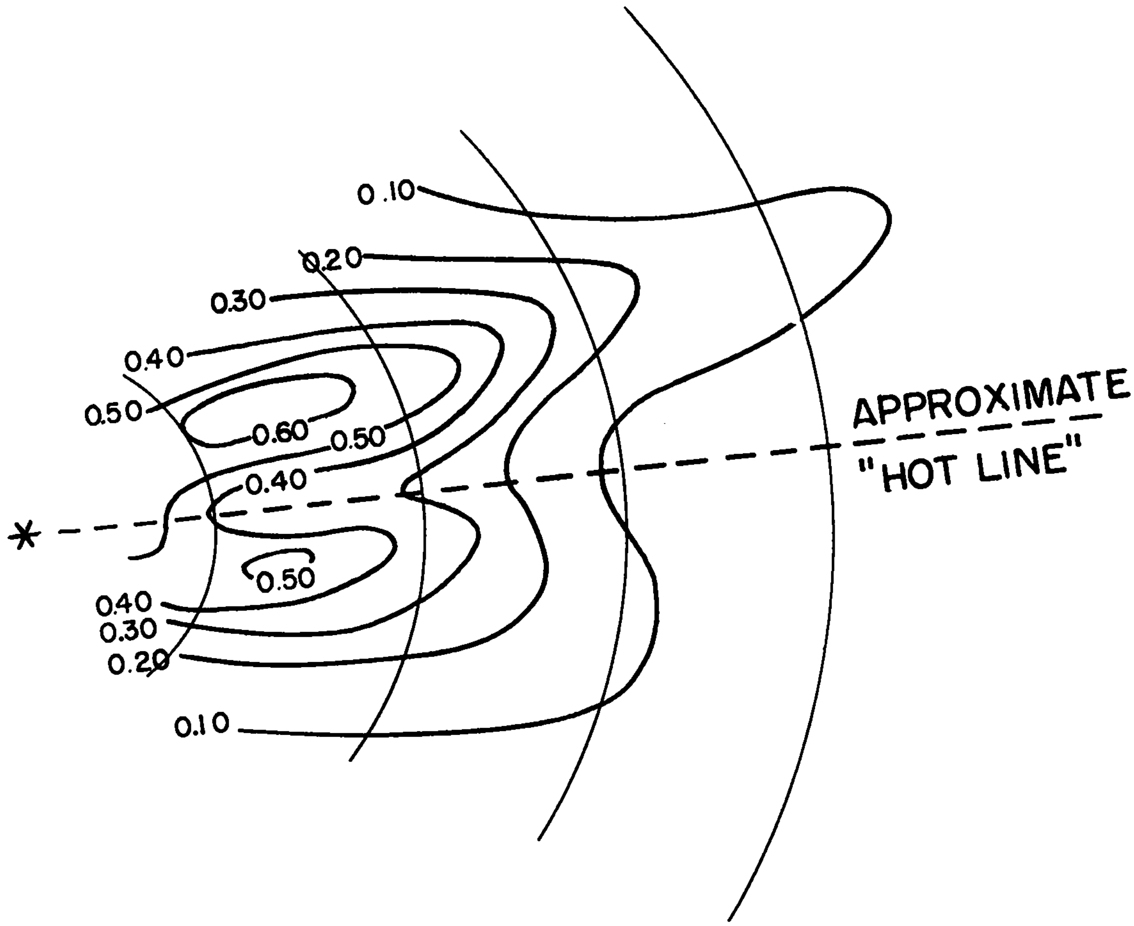

Fig. 8 The mean of the 3-hour standard deviation of fall-out intensity for the four events considered. The intensity unit is 10 r infinite dose and the distance circles are at 10-mile intervals from ground zero for a 50,000-foot, 50-kt fission-yield device. See text for interpretation and scaling to clouds of other heights and fission yields.

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Clearly the use of one-point winds is adequate for the protection of close-in installations, or of personnel on shipboard standing off shore. But for distant points it may be questioned whether any significant improvement over pure chance has occurred. Remember that for some 200 years, Spanish ships passed through the area on the route between the Isthmus of Panama and the Philippines and all this time failed to discover most of the Gilberts, Marshalls, or Carolines! Another illustration of the great expanses and small land areas involved is the fact that a hurricane, no inconsiderable object, can be completely lost between islands (cf. the Greenhouse experience).

Perhaps random shooting initially toward the void to the north will miss the outlying "targets" as often as they have been missed in the past (say nineteen times out of twenty). Perhaps in future operations also, nineteen times out of twenty the use of one-point winds for fall-out estimates will be accurate enough for safety, but even a 5 percent chance of error seems too much if there is a feasible alternative.

4. Conclusions

The marked shift in the fall-out situation during the 1-hour period illustrated in Fig. 1 from Crowson's data represents a sample of the sort of thing that can happen. We shall later discuss probabilities in terms of the standard deviations. This extreme case must be remembered since it should not simply be a mere matter of words when we say there is one chance in three, one in twenty, or what have you, of exceeding the intensities that we shall plot and discuss. A little thought will show that this kind of bodily moving parallel to itself of the major part of a hodograph is the sort of thing which can lead to the most serious changes in fall-out

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intensities over a short period of time. However, there is an encouraging aspect to this extreme situation. Two points should be made.

In the first place, the potentiality for such a situation is somewhat recognizable in advance. The upper part of the 1500-hour hodograph, Fig. 1(B), consists of winds already more or less lined up. This, then, can be brought into a "hot" situation by changes in only a small part of the atmosphere. On the other hand, a continually curving hodograph would require a whole complex of changes, <u>a priori</u> less probable simply because of the multiplicity of "just right" (or is it "wrong") changes required to occur simultaneously. Conversely, given a hodograph such as the narrow "hot" one of Fig. 1(A), which might be into an acceptable sector for fall-out, one would be aware that a change in a limited layer at the bottom of the atmosphere could spread the activity over a wide area. From either point of view, the situation is recognizable and the possibilities for a radical change will not have been ignored (this is not to guarantee that the forecast will be correct).

In the second place, the most likely situation in which changes in the wind through a limited atmospheric layer would result in great changes in the fall-out is the sort shown in Fig. 1, i.e., it is one wherein the relevant changes occur <u>in the lower part</u> of the atmosphere. Thus though little of the activity is initially in these layers, they become most important for the forecast. Since, after all, <u>every</u> particle falls through, and is influenced by the lower winds, this is not an unreasonable result. It is a fortunate one. Since more observational information is generally available for the lower level weather maps than for the higher ones, the forecasts for these lower levels ought to be the more reliable ones.

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Also, there is an operational consequence to be noted.

It may be more suitable to run the reconnaissance aircraft at low and intermediate rather than at very high (for aircraft) levels, even though initially the significant activity is mostly in these high levels. This will please the aircraft maintenance people.

Turning now from Crowson's data to the computations of this report, a second operational conclusion emerges. From the comparisons of fall-out patterns computed from simultaneous Bikini and Eniwetok winds (Fig. 4), it seems reasonable to conclude that one should not ignore the spatial variation in the winds existing at the time of the shot in making forecasts for places as far as 200 miles apart. Probably one-point winds may be used for close in, say the first 40 miles, but for greater distances, it would be desirable to take the initial spatial variability into account. This may well require a greater time for the preparation of the forecast decision. At this point we call upon the surprisingly similar orders of magnitude of the 3-hour and 6-hour standard deviations mentioned above in the discussion of Figs. 5 and 6. Since the 3-hour and 6-hour periods are essentially similar, if the additional 3 hours would enable the forecasters to use the last available analyzed map and so to take into account the spatial variability, this may well be more desirable than to sacrifice this opportunity in order to gain 3 hours.

Finally, in order to help people in making decisions on forecasts of fall-out, the map shown in Fig. 8 should be of some use. This is an estimate of the 3-hour standard deviations based upon the shot day winds for the four events. This figure is to be interpreted as follows: For a 50 kt fission yield cloud reaching to 50,000 feet, the standard deviations

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of the wind over a 3-hour period are as shown. For other yields, the intensity units, i.e., the labels of the standard deviation isolines, are to be multiplied by the factor Y/50, where Y is the actual fission yield in kilotons; for other cloud heights the distance markings, i.e., the scale of the map, change by the factor H/50, where H is the cloud height in 10^3 feet. This scaling law should be applied cautiously to clouds resulting from very big devices, since these standard deviations due to wind variability have been computed upon the basis of one-point wind fall-out plots, and we have already seen that these should not be reliable for distant fall-out. Further, there is no assurance that the variability of the tropospheric winds, here measured, is a valid measure for the variability of the stratospheric winds. This latter reservation is not too important a one, since obviously the very small sample of situations examined is by far a greater limitation upon the reliability of our conclusions. It might also be remembered that a purely computational uncertainty of ± 0.1 unit occurs.

With these limitations and scaling laws in mind, we return to the interpretation of Fig. 8. The standard deviations there plotted are a measure of the upper limit of shot-time-wind forecasts, assuming, as we have, that the forecasts are as good or better than persistence forecasts. This means that for a 50-kt, 50,000-foot cloud, the isolines as plotted will be exceeded by the 3-hour persistence wind forecast error about one time in three. If the labels of the isolines are doubled (i.e., if we look at twice the standard deviations), then these new values will be exceeded by the 3-hour persistence wind forecast error only one time in twenty.

It should be emphasized that these conclusions are with respect to

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the <u>wind errors only</u>; they do not take into account errors due to faulty estimates of yield, or cloud dimension, or to failure of all clouds "to be alike." A comment or two on these errors, although not within the essential scope of this note, may not be amiss. Errors of decision due to faulty estimates of the fission yield should not be serious. The change in the fall-out pattern due to a change in fission yield is a proportional change in the dose intensities; the possible range ought to be easily considered during the shot decision briefing. Changes in total yield lead to changes in cloud geometry; hence, possible effects due to errors from this source are not so easily considered. However, in principle, there is no reason the Fall-out Prediction Unit cannot prepare three predictions: One for the most probable, one for the maximum, and one for the minimum estimated yield. These would involve different sets of winds. In practice, limitations in number of personnel may make such a full presentation unfeasible. Errors due to failures of all clouds "to be alike", i.e., to satisfy the basic premise upon which fall-out forecasting is based, cannot now be prevented. At best, <u>if</u> such errors occur in any significant sense, we can only hope to learn to understand why clouds differ and then to treat only each of the various categories as "being alike."

5. Acknowledgments

The author is indebted to several of his Los Alamos Scientific Laboratory colleagues for technical advice which made preparation of this paper possible. R. K. Zeigler and R. H. Moore of T-Division gave advice with respect to means of estimating the standard deviation of serial data, such as that with which we were here concerned. H. I. Israel of H-Division

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provided the necessary card deck, instructions in its use, and at least one evening of his time in the 701 machine room during the computation of the basic fall-out patterns.

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