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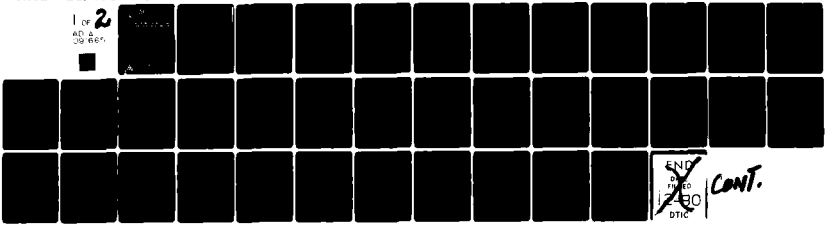

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METEOROLOGICAL FACTORS AFFECTING EVAPORATION DUCT HEIGHT CLIMATOLOGIES

Wayne Sweet
Naval Environmental Prediction Research Facility

JULY 1980

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NAVENVPREDRSCHFAC Technical Report TR 80-02	2. GOVT ACCESSION NO. AD-A097665	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) Meteorological Factors Affecting Evaporation Duct Height Climatologies		5. TYPE OF REPORT & PERIOD COVERED (1) Final rept.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Wayne/Sweet		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Environmental Prediction Research Facility Monterey, CA 93940 (14) NEPRF-TR-80-02		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS PE 62759N NEPRF WU 6.2-11
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Ocean Systems Center San Diego, CA 92152		12. REPORT DATE (11) July 1980
		13. NUMBER OF PAGES 28
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Naval Air Systems Command Department of the Navy Washington, DC 20361		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Evaporation duct
Duct climatology

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Latitudinal and seasonal variations of calculated evaporation duct height climatologies are examined to determine which of the four surface-measured input parameters to the calculation of duct height -- air temperature, sea surface temperature, dew point temperature, and wind speed -- has the largest effect on the climatological tendencies. Based on a sensitivity analysis of the four parameters, sea surface temperature appears to cause most of the latitudinal variation. (continued on reverse)

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Block 20, ABSTRACT, Continued

Seasonal variations of median duct height apparently are caused by the stability (indicated by the difference between air and sea surface temperatures) and dew point temperature, and, to a lesser extent, by wind speed.

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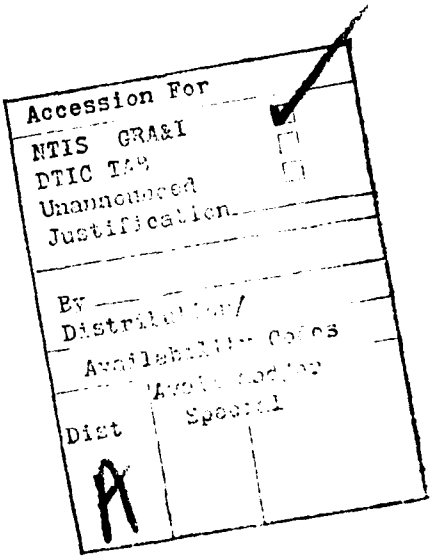

1. INTRODUCTION

Evaporation ducts affect the propagation of many surface-to-surface radars currently used by the Fleet. Duct height is the factor that determines which radar will be affected. Duct height is computer-calculated from observations of four surface-measured input parameters: air temperature, sea surface temperature, dew point temperature, and wind speed.

This report relates latitudinal and seasonal variations of calculated median heights of evaporation ducts to climatological variations of the input parameters, for ten ocean weather stations in the North Atlantic.* The range of latitudinal and seasonal variations of the median duct height contains the "crucial duct height values" for many naval radars (defined and described in NOSC, 1978). These crucial duct heights are considered to separate radar ranges into two classes: normal and extended.

An understanding of the general effects of climatic parameters on evaporation duct heights is important to fleet meteorologists who must assess and forecast refractive conditions. In regions where no evaporation duct climatologies have been developed (e.g., most of the Southern Hemisphere's oceans), climatological values of the four input parameters can give useful information about the expected behavior of evaporation duct heights; and thus can aid in the development of better assessment and forecasting techniques.

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*A climatology of evaporation duct occurrence at these stations is given in Sweet (1979); see references.

This report discusses the evaporation duct phenomenon and describes the process for determining duct height. Values of the input parameters are varied in order to determine the effects of such variations on the resulting calculations of duct height. Latitudinal and seasonal variations are explained in terms of the primary input parameters.

2. EVAPORATION DUCT HEIGHT CALCULATION

Evaporation over oceanic regions causes strong negative vertical water vapor gradients, (i.e., water vapor rapidly decreasing with height) normally within 30 meters (m) of the surface. These water vapor gradients in turn produce gradients in refractivity which are large enough to cause microwave ducts to form with tops generally up to 30 m above the surface.

The determination of duct height from temperature and water vapor profiles is not operationally practical because it is very hard to measure these parameters with the necessary resolution. Parametric techniques have been developed, however, to use four surface-measured parameters -- air temperature, relative humidity, wind speed, and sea-surface temperature -- as input to a complex set of equations (run on a programmable calculator) to determine duct height.

Inherent errors, due to measuring-instrument errors, in the scheme used to calculate duct height were examined in NAFI, 1977. Worst case situations were evaluated and large errors in the calculated duct heights were noted: 100-200% errors in some cases. Typical cases, however, would probably reveal errors only between 10% and 25%. Such shortcomings can not be considered a serious factor in climatological compilations developed from many years of data for two reasons: first, because instrument errors tend to cancel out over many years of data; and second, because few observations will be worst case combinations of all four instrument errors.

Measurement data from the ten North Atlantic ocean weather stations (OWS) shown in Figure 1 -- archived by the National Climatic Center, Asheville, NC, for the period 1949 to 1970 -- were used for this present study. These data form the most complete set available encompassing a major area within a specific oceanic region. Over all stations, data were missing only for about 10% of the observations; these breaks in continuity presumably occurred because of operational problems and/or errors in data processing. (The one exception is OWS Hotel, which was decommissioned in the 1960's and later reestablished in the early 1970's for nine months of each year.)

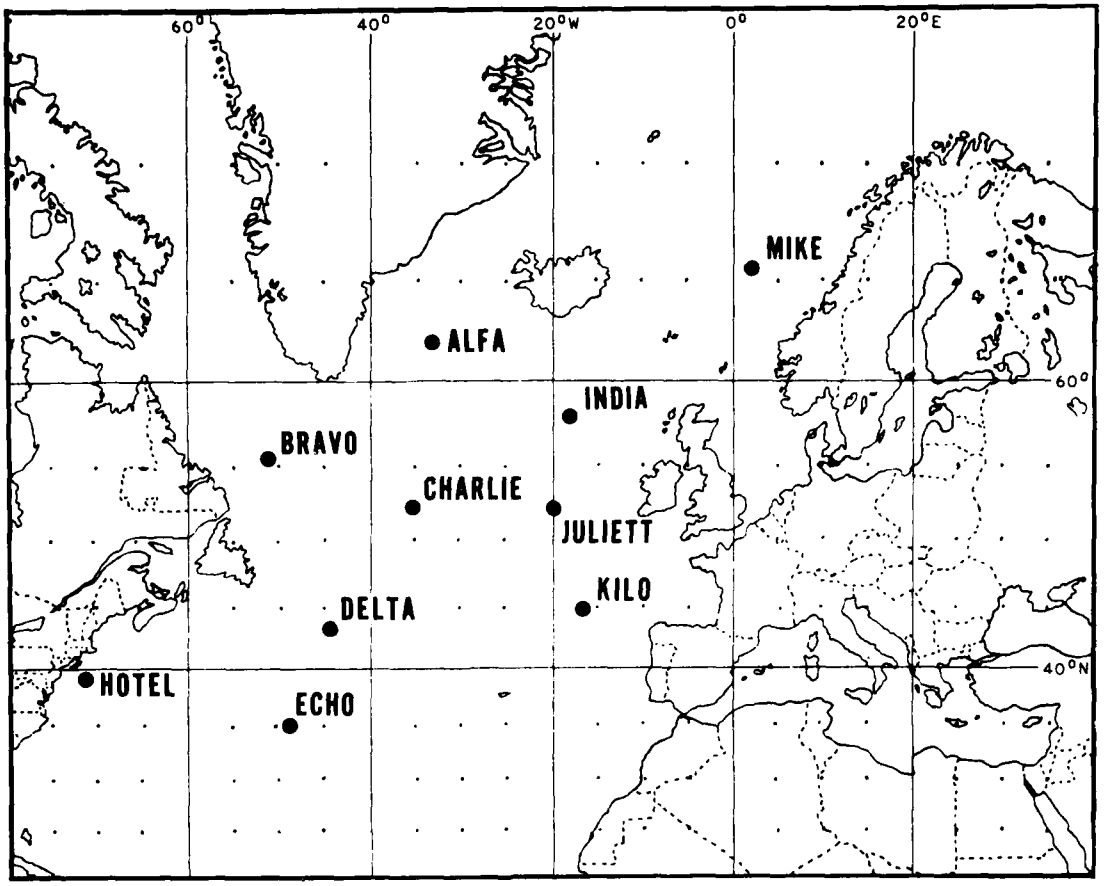

Figure 1. Locations of ocean weather stations (OWS) in the North Atlantic Ocean that provided data for the present study.

Station	Location	Station	Location
ALFA	62°N,33°W	HOTEL	36°N,70°W
BRAVO	56°N,51°W	INDIA	58°N,19°W
CHARLIE	52°N,35°W	JULIETT	52°N,20°W
DELTA	44°N,41°W	KILO	45°N,18°W
ECHO	35°N,48°W	MIKE	66°N,2°E

3. LATITUDINAL AND SEASONAL VARIATIONS

Evaporation duct heights vary with latitude; heights generally increase as latitudes decrease, a trend that is observed in all of this present study's central tendency statistics (monthly means, modes, and medians). The exceptions are OWS ALFA and BRAVO, and to some degree CHARLIE, which show smaller medians than other stations near their latitude. Figure 2 shows this variation of duct height with latitude. Note, the variation is less pronounced, and indeed not clearly supported by Figure 2, at the higher latitudes. (This high latitude disagreement will be discussed later.) Table 1 shows monthly medians of evaporation duct heights for the ten stations in order of descending latitudes.

Seasonal variations of median duct heights show a minimum during the summer and a maximum during the fall. A variation of more than 3 m in the average median duct height for the ten stations is shown in Figure 3a. The extremely large data sample size makes this variation statistically significant.

The months of maximum and minimum monthly median duct heights vary depending on the station, but overall the minimum heights occur during the period May-July and the maximum heights occur from September to December. The spread between the maximum and minimum monthly median duct heights also shows a latitudinal variation, with larger spreads occurring in the lower latitudes, as depicted in Figure 3b. The stations with the smaller minimum values show the larger of the spreads for stations located at similar latitudes.

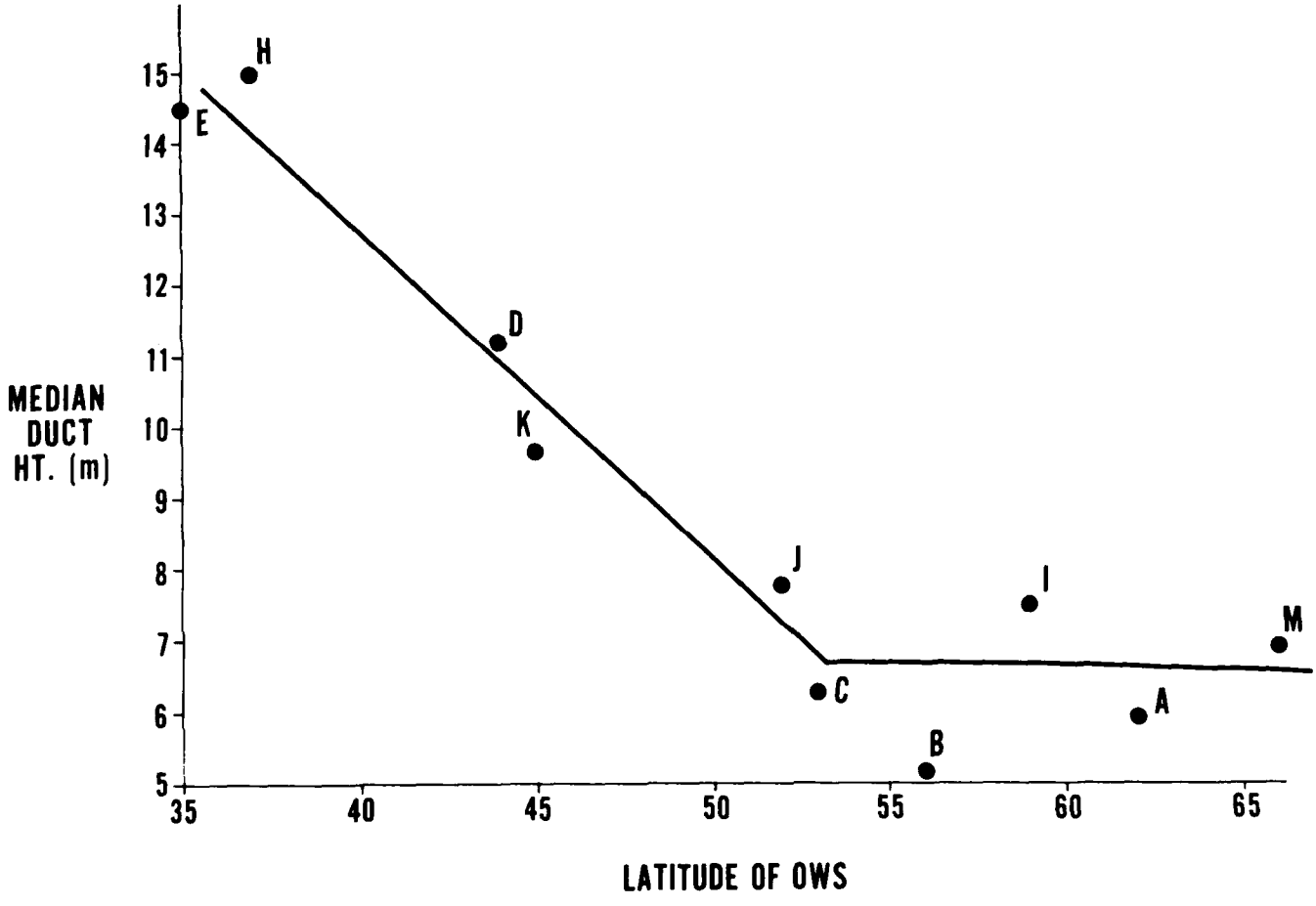

Figure 2. Plot of median duct heights versus latitude, showing the general decrease of heights with increasing latitudes. Median annual duct height is the height exceeded half of the time during the year.

Table 1. Median duct heights for each ocean weather station for each month. Average station median and average monthly median are given along the left and bottom margins, respectively.

Average (OWS)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	OWS
6.8	7.3	7.4	7.1	6.5	6.2	6.0	6.0	6.5	6.9	7.1	7.3	7.5	MIKE 66°N
5.9	6.4	6.3	6.1	5.7	5.0	4.5	4.8	5.7	6.7	6.7	6.5	6.9	ALFA 62°N
7.5	7.6	7.6	7.8	7.6	7.6	6.7	6.4	7.0	7.5	7.8	7.9	8.1	INDIA 59°N
5.1	5.5	5.1	5.3	5.0	4.1	3.5	2.6	4.1	6.5	6.9	6.1	6.1	BRAVO 56°N
6.1	7.0	6.5	6.2	5.6	5.0	4.2	3.5	5.4	7.2	7.8	7.3	7.4	CHARLIE 53°N
7.8	8.2	8.5	7.1	7.4	7.6	6.3	6.9	7.9	7.9	8.3	8.9	8.3	JULIETT 52°N
9.6	8.9	9.9	8.2	8.8	8.0	8.0	9.6	10.8	11.1	11.4	11.6	9.0	KILO 45°N
11.3	13.2	12.6	11.7	10.5	9.3	7.0	7.6	10.6	13.0	13.4	13.4	13.0	DELTA 44°N
15.1	14.1	14.2	14.0	14.9	13.7	12.7	13.8	15.7	17.9	17.5	16.5	15.8	HOTEL 37°N
14.4	14.8	14.0	14.2	12.0	10.7	11.2	14.7	16.8	17.1	16.2	16.3	15.0	ECHO 35°N
Monthly Average	9.3	9.2	8.8	8.4	7.7	7.0	7.6	9.0	10.2	10.3	10.2	9.7	--

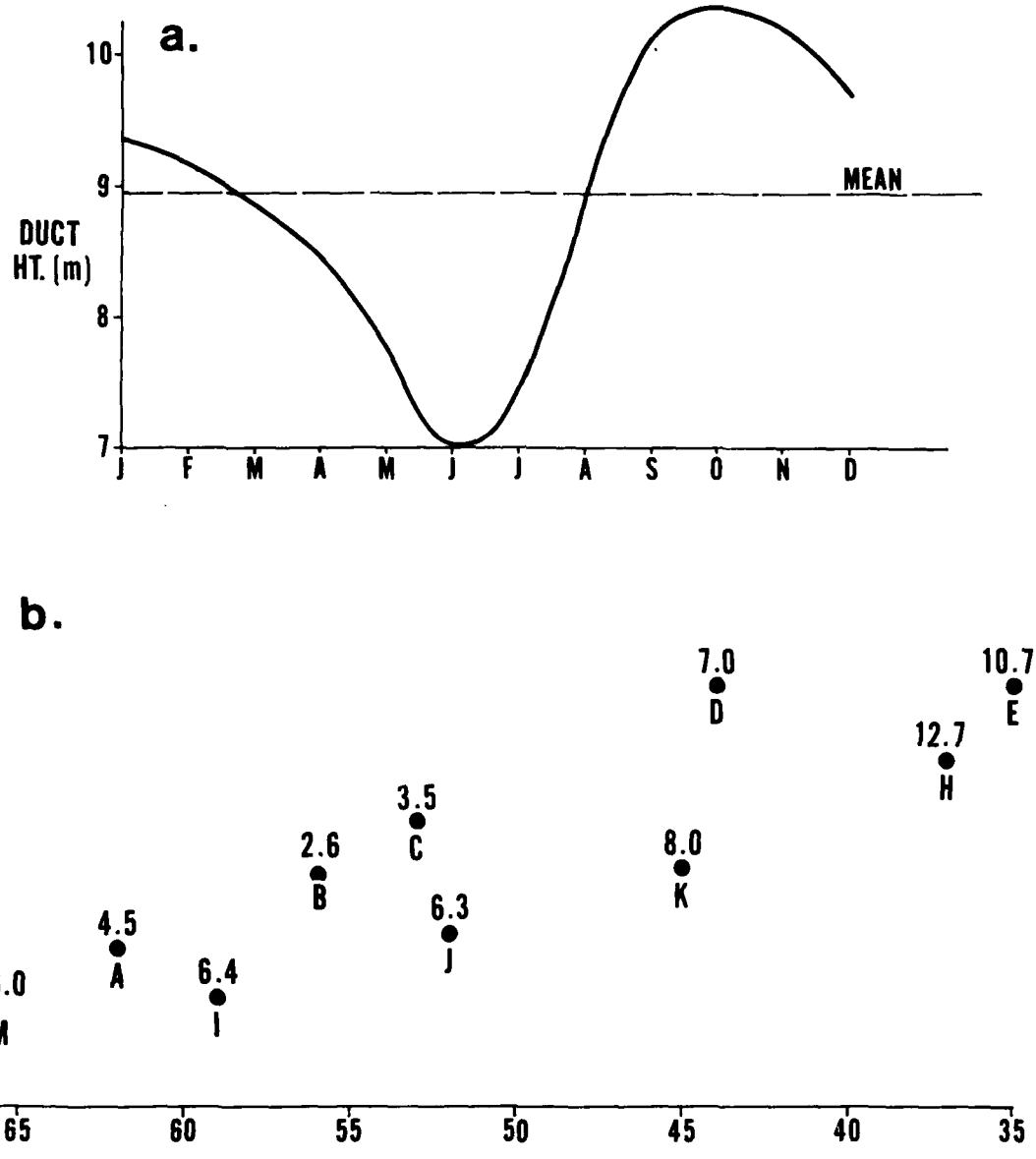

Figure 3. (a) Monthly medians of duct heights for all OWS. (b) Plot of duct height differences between maximum and minimum monthly medians. The number at each OWS plot is the minimum monthly median duct height at that station.

4. EFFECTS OF SURFACE-MEASURED PARAMETERS ON CALCULATION OF EVAPORATION DUCT HEIGHT

4.1 INTRODUCTION

The surface-measured parameters used as input to the calculation* of evaporation duct height (represented below by D) are air temperature (TA), sea surface temperature (TS), dew point temperature (TD), and wind speed (U).

Since dew point temperature (TD) can be calculated from air temperature (TA) and relative humidity (RH), and the difference between air and sea surface temperatures (hereafter represented by AS) has the physical significance of stability (h), the four parameters above can also be represented by the combination TS, RH, AS, and U.

Examination of the relationship of duct height (D) to variations in the input parameters requires some understanding of the functional dependence of D. A closed form expression of D does not exist; the equations used to find D depend in general on stability h and the vertical gradient of refractivity. This vertical gradient, ΔN, in turn, is represented by the difference in refractivity at the observation height, usually 10 meters, and at the surface, $\Delta N = N - N_s$. Using h to indicate the stability factor, then

$$D = D(h, \Delta N).$$

The stability factor is closely related to the shape of the N profile. According to boundary layer theory (Gossard, 1978),

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*Accomplished by using set of equations described in Hitney, 1975.

for neutral stability the N profile in the first few decameters (i.e., about 100 ft) has a logarithmic shape (i.e., very rapidly decreasing with height) near the surface with a gradual transition to a linear shape above (i.e., less rapidly decreasing). For slightly stable conditions the profile becomes nearly linear throughout, with only a small region (about 2-3 m) near the surface having a logarithmic curved tail. The unstable region is represented by a profile similar to the neutral case, but with a sharper curved section near the surface.

Figure 4 illustrates these three stability conditions. The numbered short horizontal lines indicate the relative duct heights for the three profiles; number 1 is unstable, 2 is neutral, and 3 is stable. These duct heights are determined by the slope of the profile; specifically, where the slope exceeds the value -157 N/km. Stable conditions allow higher duct heights since mixing from dry air aloft is at a minimum. Neutral and unstable conditions allow progressively more mixing from above, thereby suppressing the steep gradients to progressively lower levels.

Consideration of just the stability factor would lead one to expect the duct height to increase as the stability increases. Figure 5 is a plot of stability (1/L, L is the Monin-Obukhov length*) versus duct height showing such a relationship. The curves are drawn for several values of ΔN, where

$$\Delta N = N \text{ (observation ht)} - N \text{ (surface)}$$

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*L is a measure of stability that accounts for both convective mixing due to air-sea temperature differences and mechanical mixing due to wind.

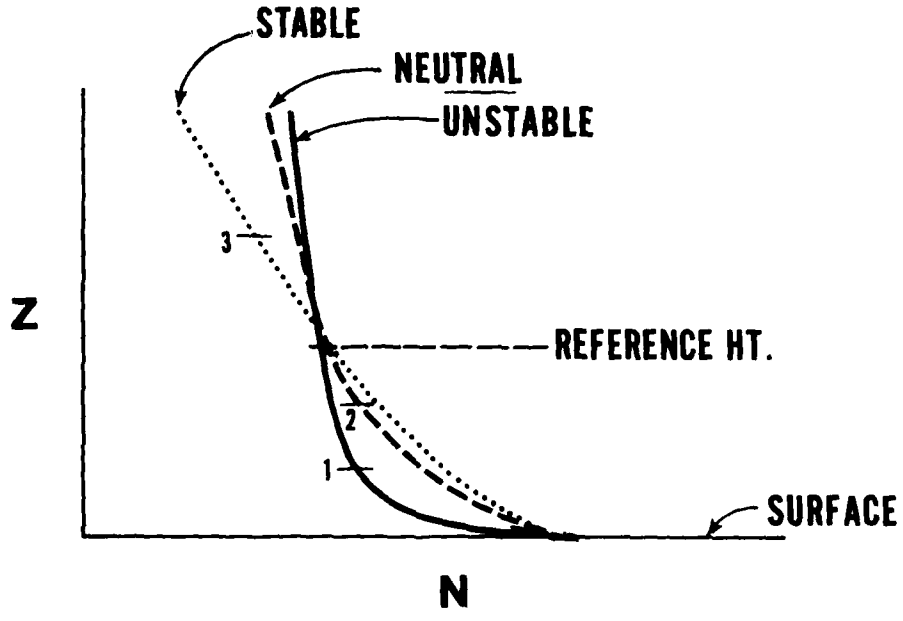

Figure 4. Three stability conditions as indicated by N profiles.

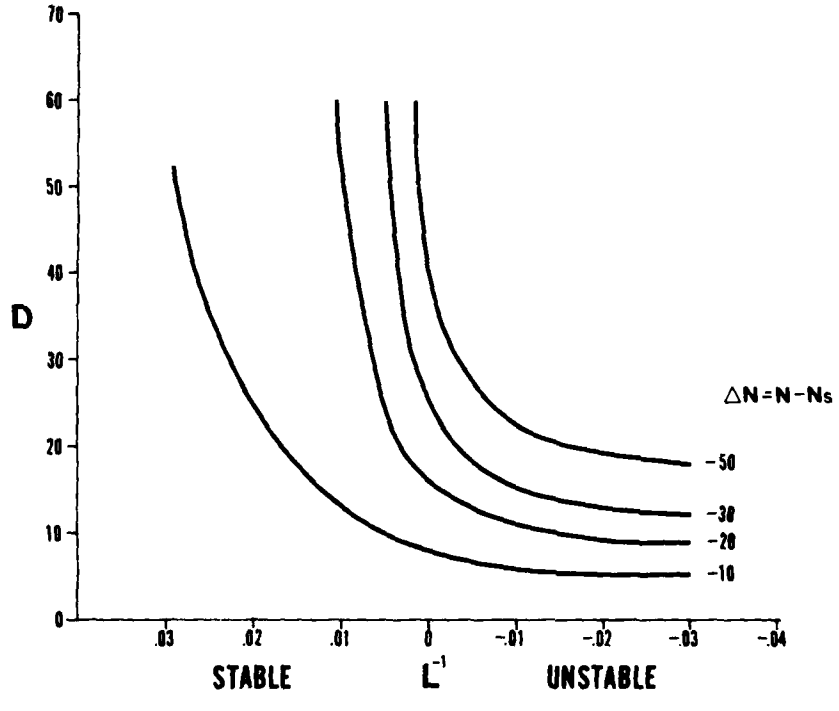

Figure 5. Plot of relationship of stability factor to duct height.

Large absolute values of ΔN lead to higher ducts. As ΔN becomes larger in absolute value, the curves change slope sharply after crossing into the stable region ($L^{-1}>0$). This rapid change in slope of the ΔN curves will be important in later discussions.

4.2 AIR-SEA TEMPERATURE

The relationship of duct height to stability is not easily interpreted in terms of the four observed input parameters, TS, TA, TD, and U, because L is a combination of both air-sea temperature difference and wind speed. Plotting duct height versus air-sea temperature difference, AS (equal to TA-TS) for various TD and U values allows direct climatological application. Four curves of duct height versus AS for various TD and U values are shown in Figure 6, a graph that reveals some unexpected characteristics.

The variation of duct height with AS shows a general increase with decreasing convective stability. The dashed curves are for a higher wind speed (30 kt) (i.e., more mechanical mixing) and show this general increase with decreasing AS. The solid curve (i.e., 15 kt wind) with the lower humidity (TD=16), however, shows a hump in the slightly stable region which the other three curves do not.

This hump can be explained by reference to Figure 7. Dashed curves (a) and (b) represent the solid curves (a) and (b) respectively in Figure 6. The hump is a result of the stability L^{-1} dominating the values of duct height near the neutral region, for the lower RH values. In the following explanation, TA is held constant, so as AS decreases, TS increases and hence $\Delta N=N-N_s$

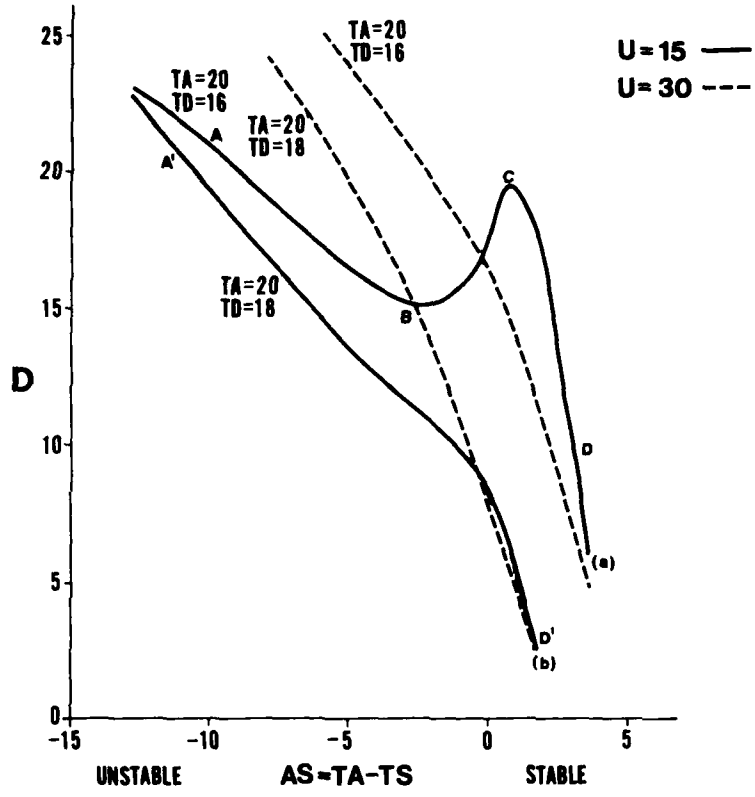

Figure 6. Plot of duct height versus AS (=TA-TS) for various values of TD (dew point temperature) and TA (air temperature).

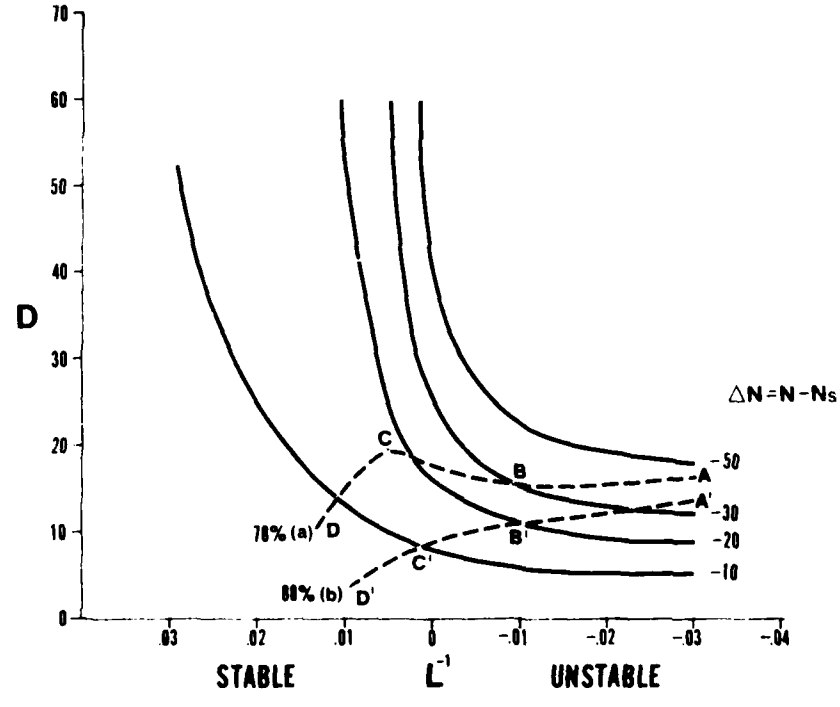

Figure 7. Neutral conditions require L^{-1} to be equal to 0; compare with Figure 6.

becomes more negative. Duct heights generally increase for the stronger ΔN gradients, other factors being held constant.

Consider first curve (a) in Figure 7. Compared to point D, point C has a larger TS value (for constant TA), a stronger ΔN gradient (more negative) and hence a much larger duct height (D) value. This larger D value results from the rapidly changing form (slope) of the various ΔN curves in the near neutral region. Point B however has a lower D value than point C since the change in ΔN, as AS aid TS increase, is more than offset by the steep slope of the ΔN curves on the slightly unstable side of neutral. Therefore the duct height decreases in the region between C and D (see Figure 6). Point A has a larger D value than point B simply because the flatness of the D versus L^{-1} allows the changing value of ΔN (as AS decreases) to force D to higher values. In comparison to curve (a), curve (b) in Figure 7 (and Figure 6) has lower values of ΔN due to the higher RH value. Curve (b) therefore remains in the region of the D versus L^{-1} family of curves which all have gradual slopes. Therefore ΔN is the dominant factor throughout the variation of AS; as a result, in Figure 6 D increases steadily from D' to A'.

For higher wind speeds (U) the mechanical mixing forces the stability L^{-1} more toward neutral, and the changing AS (and hence TS) values result from ΔN being the determining factor in duct height.

4.3 WIND SPEED

Increasing wind speeds cause increasing duct heights if sea surface temperatures are higher than the air temperatures (unstable), and decreasing duct heights if sea surface temperatures are lower than the air temperatures (stable). Figure 8 illustrates these trends for two values of TS. Increasing winds drive the stability toward neutral due to the increase in mechanical mixing. From Figure 7 it is clear that Figure 8 is correct since ΔN does not change value and the lowest of points for varying wind simply follow the given ΔN curve.

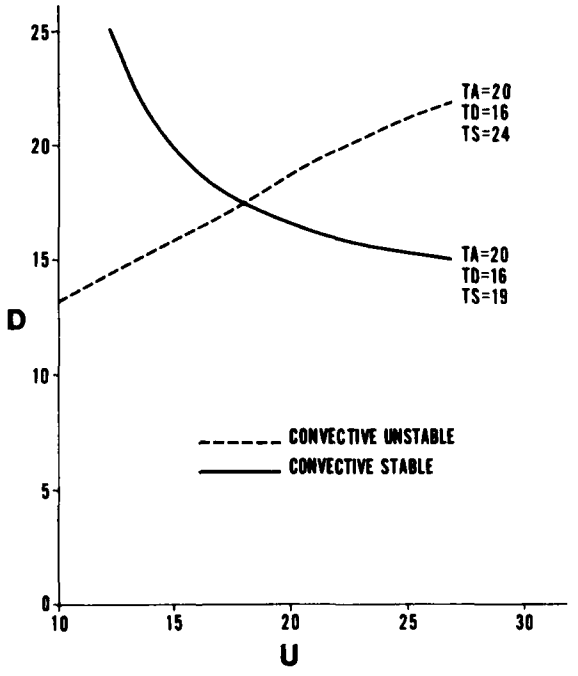

Figure 8. Variations in duct height (D) at increasing wind speeds (U) for values of air temperature (TA), dew point temperature (TD) and sea surface temperature (TS).

The preceding conclusions can be summarized for application to climatological data by realizing that sea surface temperatures force the value of air temperatures. Higher sea surface temperatures cause higher air temperatures and higher dew point temperatures. If the relative humidities and winds are in the range RH<85% and U<25 kt, respectively, then high ducts can result for sea surface temperatures slightly less than the air temperatures, (i.e., in the "hump" region of Figure 6). To summarize in tabular format,

	AS>0 Stable	AS<0 Unstable
TD	$D \alpha \frac{1}{TD}$	$D \alpha \frac{1}{TD}$
TS	$D \alpha TS$ $D \alpha \frac{1}{TS}$ *	$D \alpha TS$
U	$D \alpha \frac{1}{U}$	$D \alpha U$

*See above text.

5. CLIMATOLOGICAL CAUSES OF LATITUDINAL AND SEASONAL VARIATIONS OF MEDIAN DUCT HEIGHTS

The inverse relationship between latitude and duct height was noted in Section 3. Based on the discussion in Section 4, the cause for this increasing duct height as latitudes decrease is apparently due to the higher TS and the resulting higher TA values at the lower latitudes. Figures 9 and 10 show isopleths of TS in the North Atlantic, and median duct heights at each of the 10 ocean weather station locations, for the months of November and June, respectively. The relationships of duct heights to TS values are certainly not perfect, but they are clearly apparent. The slight exceptions to the latitudinal relationship are stations INDIA, MIKE and JULIETT; these three are in regions of predominantly warm ocean currents, and thus would be expected to have slightly higher duct heights.

The primary causes of seasonal variations are air-sea temperature differences, and wind speed and dew point temperature differences, between the maximum and minimum duct height seasons. The minimum median duct height occurs during the warm months when stability is nearly neutral or slightly stable, and the dew point temperature is higher than for the colder months. The monthly median values for TA, TS and TD for the minimum duct height and the maximum duct height are shown in Figures 11 and 12, respectively. In these figures, the spreads between the TA and TS values indicate the differences in the stability between minimum and maximum seasons. The minimum season averages between slightly

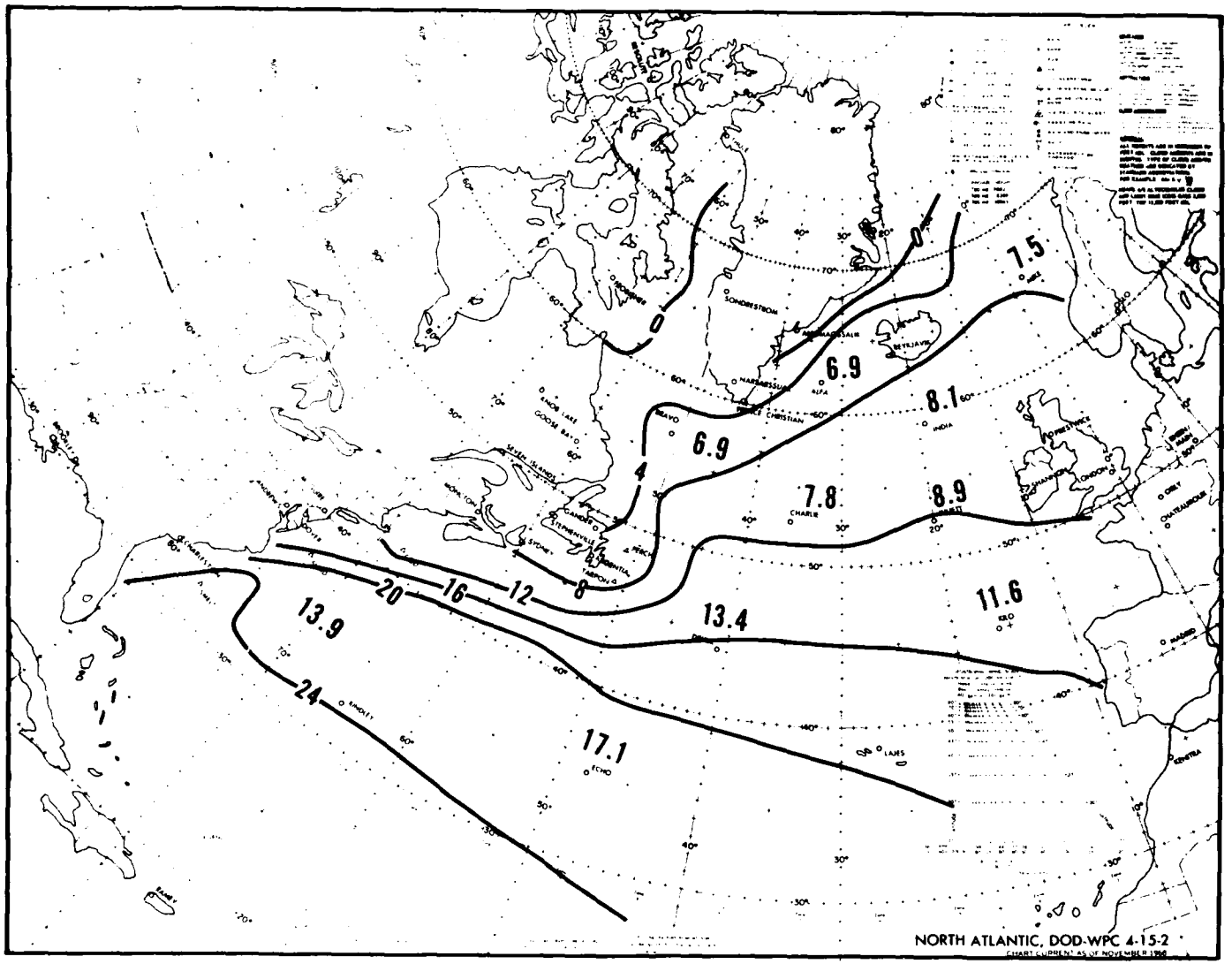

Figure 9. Sea surface temperature isopleths and maximum median duct heights for November (in meters, at each ocean weather station).

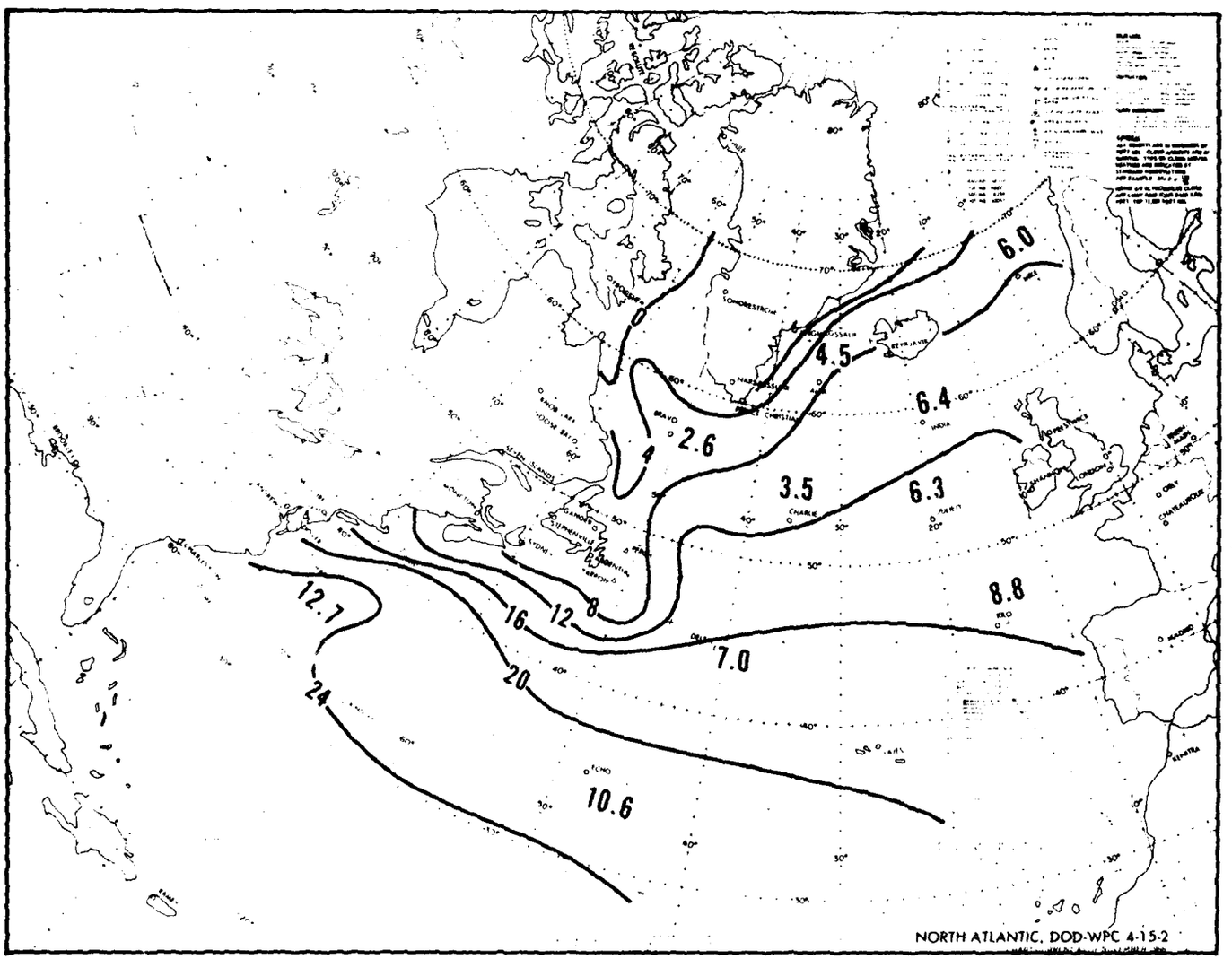

Figure 10. Sea surface temperature isopleths and maximum median duct heights for June (in meters, for each ocean weather station).

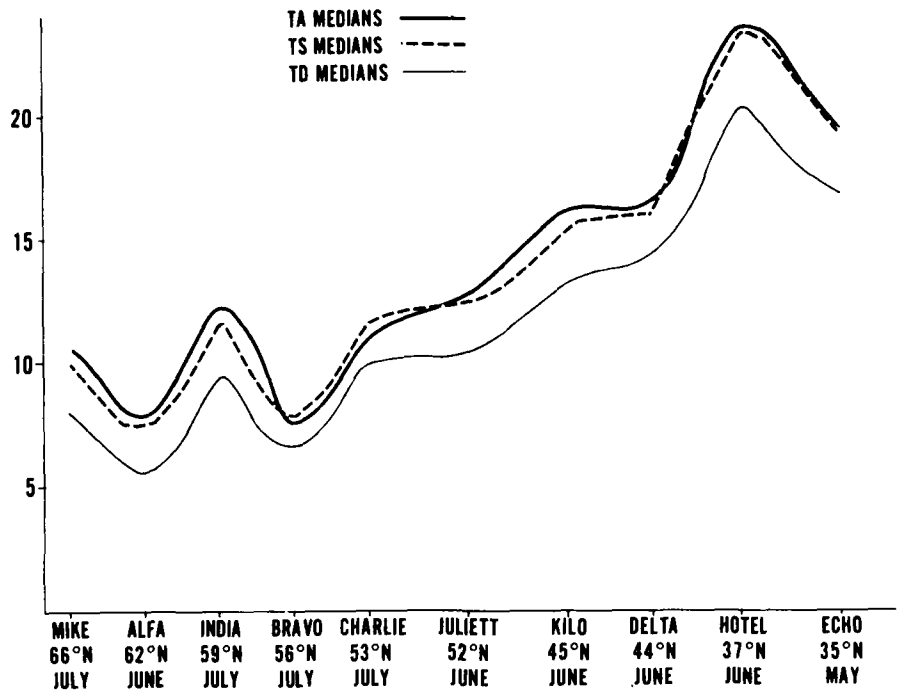

Figure 11. Median duct heights for the minimum-height season at each OWS.

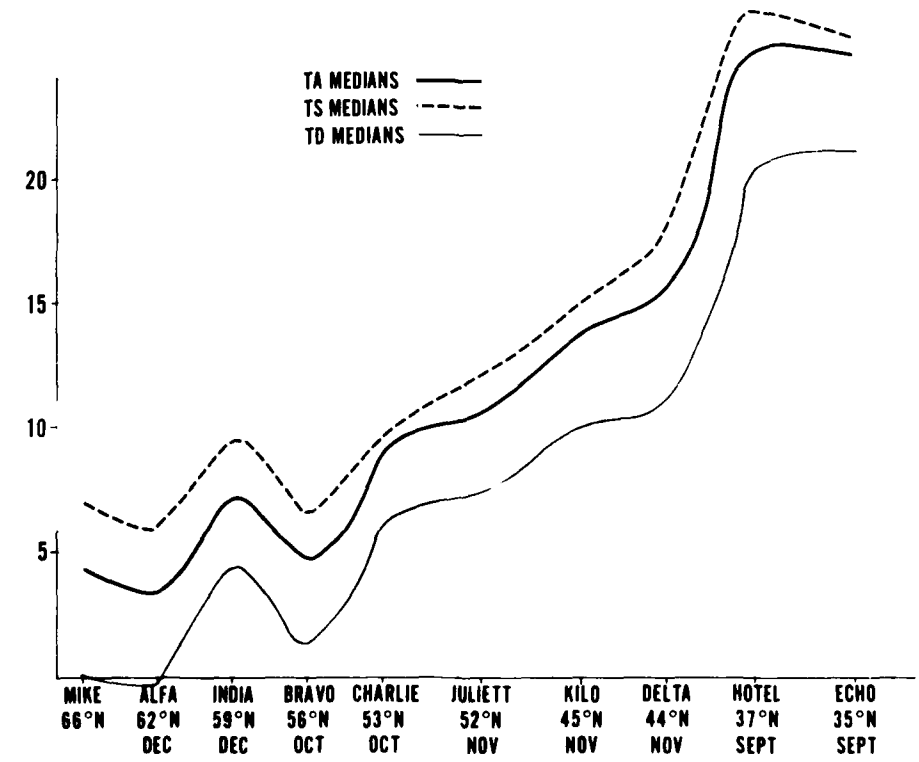

Figure 12. Median duct heights for the maximum-height season at each OWS.

stable to neutral. Also apparent in Figures 11 and 12 are the higher values of TD that occur during the minimum season. This one factor alone would cause lower duct heights due to the smaller values of ΔN.

Wind speed is also a factor in seasonal variations of duct height; in unstable conditions, duct height is proportional to wind. Table 2 summarizes the median wind values for each ocean weather station for the months of November and June. With only two exceptions, the month with the highest duct heights also has the highest median winds. The two exceptions are the two lowest-latitude stations, where winds are not as strong and have smaller seasonal variations. The overriding factor that causes the duct height seasonal variation at these two stations is apparently the variation in air temperature which causes change in the stability regime.

Table 2. Median values for wind, duct height, and TA-TS at 10 ocean weather stations in the North Atlantic.

		Maximum Season (Nov)			Minimum Season (Jun)		
OWS	LAT	Wind (Med.)	D (Med.)	(TA-TS) (Med.)	Wind (Med.)	D (Med.)	(TA-TS) (Med.)
ALFA	62	22.2	6.9	-2.6	14.0	4.5	0.2
BRAVO	56	21.6	6.9	-1.5	13.9	2.6	0.2
CHARLIE	53	21.2	7.8	-0.5	14.3	3.5	0.4
DELTA	44	21.4	13.4	-2.0	15.6	7.0	0.1
ECHO	35	12.2	16.3	-0.6	13.2	10.7	0.0
HOTEL	37	13.5	17.9	-1.7	12.9	12.7	0.3
INDIA	59	23.8	8.1	-2.1	15.3	6.4	0.7
JULIETT	52	21.9	8.9	-1.5	15.6	6.3	0.2
KILO	45	20.0	11.6	-1.1	13.7	8.0	0.6
MIKE	66	21.5	7.5	-2.5	13.2	6.0	0.5

The months with minimum duct heights are also months whose median stability is near neutral and slightly stable. Under stable condition $D\alpha\frac{1}{u}$, higher winds would lead to lower duct heights. However, high surface winds are normally associated with unstable conditions, since that situation is needed to bring down to the surface the higher winds aloft. During lower wind conditions the stability borders on neutrality, and winds are not as much a factor.

6. SUMMARY

The occurrence of higher duct heights with lower latitudes results from the generally higher sea surface temperatures which, in turn, lead to higher air temperatures. Both of these trends lead to higher ducts.

The occurrence of greater duct heights during the late fall and early winter results from this season's greater instabilities, lower relative humidities and generally stronger winds. The minimum season (late spring and early summer) results from the combination of higher relative humidities, more nearly neutral stabilities and lower mean winds. However, care must be exercised for slightly stable conditions, with low winds and humidities, since these conditions (theoretically) can lead to higher ducts than under neutral or slightly unstable conditions.

In general, in mid-latitude regions, higher duct heights occur during the late fall and early winter, and at the lower latitudinal part of the regions.

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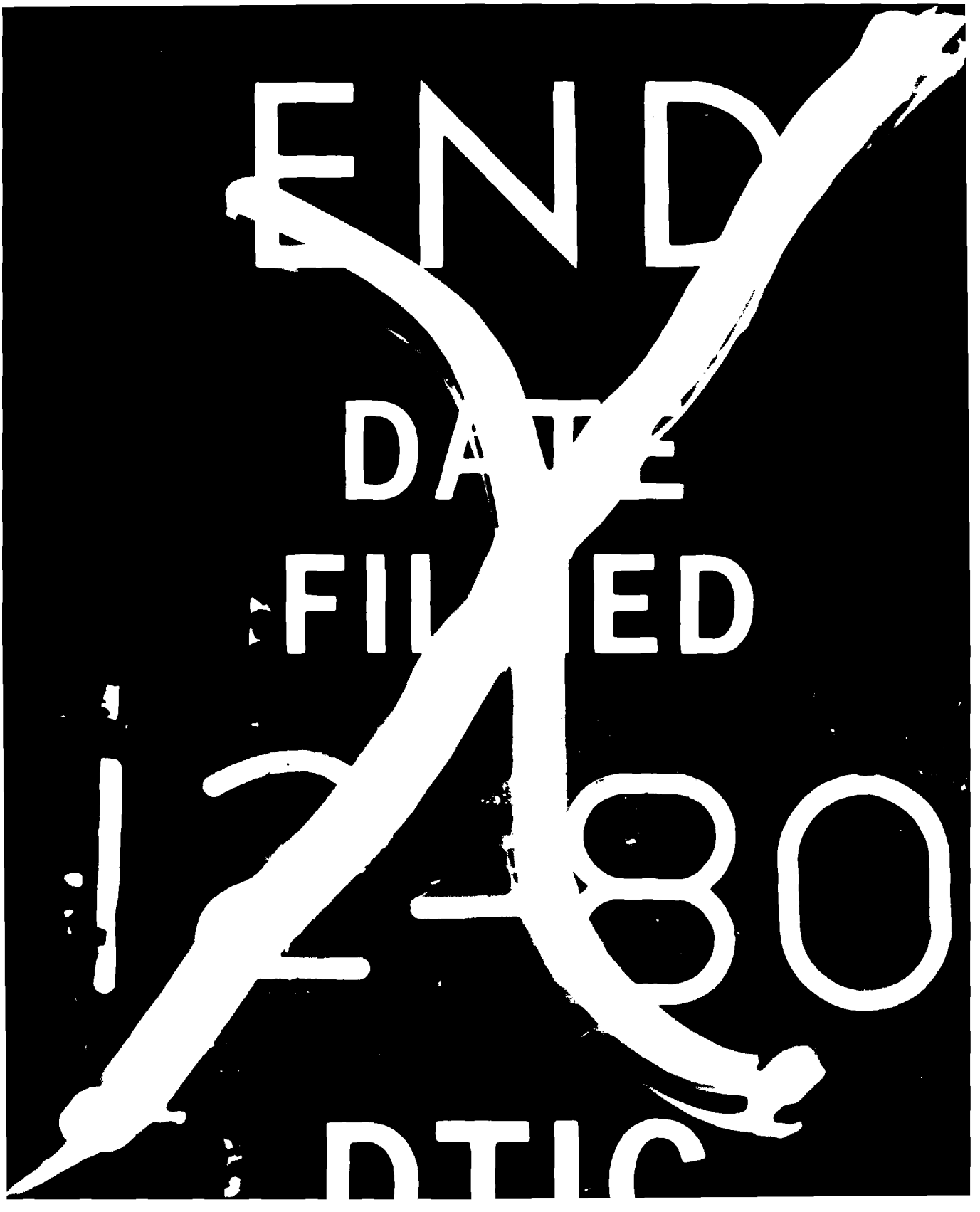
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2. On DD Forms 1473 of all subject reports listed in Pa

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3. On p. 5 of TR 80-05,

Eq. (1) should read $\Delta N = N_w(Ta) - N_w(Td)$

Eq. (2) should read $\Delta N = B[\frac{e(Ta)}{Ta^2} - \frac{e(Td)}{Td^2}] \approx$

adding Δ in Eq. (1), and deleting repeated expression $-\frac{e}{}$ Eq. (2).

Gustave Gold

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