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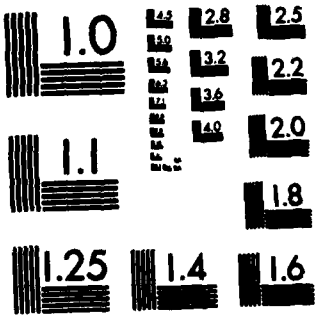

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A problem involving overestimates of tropical cyclone wind probabilities for locations that are heavily terrain-influenced is described. Previous studies on this topic are reviewed. A method is described to adjust wind probabilities for terrain, and it is applied for the two Navy ports of Cubi Point, RP, and Yokosuka, JA. Probabilities with and without terrain modifications are tested, and the results are analyzed and compared. The study concludes that the resulting lower wind probabilities are a substantial improvement over the unmodified probabilities.

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1. Introduction

The present version of the Navy tropical cyclone WIND probability model assumes the winds are over water. For locations in rough terrain this assumption causes serious overestimates of the probabilities of 30 and 50 kt winds. This report describes a method by which wind probabilities are terrain adjusted. Independent testing of the method is reported and comparisons are made of probabilities with and without the modification. Two western Pacific Navy ports, Cubi Point on Subic Bay in the Philippines, and Yokosuka in Japan, were selected for demonstration sites of wind probability terrain modification. These sites were chosen because of a combination of fleet importance coupled with good terrain protection from typhoon winds. It is presupposed that this latter factor is the reason that over water wind probabilities are too high for these bases.

2. Background

The forerunner for this work was an Air Force study of typhoons passing in the vicinity of Air Force Bases in the Pacific by Atkinson and Penland (1967)[1] and recently updated by Pettett (1980)[2]. In these studies, the winds observed at the base were described as a percentage of central winds in the passing typhoons, while the typhoons were located in various grid spaces on a grid centered on the station. Similar studies were recently completed for Cubi Point and Yokosuka by Englebretson and Jarrell (1982)[3,4]. Figure 1 shows the grid used on these latter studies.

Figure 2 depicts the maximum, median and minimum percentage of the tropical cyclones center winds observed at the station when a tropical storm or depression was

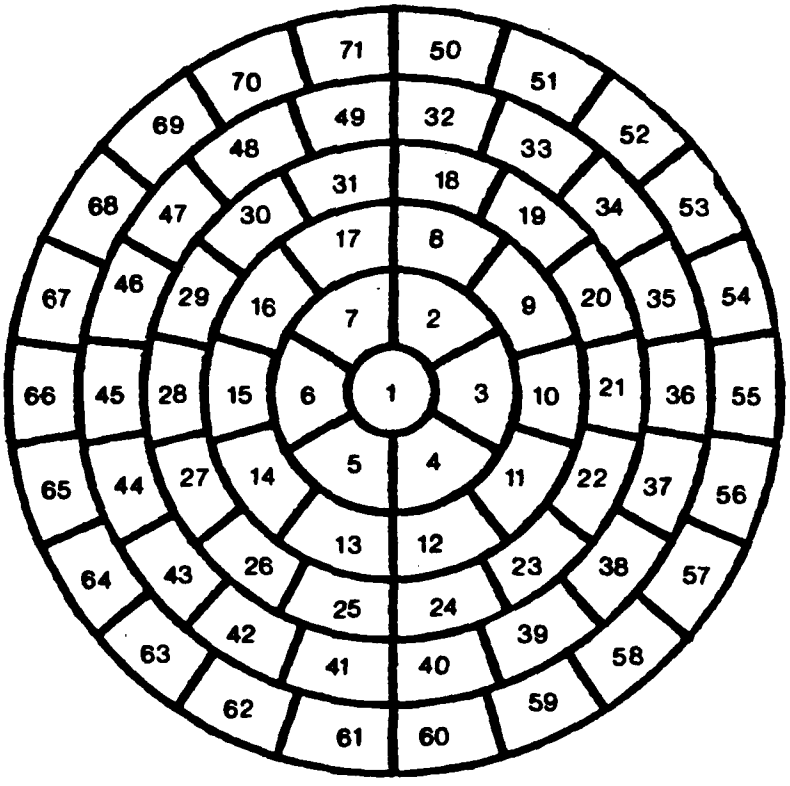

Figure 1. A 360 n mi radius circle divided into 71 equal area (5734.5 n mi^2) segments which can be centered on the station of interest. The circle is comprised of an inner circle and five surrounding rings. The radial thickness of each ring is approximately 60 n mi, but is not a constant. The segments are numbered from the inner circle and spiral outward.

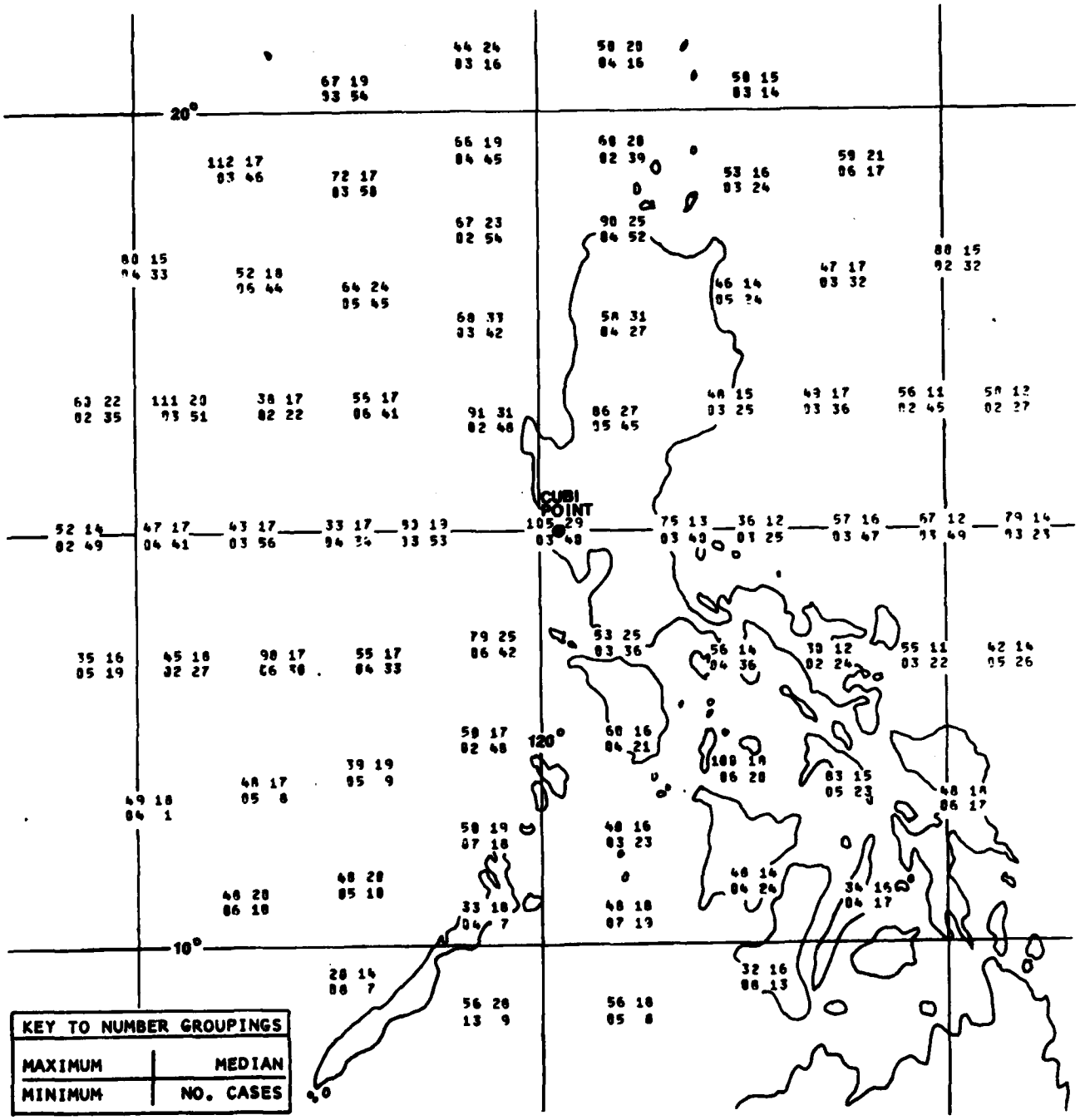

Figure 2. Depiction of the maximum, median, and minimum percentage of center winds from Cubi Point, RP, when a tropical storm or depression was located in the grid spaces.

located in the grid spaces. These percentages are often referred to as wind ratios, a convention which will be followed in later sections. Figure 3 shows the comparable maximum, median and minimum wind ratios when a typhoon was located in the grid spaces. Figures 4 and 5 are a similar set of diagrams for Yokosuka.

Figure 6 shows a graph of the typhoon wind ratio data from grid space 1 (central grid space from Figure 3) for Cubi Point. Knowing, for example, that a typhoon with 90-kt center winds will be in this grid space, the curve of Figure 6, treated as a cumulative distribution, can be used to estimate the probability of 30- or 50-kt winds. In this example, in order to receive 30-kt winds at the station, we must observe 30/90 or 33% of the maximum. From Figure 6 we see that the ratio was below 33% in about 65% of the past cases. Thus we conclude the probability of above 30-kt winds is about 35% (100-65). Similarly for 50-kt winds we must observe a wind ratio of 50/90 or 56%. Since ratios in excess of 50% have not been observed we conclude the probability is near zero of a 90-kt typhoon causing 50-kt winds at Cubi Point while it is located in sector 1. These probabilities are conditional, valid only if the conditions (the typhoon is in grid space 1 and has 90-kt center winds) are met.

The foregoing example may seem paradoxical in that it may appear impossible to have a 90-kt typhoon pass essentially over the station and yet the station observes no more than 50-kt winds. This is the very idea of terrain protection; in an actual event such as this, ninety knot winds may not have been measured anywhere, partly because there are so few anomometers. Additionally the post

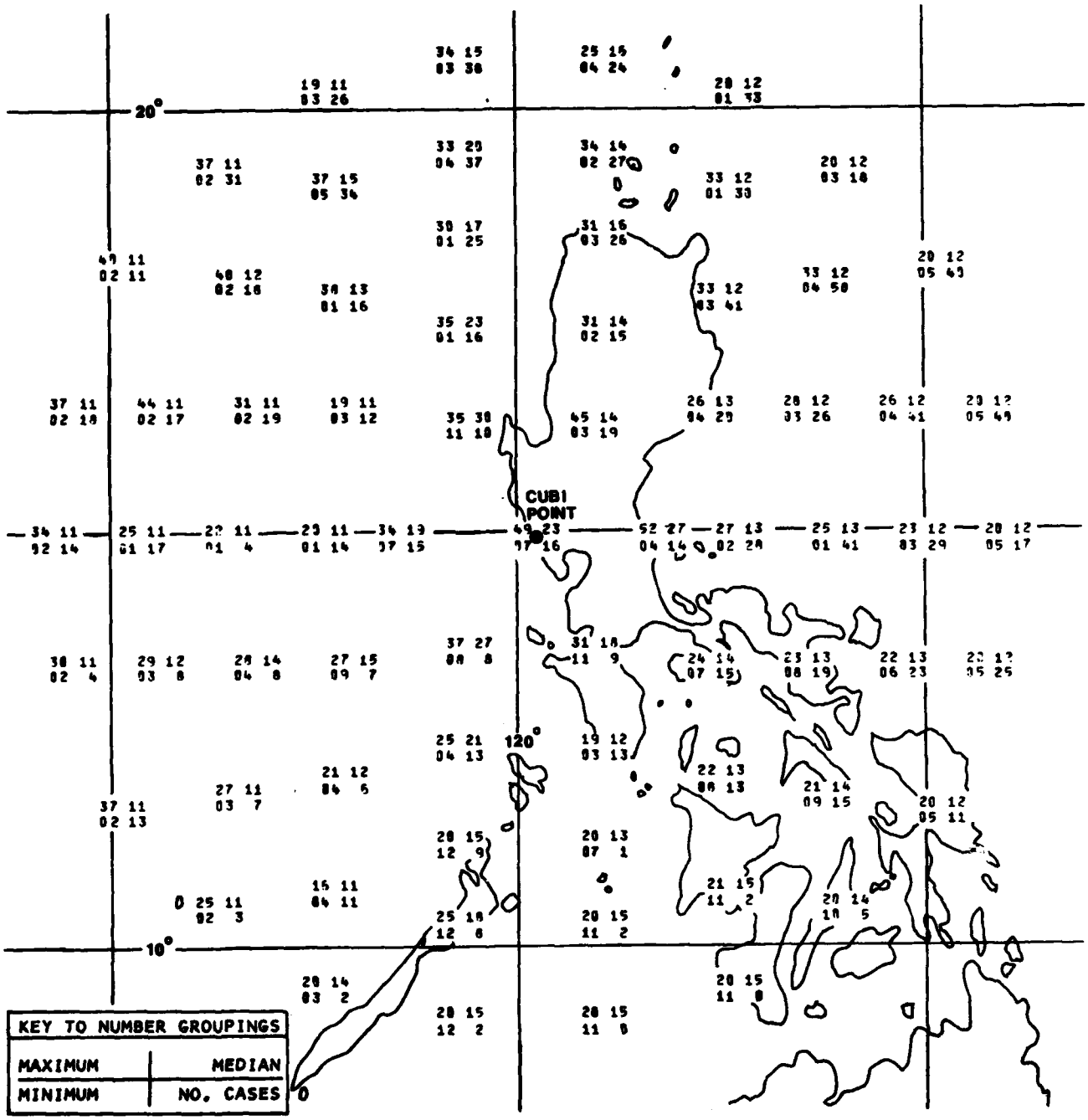

Figure 3. Depiction of the maximum, median, and minimum percentage of center winds from Cubi Point, RP, when a typhoon was located in the center grid spaces.

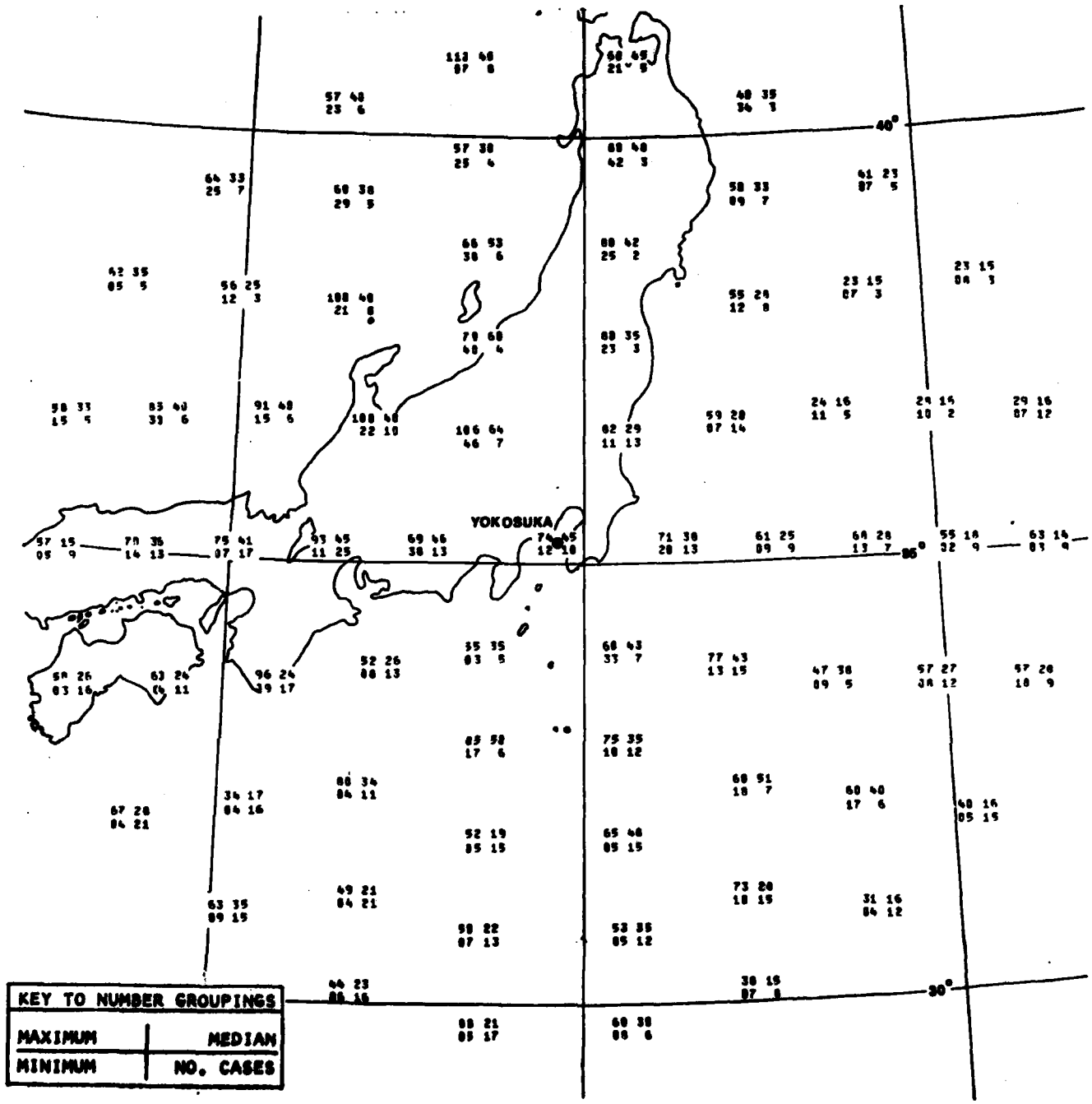

Figure 4. Depiction of the maximum, median, and minimum percentage of center winds from Yokosuka, JA when a tropical storm or depression was located in the grid spaces.

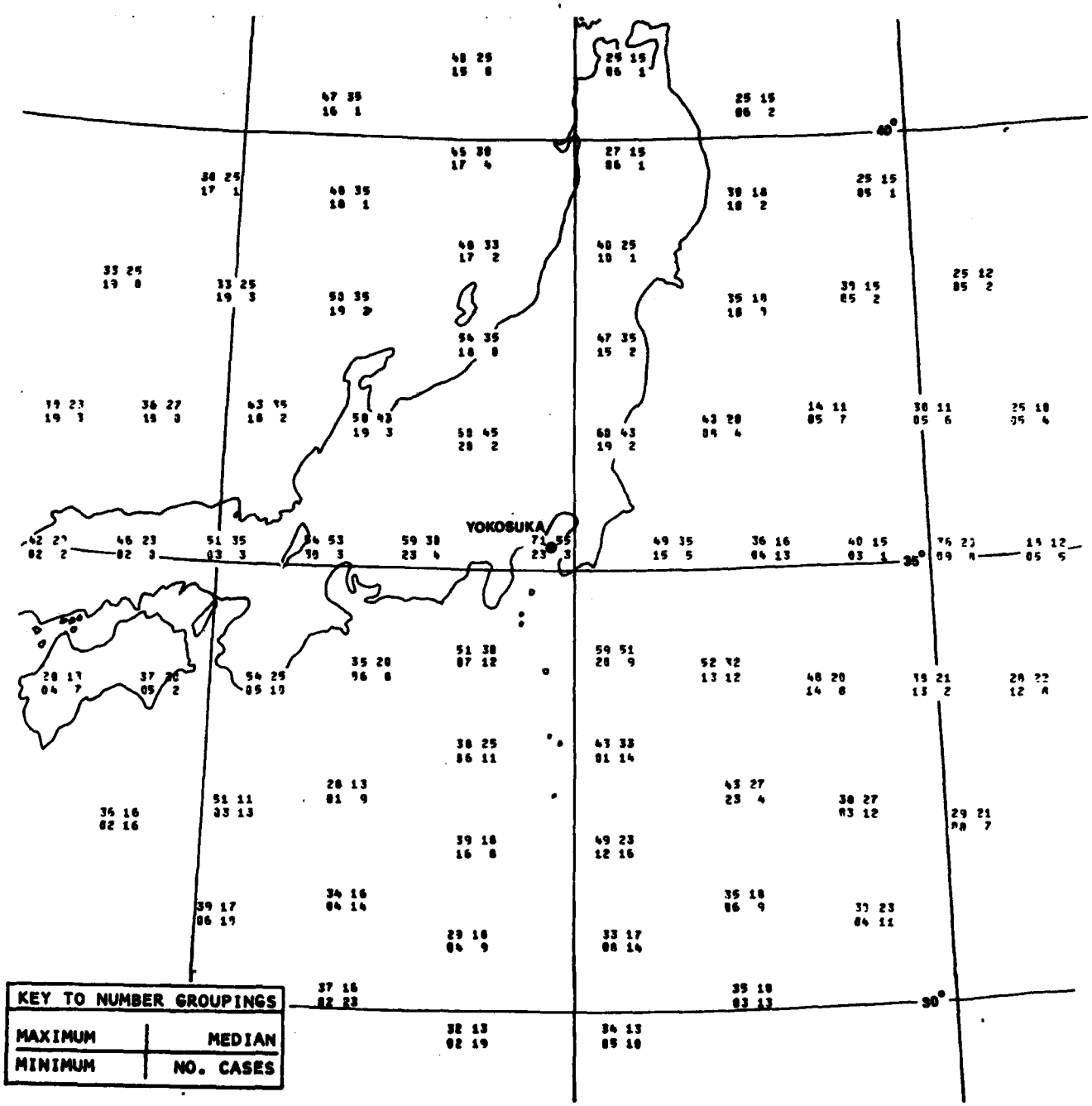

Figure 5. Depiction of the maximum, median, and minimum percentage of center winds from Yokosuka, JA when a typhoon was located in the grid spaces.

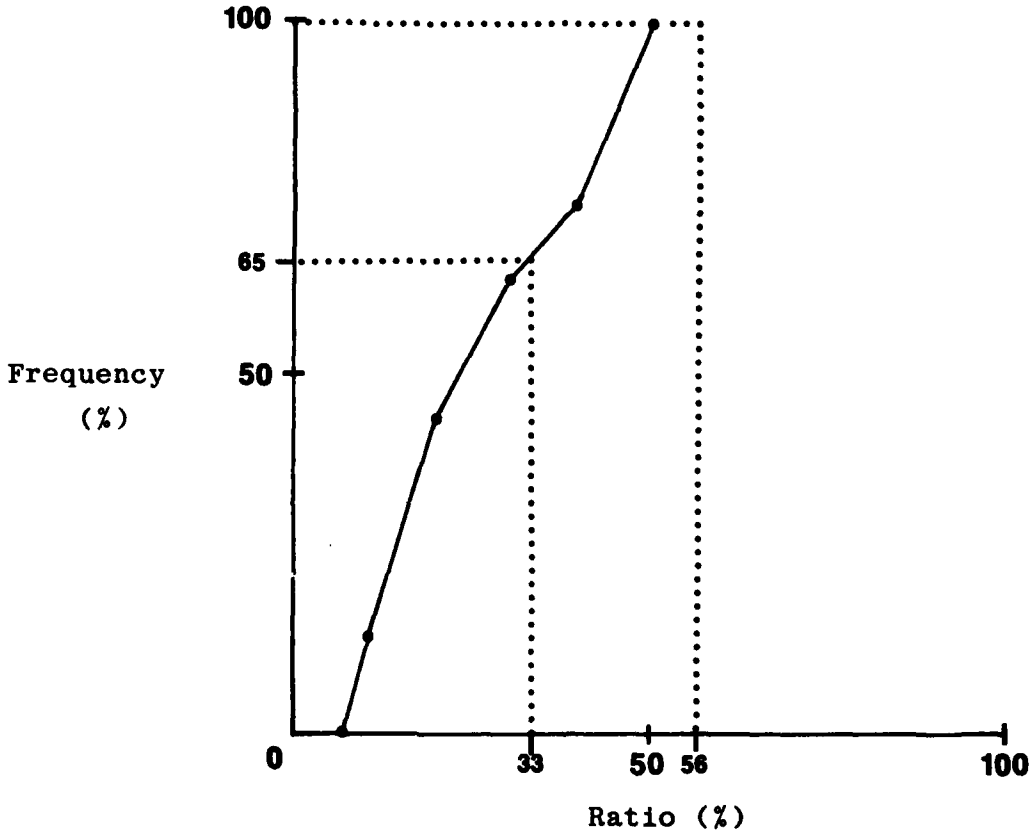

Figure 6. Cumulative frequency distribution of the ratio of winds observed at Cubi Point to typhoon center wind for typhoons located on grid space 1 (see Figures 1 and 3). The dotted lines refer to an example cited in the text.

analysis value of 90 kt represents a potential maximum wind usually determined by minimum sea level pressure. Actual sustained winds occurring, while usually not measured, may well be substantially above or below that potential depending on terrain influence. Notice from Figure 3 that 16 typhoons (winds over 63 kt) have passed through the central grid space yet sustained typhoon force winds have never been observed at Cubi Point.

The terrain wind probability program allows for the typhoon being in any grid space and having center winds of any value from 20 to 150 kts. The product of the conditional wind probability times the probability of the conditions being met is referred to as a marginal wind probability. The actual wind probabiltiy is the sum of these marginal wind probabilities over all grid spaces and all maximum central wind speeds for a particular forecast time.

This process of computing and summing marginal probabilities is much slower than the equivalent overwater computation. Consequently it is cheaper to first compute the overwater probability and then compute the terrain probability only if the overwater probability is significant (over 1%). This procedure was adopted on the WINDP modification. Figure 7 illustrates the wind probability output message for Typhoon Nancy (Oct 82) before and after the terrain modification.

3. Testing

The terrain modification was entered and tests were conducted on 1980-1981 tropical cyclones which passed within 300 n mi of Cubi Point or Yokosuka. It should be

Strike and Wind Probability Message Before Modification

```
STRIKE AND WIND PROBABILITY FORECASTS
NANCY      080600Z
KADENA AB   00ININ  12ININ  24ININ  36ININ  48ININ  60ININ  72ININ
  50 KNOT   00ININ  12ININ  24ININ  36ININ  48ININ  60ININ  72ININ
  30 KNOT   000202  12IN02  24IN02  36IN02  48IN02  60IN02  72IN02
YOKOSUKA    00ININ  12ININ  24ININ  36ININ  48ININ  60ININ  72ININ
  50 KNOT   00ININ  12IN02  24IN02  36IN02  48IN02  60IN02  72IN02
  30 KNOT   001717  121066  24IN68  36IN68  48IN68  60IN68  72IN68
YOKOTA AB   00ININ  12ININ  24ININ  36ININ  48ININ  60ININ  72ININ
  50 KNOT   00ININ  12IN01  24IN01  36IN01  48IN01  60IN01  72IN01
  30 KNOT   001313  120654  24IN55  36IN55  48IN55  60IN55  72IN55
CHEJU-DO    00ININ  12ININ  24ININ  36ININ  48ININ  60ININ  72ININ
  50 KNOT   00ININ  12ININ  24ININ  36ININ  48ININ  60ININ  72ININ
  30 KNOT   000101  12IN01  24IN01  36IN01  48IN01  60IN01  72IN01
MISAWA JA   00ININ  12ININ  24ININ  36ININ  48ININ  60ININ  72ININ
  50 KNOT   00ININ  12ININ  24ININ  36ININ  48ININ  60ININ  72ININ
  30 KNOT   00ININ  12IN02  24IN02  36IN02  48IN02  60IN02  72IN02
```

Strike and Wind Probability Message After Modification

```
STRIKE AND WIND PROBABILITY FORECASTS
NANCY      080600Z
KADENA AB   00ININ  12ININ  24ININ  36ININ  48ININ  60ININ  72ININ
  50 KNOT   00ININ  12ININ  24ININ  36ININ  48ININ  60ININ  72ININ
  30 KNOT   000202  12IN02  24IN02  36IN02  48IN02  60IN02  72IN02
*YOKOSUKA   00ININ  12ININ  24ININ  36ININ  48ININ  60ININ  72ININ
  50 KNOT   00ININ  12IN01  24IN01  36IN01  48IN01  60IN01  72IN01
  30 KNOT   000202  120235  24IN35  36IN35  48IN35  60IN35  72IN35
YOKOTA AB   00ININ  12ININ  24ININ  36ININ  48ININ  60ININ  72ININ
  50 KNOT   00ININ  12IN01  24IN01  36IN01  48IN01  60IN01  72IN01
  30 KNOT   001313  120654  24IN55  36IN55  48IN55  60IN55  72IN55
CHEJU-DO    00ININ  12ININ  24ININ  36ININ  48ININ  60ININ  72ININ
  50 KNOT   00ININ  12ININ  24ININ  36ININ  48ININ  60ININ  72ININ
  30 KNOT   000101  12IN01  24IN01  36IN01  48IN01  60IN01  72IN01
MISAWA JA   00ININ  12ININ  24ININ  36ININ  48ININ  60ININ  72ININ
  50 KNOT   00ININ  12ININ  24ININ  36ININ  48ININ  60ININ  72ININ
  30 KNOT   00ININ  12IN02  24IN02  36IN02  48IN02  60IN02  72IN02
*THESE WIND PROBABILITIES ALLOW FOR TERRAIN
```

Figure 7. Depiction of a western Pacific wind probability message for Typhoon Nancy, October 1982 before and after the terrain modification. Notice that only the wind probabilities for Yokosuka are changed. Had Subic Bay been significantly threatened, those wind probabilities would also have been terrain modified.

noted that no forecasts from these cyclones were used at any point in the development process so they represent independent test data. There were 13 storms passing Cubi Point and 5 passing Yokosuka.

Table 1 compares the average 24-hour wind probabilities before and after the terrain adjustment. The reduction is quite dramatic and reflects the effective wind protection afforded both bases by hilly terrain. The average overwater probabilities may appear surprisingly high to some readers. This is true because those with near zero (<1%) 30 kt probabilities are excluded since they were not modified. A second factor is the preselection of tropical cyclones which came within 300 n mi of the two bases thus biasing the data sample. This bias occurs because we already know the cyclones came within 300 n mi of one of the bases. The real probability of that base receiving 30-kt winds is much higher than it would be if it were simply forecast to pass within 300 n mi, which is the probability we calculate. The bias is less in short range forecasts because the fact of the cyclone being within the 300 n mi circle is nearly as well known in the short range forecasts as in the observation. Because of this bias we expect to see observations of 30- and 50-kt winds exceed what would normally be expected by chance. This should be reflected similarly in verification of the overwater as well as the terrain modified probabilities.

Table 2 compares the observed to the expected occurrences by both the overwater and terrain adjusted models for both sites. In the Cubi Point data, the actual occurrences of 30 and 50 kt winds compares markedly better in every case to expectation based on the terrain adjusted probabilities than to that based on the unmodified probabilities.

	CUBI POINT				YOKOSUKA			
	30 KT		50 KT		30 KT		50 KT	
	INST	T.INT	INST	T.INT	INST	T.INT	INST	T.INT
Before	.180	.342	.032	.097	.038	.201	.010	.056
After	.014	.077	.000	.003	.015	.086	.000	.001
Cases	132				47			

Table 1. Average 24-hour wind probabilities by overwater assumption (before) and terrain modification (after). Cases where the unmodified 30 kt probability was less than 1% are excluded from the averages since these were not modified. INST and T.INT are instantaneous and time integrated probabilities.

In the Yokosuka data the comparison was unchanged or improved in 13 of the 16 comparisons. There is a hint in the 30 kt results that probabilities might be underestimated by the terrain adjusted model. In reality this result is consistent with the test sampling bias and does not reflect on the reliablility of the terrain adjusted probabilities. The same results not being evident at Cubi Point is viewed as a statistical aberration, albeit a rather minor departure from the norm.

		Cubi Point				Yokosuka			
		0hr	24h	48hr	72hr	0hr	24hr	48hr	72hr
30-kt Instantaneous	Overwater Expected	16	24	15	5	4	3	2	1
	Terrain Expected	1	2	1	0	1	1	1	0
	Observed	0	0	0	0	2	3	2	2
30-kt Time Integrated	Overwater Expected	16	45	53	45	4	9	7	4
	Terrain Expected	1	10	14	13	1	4	3	2
	Observed	0	3	11	16	2	5	4	3
50-kt Instantaneous	Overwater Expected	2	4	3	1	1	0	0	0
	Terrain Expected	0	0	0	0	0	0	0	0
	Observed	0	0	0	0	0	0	0	0
50-kt Time Integrated	Overwater Expected	2	13	19	18	1	3	2	2
	Terrain Expected	0	0	1	1	0	0	0	0
	Observed	0	0	0	0	0	0	0	0

Table 2. Expected occurrences of 30 and 50 kt winds based on a comparison of overwater and terrain adjusted observations versus actual observations.

4. Conclusion

Of the two models (the WINDP model that assumes winds are over water, and the WINDP model that considers the site terrain), the terrain adjusted model consistently forecast lower, more realistic probabilities for the terrain protected locations. Both the Cubi Point and the Yokosuka data sets confirm that the terrain adjusted wind probabilities are a suitable measure of the threat of 30- and 50-kt winds at these bases. It is recommended, based on the results of this study, that terrain influence studies be completed for all locations where wind probabilities are calculated and where terrain influences are evident. For those sites where terrain influences have been documented, it is recommended that the WINDP be modified based on those studies.

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