ATLANTIC HURRICANE WIND PROBABILITY FORECASTING (WINDPA) (U)
OCT 81  J D JARRELL
UNCLASSIFIED

END
ATLANTIC HURRICANE WIND PROBABILITY FORECASTING (WINDPA)

Prepared By:

Jerry W. Jarrell
Science Applications, Inc.
Monterey, CA 93940

Contract No. N00228-88-C-008

OCTOBER 1981

APPROVED FOR PUBLIC RELEASE
DISTRIBUTION UNLIMITED

Prepared For:
NAVAL ENVIRONMENTAL PREDICTION RESEARCH FACILITY
MONTEREY, CALIFORNIA 93940
QUALIFIED REQUESTORS MAY OBTAIN ADDITIONAL COPIES FROM THE DEFENSE TECHNICAL INFORMATION CENTER. ALL OTHERS SHOULD APPLY TO THE NATIONAL TECHNICAL INFORMATION SERVICE.
Atlantic Hurricane Wind Probability Forecasting (WINDPA)

Jerry D. Jarrell

Science Applications, Inc. (SAI)
2999 Monterey-Salinas Highway
Monterey, CA 93940

Report Date: October 1981

Approved for public release; distribution unlimited.
## TABLE OF CONTENTS

SECTION 1. INTRODUCTION .................. 1

2. MODEL DESCRIPTION. .................... 1
   2.1 Atlantic Hurricane Strike Probability
       Program. .......................... 1
   2.2 Western Pacific Wind Probability Model
       (WINDP). .......................... 4
   2.3 Atlantic Wind Probability Model ........ 6

3. Testing the Atlantic Wind Probability
   Program (WINDPA) ..................... 8

4. Operational Products .................... 13

SUMMARY. .................................. 15
1.0 Introduction

The Atlantic Hurricane Wind Probability (WINDPA) model is a continuation of the Atlantic Hurricane Strike Probability Program developed by Jarrell\textsuperscript{1} (1981). This model extends the Atlantic strike probability model using wind probability concepts similar to those developed and presented for the western Pacific Ocean basin (Jarrell\textsuperscript{2}, 1981). Those concepts will not be presented again here except to illustrate the differences in methodology between the two models. The parameterization of the asymmetric wind distribution around the tropical cyclone and the inference of 30 and 50 knot wind radii are different and will be described.

2.0 Model Description

2.1 Atlantic Hurricane Strike Probability Program

The strike probability concept was developed by Jarrell\textsuperscript{3} (1978) and has been successfully applied to the eastern and

\begin{itemize}
\end{itemize}
western Pacific as well as the Atlantic basin. The development of strike probability theory and its extension to wind probability is based upon three basic assumptions:

(a) All forecasts related to tropical cyclones are subject to some degree of error.
(b) The size of the position forecast error is statistically related to the relative difficulty of the forecast.
(c) The occurrence of position forecast errors is random and approximates a bivariate normal probability distribution; normal in both N-S and E-W directions.

Investigators verified these assumptions in each basin in separate studies; Nicklin\textsuperscript{4}(1977) in the western Pacific, Thompson and Elsberry\textsuperscript{5}(1979) in the eastern Pacific and Crutcher\textsuperscript{6}(1980) in the Atlantic. In these studies statistical

\textsuperscript{4}Nicklin, D.S., 1977: A Statistical Analysis of Western Pacific Tropical Cyclone Forecast Errors; Naval Postgraduate School; M.S. Thesis.

\textsuperscript{5}Thompson, W.J. and R.L. Elsberry, 1979: A Statistical Analysis of Eastern Pacific Tropical Cyclone Forecast Errors; 12th Tech. Conf. on Hurricanes and Tropical Meteorology; New Orleans; April, 1979.

\textsuperscript{6}Crutcher, H.L., 1980: Tropical Storm Forecast Error and the Bivariate Normal Distribution. 13th Tech. Conf. on Hurricanes and Tropical Meteorology; AMS; Miami, FL; Dec, 1980.
methods were used to group the forecasts into three classes of relative forecast difficulty of easy, average and difficult. The resultant classifications yielded respective relative forecast error groups of below average errors (Class I), average errors (Class II) and larger than average errors (Class III). Statistical parameters were developed in each study to describe the bivariate normal distributions for each of these three classes and for 24, 48 and 72 hour forecasts. Although relative separation of groups varied in the three studies, three distinct groups emerged in each.

The statistical data provided the basis for a strike probability model for the respective basins. Using forecast positions and integrating in time and space, probabilities of a tropical cyclone strike are derived for forecasts out to 72 hours.

Crutcher (1980) used a clustering model (NORMIX) to develop three discrete bivariate normal populations of Atlantic position forecast errors. Because uncertainty is involved in categorizing a particular forecast as a member of a single forecast difficulty class (even after-the-fact it is a probabilistic problem), a method (Jarrell, 1981) was developed to assign "probability of class membership" to each forecast. A series of stepwise linear regression equations were fit to predictors relating class probabilities to the predictors. A forecast would have a likelihood of belonging to Class I, II or III and possessing those populations characteristics. Each of
these predicted probabilities is constrained to $0 \leq P_x \leq 1$
and that $P_1 + P_2 + P_3 = 1$. The actual strike probability
then is derived from three separate runs; each run using the
bivariate parameters from a different population. The final
probabilities are a sum weighted by the predicted class
probabilities. This method also forms the basis of the Atlantic
wind probability model class selection.

2.2 Western Pacific Wind Probability Model (WINDP)

The wind probability model enhances the strike model by
providing probabilities of sustained winds of 30 and 50 knots at
a user specified site. A definite advantage is realized for the
user in that he can relate probabilities to a recognized
destructive wind force (i.e., 30 or 50 knots) rather than to an
arbitrarily selected distance which constitutes a tropical
cyclone strike. The WINDP model is based on the strike model
plus an evaluation of maximum wind and wind radius forecasts.
This evaluation is based on the Riehl\textsuperscript{7} (1963) profile
\[VR^{1/2} = \text{constant}, \quad \text{or} \quad R_C = \left(\frac{V_m}{V_c}\right)^2 R_m,\]
where
$R_C$, $V_C$ are a radius and wind speed of concern and $V_m$, $R_m$
are a maximum wind speed and associated radius. Using forecast
warning data to obtain $V_m$ and inferring $R_m$ from the radius
of 50 or 30 knot winds, $R_C$ can then be approximated.

\textsuperscript{7}Riehl, H., 1963: Some Relations Between Wind and Thermal
Structure of Steady State Hurricanes; Journal of Atmospheric
Science; Vol. 20; July, 1963, pp 276-287.
$R_m$ and $V_m$ are treated as random variables. They are forecast values and are assumed to be related. All values of $V_m$ are considered and its probability of occurrence estimated from a wind error algorithm. For each such $V_m$, an expected value of $R_m$ is predicted and from $Vr^{1/2} = \text{constant}$, a value of $R_c$ is computed. The marginal probability of the point of interest receiving winds $\geq V_c$ (given the currently assigned $V_m$ value) is the probability that the cyclone passes within distance $R_c$ of the point. The total probability that a point will receive winds of at least $V_c$ at a time step is then estimated by summing over all $V_m$ values.

Asymmetry of tropical cyclone storm pattern (i.e., a larger semicircle for equal isotach winds to the right of storm track) is treated as a series of circular isotachs offset to the right of the forecast track. The forward speed of motion ($S$) of a storm is added to a stationary storm maximum wind ($V_s$) to approximate the maximum wind in right semicircle ($V_m = V_s + S$), and subtracted ($V_s - S$) to approximate the left semicircle. An offset distance is then calculated by substituting into the Riehl equation and simplifying to obtain:

$$D = \frac{2S(V_m - S)}{V_c^2}R_m,$$

where $V_m = V_s + S$. The offset is then applied to the left of the point of concern (to compensate for larger storm semicircle on right side of storm) and used to determine a center for integration. Both wind profile derivation and asymmetric offset are fully developed by Jarrell$^2$(1981) for the interested reader.
2.3 Atlantic Wind Probability Model

The basic differences to be observed in the Atlantic model as compared to the western Pacific are minor in nature and lie in the derivation of the 50 and 30 knot wind profiles and the method in which asymmetry is handled.

The basis for derivation of the wind profiles is from work by Tsui\(^8\) (1980). Tsui extracted wind radius data from tropical cyclone warnings issued by the Joint Typhoon Warning Center on Guam for a 12-year period (1966 to 1977). From this data set he estimated the profile of the tangential wind speed along the radial axis to be exponential. The study also indicated that the size of a tropical cyclone is statistically related to maximum wind and persistence and that the asymmetric shape of the isotach is correlated to the speed of movement.

The asymmetric shape of the wind distribution was parameterized by expressing all directional radii as fractions of the radius on the right side. For example the average fraction of the left side of the 50-knot wind radius is 0.73 and the 30-knot wind radius is 0.81. This asymmetry is related to speed of storm movement and is more pronounced at higher speeds.

\(^8\)Tsui, T.L., 1980: Surface Wind Distribution of Western North Pacific Tropical Cyclones; 13th Tech. Conf. on Hurricanes and Tropical Meteorology; Miami, FL; Dec, 1980.
By scaling of both the wind and the right side wind radius, data was then composited and fitted to a single profile,

\[ \frac{V}{V_{\text{max}}} = \exp(-0.693R) \]

where \( V \) is the wind speed of interest, \( V_{\text{max}} \) is the maximum wind (intensity) and \( R \) is the ratio of the radius associated with \( V \) to the radius associated with winds of one half \( V_{\text{max}} \) in a tropical cyclone.

The advantage of the Tsui profile over the Riehl profile for this purpose relates to the scaling radius used. Riehl uses the radius of maximum winds (\( R_m \)) as his scaling radius. \( R_m \) is small (on the order of 20-30 miles) and is subject to very large percentage errors. Tsui, on the other hand, uses the radius of 50% of the maximum wind (\( R_{\text{half}} \)) as his scaling radius. \( R_{\text{half}} \) is larger (typically 50-150 miles) and is also far enough removed from the central core of winds to be identifiable in synoptic ship reports. For both of these reasons, \( R_{\text{half}} \) is subject to smaller percentage errors than \( R_m \). Since in both cases the scaling radius is used in ratio to some other isotach radius, percentage error is the relevant measure of accuracy.
With the above relationship plus knowledge of the maximum wind and its radius and one observed wind, an estimate of the wind field around a tropical cyclone can be deduced. Thus with Tsui's wind profile any wind radii may be estimated and storm asymmetry handled with a simple empirical relationship.

3.0 Testing the Atlantic Wind Probability Program (WINDPA)

The methodology used in testing WINDPA predicted values against observed values is identical to that used in the western Pacific by Jarrell\(^2\)(1981). An array of 30 points in the Atlantic and Gulf of Mexico was selected (figure 1). WINDPA values for 30 and 50 knots were calculated at 12 hour intervals from the effective synoptic time of the National Hurricane Center (NHC) forecasts for the 1980 season. Since most of these 30 points are not observing stations, actual verifying winds were not generally available. Consequently a verifying "warning time" probability greater than 50% constituted a verifying strike.

Tables 1, 2, 3 and 4 compare the expected to the observed occurrences of 30 and 50 knot winds. Predictions are associated with percentage groups of increasing width, < 1/2%, 1/2 to 1 1/2%, . . . etc. Time integrated probabilities were verified only if a continuous record was available over the entire time period.

- 8 -
Figure 1. Location of test points in Atlantic and Gulf of Mexico.
### Table 1. Instantaneous Probabilities.
50 kt winds - Expected versus Observed.

<table>
<thead>
<tr>
<th>A&lt;P&lt;B N E O</th>
<th>24 Hr</th>
<th>48 Hr</th>
<th>72 Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1%</td>
<td>5684</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1% - 1½</td>
<td>39</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1½ - 3½</td>
<td>30</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3½ - 7½</td>
<td>27</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>7½ - 15½</td>
<td>23</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>15½ - 31½</td>
<td>14</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>31½ - 63½</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>&gt;63½</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>ALL</td>
<td>5820</td>
<td>9</td>
<td>8</td>
</tr>
</tbody>
</table>

### Table 2. Instantaneous Probabilities.
30 kt winds - Expected versus Observed.

<table>
<thead>
<tr>
<th>A&lt;P&lt;B N E O</th>
<th>24 Hr</th>
<th>48 Hr</th>
<th>72 Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; ½%</td>
<td>5576</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>½% - 1½</td>
<td>65</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1½ - 3½</td>
<td>50</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3½ - 7½</td>
<td>34</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>7½ - 15½</td>
<td>29</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>15½ - 31½</td>
<td>35</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>31½ - 63½</td>
<td>31</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>&gt;63½</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>ALL</td>
<td>5820</td>
<td>29</td>
<td>29</td>
</tr>
</tbody>
</table>

*Difference significant at 5% level. (None of these are significant when it is assumed that only 1/3 of cases are independent.)
### Table 3. Time Integrated Probabilities.

50 kt winds – Expected versus Observed.

<table>
<thead>
<tr>
<th>A&lt;P&lt;B</th>
<th>24 Hr</th>
<th>48 Hr</th>
<th>72 Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>E</td>
<td>O</td>
</tr>
<tr>
<td>&lt; 2%</td>
<td>4980</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1/2-1</td>
<td>50</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1 1/2-3</td>
<td>22</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3 1/2-7</td>
<td>18</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>7 1/2-15</td>
<td>33</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>15 1/2-31</td>
<td>19</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>31 1/2-63</td>
<td>27</td>
<td>13</td>
<td>11</td>
</tr>
<tr>
<td>&gt;63</td>
<td>11</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>ALL</td>
<td>5160</td>
<td>31</td>
<td>21</td>
</tr>
</tbody>
</table>

### Table 4. Time Integrated Probabilities.

30 kt winds – Expected versus Observed.

<table>
<thead>
<tr>
<th>A&lt;P&lt;B</th>
<th>24 Hr</th>
<th>48 Hr</th>
<th>72 Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>E</td>
<td>O</td>
</tr>
<tr>
<td>&lt; 2%</td>
<td>4836</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1/2-1</td>
<td>61</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1 1/2-3</td>
<td>47</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3 1/2-7</td>
<td>42</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>7 1/2-15</td>
<td>36</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>15 1/2-31</td>
<td>50</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>31 1/2-63</td>
<td>47</td>
<td>22</td>
<td>17</td>
</tr>
<tr>
<td>&gt;63</td>
<td>41</td>
<td>33</td>
<td>28*</td>
</tr>
<tr>
<td>ALL</td>
<td>5160</td>
<td>74</td>
<td>57*</td>
</tr>
</tbody>
</table>

* difference significant at 5% level. (None of these are significant when it is assumed that only 1/3 of cases are independent.)
### Table 5. Time Integrated STRIKPA.

<table>
<thead>
<tr>
<th>INST</th>
<th>24 Hr</th>
<th>48 Hr</th>
<th>72 Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>A&lt;P&lt;B</td>
<td>N</td>
<td>E</td>
<td>O</td>
</tr>
<tr>
<td>&lt; ½</td>
<td>5019</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>½ - 1½</td>
<td>32</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1½ - 3½</td>
<td>20</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3½ - 7½</td>
<td>23</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>7½ - 15½</td>
<td>18</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>15½ - 31½</td>
<td>25</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>31½ - 63½</td>
<td>16</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>&gt;63½</td>
<td>7</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>ALL</td>
<td>5160</td>
<td>23</td>
<td>15</td>
</tr>
</tbody>
</table>

*difference significant at 5% level. (None of these are significant when it is assumed that only 1/3 of cases are independent.)*

### Table 6. Instantaneous STRIKPA.

<table>
<thead>
<tr>
<th>INST</th>
<th>24 Hr</th>
<th>48 Hr</th>
<th>72 Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>A&lt;P&lt;B</td>
<td>N</td>
<td>E</td>
<td>O</td>
</tr>
<tr>
<td>&lt; ½</td>
<td>5707</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>½ - 1½</td>
<td>35</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1½ - 3½</td>
<td>22</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3½ - 7½</td>
<td>21</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>7½ - 15½</td>
<td>17</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>15½ - 31½</td>
<td>18</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>31½ - 63½</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>&gt;63½</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>ALL</td>
<td>5820</td>
<td>8</td>
<td>5</td>
</tr>
</tbody>
</table>
Significance of the differences between the expected and the observed, as discussed in previous reports (Jarrell, 1981), is difficult to assess, but using previously developed tests, agreement appears to be very good. The instantaneous probabilities show excellent correlation at all forecast lengths with minor underforecasting at the longer forecast times (48 and 72 hr). The time integrated probabilities displayed a slight tendency toward overforecasting for both 50 kt and 30 kt winds. This was not at a significant level (see note accompanying tables) and the overall results are considered statistically sound. An instantaneous and a time integrated strike probability (STRIKPA) was run on the same data base (Table 5 and 6) and showed comparable agreement between predicted and observed occurrences.

4.0 Operational Products

The Atlantic wind probability program will be available for the preselected points receiving the Atlantic strike program. (The STRIKPA program is actually integrated into the WINDPA program). Probabilities will be given in two modes, instantaneous and time integrated, and at 0, 12, 24, 36, 48, 60 and 72 hours after the warning time. The instantaneous probability will be the probability at the stated time (i.e., 12 hr) and the time integrated will be summed for the 0 to X hour time interval for an estimate of the probability that the event will be observed within that period of time.
The greatest source of probable error for the WINDPA program will be erroneous input data. An internal check for unusual motion (expected to occur only 5% of the time in nature) will be made and suspect motion flagged. The user should then recheck input data for accuracy.

When the forecast track approaches land mass the forecaster should be aware of program bias. This should be minor for seaward approach to low coastal areas or over smaller islands. However, in other cases land influences will appear as rapid decreases in the instantaneous wind probabilities (especially 50 kt winds) near forecast landfall time. This will bias probabilities — overstate them for inland sites and understate them for coastal sites. Time integrated probabilities will be less biased. This problem is caused by wind forecasts being influenced by track forecasts where landfall is concerned. A bad track forecast may cause a bad wind forecast. This was not accounted for either in development nor testing; hence the test results simulate expected actual operational results and some of the minor disparities between expected and observed occurrences no doubt stems from this problem.
SUMMARY

The wind probability model for the Atlantic is largely based on the strike probability program for the Atlantic and the wind probability program for the western Pacific - both currently operational. The single important improvement represented in the concept is the addition of the Tsui wind profile. Test results of the Atlantic WINDPA program demonstrated excellent agreement between expected and observed results.
DISTRIBUTION

COMMANDER IN CHIEF
U.S. ATLANTIC FLEET
NORFOLK, VA 23511

CINCANNATI
ATTN: NSAP SCI, ADV., CODE 004
NORFOLK, VA 23511

CINCPACFLT
PEARL HARBOR, HI 96860
COMMANDER
SECOND FLEET
FPO NEW YORK 09501

COMSECONDFLT
ATTN: NSAP SCI, ADVISOR
ACOS TACTICAL DEV. & EVAL.
BOX 100
CINCPACFLT COMPOUND
NORFOLK, VA 23511

COMMANDER
THIRD FLEET
PEARL HARBOR, HI 96860

COMMANDER
SEVENTH FLEET (SP 30W)
ATTN: FLEET METEOROLOGIST
FPO SAN FRANCISCO 96601

COMMANDER
U.S. NAVAL FORCES, AZORES
APO NEW YORK 09406

COMMANDER
U.S. NAVAL FORCES, CARIBBEAN
FPO MIAMI 34051

COMMANDER
U.S. NAVAL FORCES, ICELAND
FPO NEW YORK 09571

COMMANDER NAVAL AIR FORCE
U.S. ATLANTIC FLEET
NORFOLK, VA 23511

COMMANDER NAVAL AIR FORCE
U.S. ATLANTIC FLEET (30F)
ATTN: NSAP SCIENCE ADVISOR
NORFOLK, VA 23511

COMMANDER NAVAL SURFACE FORC
U.S. ATLANTIC FLEET
NORFOLK, VA 23511

COMMANDER
MINE WARFARE COMMAND
ATTN: NSAP SCIENCE ADVISOR
CODE 006
CHARLESTON, SC 29408

COMSUBFORC,
U.S. ATLANTIC FLEET
ATTN: NSAP SCIENCE ADVISOR
NORFOLK, VA 23511

COMMANDER
AMPHIBIOUS GROUP 2
ATTN: METEOROLOGICAL OFFICER
FPO NEW YORK 09501

COMMANDING OFFICER
USS J. R. KENNY
ATTN: METEOROLOGICAL OFFICER, OA DIV.
FPO NEW YORK 09538

COMMANDING OFFICER
USS NIMITZ (CVN-68)
ATTN: METEOROLOGICAL OFFICER, OA DIV.
FPO NEW YORK 09542

COMMANDING OFFICER
USS D. D. EISENHOWER (CVN-69)
ATTN: METEOROLOGICAL OFFICER, OA DIV.
FPO NEW YORK 09542

COMMANDING OFFICER
PCO, CARL VINSON (CVN-70)
ATTN: OA DIVISION
SUPERVISOR OF SHIPBUILDING,
CONVERSION & REPAIR
NEWPORT NEWS, VA 23607

COMMANDING OFFICER
USS SARATOGA (CV-60)
ATTN: METEOROLOGICAL OFFICER, OA DIV.
FPO NEW YORK 09587

COMMANDING OFFICER
USS GUADALCANAL (LPH-7)
ATTN: METEOROLOGICAL OFFICER
FPO NEW YORK 09562

COMMANDING OFFICER
USS GUAM (LPH-9)
ATTN: METEOROLOGICAL OFFICER
FPO NEW YORK 09563

COMMANDING OFFICER
USS INCHON (LPH-12)
ATTN: METEOROLOGICAL OFFICER
FPO NEW YORK 09529

COMMANDING OFFICER
USS IWO JIMA (LPH-2)
ATTN: METEOROLOGICAL OFFICER
FPO NEW YORK 09561

COMMANDING OFFICER
USS HASSAU (LHA-4)
ATTN: METEOROLOGICAL OFFICER
FPO NEW YORK 09557

COMMANDING OFFICER
USS SAIPAN (LHA-2)
ATTN: METEOROLOGICAL OFFICER
FPO NEW YORK 09549

COMMANDING OFFICER
USS PUGET SOUND (AD-38)
ATTN: METEOROLOGICAL OFFICER
FPO NEW YORK 09544

COMMANDING OFFICER
USS LASALLE (AGF-3)
ATTN: METEOROLOGICAL OFFICER
FPO NEW YORK 09577

COMMANDING OFFICER
OCEANO. DEV. SQDN 8-VX-8
ATTN: 3)
NAVAL AIR STATION
PATUXENT RIVER, MD 20670

COMMANDING OFFICER
AIR TEST & EVAL. SQDN 1-VX-1
NAVAL AIR STATION
PATUXENT RIVER, MD 20670

COMMANDING GENERAL
FLEET MARINE FORCE, ATLANTIC
ATTN: NSAP SCIENCE ADVISOR
NORFOLK, VA 23511

COMMANDER IN CHIEF ATLANTIC
FPO NEW YORK 09537

SAILORS
ASW RESEARCH CENTER
FPO NEW YORK 09519

SPECIAL ASSIST. TO THE ASST.
SECRETARY OF THE NAVY (HAD)
The Pentagon, Room 4741
Washington, DC 20350

COMMANDING OFFICER
USS MOUNT WHITNEY (LCC-20)
ATTN: METEOROLOGICAL OFFICER
FPO NEW YORK 09517

CHIEF OF NAVAL OPERATIONS
(OP-952)
U.S. NAVAL OBSERVATORY
Washington, DC 20390

CHIEF OF NAVAL OPERATIONS
(OP-968)
NAVY DEPT
Washington, DC 20390

CHIEF OF NAVAL OPERATIONS
ATTN: DR. R. JAMES, OP-9521
U.S. NAVAL OBSERVATORY
34TH & MASS. AVE. NW
Washington, DC 20390

CHIEF, ENV. SERV. DIV.
U.S. NAVAL OBSERVATORY
WASH., DC 20390

CHIEF, NAVY OBSERVATORY
U.S. NAVAL OBSERVATORY
WASH., DC 20390

DEP. 2, HQ AWS
THE PENTAGON
WASHINGTON, DC 20330

NAVAL DEPUTY TO THE ADMIN.
NOAA, N.Y. ZOO, PAGE BLDG. #1
3300 WHITENHAWN ST. NW
Washington, DC 20235

OFFICER IN CHARGE
NAVACCMPCHET
FEDERAL BLDG.
ASHEVILLE, NC 28801

CHIEF PETTY OFFICER IN CHARGE
NAVACCMPCHET
CHASE FIELD
BEEVILLE, TX 78103

OFFICER IN CHARGE
NAVACCMPCHET
U.S. NAVAL AIR STATION
BRUNSWICK, ME 04011

OFFICER IN CHARGE
NAVACCMPCHET
NAVACCMPCHET
NAVAL AIR STATION
CECIL FIELD, FL 32215

OFFICER IN CHARGE
NAVACCMPCHET
NAVAL AIR STATION
CHARLESTON, SC 29408

OFFICER IN CHARGE
NAVACCMPCHET
NAVAL AIR STATION
CORPUS CHRISTI, TX 78419

CHIEF PETTY OFFICER IN CHARGE
NAVACCMPCHET
NAVAL AIR STATION
DALLAS, TX 75211
FLORIDA STATE UNIVERSITY
ENVIRONMENTAL SCIENCES DEPT.
TALLAHASSEE, FL 32306

UNIVERSITY OF HAWAII
METEOROLOGY DEPT.
2525 CORREA ROAD
HONOLULU, HI 96822

CHAIRMAN
UNIVERSITY OF WISCONSIN
METEOROLOGY DEPT.
1225 W. DAYTON STREET
MADISON, WI 53706

Texas A&M University
METEOROLOGY DEPT.
COLLEGE STATION, TX 7743

CHAIRMAN
RUTGERS UNIVERSITY
DEPT. OF METEOR. & PHYS. OCEANO.
COOK COLLEGE, P.O. BOX 231
NEW BRUNSWICK, NJ 08903

DIRECTOR OF RESEARCH
ST. THOMAS UNIVERSITY
INSTITUTE FOR STORM RESEARCH
3812 MONTROSE BLVD.
HOUSTON, TX 77006

CHAIRMAN
SAN JOSE STATE UNIVERSITY
METEOROLOGY DEPT.
SAN JOSE, CA 95192

SCRIPPS INSTITUTION OF OCEANO.
LIBRARY DOCUMENTS/REPORTS SECTION
LA JOLLA, CA 92037

DIRECTOR
OLD DOMINION UNIVERSITY
OCEANOGRAPHIC INSTITUTE
NORFOLK, VA 23508

OFFICER IN CHARGE
NAVOCANADIAN
U.S. NAVAL AIR STATION
FPO NEW YORK 09560

UNIVERSITY OF MIAMI
RSMAS LIBRARY
4600 KICKEENBACKER CAUSEWAY
MIAMI, FL 33149

DIRECTOR
LOUISIANA STATE UNIVERSITY
ATTN: O. HUN, COASTAL STUDIES
BATON ROUGE, LA 70803

CHAIRMAN
ATMOS. SCIENCES DEPT.
UNIVERSITY OF VIRGINIA
CHARLOTTESVILLE, VA 22903

UCLA
ATMOSPHERIC SCIENCES DEPT.
405 HILGARD AVE.
LOS ANGELES, CA 90024

COLORADO STATE UNIVERSITY
ATMOS. SCI. DEPT. LIBRARY
FOOTHILLS CAMPUS
FT. COLLINS, CO 80523

UNIVERSITY OF MARYLAND
METEOROLOGY DEPT.
COLLEGE PARK, MD 20742

THE EXECUTIVE DIRECTOR
AMERICAN METEOR. SOCIETY
45 BEACON STREET
BOSTON, MA 02108

AMERICAN MET. SOCIETY
METEOR. & GEOASTRO. ABSTRACTS
P.O. BOX 1736
WASHINGTON, DC 20013

DIRECTOR, JTWC
BOX 17
FPO SAN FRANCISCO 96630

WORLD METEORO. ORGANIZATION
ATS DIV. (ATTN: M. SUZUKI)
CH-1211, GENEVA 20
SWITZERLAND

LIBRARIAL
UNIVERSITY OF MELBOURNE
METEOROLOGY DEPT.
PARKVILLE, VICTORIA 3052
AUSTRALIA

BUREAU OF METEOROLOGY
ATTN: LIBRARY
PO BOX 1209, GPO
MELBOURNE, VIC, 3001
AUSTRALIA

LIBRARY
ATMOSPHERIC ENVIRONMENT SERVICE
4905 DUFFERIN STREET
DOWNSVIEW M3H 5T4
ONTARIO, CANADA

DIRECTOR OF NAVAL OCEANOGRAPHY
& METEOROLOGY
MINISTRY OF DEFENCE
OLD WAR OFFICE BLDG.
LONDON, S.W.1. ENGLAND

METEOROLOGICAL OFFICE LIBRARY
LONDON ROAD
BRACKNELL, BERKSHIRE
RG 12 252
ENGLAND

COMMANDER IN CHIEF FLEET
ATTN: STAFF METEOR. & OCEANOGRAPHY OFFICER
NORTHWOOD
MIDDLESEX MAG 3HP
ENGLAND

THE DIRECTOR
INDIAN INSTITUTE OF TROP. METEO.
RAMAURG HOUSE
PUNE 411-005
INDIA

FEDERAL COORDINATOR FOR METEORO.
SERVICES & SUPPORTING RESEARCH
6010 EXECUTIVE BLVD.
ROCKVILLE, MD 20852