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COST EFFECTIVENESS OF TYPHOON FORECAST IMPROVEMENTS

by

SAMSON BRAND AND JACK W. BLELLOCH

MAY 1974

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CONTENTS

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1. INTRODUCTION

One of the more difficult problems a military commander faces in the western North Pacific region is the question of whether or not to evacuate or sortie from a base or port due to an approaching tropical cyclone. When the commander finds himself in a situation where a storm suddenly appears 1000 n mi away and then the storm rapidly becomes 700 and then 400 n mi away, he has to make a decision whether to evacuate or sortie or to remain in base or port. This decision depends on a number of factors including the environmental aspects, the inherent safety and facilities of the base or harbor, and the types and numbers of the aircraft or ships involved. Because of the number of tropical cyclones traversing the western North Pacific each year (approximately 35), and the large number of ports and bases or installations that are used directly and indirectly by the U.S. military which may be in the paths of these tropical cyclones, such decisions, whether right or wrong, are made frequently.

In a typical year, there are approximately 150 days in which there are one or more tropical cyclone warnings issued by the Joint Typhoon Warning Center, Guam for the western North Pacific area. In addition, there are over 50 days in which 2 or more storms are present at the same time. To dramatically emphasize the problem, Figure 1 shows the surface synoptic map for the western North Pacific for 1200Z, 22 August 1960. The map shows five named tropical cyclones present at one time. This is not the typical everyday situation in the western North Pacific, but it does emphasize the fact that there are a lot of storms there.

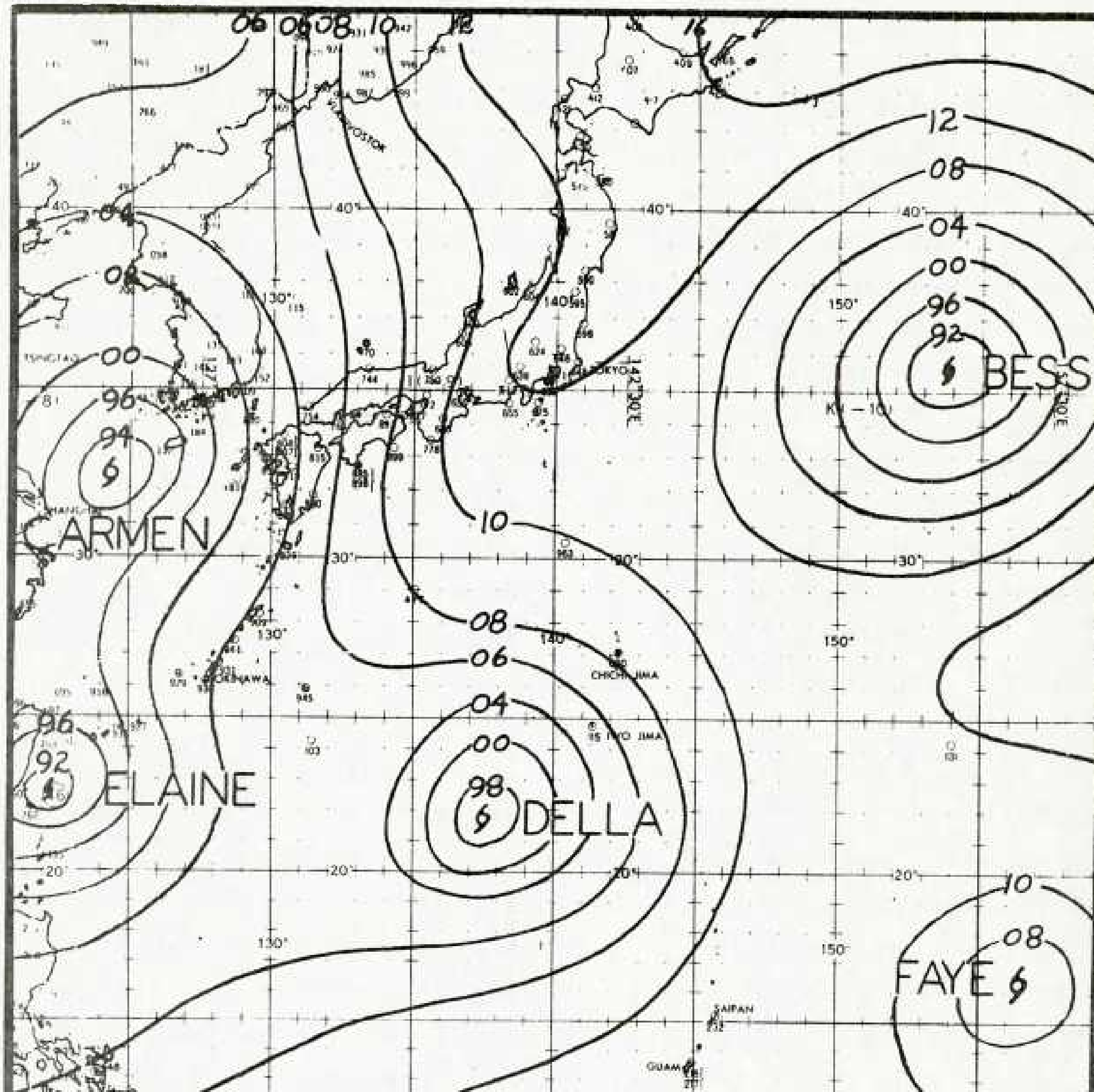

Figure 1. Surface synoptic map for 1200Z, 22 August 1960 (taken from cover of the 1960 Annual Typhoon Report (U.S. FWC/JTWC, 1960)).

Decision making is extremely dependent on the forecast track of the tropical cyclone as well as the forecast error associated with the storm track. In this study, an attempt has been made to examine this forecast error and discuss what improvements in this error would mean in terms of decision making, which in turn can be related directly to Department of Defense cost saving.

This study deals mainly with U.S. Navy cost saving in the western North Pacific region; but other DOD installations will also be discussed. It should be emphasized that decision lead times for ships are, of course, much longer than for aircraft evacuation or base preparedness. Ships have to get underway well before winds/seas start to significantly affect their ability to maneuver clear of a harbor and thereafter their speed-of-advance. Since decision errors are a function of forecast errors which are a function of time from the initial warning, a greater number of incorrect decisions could be expected for ships than for aircraft evacuation or base closures.

2. THE COST OF TYPHOON PREPAREDNESS, EVACUATION AND SORTIE

There are approximately fifty ports, used by the U.S. Navy or contracted DOD vessels in the western North Pacific area, which are liable to be affected by tropical cyclones. In addition, there are approximately 10 major Air Force bases and numerous other Army, Navy and Marine Corps installations located in the possible paths of these storms.

When a tropical cyclone develops and proceeds on a typical path in the western North Pacific, it can, on the average, critically affect several of these ports, bases or installations. This is discussed in further detail in the next section. In this section the costs concerning the decision to prepare and evacuate due to this threatening condition are examined in general terms.

The cost problem is much more complicated than simply analyzing the cost of preparation and evacuation or sortie. It includes such factors as estimated damage costs, lost time and recovery time, and even fuel availability. There are also intangible factors such as crew morale if a ship, for example, has to sail from a port soon after entering following a long tour at sea. Additionally, there are the strategic disadvantages brought about by evacuation, sortie, evasion or base closures and the resulting inability to support or complete a required mission. These factors are difficult to measure.

Malone and Leimer (1971) examined 22 Department of Defense hurricane-affected bases and installations in the western North Atlantic area to determine the savings to DOD if hurricane forecasts were improved. In terms of individual base or installation costs, they showed that the average hurricane preparedness and evacuation costs (including direct out-of-pocket costs, costs of manpower diverted from normal activities to storm preparations, and costs of manpower idled by cessation of normal activities) for each of the 22 western North Atlantic bases and installations was:

$8,100 if the tropical cyclone was forecast to result in 50-kt winds at the base or installation in 72 or 48 hr;

$45,000 if the tropical cyclone was forecast to result in 50-kt winds at the base or installation in 24 hr; and

$124,000 if the tropical cyclone was forecast to result in 50-kt winds at the base or installation in 12 hr.

By examining the number of unnecessary warning conditions issued by these bases and installations (based on 50-kt wind criteria warnings) and relating this to the cost of the warnings for each of the bases and installations, they found that the annual savings for the 22 installations would be $1.7 million if there was a 20% improvement in tropical cyclone forecasting. A 40% improvement was found to be equal to $3.2 million saved annually. If these cost savings are then related to the total number of western North Atlantic bases and installations that are affected by hurricanes (there were 167 major DOD installations that fit this category at the time of their study), the annual cost savings to DOD for a 20% improvement in forecasting would be equivalent to $1.7 \times \frac{167}{22}$ = $12.9 million. The annual cost savings to DOD for a 40% improvement in tropical cyclone forecasting in the western North Atlantic would be equivalent to $3.2 \times \frac{167}{22}$ = $24.3 million.[1]

[1]Since 1971 there have been a number of bases or installations closed in the western North Atlantic region, but this would be partially balanced by the present day higher costs. Also Malone and Leimer (1971) did not include evacuation costs of ships in port or evasion costs at sea.

In the western North Pacific area there are fewer U.S. military bases and installations than in the Atlantic but the costs of preparation and evacuation or sortie for an individual base and installation can be significantly more when considered on an annual basis. This is due essentially to the greater average number of western North Pacific tropical cyclones compared to Atlantic tropical cyclones (35 versus 10) and to the fact that evacuation of aircraft, for example, in the Pacific means traveling over a vast distance to a safe base or installation. Evacuation of aircraft from Guam, Okinawa, the Philippines, Japan or Taiwan can cost nearly twice as much (based on past experience - approximately $300,000 per evacuation) compared to the cost of evacuation from Atlantic or Gulf Coast bases.[2]

Naval vessels or contracted DOD vessels operating or traversing the western North Pacific area do not, of course, have the flexibility that aircraft have under threatening conditions and will, therefore, evade or sortie quite often well in advance of typhoon conditions. Typhoon evasion at sea can be disruptive in terms of ship routing or in operations. An example, schematically illustrated in Figure 2, shows the sea conditions associated with a typical recurving typhoon in the path of a ship crossing the Pacific. The greatest cost arises when the ship has to evacuate or sortie from a harbor which is not designated as a safe "typhoon haven."[3]

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[2]It should be noted that the cost of jet aircraft fuel went from $6.80 a barrel to $11.21 a barrel between 1 July 1973 and 1 February 1974. Evacuation costs for this coming typhoon season and future typhoon seasons would have to take this increase or further fluctuations into consideration.

[3]The Environmental Prediction Research Facility is presently evaluating 20 western North Pacific and Indian Ocean ports as typhoon havens. See for example, Mautner and Brand, 1973 (Hong Kong) and Brown, 1974 (Kaohsiung and Chilung, Taiwan).

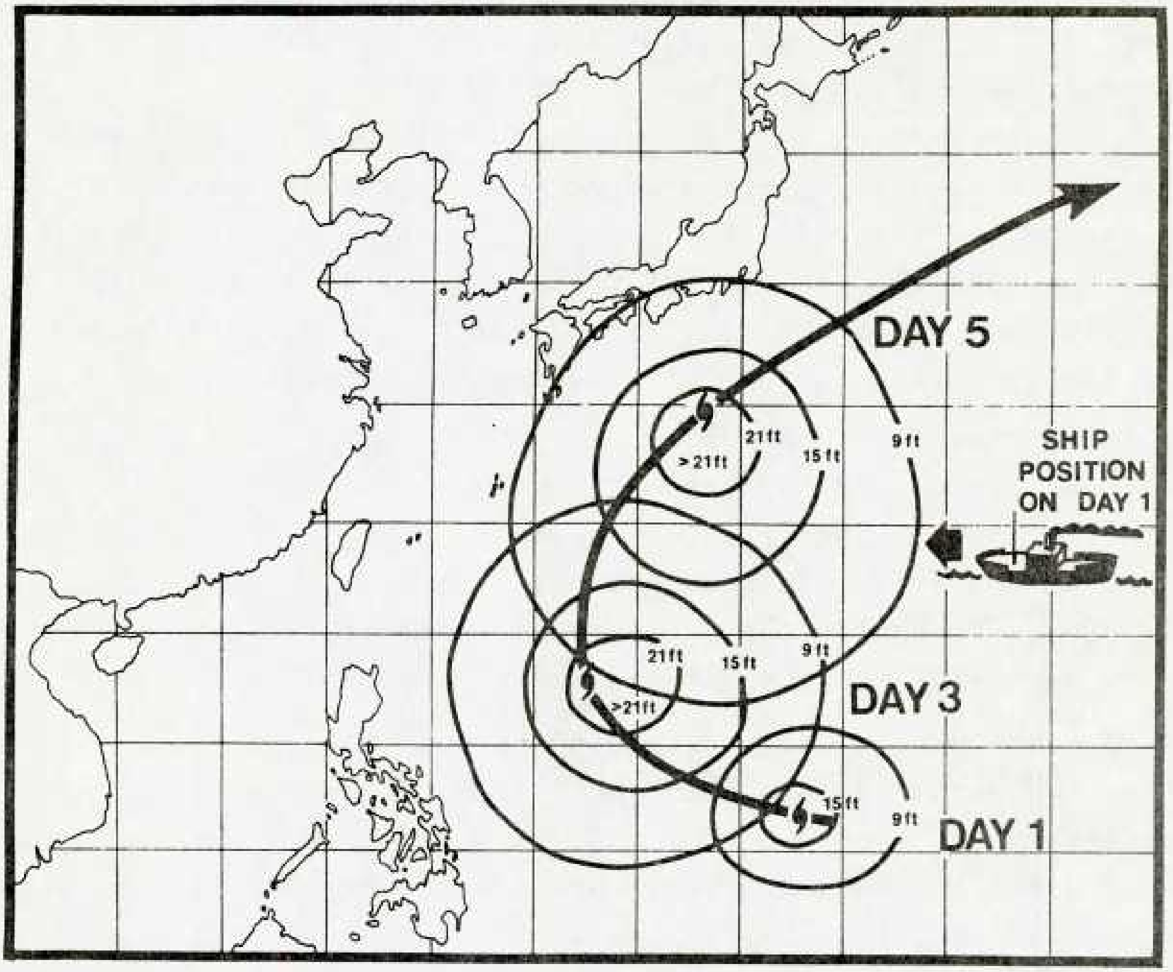

Figure 2. Schematic example of the ship routing problem encountered by ships traversing the western North Pacific during the typhoon season. This example shows representative sea-height values about a typical recurving typhoon. Note that sea conditions associated with the storm can cover a much larger area than the wind associated with the storm.

This problem is schematically illustrated in Figure 3, which summarizes the objective of the EPRF typhoon haven research study. The insert of this figure shows the USS REGULUS aground in Hong Kong harbor after a wrong decision concerning Typhoon Rose (August, 1971) was made. This error cost the U.S. Navy approximately $8-10 million.

On any particular day there are well over 50 Naval vessels, and approximately 50 chartered or contracted DOD vessels, traversing, operating, or in port in the western North Pacific region. Usually over half of these will be in port. Under threatening conditions, the sortie and return-to-port costs for these ships can be attributed to the following:

(a) Fuel consumption
(b) Pilot and tug fees
(c) Boat transportation to ship
(d) Getting ship ready to get underway
(e) For contracted DOD vessels there is the daily rate plus overtime costs to personnel.

These costs vary greatly depending on the size and type of ship, the port and available facilities, and the environmental conditions involved.

During sortie conditions, present day fuel costs can range, on the average, from $1,500/day for small ships (destroyers, etc.) to $5,000/day for medium size ships (amphibious or supply type) and to $30,000/day for large ships (carriers).

Pilot and tug fees vary greatly for western North Pacific ports, but can range from a few hundred dollars for small ships to over $5,000 (the cost for leaving and returning) for carriers for certain ports.

Under threatening conditions, costs of boat transportation to ships vary from less than a hundred dollars (small ships) to thousands of dollars for a carrier for certain ports.

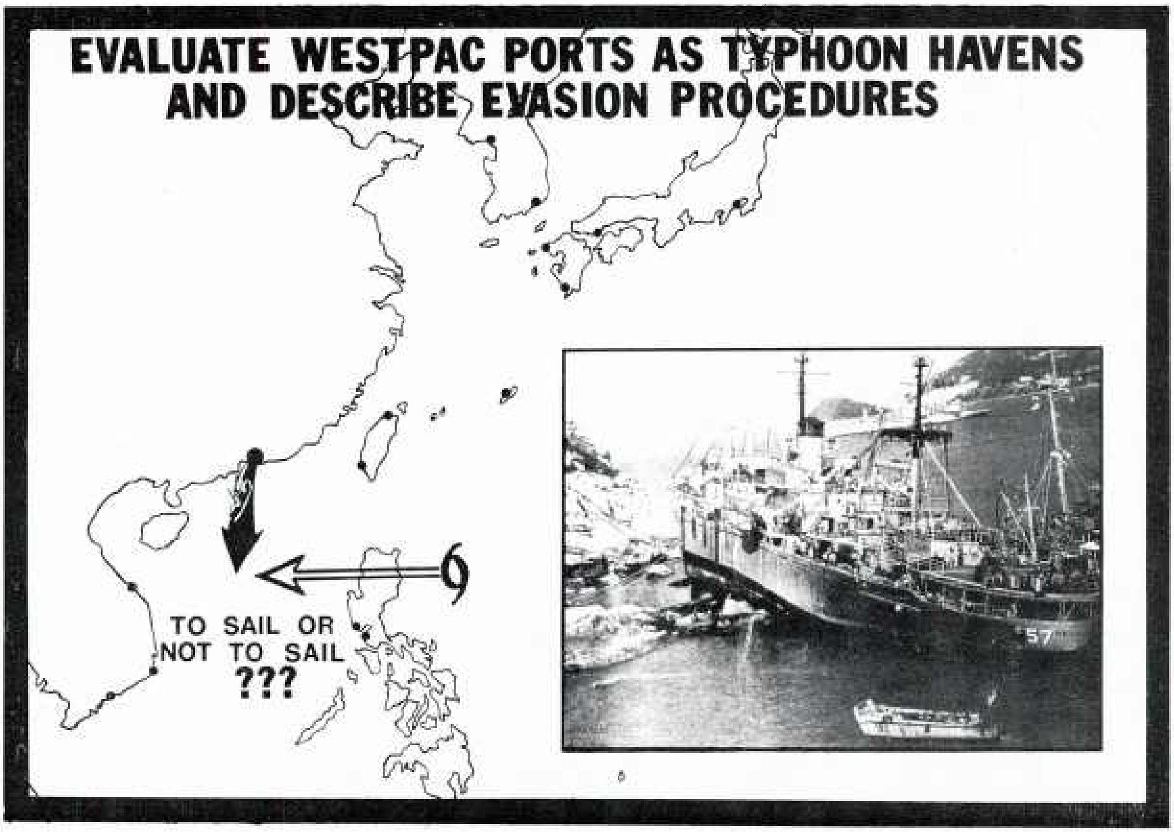

Figure 3. Schematic illustration describing the objective of the Environmental Prediction Research Facility typhoon haven research study. The insert shows the USS REGULUS aground in Hong Kong harbor after the passage of Typhoon Rose (August, 1971). Several of the ports that are presently being evaluated are shown as black dots.

The costs to "light off" the boilers and make ready for getting underway can range from hundreds of dollars to thousands of dollars for large ships.

For the nearly 50 chartered or contracted DOD vessels to be found in the western North Pacific on a typical day (of which approximately one half would be in port), the evacuation and evasion cost to DOD is very high. These ships, on the average, receive a daily rate of $8-10,000 to meet all expenses including fuel. If these ships have to sortie from port, DOD pays for each day during the period of evacuation plus overtime wages to the personnel. For those contracted or chartered vessels at sea traversing the western North Pacific area, the DOD cost of typhoon evasion or delays in ship routing is $8-10,000 per day for each day of lost time from their destination.

It is apparent that the annual cost for typhoon evasion and sortie in the western North Pacific for Naval vessels and contracted and chartered DOD vessels can reach into the millions of dollars.

Thus far the emphasis here has been on ship sortie or evasion costs, but it should also be kept in mind that, under threatening conditions, preparedness and evacuations can cost DOD millions of dollars at the many military installations located in the western North Pacific. These include: Army depots, forts, fields and arsenals; naval air stations, bases and training centers; Air Force bases; and Marine Corps bases and air stations. As indicated earlier, the costs for this type of preparation and evacuation are extremely high. The question then arises: How much of the total costs in the western North Pacific could be saved each year by making better decisions in terms of forecast improvements? This question is discussed in the next section.

3. COST EFFECTIVENESS OF TYPHOON FORECAST IMPROVEMENTS

Decision making for evacuation, sortie, or preparedness at any level is heavily based on the forecast track of the storm in question. Additionally, decisions by commanders also depend on the confidence or error associated with storm forecasting. This section examines the movement forecast errors associated with storms in terms of right-angle forecast error; that is, the forecast error to the right or left of the best track.[4] (See Figure 4.)

This right-angle forecast error differs from the vector error in that it depicts the error from the actual track. For 48 hr, for example, the average right-angle forecast error in the western North Pacific is approximately 145 n mi as compared to 244 n mi for the average 48-hr vector error.

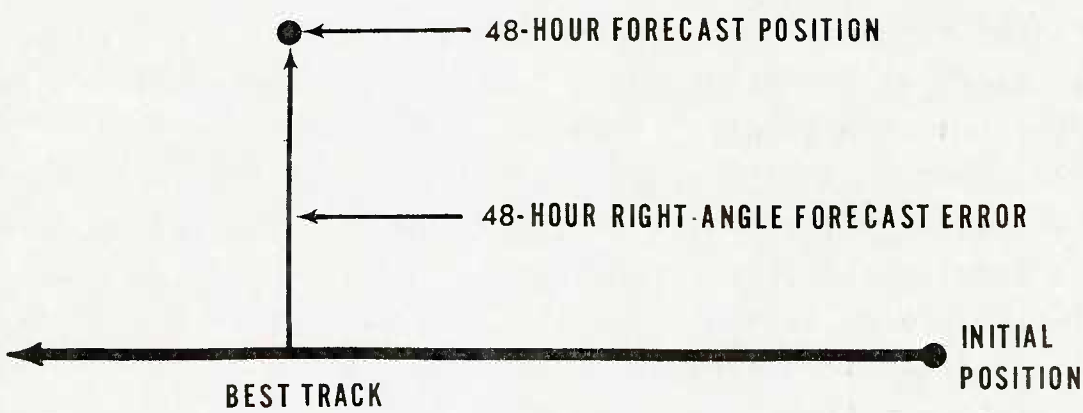

Figure 4. Schematic presentation of 48-hr, right-angle forecast error.

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[4] A post-analysis track incorporating all available information.

As a storm approaches a base or port, this right-angle forecast error becomes quite important because it is related to the forecast Closest Point of Approach (CPA) of the tropical cyclone. It is this forecast CPA which is important in decision making for bases and ports because the CPA values relative to these installations are associated with the critical wind speeds they will experience. If the commander could be assured of an accurate forecast of this critical wind speed, he could then make the correct decision for his installation.

As an example, the case of Okinawa (26.5N, 128.0E) was examined. It was first necessary to determine how many tropical cyclones passed near or had their CPA close to the island. In order to do this, the tracks of all tropical cyclones between 1947 and 1970 were examined and the CPA for each track was plotted relative to Okinawa for all CPA values within 600 n mi (see Figure 5A). A total of 339 tropical cyclones passed within 600 n mi of Okinawa in this 24-yr period. A plot was also made of the number of CPA values as a function of incremental radial distances out from Okinawa (0-60 n mi, 60-120 n mi, etc.). This can be seen in Figure 5B. For example, 34 tropical cyclones passed Okinawa with their CPA between 300 and 360 n mi.

To examine the cost effectiveness of 48-hr typhoon forecast improvements, certain assumptions were made in the following idealized depiction. These are:

(1) The western North Pacific right-angle forecast error for 48 hr is approximately 145 n mi.

(2) The distance from the storm center for a typical typhoon to the 30-kt isotach (wind) is about 200 n mi.

A criterion of 30 kt was set for evacuation or sortie and an examination was made as to what a 20% improvement in 48-hr forecast error would mean in terms of decision making for Okinawa. Based on the above assumptions, if a storm is approximately 2 days from Okinawa and if Okinawa falls within

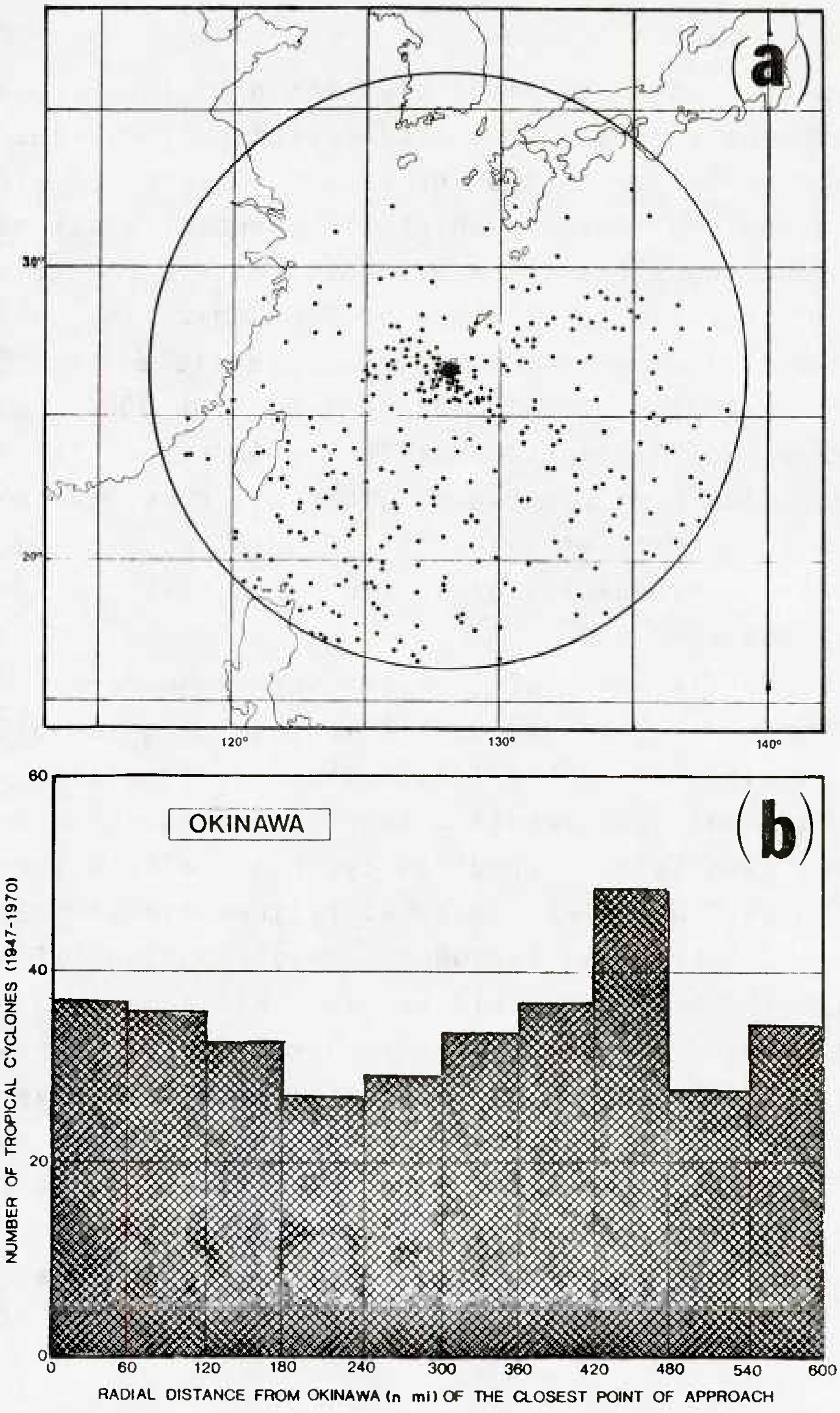

Figure 5. The Closest Point of Approach (CPA) for each tropical cyclone (1947-70) within 600 n mi of Okinawa (26.5N, 128.0E) is shown in section A (plotted as a dot). A total of 339 tropical cyclones passed within 600 n mi of Okinawa in this 24-yr period. Section B shows the number of tropical cyclones as a function of their CPA values at incremental radial distances from Okinawa. The radial distances are given in increments of 60 n mi. For example, 34 tropical cyclones passed Okinawa with their CPA between 300 and 360 n mi.

200 n mi (distance to 30-kt wind) plus 145 n mi (average 48-hr right-angle forecast error) from its predicted track, then the decision would be for evacuation or sortie. Figure 6A presents a schematic example of this in which the forecast track of a tropical cyclone shows the storm will pass with a CPA relative to Okinawa (in approximately 48 hr) of 330 n mi. The decision for this example is, then, to evacuate or sortie and the DOD cost for this example is arbitrarily set at $100,000.

If there was a 20% improvement in the 48-hr, right-angle forecast error (145 n mi reduced to 116 n mi) then Okinawa falls outside this critical value (see Figure 6B) and the decision is for no evacuation or sortie. The cost savings to DOD then would be $100,000.

For this idealized example, we can then examine how many tropical cyclones per year would fall in this range of 316 n mi (200 + 116) to 345 n mi (200 + 145). Since 34 tropical cyclones (1947-1970) had their CPA relative to Okinawa between 300-360 n mi, then approximately 17 tropical cyclones fall in the range from 316-345 n mi. Seventeen tropical cyclones in 24 years is equivalent to 0.71 tropical cyclones per year passing with their CPA to Okinawa in this "critical" range. This same type of approach can be used for other western North Pacific ports/bases (see Figures 7-13). Because of protective or dissipative land effects, the 600 n mi radial circle is not used for all the situations. For example, Figure 7 for Hong Kong shows only those CPA values for tropical cyclones in the semicircle to the south and east relative to Hong Kong. It is tropical cyclones in this region which cause the severe winds at Hong Kong.[5]

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[5] See ENVPREDRSCHFAC Technical Paper No. 9-73, "An Evaluation of Hong Kong Harbor as a Typhoon Haven" (Mautner and Brand, 1973), for a detailed discussion on the effects of tropical cyclones on the harbor.

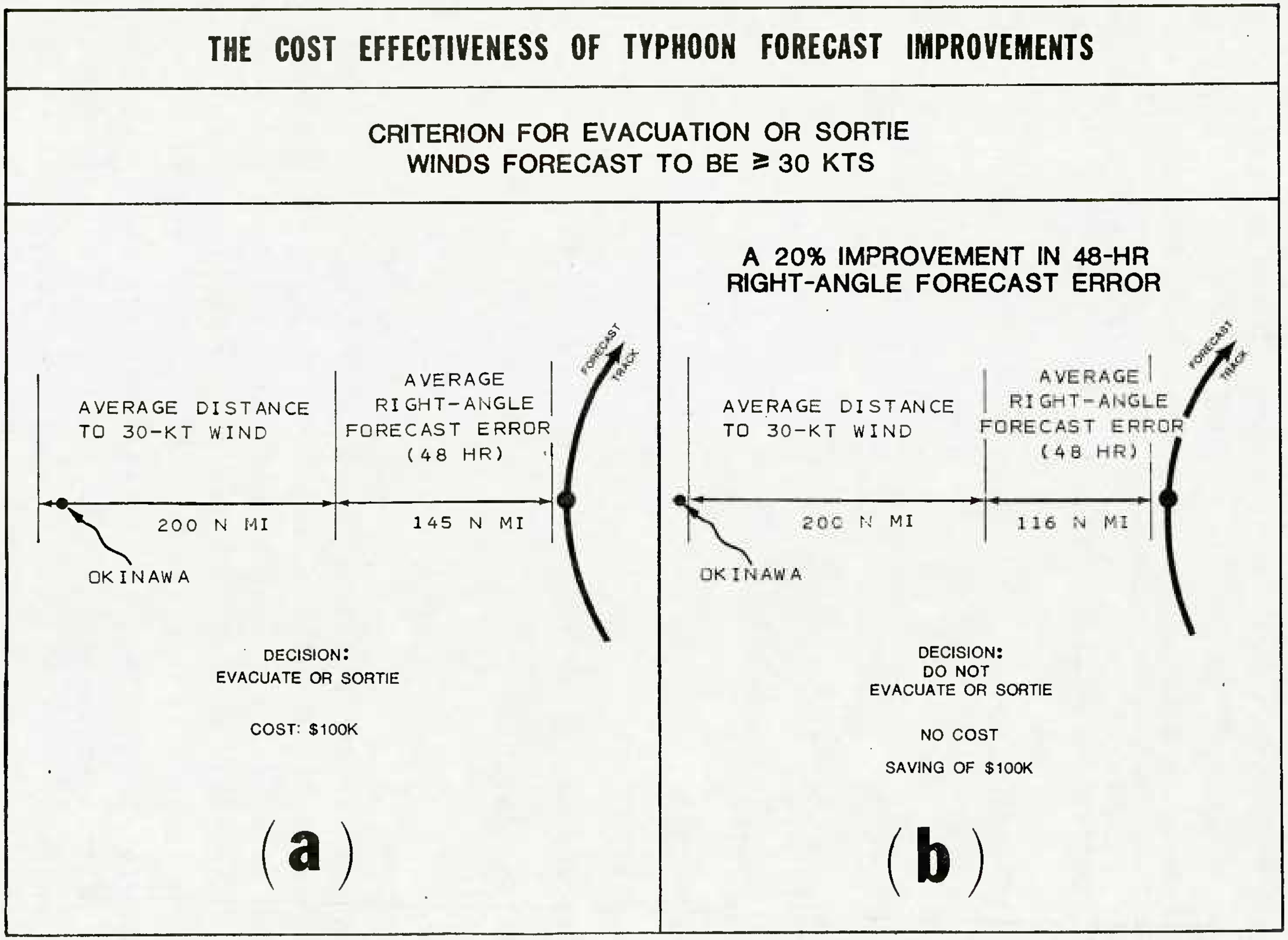

Figure 6. Schematic illustration of the cost effectiveness of a 20% improvement in 48-hr, right-angle typhoon forecast error.

Table 1 summarizes these "critical" range values for decision making, at the criterion level of 30-kt winds, for the selected ports/bases shown in Figures 5 and 7-13.

Table 1. The number of tropical cyclones/year falling in the 316-345 n mi "critical" range for several western North Pacific ports/bases. The range is based on a 20% improvement in the average 48-hr right-angle forecast error.

Ports/Bases	Number of tropical cyclones/ year in the 316-345 n mi range
Okinawa	0.71
Hong Kong	0.62
Manila Bay/Subic Bay, Philippines	1.12
Kaohsiung, Taiwan	0.90
Chilung (Keelung), Taiwan	0.87
Sasebo, Japan	0.48
Yokosuka/Yokohama, Japan	0.46
Guam, Mariana Islands	0.69
Total	5.85

In the idealized model (schematically shown by Figure 6) each tropical cyclone falling in the critical range represents a decision which could have been different had the forecast error been improved by 20%. The total number of tropical cyclones in Table 1 represents 5.85 "incorrect" decisions for the 8 ports/bases considered. These incorrect decisions then could be related to potential cost saving. If each incorrect decision means an average cost liability of $50,000, then the annual savings would be $292,500 per year for this sample.[6] Note that this is only a small sample of the total number of bases, installations and ports used by the U.S. military in the western North Pacific. It is apparent that even if conservative cost estimates of incorrect decision making at all levels from early preparation to mass evacuation or sortie are used, the cost can run into millions of dollars per year. It is this cost which could be saved by DOD, if average forecast errors are reduced by 20%.

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[6]Some of these ports/bases are considered sheltered from the effects of tropical cyclones and thus the cost would be less than this average value and be in the form of preparedness and diverted and idled manpower. Above average costs could be expected for some of the others where evacuation and sortie become a necessity under the threatening conditions.

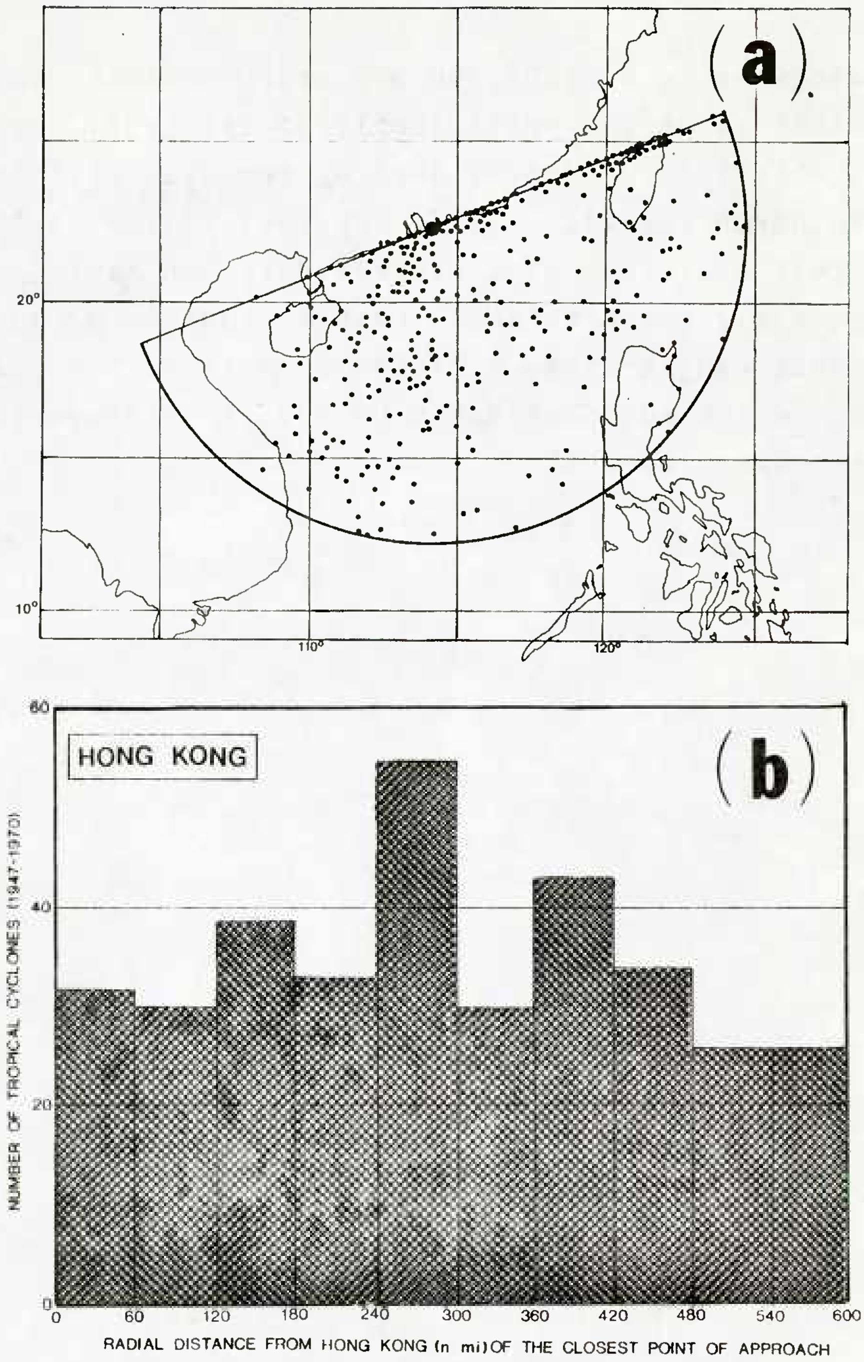

Figure 7. The Closest Point of Approach (CPA) for each tropical cyclone (1947-70) passing within the given 600 n mi semicircle to the southeast of Hong Kong (22.3N, 114.2E) is shown in section A (plotted as a dot). A total of 348 tropical cyclones passed within 600 n mi of Hong Kong for this semicircle in this 24-yr period. Section B shows the number of tropical cyclones as a function of their CPA values at incremental radial distances from Hong Kong for this semicircle. The radial distances are given in increments of 60 n mi. For example, 30 tropical cyclones passed Hong Kong with their CPA (ESE semicircle) between 300 and 360 n mi.

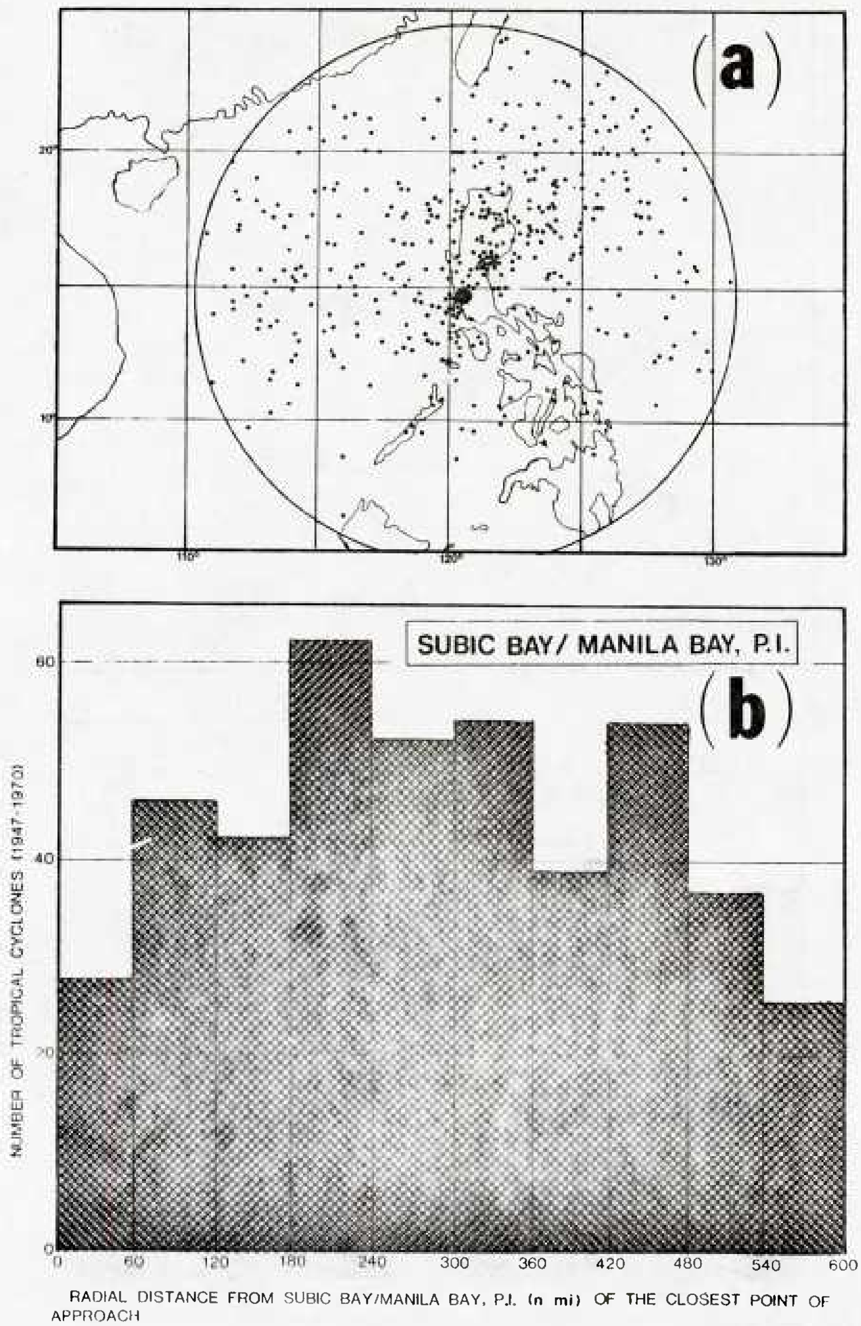

Figure 8. The Closest Point of Approach (CPA) for each tropical cyclone (1947-70) passing within 600 n mi of Subic Bay/Manila Bay, Philippines (14.7N, 120.6E) is shown in section A (plotted as a dot). A total of 439 tropical cyclones passed within 600 n mi of Subic Bay/Manila Bay in this 24-yr period. Section B shows the number of tropical cyclones as a function of their CPA values at incremental radial distances from Subic Bay/Manila Bay. The radial distances are given in increments of 60 n mi. For example, 54 tropical cyclones passed Subic Bay/Manila Bay with their CPA between 300 and 360 n mi.

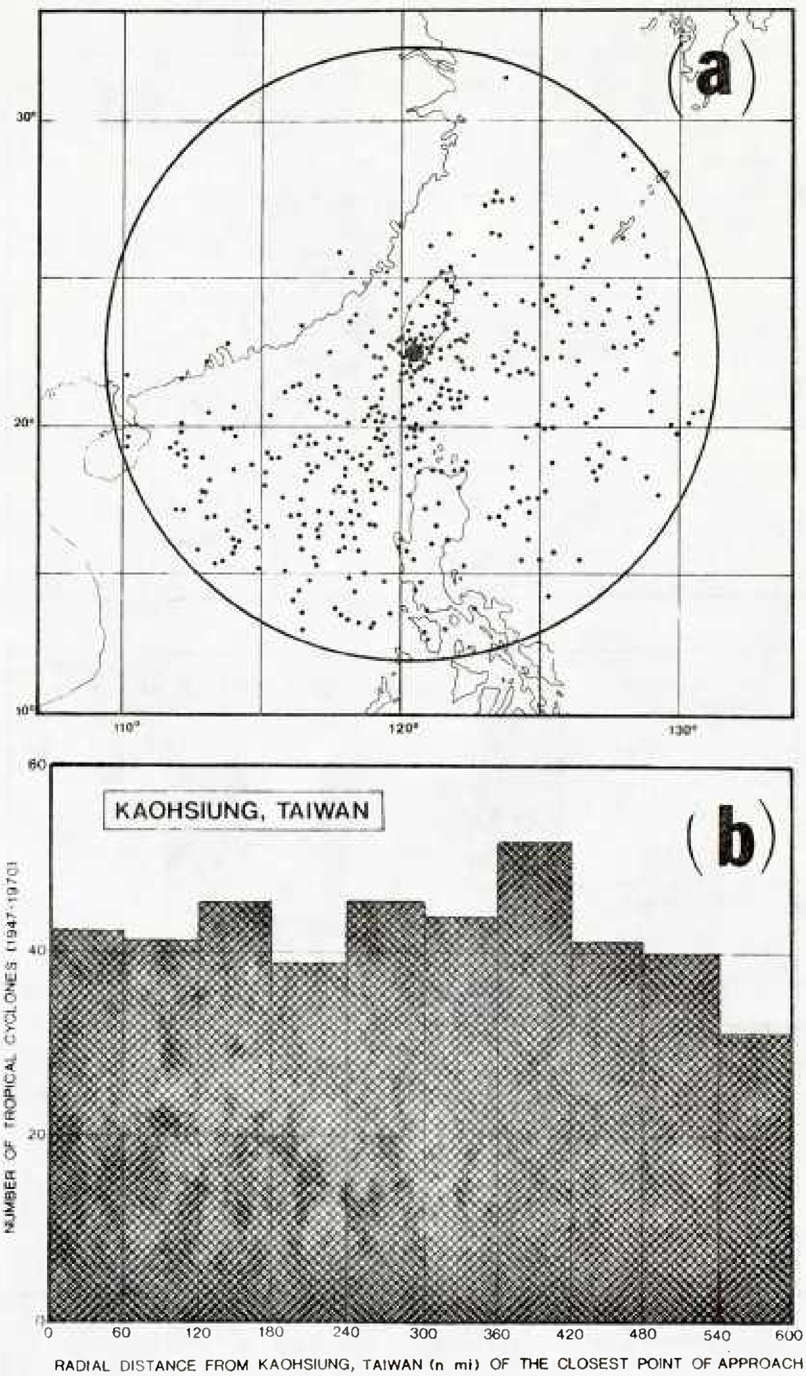

Figure 9. The Closest Point of Approach (CPA) for each tropical cyclone (1947-70) passing within 600 n mi of Kaohsiung, Taiwan (22.6N, 120.3E) is shown in section A (plotted as a dot). A total of 418 tropical cyclones passed within 600 n mi of Kaohsiung in this 24-yr period. Section B shows the number of tropical cyclones as a function of their CPA values at incremental radial distances from Kaohsiung. The radial distances are given in increments of 60 n mi. For example, 43 tropical cyclones passed Kaohsiung with their CPA between 300 and 360 n mi.

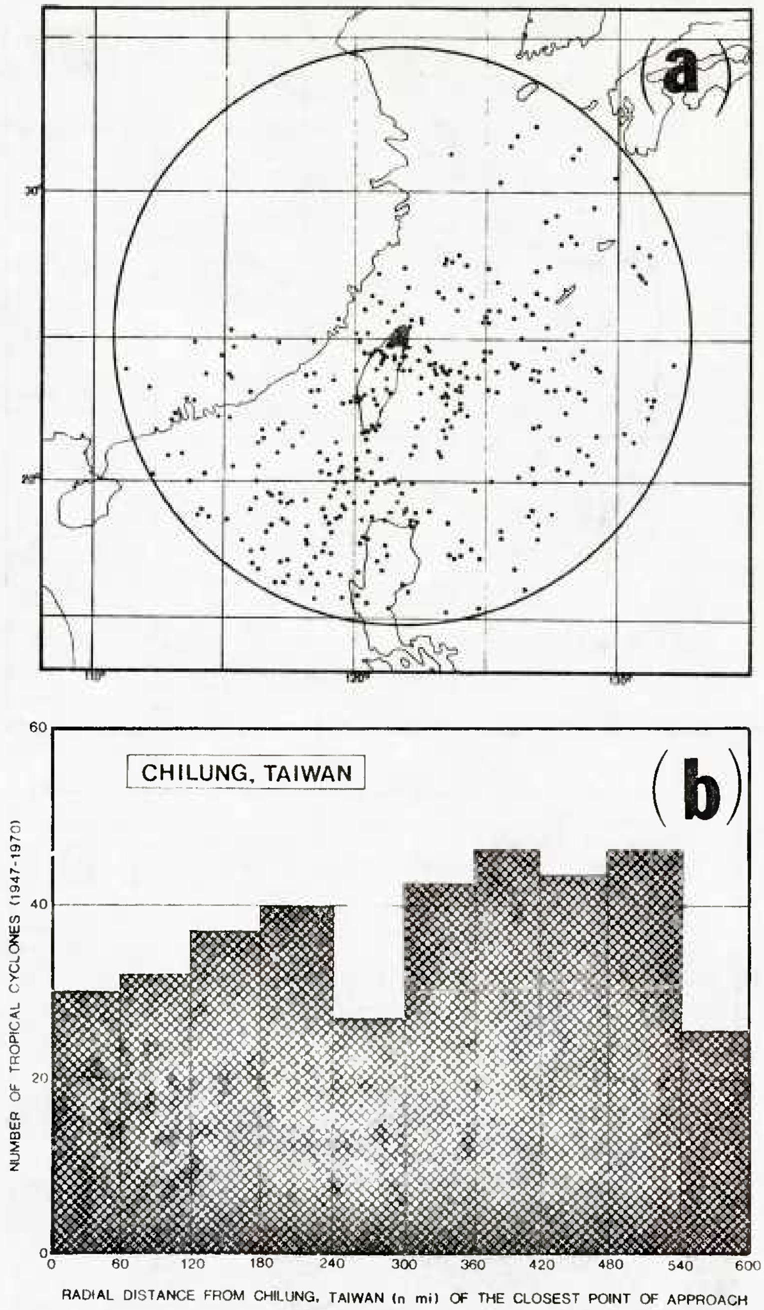

Figure 10. The Closest Point of Approach (CPA) for each tropical cyclone (1947-70) passing within 600 n mi of Chilung (Keelung), Taiwan (25.1N, 121.7E) is shown in section A (plotted as a dot). A total of 369 tropical cyclones passed within 600 n mi of Chilung in this 24-yr period. Section B shows the number of tropical cyclones as a function of their CPA values at incremental radial distances from Chilung. The radial distances are given in increments of 60 n mi. For example, 42 tropical cyclones passed Chilung with their CPA between 300 and 360 n mi.

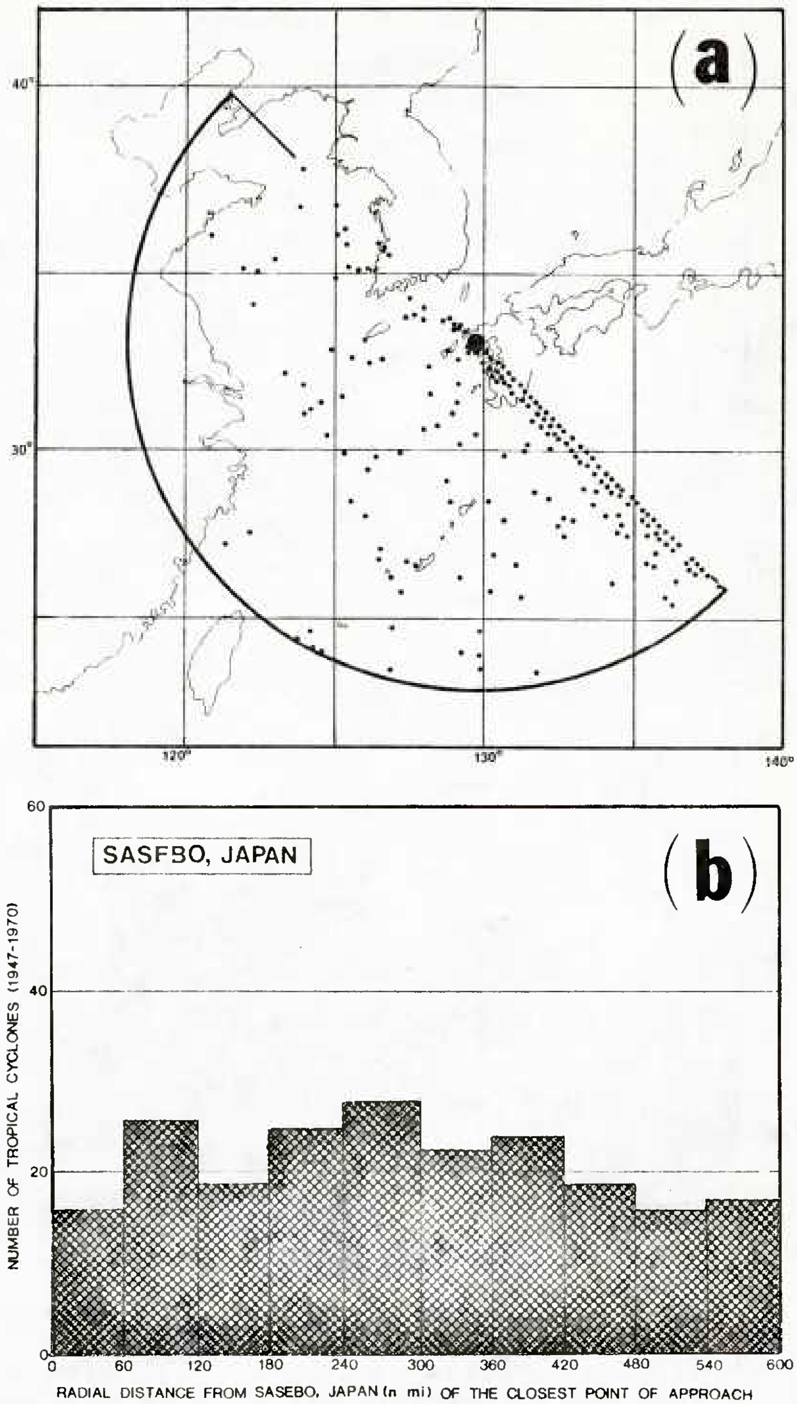

Figure 11. The Closest Point of Approach (CPA) for each tropical cyclone (1947-70) passing within the given 600 n mi semicircle to the southwest of Sasebo, Japan (33.1N, 129.7E) is shown in section A (plotted as a dot). A total of 213 tropical cyclones passed within 600 n mi of Sasebo for this semicircle in this 24-yr period. Section B shows the number of tropical cyclones as a function of their CPA values at incremental radial distances from Sasebo for this semicircle. The radial distances are given in increments of 60 n mi. For example, 23 tropical cyclones passed Sasebo with their CPA (SW semicircle) between 300 and 360 n mi.

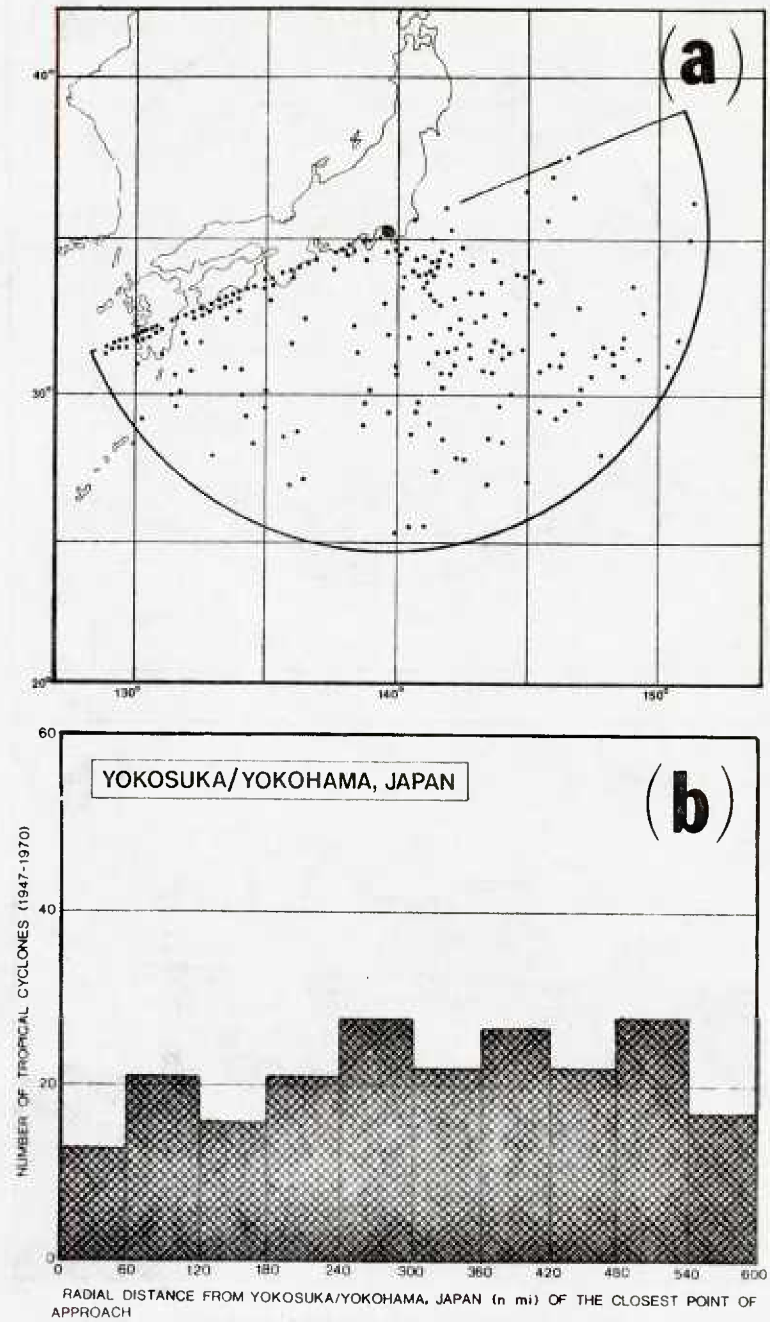

Figure 12. The Closest Point of Approach (CPA) for each tropical cyclone (1947-70) passing within the given 600 n mi semicircle to the southeast of Yokosuka/Yokohama, Japan (35.4N, 139.6E) is shown in section A (plotted as a dot). A total of 215 tropical cyclones passed within 600 n mi of Yokosuka/Yokohama for this semicircle in this 24-yr period. Section B shows the number of tropical cyclones as a function of their CPA values at incremental radial distances from Yokosuka/Yokohama for this semicircle. The radial distances are given in increments of 60 n mi. For example, 22 tropical cyclones passed Yokosuka/Yokohama with their CPA (ESE semicircle) between 300 and 360 n mi.

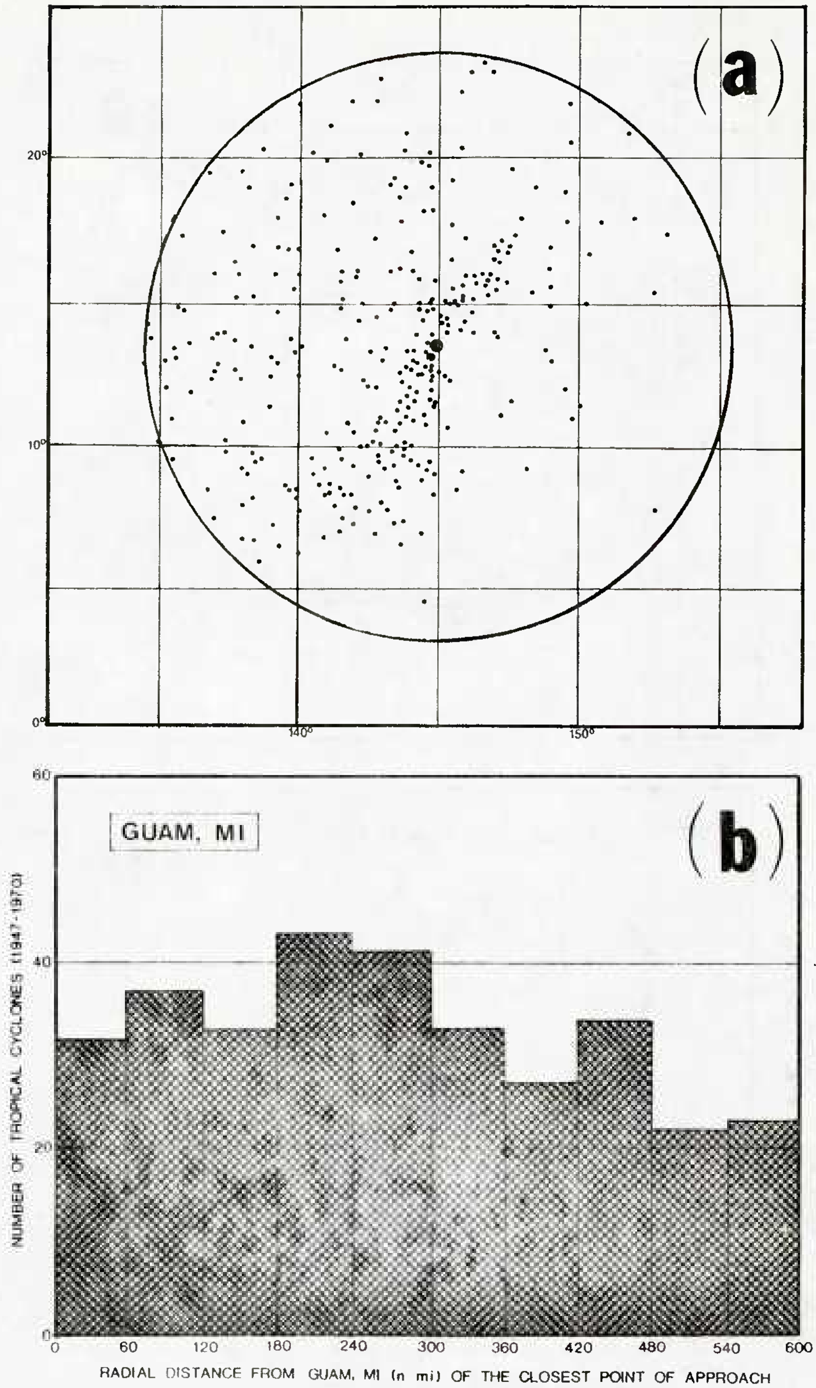

Figure 13. The Closest Point of Approach (CPA) for each tropical cyclone (1947-70) passing within 600 n mi of Guam (13.5N, 144.8E) is shown in section A (plotted as a dot). A total of 325 tropical cyclones passed within 600 n mi of Guam in this 24-yr period. Section B shows the number of tropical cyclones as a function of their CPA values at incremental radial distances from Guam. The radial distances are given in increments of 60 n mi. For example, 33 tropical cyclones passed Guam with their CPA between 300 and 360 n mi.

3. The distance to the radius of the 30-kt wind is a variable for every tropical cyclone and is also a difficult parameter to forecast. Additionally, the track of the tropical cyclone relative to the port or base would determine whether the port or base was in the left or right semicircle relative to the storm. Winds are generally stronger in the right semicircle. Also, some installations are located in developing storm regions and thus the 30-kt isotach would be less than 200 n mi from the tropical cyclone, since the storm would, in general, be of less than typhoon intensity.

4. Decision making at a wind criterion other than 30 kt. The decision arguments presented previously are for the 30-kt isotach, but can be set at other wind levels such as 50 kt. The average distance to the 50-kt isotach for typhoons is approximately 100 n mi, and this could be used instead of the 200 n mi value (30-kt isotach) discussed above. Note that the CPA values discussed previously were for tropical cyclones of all intensities, and some, of course, had a maximum wind less than 50 kt at the time of CPA. Nevertheless, tropical cyclones can intensify quite rapidly. In the western North Pacific they can be expected, on the average, to increase in maximum wind at a rate of approximately 31 kt/24 hr at some stage in their life cycle. In fact, approximately 17% of western North Pacific tropical cyclones can be expected to increase at a rate of 50 kt/24 hr at some stage in their life cycle (Brand, 1973).

5. The number of tropical cyclones/year passing at "critical" range values (function of the forecast error improvement) relative to each base, installation or port is a variable. This can vary greatly depending on the location with respect to tropical cyclone activity. In addition the annual cost of this variable is different for each base, installation or port.

6. The CPA estimate at 48 hr from warning time is only an initial best guess. Since the average right-angle forecast error varies as a function of time from the initial warning (70 n mi for 24 hr, 145 n mi for 48 hr and 215 n mi for 72 hr), variations in this error could occur depending on the time of the CPA.

7. The time of the CPA does not necessarily indicate the time the installation will receive the highest winds.

8. The arguments presented have been oriented toward a "go" or "no go" decision. In actuality, decision analysis has to include the various levels of preparedness and evacuation as related to the increase in threat. Appleman (1962) examined the probability of critical wind speeds affecting air bases during the passage of tropical cyclones based on climatological mean forecast errors for the Atlantic and Pacific. This type of approach would be extremely beneficial in decision analyses at all levels if oriented toward the individual tropical cyclone being forecast, and toward the threatened installation or port of interest.

9. In addition, typhoon forecast error improvements will also be beneficial to ship routing procedures and ship deployment in the western North Pacific. Since ship routing may at times require synoptic information for more than 3 days (present day warnings extend to 72 hr), research in the area of longer range typhoon forecasting would thus be beneficial. Both short and long range typhoon forecast improvements would aid in ship operating and evasion decisions.

Thus far the emphasis here has been on DOD benefits from improved forecasting of tropical cyclones, but it should also be mentioned that there are millions of dollars lost each year by civilian populaces and countries which could be saved by improvements in forecasting of tropical cyclones.

Sugg (1967) examined the economic aspects of hurricanes in the western North Atlantic and related that the cost of these tropical cyclones to the U.S. and Canada is exceedingly great. He estimated the average annual cost in the 1967 era to the U.S. and Canada for hurricanes (including damage, reconnaissance, communications, protection, evacuation, etc.) was $310 million with a possible maximum annual cost of $2.0 billion. He estimated or projected the cost to the 1975 era and gave a value of $410-590 million for an average value, with a possible maximum value of $2.7-4.0 billion annually for a very destructive year. His projections were based on a slower population growth rate for coastal areas and a lower inflation rate than at present and would thus be low in estimation. Nevertheless, if it is assumed that a 20% improvement in forecast errors would decrease these costs by only 1% (in the 1975 era) the cost savings would be $4.1-5.9 million for an average year and $27-40 million for an exceedingly destructive year.

The benefits of tropical cyclone forecast improvements, whether in the Atlantic or the Pacific Ocean, are difficult to measure in terms of a pure dollar value, but it is obvious that many American interests besides DOD (and other nations as well) would benefit from these improvements. Forecast improvements in the past decade have probably significantly reduced the economic losses due to tropical cyclones. As the coastal populations and inflation increase at a higher rate than in the years past, it becomes evident that improvements in tropical cyclone movement and intensity forecasting just cannot keep pace with, much less reduce, the level of this cost. Pure economics dictate the need for accelerated research in these areas.

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