NASA-CR-167497

A COMPARISON OF IN-CLOUD
HCl CONCENTRATIONS FROM THE
NASA/MSFC MDM TO MEASUREMENTS
FOR THE SPACE SHUTTLE LAUNCH
12 April 1981

Final Technical Report

by

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(NASA-CR-167497) A COMPARISON OF IN-CLOUD HCl CONCENTRATIONS FROM THE NASA/MSFC MDM TO MEASUREMENTS FOR THE SPACE SHUTTLE LAUNCH Final Technical Report (Kearney State Coll., Nebr.) 42 p HC A03/MF A01 CSCL 13B G3/45

N82-17653
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08822

In Partial Fulfillment of
Contract Requirements for

Contract Number NAS 9-16162

CONTENTS

TABLES

FIGURES

ABSTRACT

The NASA/MSFC - Multilevel Diffusion Model (MDM) Version 5 used by the Environmental Effects Office at JSC was modified to include features of more recent versions. The MDM was used to predict in-cloud HCl concentrations for the April 12 launch of the Space Shuttle (STS-1). The maximum centerline predictions were compared with measurements of maximum gaseous HCl obtained from aircraft passes through two segments of the fragmented Shuttle ground cloud. The model over-predicted the maximum values for gaseous HCl in the lower cloud segment and portrayed the same rate of decay with time as the observed values. However, the decay with time of HCl maximums predicted by the MDM was more rapid than the observed decay for the higher cloud segment, causing the model to under-predict concentrations which were measured late in the life of the cloud. The causes of the tendency for the MDM to be conservative in over-estimating the HCl concentrations in the one case while tending to under-predict concentrations in the other case are discussed.

Further comparisons of the MDM predictions for in-cloud HCl concentrations were made for Titan III launches in which aircraft measurements of HCl were available. These comparisons indicated that the model is conservative and over-predicts the maximum HCl concentrations early in the cloud's history. Results for in-cloud HCl concentrations for some of the meteorologies characteristic of Cape Canaveral are presented.

INTRODUCTION

The primary objectives of the work reported on here were to: (1) Develop the capabilities of the NASA/MSFC Multilayer Diffusion Model (MDM) Version 5 to obtain in-cloud predictions of HCl concentrations for the Space Shuttle, and (2) To use the MDM for comparisons with the field measurements on the first Shuttle launch for the purpose of model validation.

Additional objectives of the work reported on here included obtaining information on: (1) The capabilities of the MDM for predicting in-cloud concentrations of HCl for Titan III launches, and (2) The in-cloud HCl concentrations which may be expected to be encountered for Space Shuttle launches at Cape Canaveral under average meteorological conditions.

The results reported here include the procedures used to implement the in-cloud prediction capabilities for the MDM on a PDP-11/45 at the Environmental Effects Office at JSC. The documentation is given for the changes made in the MDM which allow the selection of Version 6 Shuttle parameters already in the program. Version 7 parameters were added to the selection of options available for Space Shuttle launch parameters. A comparison of the HCl predictions by the MDM for a given meteorology using the three versions of Shuttle launch parameters indicated that there was an insignificant difference between their predictions.

The MDM validation for the April 12, 1981, Space Shuttle launch (STS-1) showed that the model predictions for the lower cloud segment in an unstable setting closely portrayed the decay of HCl with time but over-predicted the magnitude of gaseous HCl. One factor which could be expected to cause the measured HCl concentration to be below model predictions is that this segment of the cloud had a high relative humidity.

In-cloud measurements indicated that this resulted in a large fraction of HCl being involved in aerosol rather than gaseous form. The MDM predictions for the higher cloud segment which drifted westward from the launch site were less than the measured values. The upper cloud was not sampled until after passes through the lower cloud had been completed or about 50 minutes after launch. The MDM predictions for HCl which were for a much later period in the cloud's history were lower than those observed. This may be due in part to the assumption in the MDM that the diffusion processes continue at a constant rate throughout the cloud history. The diffusion rate is determined by the standard deviation in the horizontal wind from values near the surface. As the launch cloud enters a more stable environment, as was the case for the upper cloud segment, this assumption would tend to cause the MDM to over-estimate the rate of decay of HCl within the cloud. Measurements also indicated that essentially all the HCl was in gaseous form in this cloud which had low relative humidity.

Predictions for in-cloud HCl concentrations for Titan launches indicated a tendency for the MDM to over-estimate the concentrations. The in-cloud HCl concentrations for Shuttle launches predicted by the MDM for the standard meteorologies at Cape Canaveral closely parallel those for Titan launches for the same atmospheric conditions.

MODIFICATIONS OF THE MDM

The Environmental Effects Office at JSC has used the NASA/MSFC Multilayer Diffusion Model Version 5 by Dumbauld and Bjorklund (1) to predict surface concentrations of HCl for rockets using solid fuel boosters (Glasser et al., 2, 3). In its original form the MDM was run on UNIVAC but it was modified in 1977 by Joe Yoder to run on a PDP 11/45. Further changes were made in 1979 by Larry Ray of JSC including the addition of Version 6 parameters (Dumbauld and Bjorklund, 4) which included new values for the Space Shuttle.

Attempts to use the MDM in its earlier and modified forms at JSC to give HCl concentrations at levels other than the surface were not successful. To implement this capability of the MDM, it was necessary to modify two statements in subroutine SETUP DAT., i.e., NPTS which identifies the number of levels in the cloud at which concentrations are desired and ZZL which is the parameter for the height of these levels in meters. Invisible errors in this routine, i.e., blank spaces which did not show in printouts frustrated earlier attempts to obtain in-cloud concentrations. With these modifications the MDM will output HCl concentrations at any level up to the cloud stabilization height.

Because of the great length and complexity of the MDM, even small modifications can be difficult to accomplish or can cause unexpected problems. This is particularly true if more than one segment of the program is involved. Richard Roenfeldt made changes in the MDM which implemented the Version 6 constants. For example, even though Version 6 constants had been put into the program and when called, the program indicated they had been used, careful checking on the outputs, however, showed Version 5 constants were used in all cases. Appendix A gives the documentation on changes required to implement Version 6 and Version 7 constants. Richard Roenfeldt made these and other changes in the MDM relative to this report. Table 1 gives the most recent constants for the MDM which have been used in the REEDM version of the MDM being used at KSC. These constants do not differ substantially from Versions 5 and 6 constants and did not cause significant differences in HCl predictions when run on identical cases.

MDM PREDICTIONS FOR STS-1

The most important aspect of the work reported here is the validation of the MDM for predicting in-cloud HCl concentrations for Space Shuttle launches. The results of field measurements of HCl from aircraft flights through the ground launch cloud for STS-1 as reported by Sebacher et al. (5) were used in this validation.

The Data

The meteorological sounding at launch time (T-0) for STS-1 on April 12, 1981, is given in Table 2. This data was obtained by telephone transmission through the interface with the KSC computer and was used in the MDM predictions reported here. An abbreviated version of the meteorology giving a few of the levels is provided in Table 3. A graph of the temperature and dewpoint temperatures as a function of height from these tables is shown in Figure 1. On this same Figure the height predicted by the MDM for stabilization of the launch cloud (1187 m) is given. The flights through the fragmented launch clouds A which ranged from 850 m to 900 m, and for Cloud B from 1600 m to 1870 m are also given for reference purposes.

The temperature sounding of Figure 1 clearly shows a shallow surface inversion and a moderate upper level inversion and stable layer extending from 3256 feet to 7000 feet. This type of sounding is characteristic of weather regimens for the Cape in which the Bermuda High extends over the Florida Penisula. Subsidence in the high pressure area produces the inversion and stable layer at upper levels. This stable layer is responsible for suppressing the observed stablization height for Cloud B but the inversion is not intense enough to suppress the launch cloud to the level predicted by the MDM.

Examination of the wind directions in Table 3 indicate a vertical shear of the horizontal wind throughout the mixing layer and across the inversion. This shear helped to fragment the Space Shuttle launch cloud which was observed to stabilize in five segments each at a different height.

Figure 2 provides a view of this wind shear at the launch site. Arrows represent the magnitude and direction of wind for the heights in Table 3. The wind direction near the 1000 foot level is generally northward nearly along the shoreline of the Cape and corresponds to the direction the lower cloud (Cloud A) was observed to travel. Figure 3 gives a rough sketch of the path taken by Cloud A for the first 24 minutes of observation. The wind direction at the 6000 foot level is toward the west and more nearly corresponds to the direction that the upper cloud (Cloud B) was observed to travel. The direction of cloud movement predicted by the MDM is intermediate to the two clouds and is represented by crosshatching in Figure 2.

The fragments of the Shuttle launch cloud were observed to reach stabilization height 8 minutes after launch. Sampling of Cloud A for HCl gases and aerosols and for particulates begin at 8.6 minutes after launch for Cloud A and continued at 2 to 5 minute intervals until 45 minutes after launch. The higher cloud was similarly sampled from 49 minutes until 2 hours and 8 minutes after launch. Examples of the HCl measurements for aircraft passes through the upper and lower clouds are given in Figure 4 (from Sebacher et al., 5). The low altitude segment, Part (a) of Figure 4 shows that Cloud A has a high relative humidity and has a small fraction of HCl in gaseous form while much of the HCl is contained in aerosol form. The high altitude segment, Part (b) of Figure 4 shows that Cloud B has a low relative humidity and has nearly all of its HCl in non-aerosol form. The maximum value of gaseous HCl for each pass through Clouds A and B is given in Table 4. The maximum total HCl are plotted in Figure 5 (Sebacher, 5) along with particulate concentration, relative humidity and temperature. It should be noted that these values are plotted as a function of time after launch. This adds an element of uncertainty when making comparisons with HCl predictions from the MDM since these predictions are given as a function of distance from the point of launch.

The in-cloud HCl predictions computed here were obtained from the MDM using the meteorology from Table 2. In-cloud concentrations were computed for four different levels corresponding roughly to the upper and lower limits of aircraft sampling heights for Clouds A and B (see Figure 1). Values of maximum centerline HCl for 850 m and 900 m were obtained for the lower cloud and for 1600 m and 1800 m for the upper cloud (Table 5).

The maximum peak HCl predictions for the lower cloud at the 850 and 900 meter levels given in Table 5 differ by less than 1%, while those for the upper cloud differ by less than 10%. The maximum peak (centerline) HCl concentrations from Table 5 are plotted in Figure 5. HCl measurements recorded in Table 4 were made as a function of time in reference to the launch. The MDM predictions, however, are output as a function of distance of the launch cloud from the launch site. In order to make a comparison of these MDM predictions with the HCl measurements, it is necessary to make some assumption relative to the equivalence between the time from launch and distance of the launch cloud from the launch site. The most reasonable assumption would be to consider that the cloud fragments move with a speed equal to the average wind speed of the layer at which the particular cloud stabilized. From Table 2 the wind speed decreases from 12 knots at 2000 feet to 9 knots at the 3000 foot level. Since Cloud A drifted northward at alittudes from 650 meters (2,133 feet) up to 950 meters (3,117 feet), it would be reasonable to assume that it experienced an average wind on the order of 10.5 knots (5.4 m/sec). The second cloud segment was observed to drift westward at altitudes from 1350 meters (4,429 feet) up to 1380 meters (6,168 feet). From Table 2 the wind increases from 8 knots at the 4000 foot level to 16 knots at the 6551 foot level making it reasonable to assume an average wind on the order of 12 knots (6.17 m/sec) for Cloud B. It is necessary to add to the values output by the MDM the amount of time elapsed from launch to cloud stabilization which was at 1250 m and 2500 m downwind from the launch site according to the MDM. Using an average wind speed for the rising launch cloud of 10.5 knots gives a time to cloud stabilization for the lower cloud of 5 minutes, 21 seconds and a time of 7 minutes, 43 seconds for the upper cloud. This is close to the 8 minutes to cloud stabilization that was reported to be observed by Sebacher (5). It will be noted later in this report that a shift of the time scale by several minutes in either direction will not significantly alter the conclusions reached relative to the comparison of observed and predicted HCl concentrations. The values for the correspondence between time and distance scales for Clouds A and B using the assumptions discussed are tabulated in Table 6 along with HCl predictions from Table 5 and are used in Figures 7 and 8 to compare HCl observations and predictions.

The Analysis

In Figure 7 the MDM predictions for peak centerline HCl concentrations given by the solid line exceed the peak values of gaseous HCl represented by squares which were through the lower cloud. The agreement between the magnitude of the observed and measured values of gaseous HCl is fair considering the uncertainties inherent in both methods of determining it.

The rate of decay of HCl with time is in particularly good agreement for both predicted and measured values. The lower cloud is in a region where the atmosphere is less stable than where the upper cloud is located. This may be determined by looking at the temperature profile in the plot of the MET sounding in Figure 1. The rate of decay of HCl concentration as determined by the MDM is largely a function of the standard deviation of the horizontal wind speed (σ) as used in the diffusion calculations. This parameter was obtained from the KSC computer which calculates σ using an objective routine that analyzes the variances in wind direction. The value of $\sigma = 13$ which was used is relatively large as parametric studies (Glasser, 1) have shown. This value of σ would appear to be representative for HCl concentration decay in the region below the upper level inversion shown in Figure 7.

The magnitude of HCl concentrations predicted by the MDM has been shown to be conservative in other studies which have used it to predict surface concentrations of HCl for Titan launches. The over-prediction of in-cloud HCl would also be expected because of conservative assumptions which have been built into the MDM. Another factor which would tend to cause the predicted HCl values to be larger than the measured values for this particular case is the large amount of HCl that is in the aerosol form. The measured values for total HCl (gaseous plus aerosol) is given in Table 4 and plotted in Figures 4, 5, and 7. In Figure 7 it can be seen that the MDM predicted value lies about midway between gaseous and total HCl concentrations. The rate of decay of total HCl closely parallels the rate of decay of the predicted and measured HCl in gaseous form.

The agreement between measured and observed HCl could also be affected by the assumptions used in relating measured sampling time to predict cloud position. The data on observed cloud position given in Figure 3 indicates Cloud A is 5 km from the launch site in 10 minutes and 10 km from the pad 39 in 24 minutes. This compares with the calculations used on the MDM predictions given in Table 6 where at 5 km the time is 15 minutes, 36 seconds and at 10 km the time is 30 minutes, 52 seconds. To bring the time assumed for the MDM cloud position into agreement with the cloud positions in Figure 3 would require a subtraction of about 6 minutes which would have the effect of shifting the MDM prediction to the position of the dashed line in Figure 7. This is not enough to affect the analysis of the comparison of observed and measured HCl values given here.

In Figure 8 the MDM predictions for HCl in Cloud B, represented by a solid line, are compared to measurements of gaseous and total HCl concentrations. The MDM predictions in contrast to those for the lower cloud significantly under-predict by a factor of about 3 the gaseous HCl. The measurements of gaseous and total HCl also do not display the decay with time predicted by the model. In fact, the gaseous HCl values decay relatively slowly over the 70 minutes of sampling time as indicated by the dashed line in Figure 8.

The reasons for the lack of agreement are probably related to the fact that the upper cloud has entered a stable environment above the inversion (note Figure 1). In this environment mixing processes are inhibited while the MDM essentially assumes the same rate of decay established by the choice of σ in the surface environment. It would have been useful to have HCl concentration measurements of Cloud B early in its history to check on the role of the decay rate in this over-prediction by the MDM.

Another difference between the lower and upper clouds is that Cloud B had a low relative humidity causing the HCl concentration to be almost entirely in the gaseous phase. The measurements of total and gaseous HCl plotted in Figure 7 show a great degree of variability perhaps suggestive of the difficulty in making accurate measures under these circumstances. The error range in these measurements was provided by Richard Bendura of LRC as $\pm$ 20% with a precision of measurement of 0.5 ppm. The variability of the data could also be related to the difficulty of aircraft sampling when the cloud has become diffuse with the passage of so much time.

One problem with the use of the MDM for making these predictions is certain to cause the HCl values to be under-estimated is the following. The MDM will not compute HCl concentrations above the mixing height which must be chosen subjectively prior to running the program. From Figure 1 the height of the surface mixing layer is clearly at the base of the upper level inversion. In order to have the MDM calculate concentrations above this level, it was necessary to assume the mixing would occur throughout the layer from Cloud B to the surface. This assumption is not realistic and causes the concentrations of HCl to be reduced at every level. It is, therefore, quite probable that the under-prediction of HCl concentrations in the upper cloud are related to problems inherent in the MDM which prohibit it from more realistic modeling changes encountered in the real atmosphere.

ADDITIONAL COMPUTATIONS

The proceeding material completes the report as required for the original grant application (Appendix B). During the period of work on Phase I, which was for one month at JSC, the objectives of Phase II, which was projected to require six months, were also primarily completed. Because the capabilities of the MDM for predicting in-cloud HCL concentrations were implemented so quickly, additional in-cloud data was developed while awaiting the Space Shuttle launch and while work on modifying the MDM proceeded. Since that data does not appear to contribute much that is new in the way of insights into the subject of HCl concentration predictions and since complete documentation of these data would produce a very lengthly report of potentially little merit or interest, the nature of the data will only be briefly summarized to indicate what is available.

One area of interest was the in-cloud HCl concentration predictions for rocket launches using solid fuel boosters for which in-cloud HCL measurements had been made.

In-cloud predictions were made for Titan III launches for a number of different weather regimens including one using MET data for the May 20, 1975, Titan launch for which HCl measurements were available. Examination of the case appeared only to confirm the results by Rudolph (6) which indicated the tendency of the MDM to over-predict HCl values for Titan and Delta launches for the period studies, 1973-1978. An example of the type of data developed for Titan launches is given in Table 7 for February 27, 1965, which gives the peak HCl concentrations for each 100 meter level through the mixing layer. The highest HCl values center on 700 meters while the cloud stabilized at 900 meters.

The highest HCl values also occur closest to the launch site, 7500 meters, while at levels away from cloud center the peak HCl concentration occur at greater distances, indicating the time lag as diffusion takes place both upward and downward.

Another area of interest is the effect of the different weather regimens found to occur at Cape Canaveral as presented by Siler (7), on in-cloud HCl concentrations for Shuttle launches. In this analysis, the weather regimens in which the subtropical ridge dominates the weather of the Cape are classed as A1, A2 or A3 depending on whether the pressure center lies close, south or north of Canaveral. The April 12 Shuttle launch occurred under A1 conditions which have the greatest probability of occurring (20%) of any of the six weather types characteristic of the region. Under these conditions the probability of onshore transport of the launch cloud is over 90%. A vertical profile of A1 weather from the day of the Shuttle launch, April 12, 1981, is given in Table 8.

The vertical profiles of peak HCl from MDM predictions in Table 8 can be related to the results of the Shuttle launch in the previous discussions. In the MDM predictions with the 5000 foot mixing layer assumption, the HCl increases to the 1300 m level to 65 ppm while in the case with the 3750 foot mixing level, the HCl increases to 26 ppm at the 600 m level. The effect of changing σ from 4.5 to 9.0 is to markedly decrease HCl concentrations at the cloud center and to increase values below the cloud indicating rapid mixing of HCl throughout the layer. This demonstrates the effect of an increase in σ on decreasing the HCl predictions by the MDM. The over-prediction of HCl for the upper cloud in the Shuttle launch has been considered to possibly be attributed to the σ of 12.0 used in those predictions.

MDM predictions for HCl concentrations were made for several levels in the vertical for MET conditions representing each of the weather types developed by Siler (7). These predictions were made for both Shuttle and Titan launch parameters. Although this rather large amount of data represents a kind of climatology of in-cloud HCl concentration predictions, its value is somewhat reduced by the lack in uniformity in assumptions. This is because the data was developed over several months while changes were being made in the MDM itself.

CONCLUSIONS

This work represents a first attempt to compare in-cloud HCl concentration predictions to in-cloud aircraft measurements of HCl for the Space Shuttle launch. The inadequacy of the NASA/MSFC MDM to accurately portray the actual complexities of the diffusion process and particularly to cope with the effect of changing conditions which rocket launch clouds encounter as they drift from the site are well known and have been given consideration in numerous studies. If there is a general conclusion from the work presented here, it is that in spite of the numerous experimental and theoretical difficulties in obtaining the in-cloud HCl concentrations, the agreement is at least within an order of magnitude.

The fragmentation of the Shuttle launch cloud on the April 12, 1981, launch presents a serious difficulty for the MDM at the onset since only simple cloud geometries are assumed. In spite of these difficulties, the decay rate of peak HCl concentrations in the lower cloud are well portrayed by the MDM and are only slightly over-predicted. The over-predictions may be understandable as discussed because of the significant amount of HCl which is in aerosol form due to the high relative humidity of the lower cloud.

The decay of HCl concentrations predicted by the MDM for the upper cloud is much more rapid than observed over the 70 minute sampling period. As discussed, this could be related to the use of a standard deviation of the horizontal wind direction (σ) that is appropriate for estimating the diffusion processes in the lower cloud which is in an unstable environment. The upper cloud, however, is in a region of generally high stability which reduces mixing. This could also account for the magnitudes of HCl being under-predicted particularly since the upper cloud was not sampled until about 50 minutes had elapsed. In general, it is apparent from this study that the MDM can produce in-cloud HCl values that fall within a reasonable range of measurement. Comparisons of MDM HCl concentrations with surface HCl measurements show less agreement since studies indicate it over-predicts by an order of magnitude or more.

If more refinement is required in the knowledge of in-cloud HCl, it is likely that both the model and the measurements will have to be improved.

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TABLE 1. MDM Preprocessor Parameters

The most recent constants for the MDM Preprocessor as provided by Hans Rudolph, KSC, May 1977. Referred to as Version 7 constants in this report, they do not differ substantially from Version 6 (Bjorklund, 4) and Version 5 (Bjorklund, 3) constants.

VPAR #		SHUTTLE	TITAN	DELTA II	DELTA IV
1. QC1	Expenditure Rate grams/sec; norm	1.521923 E7	5.437528 E6	8.360685 E5	1.057557 E6
2. QC2	Exp. Rate g/s; one motor on pad burn	6.882968 E6	2.718764 E6	9.09811 E4	1.482923 E5
3. QC3	Exp. Rate g/s; motor explode on pad	3.4141484 E6	1.359382 E6	2.729434 E5	3.70731 E5
4. QT1	Source Strength grams; normal	1.8947941 E9	3.2625168 E8	2.887598 E7	6.70269 E7
5. QT2	Source Strength grams; abnormal	8.56929516 E8	1.6312584 E8	3.14229 E6	9.398616 E6
6. QT3	Source Strength grams; explosion	1.71385903 E9	3.2625168 E8	1.885373 E7	4.699308 E7
7. AA	Rise Parameter $t = aZ^b+c$	0.6522129	0.429580469	0.922156	1.245756
8. BB	Rise Parameter Z = Height, Meters	0.4680846	0.5184223	0.432703	0.4180947
9. CC	Rise Parameter t = Time, Sec	0.375	5.0	0.54	0.0
10. HEAT N	Heat Output cal/gms	1479.7	2020.1	1766.0	1449.9
11. HEAT M	cal/gm	1062.35	1010.55	1000	1000
12. HEAT A	cal/gm	1000.0	1000.0	690.0	411.18

TABLE 2. Complete Radiosonde Data for STS-1

Radiosonde data for Cape Canaveral on 1212 Z April 12, 1981, corresponding to the launch of STS-1. These values were used in MDM predictions for in-cloud HCl concentrations. The data was obtained by telephone link to KSC computer with the cooperation of Hans Rudolph of KSC.

```
0001  TEST NBR 07100 T-0 DATA            VD1212
0002  RAWINSONDE RUN AN/GMD-1
0003  CAPE CANAVERAL AFS, FLORIDA
0004  1212Z  12 APR 1981
0005  ASCENT NBR   0154
0006
0007
0008     ALT   DIR SPD  TEMP  D/PT   PRESS    RH ABHUM DENSITY I/R V/S   SHE
0009      FT   DEG KTS DEG C DEG C    MBS    PCT  G/M3   G/M3   N  KTS /SEC
0010
0011
0012  000016 110 004  17.0  15.9 1023.40 093 13.53 1220.55 354 666 .000
0013  001000 136 012  19.1  14.8 0988.46 076 12.52 1170.73 336 669 .014
0014  002000 142 012  16.2  13.5 0953.98 084 11.60 1141.37 325 665 .002
0015  003000 136 009  14.1  11.7 0920.41 086 10.41 1109.97 311 663 .005
0016  004000 099 008  15.1   -.6 0887.90 037 04.70 1070.17 267 663 .010
0017  005000 079 012  15.3  -2.2 0856.56 030 03.92 1032.15 254 663 .009
0018  006000 074 015  14.2  -2.7 0826.26 031 03.77 0999.51 246 662 .005
0019  007000 075 017  14.0  -2.2 0797.01 033 03.93 0964.53 239 661 .003
0020  008000 075 018  11.8  -3.5 0768.67 034 03.60 0937.70 231 659 .002
0021  009000 073 019  10.1  -4.4 0741.15 035 03.36 0909.42 223 657 .001
0022  010000 071 019   8.0  -7.5 0714.42 033 02.70 0883.75 214 654 .001
0023  011000 072 017   5.7  -9.0 0698.46 034 02.41 0858.62 205 651 .002
0024  012000 073 015   3.4  -9.6 0663.25 039 02.31 0833.98 200 649 .004
0025  013000 076 012   1.3 -10.3 0638.77 042 02.21 0809.55 194 646 .005
0026  014000 066 009  -1.0 -12.4 0615.00 041 01.89 0786.06 187 644 .006
0027  015000 040 008  -2.8 -16.8 0591.94 033 01.32 0762.11 178 641 .007
0028  016000 010 007  -3.8 -20.1 0569.63 027 01.00 0736.03 170 640 .007
0029  017000 335 007  -4.6 -21.8 0548.09 025 00.86 0710.50 164 639 .007
0030  018000 313 007  -6.8 -23.7 0527.25 025 00.73 0689.23 158 636 .005
0031  019000 233 005  -8.8 -25.5 0507.04 024 00.63 0657.93 153 634 .006
0032  020000 260 005 -11.4 -27.5 0487.45 025 00.53 0648.35 148 631 .003
0033  TERMINATION       98612 GEOPFT  30057 MTRS GEOP    11.9 MBS
0034  TROPOPAUSE    42602  FEET    179.00 MB  -62.6 C    99.9 C    66N
0035  MANDATORY LEVELS
0036  ALT FT DIR KTS  TEMP  D/PT PRESS    RH
0037  GEOPOT
0038
0039
0040  003670 131 011   20.2   15.5 1000.0  75
0041  002114 143 012   15.9   13.3 0950.0  85
0042  003618 115 008   14.4    5.4 0900.0  62
0043  005205 077 013   14.9   -2.4 0850.0  30
0044  006834 075 017   14.1   -2.2 0800.0  32
0045  008559 074 019   10.6   -4.1 0750.0  35
0046  010532 071 018    6.9   -8.9 0700.0  32
0047  012512 074 014    2.3  -10.0 0650.0  40
0048  014616 049 008   -2.3  -15.5 0600.0  35
0049  016872 338 007   -4.5  -21.7 0550.0  25
0050  019310 270 005   -9.6  -26.1 0500.0  25
0051  SIGNIFICANT LEVELS
0052  ALT FT DIR KTS  TEMP  D/PT PRESS  I/R
0053
0054
0055  000016 110 004   17.0   15.9 1023.40 354
0056  000501 125 010   20.8   16.1 1006.00 345
0057  000785 135 011   19.7   15.1 0996.00 338
0058  003256 131 008   13.6   11.3 0912.00 307
0059  004122 094 009   15.4   -2.5 0884.00 260
0060  006552 074 016   14.6   -2.3 0810.00 242
0061  014647 049 003   -2.3  -15.5 0600.00 181
0062  017004 335 007   -4.6  -21.8 0548.00 164
0063  018702 293 005   -8.2  -25.0 0513.00 154
0064
0065  NNNN

:LI,VB1210::22
VD121C T=00003 IS ON CR00022 USING 00013 BLKS R=0000
```

TABLE 3. Abbreviated Radiosonde Data for STS-1

Data for Cape Canaveral on 1212 Z April 12, 1981, corresponding to the launch of STS-1. Data was provided by Richard Bendura of LRC but corresponds to excerpts from the complete MET data set in Table 2.

Altitude, ft.	Wind Direction, °	Wind Speed, kt.	Temperature °C	Dew Pnt. °C	Pressure mb	Rel. Hum., %
16	110	4	17.0	15.9	1023.4	93
1000	136	12	19.1	14.8	988.46	76
2000	142	12	16.2	13.5	953.98	94
3000	136	9	14.1	11.7	920.41	86
4000	099	8	15.1	- .6	887.90	37
5000	079	12	15.3	-2.2	856.56	30
6000	074	15	14.2	-2.7	826.26	31

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TABLE 4. In-Cloud HCl Data for STA-1

The HCl data obtained by aircraft passes through the Shuttle launch cloud fragments A and B. The values represent the peak HCL concentrations from each pass as provided by Richard Bendura of LRC, and used in reports by Sebacher et al. (5).

Cloud Fragment	Aircraft Pass No.	Time from Launch (min:sec)	Total HCl** Aerosol Gaseous (ppm)	Gaseous HCl (ppm)
	1	9:00	17.5	3.6
	2	14:39	11.5	2.2
A	3	19:32	5.5	1.4
Lower	4*	23:33	0.8	0.2
Cloud	5	27:33	4.2	1.0
	6	31:57	5.0	1.6
	7	34:48	3.0	0.6
	8	39:18	3.5	1.2
	9	43:25	3.2	1.0
	10	54:26	6.5	4.6
	11	57:50	6.5	3.8
	12	62:40	3.5	3.8
	13	69:47	5.2	4.5
B	14	84:59	2.5	2.5
Upper	15	91:58	3.0	2.1
Cloud	16	93:41	2.6	2.6
	17	95:16	3.0	2.4
	18	99:55	1.6	2.0
	19	105:14	1.8	2.0
	20	109:54	4.2	3.6
	21	114:28	2.3	2.6
	22	118:50	2.0	2.5
	23	123:35	1.5	2.2
	24	128:24	2.7	3.0

* Pass 4 was below the visible cloud.

** HCl values are ± 20% or 0.5 ppm - whichever is greater.

TABLE 5. Peak In-Cloud HCl Predictions for STS-1

The peak maximum (centerline) HCl concentrations from MDM predictions using the MET data of Table 2. These in-cloud concentrations are for the 850 and 900 meter levels for Cloud A and the 1600 and 1800 meter levels for Cloud B.

Range - Distance From Launch (meters)	Maximum Peak (Centerline) HCl Concentration (ppm) at Levels			
	850 m	900 m	1600 m	1800 m
1250	24.00	23.97		
2500	14.15	14.37	56.53	61.00
3750	8.03	8.11	27.48	29.58
5000	5.01	5.03	15.69	16.40
6250	3.51	3.52	9.74	10.05
7500	2.71	2.71	6.40	6.55
8750	2.21	2.21	4.41	4.49
10000	1.85	1.85	3.19	3.23
11250	1.57	1.57	2.41	2.43
12500	1.34	1.34	1.89	1.90
13750	1.16	1.16	1.53	1.54
15000	1.01	1.01	1.28	1.28
16250	0.89	0.89	1.08	1.08
17500	0.79	0.79	0.93	0.93
19750	0.70	0.70	0.81	0.81
20000	0.63	0.63	0.71	0.71
25000			0.46	0.46
30000			0.32	0.32
35000			0.23	0.23
40000			0.18	0.18
45000			0.14	0.14

TABLE 6. Time-Distance and HCl Predictions for the STS-1 Launch Clouds A and B

The relationship between the time of travel from launch (used in aircraft measurements) and the distance of travel for the launch cloud (used in the MDM predictions). The lower cloud (A) is assumed to travel at an average of 10.5 knots (5.4 m/sec) and the upper cloud (B) travels at 6.17 knots (6.17 m/sec). The corresponding maximum centerline HCl concentrations are taken from Table 5.

Distance From Launch Site (m)	Time of Travel Cloud A (min):(sec)	MDM Maximum HCl Predictions at 850 m (ppm)	Time of Travel Cloud B (min):(sec)	MDM Maximum HCl Predictions at 1800 m (ppm)
1250	5:21	24.00		
2500	7:43	14.15		
3750	11:34	8.03		
5000	15:36	5.01		
6250	19:17	3.51		
7500	23:09	2.71		
8750	27:00	2.21		
10000	30:52	1.85		
11250	34:43	1.57		
12500	38:55	1.34		
13750	42:25	1.16		
15000	46:29	1.01		
17500			47:16	0.93
20000			54:02	0.71
25000			67:31	0.56
30000			81:02	0.32
35000			94:32	0.23
40000			108:02	0.18
45000			121:33	0.14

TABLE 7. Example Vertical Profiles of HCl from the MDM for Titan III February 27, 1965, Launch

The HCl concentrations are peak values predicted by the MDM for each 100 meter level. The MET data is for 0517Z February 27, 1965, and the depth of the mixing layer is 3529 feet, the cloud rise is 904 meters, and the standard deviation in the hirozintal wind direction is 7.

Altitude (m)	Distance From Launch (m)	MDM Prediction of Peak HCl (ppm)
0	11250	0.95
100	10000	1.08
200	8750	1.61
300	8750	3.03
400	7500	8.20
500	7500	16.78
600	7500	25.81
700	7500	29.80
800	8750	9.40
900	8750	8.30
1000	8750	7.26

TABLE 8. Example Vertical Profiles of HCl From the MDM for Shuttle Launch April 12, 1981, Launch

The HCl concentrations are peak values predicted by the MDM for each 100 meter level. The MET data is for 000Z April 12, 1981, the day of the Shuttle launch. The depth of the mixing layer is 5000 feet and 3750 feet, the cloud rise 1207 meters and 787 meters and the standard deviation of the horizontal wind direction was 4.5 and 9.

Altitude (m)	Peak HCl MDM (ppm) $\sigma = 4.5$	Distance From Launch (m)	Peak HCl MDM (ppm) $\sigma = 9.0$	Distance From Launch (m)
0	12500	1.24	5000	3.56
100	12500	1.28	5000	3.79
200	10000	1.40	2500	4.48
300	1250	2.88	1250	6.39
400	500	5.34	500	10.57
500	500	5.34	500	18.89
600	500	10.67	500	26.44
700	500	21.24	1250	19.77
800	500	21.24	1250	19.01
900	500	31.57	1250	17.13
1000	1250	38.15	Mixing height was reduced	
1100	1250	38.64	from 5000 feet to 3750	
1200	1250	49.85	feet and cloud rise reduced	
1300	2500	65.00	from 1207 m to 787 m.	
1400	2500	64.00		

FIGURE 1. Plot of MET Data For 1212 Z April 12, 1981

The vertical profiles of temperature (solid line) and dewpoint temperature (dashed line) taken from Table 2. The stabilization height at 1187 m was predicted for the Shuttle launch cloud by the cloud rise portion of the MDM. The 850 and 900 m levels represent the levels used for in-cloud HCl predictions and for aircraft sampling in the lower (Cloud A) portion of the gragmented ground cloud. Aircraft sampling and MDM predictions for the upper fragment (Cloud B) were in the 1600 to 1800 meter range.

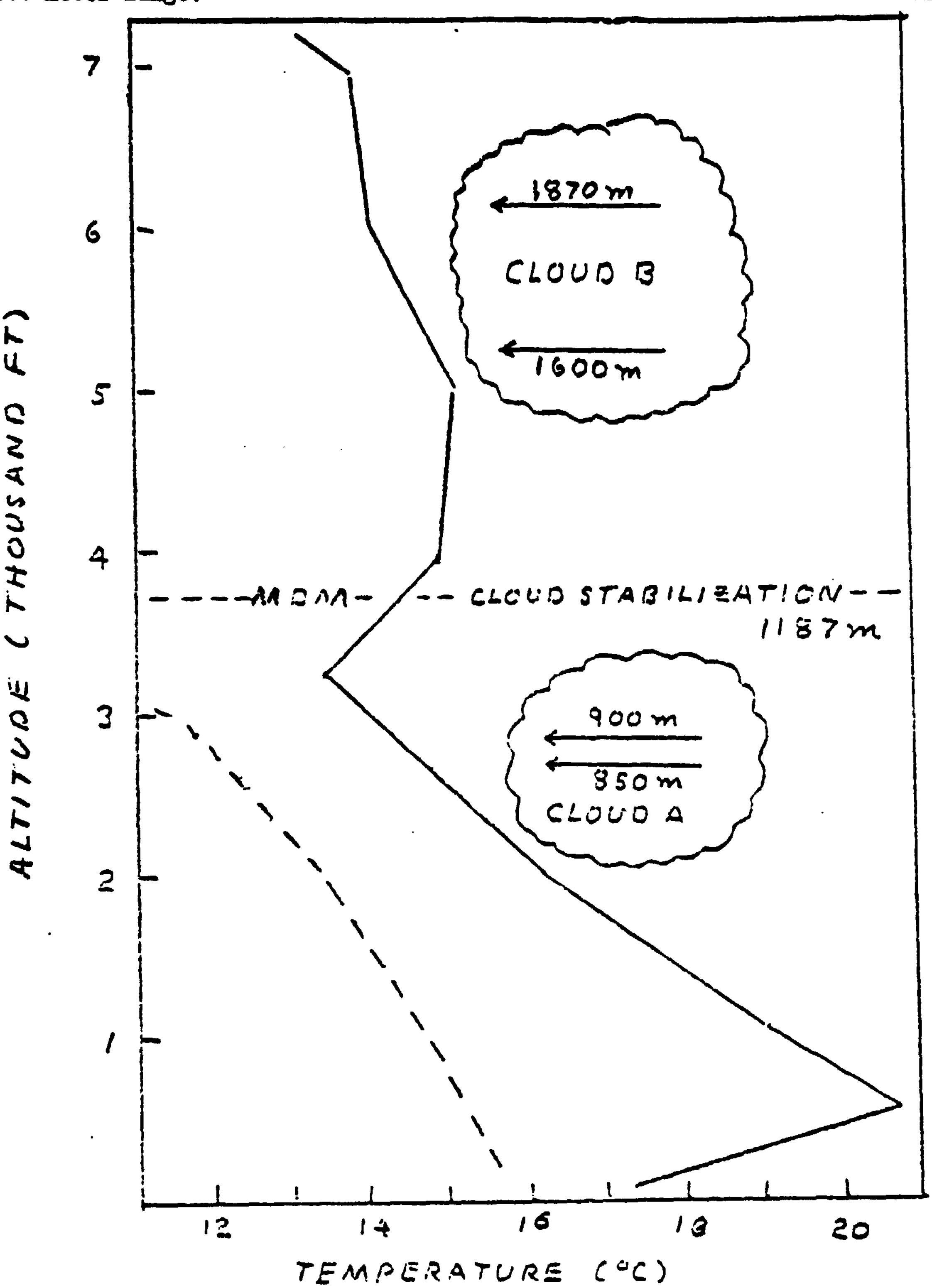

FIGURE 2. Plot of Vertical Shear in the Horizontal Wind for 1212 Z April 12, 1981

The magnitude and direction of the wind speed are represented by arrows for each of the levels of MET data from Table 3. The MDM predicted the Shuttle launch cloud would move in the direction marked by crosshatching.

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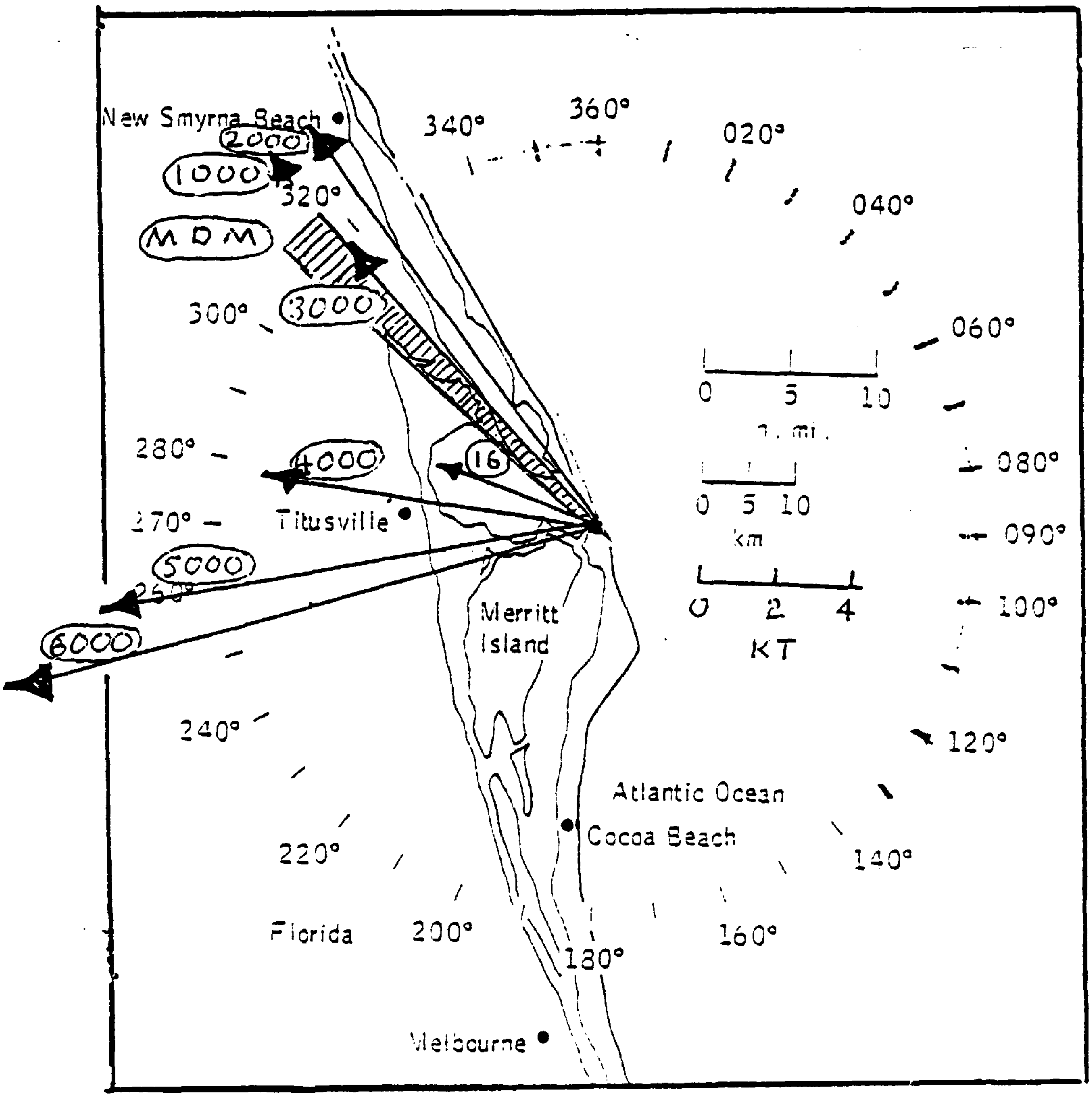


FIGURE 3. Cloud Track for Cloud A of STS-1

A rough sketch of the movement of the lower cloud fragment A from the Shuttle launch at 1212 Z April 12, 1981. The movement, which roughly parallels the coastline of Cape Canaveral, is indicated as a function of time. Sketch provided by Richard Bendura of LRC.

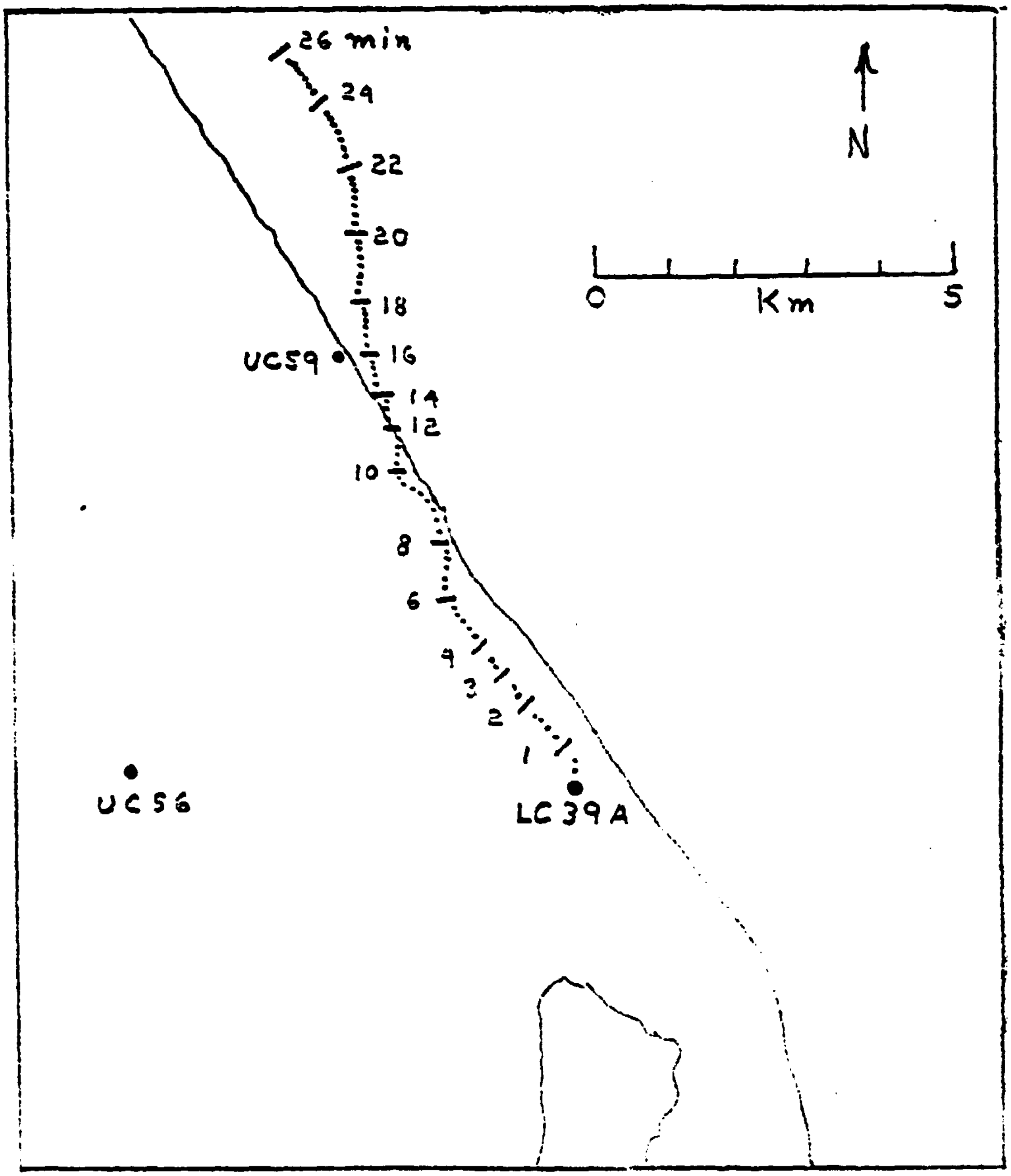
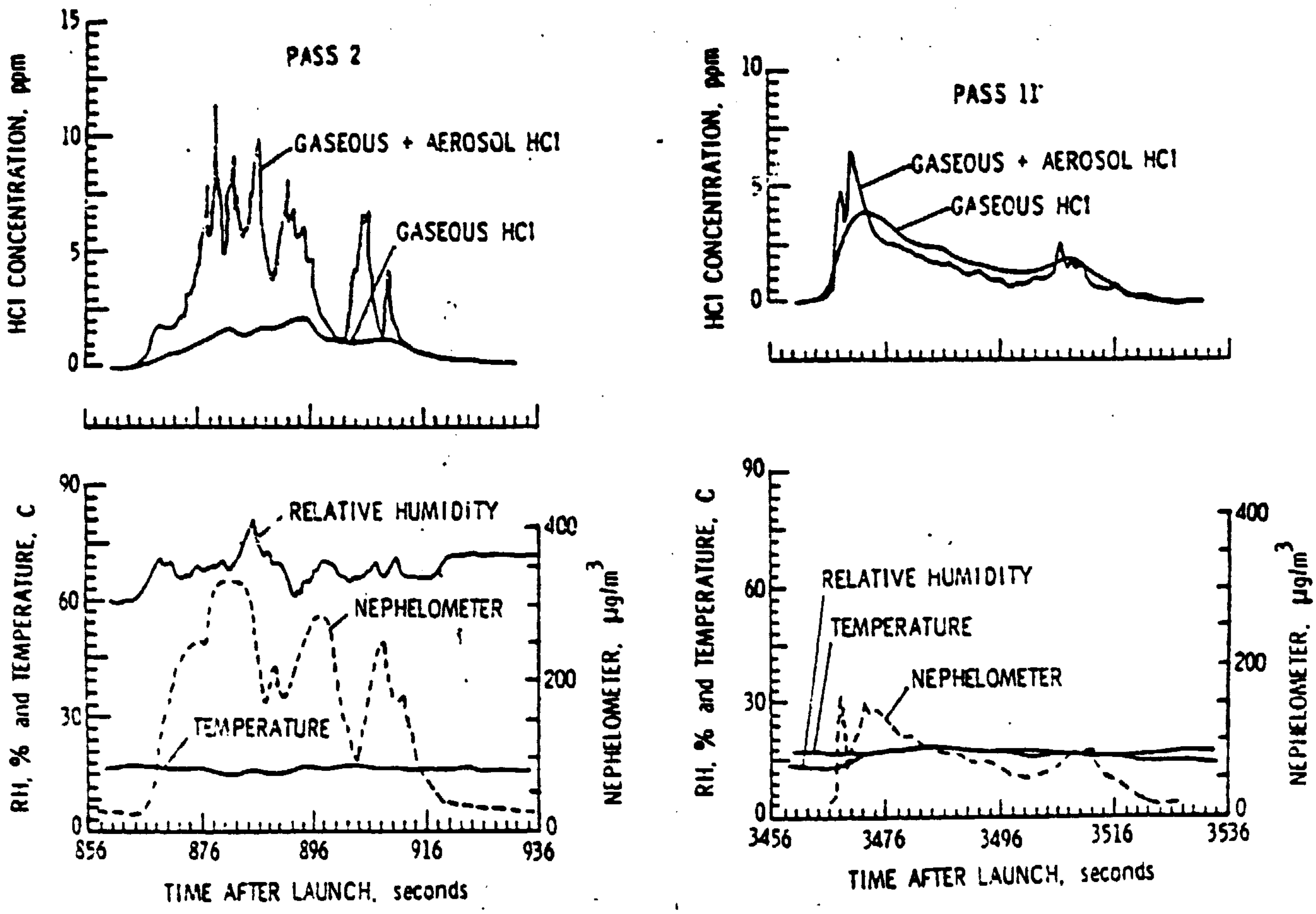


FIGURE 4. Examples of In-Cloud Measurements for STS-1

Typical measurements for total HCl, gaseous HCl, particulate concentration, relative humidity, and temperature for Aircraft Pass 2 through Cloud A and Aircraft Pass 11 through Cloud B. Graphs are from Sebacher et al. (5).

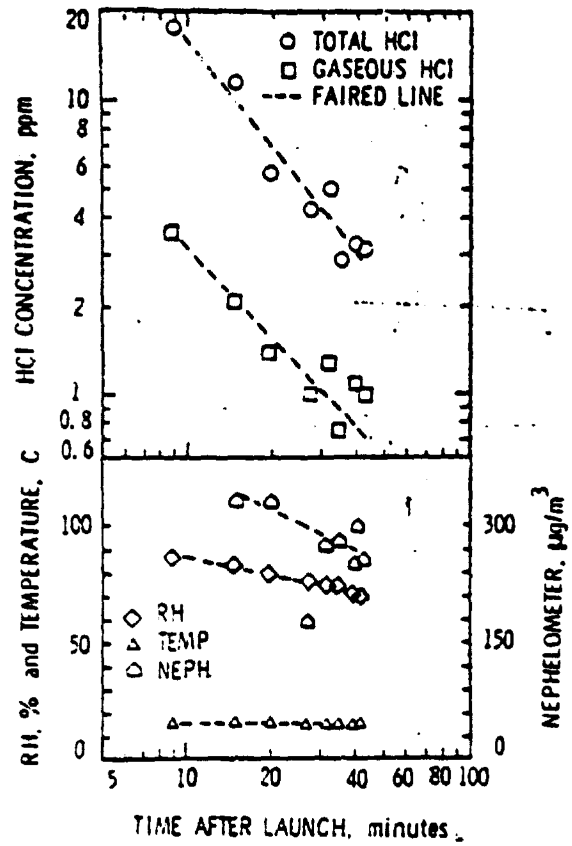


(a) Low Altitude Segment

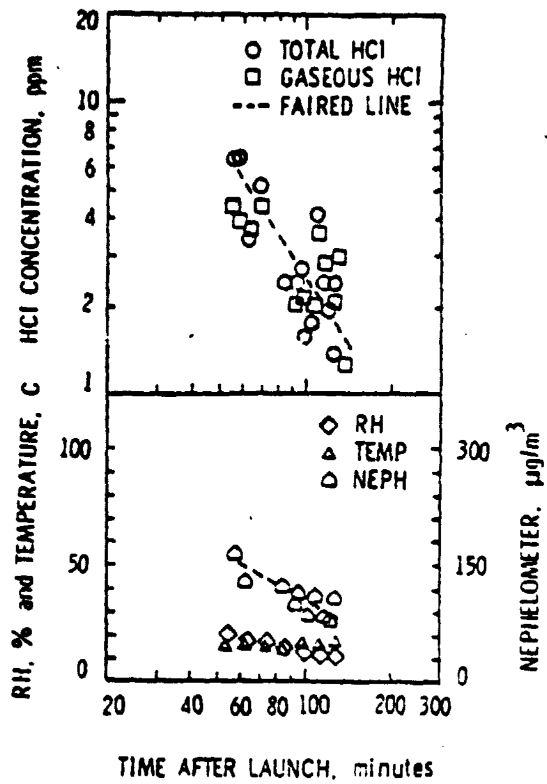
(b) High Altitude Segment

FIGURE 5. Peak Values for In-Cloud Sampling of STS-1

The values plotted here represent the peak measurements of total HCl, gaseous HCl, particulate concentration, relative humidity, and temperature for each pass through the upper and lower Space Shuttle Ground Cloud vs. the time after launch. The graphs are from Sebacher et al. (5).



(a) Low Altitude Segment



(b) High Altitude Segment

FIGURE 6. MDM Predictions of HCl for STS-1 as a Function of Distance

The MDM predictions of the upper fragment of the Space Shuttle launch cloud for the 1600 meter level is given by the upper curve. The lower curve is the prediction for the 900 meter level of the lower cloud fragment using the MET data from Table 2.

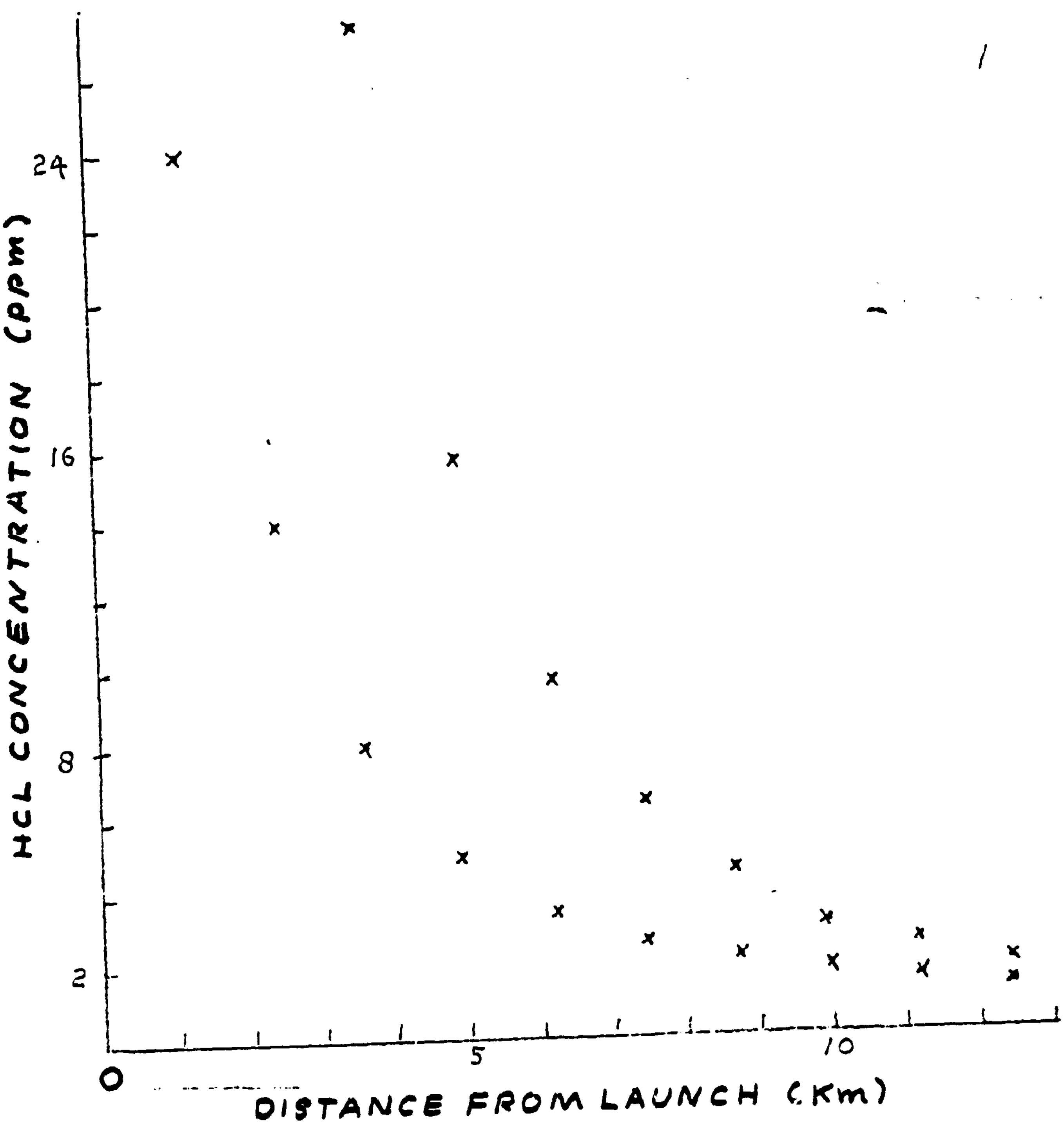


FIGURE 7. Measured and Predicted In-Cloud HCl Concentrations for Cloud A, STS-1

The solid line represents the in-cloud HCl concentrations predicted by the MDM for the 850 meter level. The data points marked with an X are for total HCl including gaseous and aerosol. The data points marked with a square are for the measurements of gaseous HCl only. The numbers by the data points indicate the flight pass number. The data values are for the lower cloud (A) taken from Table 4, Sebacher et al. (5). The dashed line represents an adjustment of MDM predictions taking into account observed movements of Cloud A given in Figure 3.

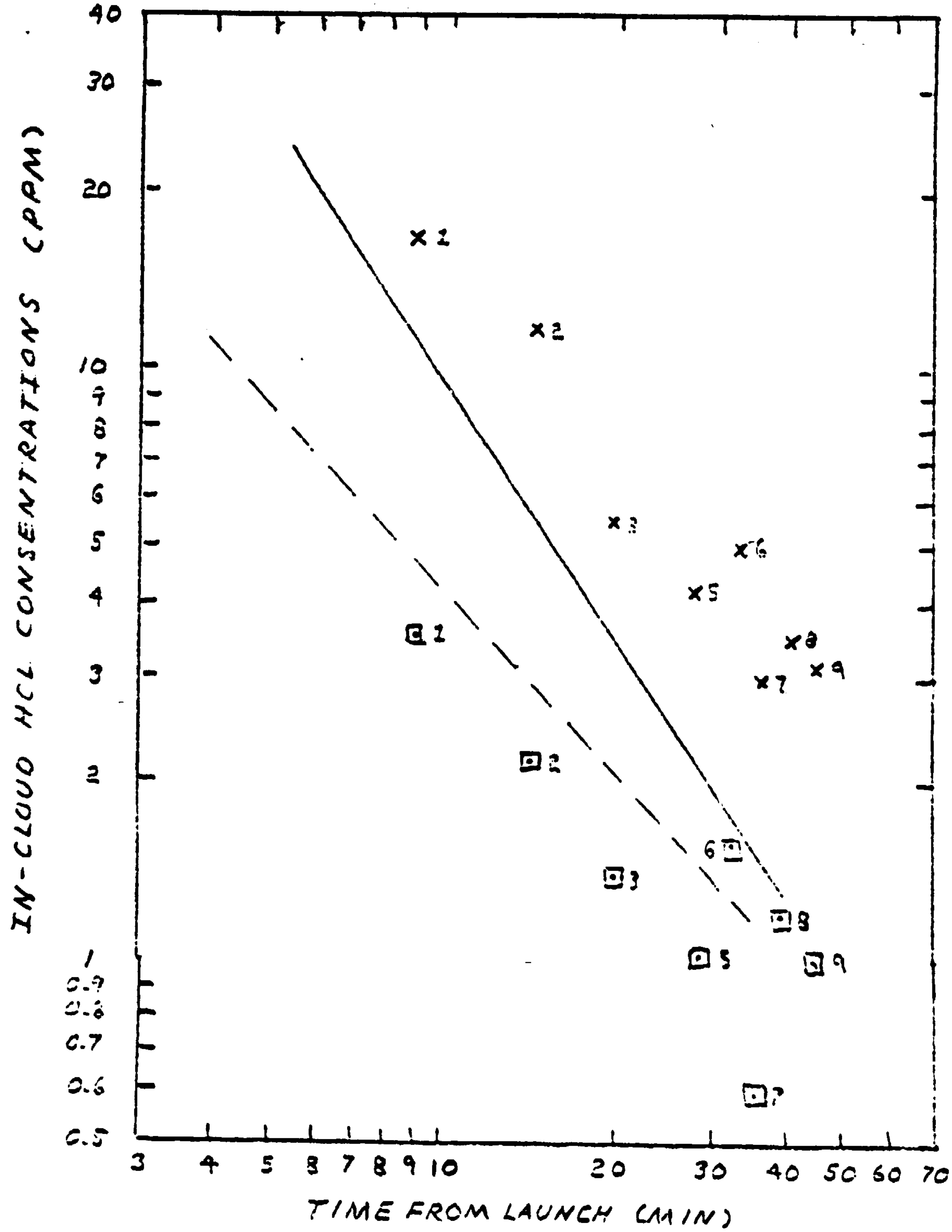
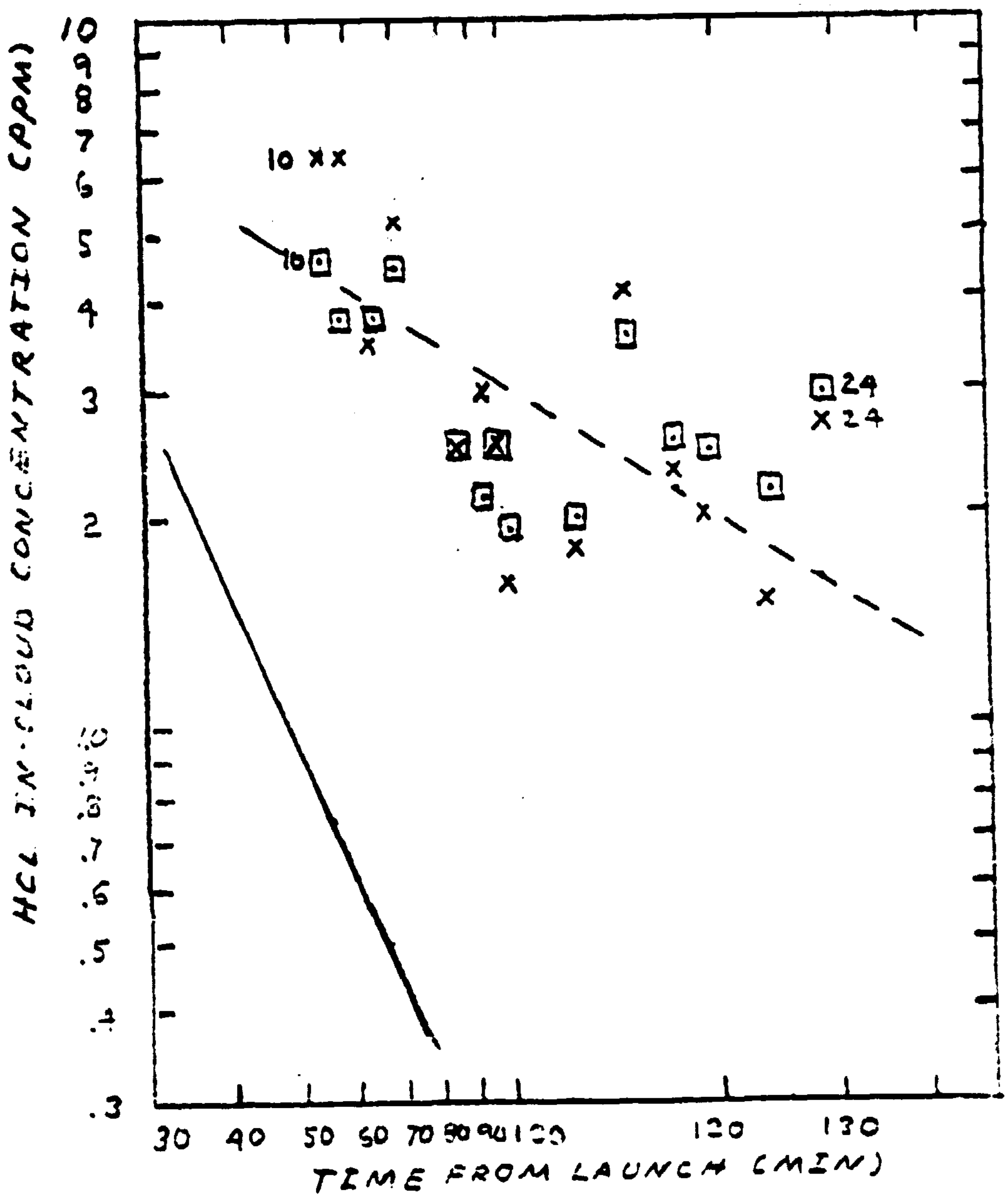


FIGURE 8. Measured and Predicted In-Cloud HCl Concentrations for Cloud B, STS-1

The solid line represents the in-cloud HCl concentrations predicted by the MDM for the 1600 or 1800 meter level. The data points marked with an X are for total HCl including gaseous and aerosol. The data points marked with a square are for the measurements of gaseous HCl only. Some of the data points have corresponding flight pass numbers adjacent to them. The data values are for the upper Cloud (B) taken from Table 4, Sebacher et al. (5).



APPENDIX A

NASA Documentation

A. Task-building the CLOUD module:

The major problem with making changes to the programs were to task-build the system after changes have been made. Once each program has been compiled, the task must be built before being executed. To do so, the following options must be in effect: 'ASN DKx:=DV:' where x is the disk that contains the CLOUD routines. Then, the command: 'TKB @CLOUD' must be issued. This begins the task-building process. If a message 'Not contigous disk space' is received, programs must be either eliminated or Purged from the program disk in order to make enough room for the task.

B. Programming changes in the CLOUD routines:

1. An addition of version 7 constants (CONST7.FTN).
   The subroutine CONST7.FTN is an exact duplicate of the subroutine CONST6.FTN except for the data statements.

2. System library:
   The file LIB.OLB is used as the system library during the task-building procedure. Once the CONST7.FTN and KEYIN.FTN routines were complete, these routines had to be added and replaced to the system library.
   a. Addition of CONST7 to the system library.
      To add CONST7, the command:
      'LBR LIB.OLB=CONST7/IN'
      was issued.
   b. Replacement of KEYIN in the system library:
      To replace KEYIN, the command:
      'LBR LIB.OLB=KEYIN/RP'
      was issued.

3. CALL routines to properly use and assign the version 6 and 7 constants. In order to get the constants to work properly, two statements had to be added to the program PREPOS.FTN of the system:

```
IF (NVERSN.EQ.6) CALL CONST6
IF (NVERSN.EQ.7) CALL CONST7
```

   these two statements were added to PREPOS.FTN at the beginning of the program immediately after the statement 'CALL OPFILE'.

APPENDIX B

GRANT PROPOSAL

IN-CLOUD HCL PREDICTIONS FOR SPACE SHUTTLE LAUNCHES

ABSTRACT

The primary objective of the work proposed here will be to develop the capabilities of the NASA/MSFC Multilayer Diffusion Model (MDM) to obtain in-cloud predictions of HCl concentrations in the Space Shuttle ground launch cloud. This will include documenting the procedures for running the MDM on a PDP 1145 and establishing the effect on in-cloud HCl concentrations using parameters characteristic of the standard meteorologies encountered at Cape Canaveral. This information will then be used to establish an appropriate aircraft sampling pattern prior to the March 1981 Space Shuttle launch to both obtain representative measurements of in-cloud HCl concentrations and to aid in verification of model predictions.

SCHEDULE AND DESCRIPTION OF PROPOSED WORK

The approach used to carry out the above objective would include the following phases:

PHASE I: (One month full time at JSC starting Aug. 1, 1980)

a. During this time it will be necessary to become reacquainted with the operation of the MDM as it is programmed to run on the PDP 1145 and with the modifications which have been made by Larry Ray.

b. Some time will be devoted to selecting the meteorological data which will be used for in-cloud concentration predictions. The data sets should include representative meteorologies used in previous studies (ref. 1) and from more recent and extensive case studies by Richard Siler. Data should also include the test case used to verify the model in reference 2.

c. This data will be formated (probably on disk) so that minimal effort will be required by JSC personnel when setting up the computer to run from a remote terminal.

d. The feasibility of linking the JSC computer facility to an intelligent terminal at Kearney State College will have been tested prior to assignment of this contract. However, an important additional activity during this period will be to further initiate and check out all phases of the operation and input and output for the MDM on the PDP 1145 as activated by means of remote terminal from Kearney State College.

PHASE II. (Six months ½ time at Kearney State College from Sept. 1 to Feb. 28, 1980-81)

a. The initial step to obtaining the in-cloud predictions will be to determine whether the portion of the MDM responsible for the predictions is intact on the program disk being used.

b. If the program is intact, it will be necessary to determine the appropriate programming to access the output for various in-cloud levels. If the subroutines for in-cloud concentrations of HCl are not intact, it will be necessary to determine the appropriate programming and reintroduce it.

c. If test case meteorological data exist for which in-cloud predictions have previously been made, they will be used in this phase to check on the reasonableness of the predictions once they are obtained. Another check on the accuracy of the results may be to check on the conservation of HCl at various times after cloud stabilization.

d. As soon as the in-cloud predictions obtained are judged to be reasonable, several meteorological cases characterizing different stability regimens at Cape Canaveral will be used. The results from these cases will be graphed to display the vertical profiles of HCl as a function of time and/or distance from the point of cloud stabilizations. Particular attention will be paid to the level at which maximum concentrations of HCl occur for the different stability classes.

PHASE III. (Three months ½ time at Kearney State College, March 1 - May 30, 1981)

Some of the objectives in Phase II may run over into Phase III, because of the uncertainty in the amount of time which will be required to successfully obtain in-cloud HCl predictions from the MDM.

a. As the proposed Space Shuttle Launch date in March 1981 approaches, the MDM predictions will be continuously updated as more refined meteorological data relative to the conditions at the launch site are received.

b. If the Space Shuttle is launched on schedule and suitable HCl concentrations have been obtained, these results should be matched against the MDM predictions to verify the model for the meteorological conditions existing at launch time.

c. Criteria for in-cloud air sampling patterns will be established for future launches based on a knowledge of the HCl predictions from Phase II and of the Cloud Stabilizations heights and its dependence on meteorological parameters as determined in previous studies.

d. A final report covering all activities and results obtained over the contract period will be written.

References

1. Susko, Michael; and J. Briscoe Stephens: Baseline Meteorological Soundings for Parametric Environmental Investigations at Kennedy Space Center and Vandenberg Air Force Base, Marshall Space Flight Center, Alabama NASA TMX-64986, February 1976.

2. Dumbauld, R. K.; and J. R. Bjorklund: NASA/MSFC Multilayer Diffusion Models and Computer Programs, Version 5. H. E. Cramer Co., Inc., NASA CR-2631, December 1975.