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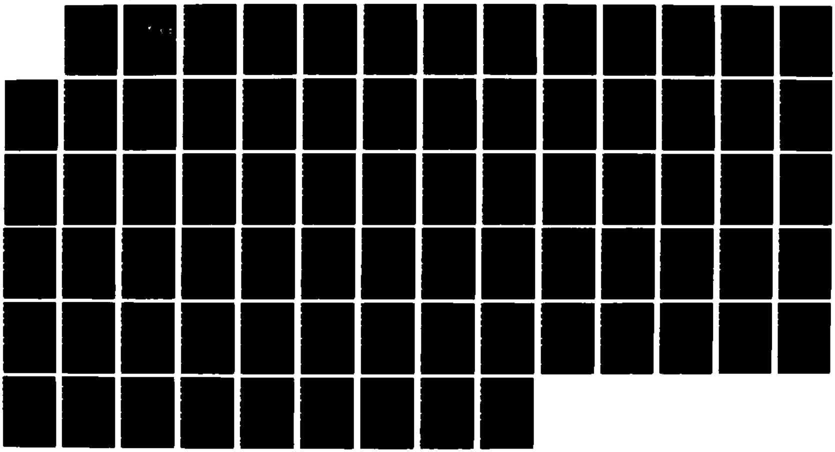

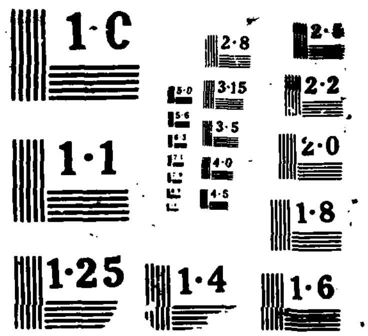
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# NAVAL POSTGRADUATE SCHOOL
## Monterey, California





# THESIS

THE VISIOCEILOMETER AND ITS
TACTICAL APPLICATIONS

by

Mary A. Bridges

December 1987

Thesis Advisor: H.J. Larson

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This thesis investigates the tactical applicability of the visioceilometer in terms of its ability to measure visual range and to identify the density level of an obscurant. This is accomplished by analyzing test data obtained from Smoke Week VIII tests conducted at Eglin Air Force Base, Florida. Thirty smoke clouds from a total of seven obscurants are examined. The accuracy and consistency of agreement between the visioceilometer and the multispectral imagery digital acquisition system (MIDAS) measurements of visual range is examined. The visioceilometer and a human observer identification of the density level of an obscurant is compared to examine the agreement between the two.

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# The Visioceilometer and Its Tactical Applications

by

Mary A. Bridges
Captain, United States Army
B.S., South Carolina State College, 1976
M.A. Webster College, 1979

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requirements for the degree of

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December 1987

Author: Mary A. Bridges
Mary A. Bridges

Approved by: H. J. Larson
H.J. Larson, Thesis Advisor

Michael Tedeschi
M. Tedeschi, Second Reader

P. Purdue
Peter Purdue, Chairman,
Department of Operations Research

J. M. Fremgen
James M. Fremgen,
Acting Dean of Information and Policy Sciences

## ABSTRACT

This thesis investigates the tactical applicability of the visioceilometer in terms of its ability to measure visual range and to identify the density level of an obscurant. This is accomplished by analyzing test data obtained from Smoke Week VIII tests conducted at Eglin Air Force Base, Florida. Thirty smoke clouds from a total of seven obscurants are examined. The accuracy and consistency of agreement between the visioceilometer and the multispectral imagery digital acquisition system (MIDAS) measurements of visual range is examined. The visioceilometer and a human observer identification of the density level of an obscurant is compared to examine the agreement between the two.

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# I. INTRODUCTION

## A. BACKGROUND

### 1. Nature of the Problem

The Army requires an instrument that can accurately measure visibility or visual range and cloud height in tactical areas. This instrument must provide data that does not require a trained specialist to interpret and must have the capability of being remotely operated. For example, it does not require the operator to go onto the battlefield to measure visual range. An additional requirement of this measuring device is that it should measure visibility in any direction the operator selects and measure cloud height through clear air or obscuring phenomena.

The visioceilometer, a portable system for measuring obscurants, was developed by the US Army Atmospheric Science Laboratory (ASL), White Sands Missile Range, New Mexico, to support aircraft landings, optically dependent weapon firings, and operations where the atmospheric extinction (the scattering and/or absorption of light as it passes through the atmosphere), needs to be remotely measured. [Ref 1] This thesis investigates the performance of the visioceilometer in meeting these tactical requirements.

### 2. The Need for Visibility and Cloud Ceiling Height Information

Visibility, as observed by the human eye, is a very complex parameter which depends on many factors other than the obscuring medium. It is important to select a definition of visibility which can be related to a variety of instruments as well as the human eye. Visibility is defined as, "the greatest distance at which selected objects can be seen and identified." [Ref 2]

Cloud ceiling or the base of a cloud has been defined as the height of the lowest layer of the cloud cover, where 5/8 or more of the cloud cover is predominantly opaque. Recently, the cloud base has been redefined as that point in the cloud where the optical extinction (scattering and/or absorption of light as it passes through the atmosphere) reaches 7 km. [Ref 3] The latter definition is used for earlier cloud ceiling height tests. These test results are discussed in Chapter IV.

Visual range and cloud height are crucial environmental parameters that influence flight safety and modern weapon system performance and effectiveness. Up-to-date information on visibility and cloud ceiling height are required for tactical decision making under battlefield conditions. Visual range and the presence and extent of clouds are two visibility related factors that must be established under real-time conditions.

Measurements of visual range and cloud ceiling height are especially vital on today's battlefield and will be on the battlefield of the future. The battle of the future will see the employment of sophisticated electro-optical combat systems. These systems will either send visual data back to an operator for decision making or make decisions based on internal logic. Weather and battle-induced conditions may profoundly affect the operational effectiveness of conventional weapons sighting systems and the decisions the tactical commander must make for deploying them. Artillery commanders need ceiling height and visibility measurements to determine the maximum range at which targets can be detected and engaged by small ammunition. Cloud height and visual range also impact the choice and effectiveness of electro-optically guided munitions. In addition, they affect the enemy's ability to conceal his actions, avenues of approach, and cross-country movements. [Ref 4]

Slant visual range, cloud ceiling height, and visibility are all important factors for both offensive and defensive air operations. Aviation and air traffic control uses include:

a. Accurate airfield observations for flight safety

b. Controlling aircraft in mountainous terrain in marginal weather or night operations

c. Visual and electro-optical target acquisition

d. Nap of the earth mission planning and survivability

e. Landing zone and forward area rearmament and refueling point operations

Many other nonaviation elements require visibility and ceiling height measurements as well. For example, air defense forces need the range and altitude at which enemy aircraft must be visually acquired. Units engaged in fording river operations need visibility for safety and concealment. In desert climates, ranging to the edge of a dust storm could be a tactical use.

3. Tactical Measurement Problems

The measurement of visibility and cloud ceiling height in a combat zone presents special problems. The measuring device must be small, light weight (one man transportable), and rugged. Currently there is no system available that meets the Army's requirements. Current means of measuring visibility and cloud height on the battlefield require that a trained specialist be sent into the battle zone to collect data. Measurements are then estimated from this data. Quantitative measurements are obtained at airfields that use fixed bulky instruments such as transmissonmeters, which measure visibility or runway visual range from known reference points, and rotating beam ceilometers (RBCs) that measure cloud ceiling height.

Transmissonmeters and rotating beam ceilometers (RBCs) have been used for many years at Army airfields to obtain visibility and cloud height information. However, most tactical airfields do not have such instruments, especially at landing zones or forward area rearmament and refueling points. These instruments and instruments of this type are not readily adaptable for deployment in tactical areas. They are either too bulky and heavy, and/or they require an expert to interpret the data obtained from them.

## B. PURPOSE

The purpose of this document is to analyze test data and draw conclusions about the application and accuracy of the visioceilometer system for measuring visual range. cloud ceiling height, and obscurant density in tactical areas.

## C. SCOPE

This document examines the visioceilometer in terms of its applicability in tactical areas. It examines how well the visioceilometer responds to different types of obscurants in a simulated battle area. The performance of the visioceilometer in measuring visual range and density levels of obscurants is examined by analyzing data obtained from Smoke Week VIII tests conducted 16-27 May 1986 at Eglin Air Force Base, Florida.

Chapter II describes two systems that are currently used to make visibility and cloud ceiling height measurements as well as the MIDAS system which was employed during Smoke Week VIII. Also included in Chapter II is a detailed examination of the visioceilometer system. How the data was collected will be covered in Chapter III. Chapter IV covers the analysis of the data and outlines the results. Conclusions drawn based on the analysis are covered in Chapter V.

This document is limited to the analysis of visual range and density levels of obscurants. However, the same principles apply in measuring cloud ceiling height. Results from previous cloud height measurement tests are also discussed.

It is beyond the scope and intention of this document to discuss in detail the theory and fundamentals underlying the concept of visual range and the factors that influence it. Only those aspects that are specific and relevant to the measurement of visual range by means of the visioceilometer will be treated herein.

## II. VISIBILITY AND CLOUD CEILING HEIGHT MEASURING SYSTEMS

Two systems widely used in the military to measure visibility and cloud ceiling height are the transmissionmeter, which measures visibility or runway visual range, and the rotating beam ceilometer (RBC), which measures cloud ceiling height.

### A. VISIBILITY MEASURING SYSTEM

The transmissonmeter, used to measure visual range, requires a special alignment before measurements can be made. The system is a double-ended measuring device: an optical source of suitable wavelength and intensity is placed in one position and the detector is placed in another. It then measures transmission between the source and detector. A trained weather specialist must interpret these measurements to determine visual range. Under the same obscurant conditions the transmissonmeter should indicate the same atmospheric visibility in daylight or at night. Some airfields also employ manual means of measuring visual range from known distance markers. A reference marker is identified at some distance away. If it can be seen, then the report is that visibility is out to at least the marker's range. These observations are made only in daylight and only for horizontal distances. Under field conditions, this procedure is not always practical or even possible.

## B. CLOUD HEIGHT MEASURING SYSTEM

The rotating beam ceilometer (RBC) is the standard system used to measure cloud ceiling height. The radar signal from this system is fired vertically. If a cloud is encountered the signal is scattered back and presented on a cathode ray tube (CRT) display. Correct interpretation of these results requires a highly trained and experienced observer.

The scaled down version of the RBC, designated for tactical use, still presents many problems in actual use. It weighs nearly 300 pounds and requires concrete pads for a solid support base, in addition to requiring a trained observer to interpret the data received.

## C. THE MULTISPECTRAL IMAGERY DIGITAL ACQUISITION SYSTEM (MIDAS)

The multispectral imagery digital acquisition system, (MIDAS), was developed by Mr. George R. Blackman, at the US Army Atmospheric Science Laboratory (ASL). The MIDAS system is a video/computer program that describes the temporal dimensionality and transport of smoke clouds. This system is capable of graphically displaying the estimated outline of the smoke cloud at desired time intervals. It also displays the three dimensional characterization of the smoke in terms of its geometric growth, transport, and ultimate dissipation. This is done through a series of ellipsoids generated by images received from two video cameras directed at the center of the obscurant.

## D. VISIOCEILOMETER, THE PROPOSED SYSTEM

### 1. System Development

Theoretical studies in laser radar, or lidar, for visibility measurements at the US Army Atmospheric Science Laboratory (ASL) by Dr. James T. Klett (1980) resulted in a breakthrough in lidar analysis. [Ref 5] This breakthrough allowed the analysis of lidar returns in low visibility conditions that impact Army operations. Using modern state-of-the-art microelectronics, proven laser technology, and improved lidar analysis theories, ASL has demonstrated the ability to measure visibility in a wide range of atmospheric conditions automatically with a single laser pulse.

The tactical visioceilometer is constructed to emit this single laser pulse. Previously most lidar systems required large amounts of power to operate and were quite large. The visioceilometer, a lidar, is now small, light, rugged, battery-operated, simple to use, and completely self-contained.

### 2. System Description

The visioceilometer, a system for measuring obscurants, is a hand-held, battery operated light detection and ranging, laser radar or lidar, device that can measure visibility from 10 meters to 199,999 meters and cloud ceiling heights from 50 meters to 3000 meters. It consists of three interconnected units (the optical unit, the signal processing unit, and the data processing unit), which operate together to produce a measurement of visibility or cloud ceiling height. The optical unit (OU) is a hand-held device similar in size and weight to field glasses. The OU contains the viewfinder scope, laser (yett-aluminum-green (YAG)), silicon photoavalanche detector, and the signal amplifier. This modified laser rangefinder was developed jointly by ASL and the Night Vision and Electro-Optics Laboratory, Fort Monmouth, NJ, and built by the RCA Corporation. The signal processing unit (SPU) is worn on the hip and contains a 20 megahertz analog to digital (A/D) transient recorder and microprocessor. The data processing unit (DPU) consists of a battery operated microprocessor which is IBM hardware and software compatible. It contains 640 k of memory, two 780 k disk drives, and has a graphical presentation capability by means of a liquid crystal display (LCD). The DPU is used when the visioceilometer is configured for research and development usage which requires archival of the data.

The YAG laser, in the OU, emits a single 6 nanosecond pulse at a wave length of 1.06 micrometers into a narrow 1.0 milliradian divergent beam. The atmosphere reflects the light back towards the receiver optics according to atmospheric aerosols or targets. The received flux is detected by a silicon photoavalanched detector, and the signal is compressed by a logarithmic amplifier. The output of the laser is monitored by a temperature-compensated photodiode. The monitor pulse and the lidar return signal are sent by coaxial cable to the SPU where they are digitized and analyzed. In the SPU, the microprocessor analyzes the return for visibility, visual range, or cloud ceiling height, according to the switch setting of the OU. A 6-digit light-emitting diode (LED) indicator is used to display the results in the eyepiece of the OU. C, V, or R shaped LED marks are used to indicate the mode selected by the operator for ceiling, visibility or range.

The SPU also contains an optional output of raw data capability via an external RS232 plug. The digitized LIDAR data is transferred to the optional external data processing unit (DPU), rather than being analyzed in the SPU. When the DPU receives the lidar shot, it immediately saves it on disk for archival purposes. It then analyzes it and displays the results on the screen along with a graphic plot of the received lidar return. This feature considerably increases the versatility of the visioceilometer as a research tool, in addition to its value as a tactical device. The optional data processing unit (DPU) was used during the Smoke Week VIII tests.

The second generation version of the visiceilometer was used during the Smoke Week VIII test. Characteristics of the visiceilometer are listed in Table 1.

TABLE 1

VISIOCEILOMETER CHARACTERISTICS [Ref. 1]

| | |
|---|---|
| Beam divergence | 1.0 milliradian |
| Receiver field of view | 3.0 milliradian |
| Laser energy | 13 millijouls average |
| Pulse half-width | 6 nanosecond |
| Receiver aperture | 50 millimetres |
| Laser exit diameter | 16 millimeters |
| Optics axis separation | 50 millimeters |
| Sample rate | 20 megahertz |
| Sample range | 3,412 meters |
| Analog to digital converter | 10 bits |
| Weight | 5 pounds Optical Unit |
| | 8 pounds Signal Processing Unit |
| | 10 pounds Data Processing Unit |
| Size | 6"x2"x6" Optical Unit |
| | 6"x4"x6" Signal Processing Unit |
| | 12"x12"x3" Data Processing Unit |
| Power | Batteries or external power |

# III. DATA COLLECTION

## A. SMOKE WEEK VIII TEST

Data used for this analysis was collected during the Smoke Week VIII tests conducted at Eglin Air Force Base, Florida, 16-27 May 1986. The purpose of the Smoke Week tests was to evaluate smoke/obscurants predictive models, and electro-optical (EO) system technology under simulated battlefield conditions. The visioceilometer participated in the test to evaluate its performance in a smoke/obscurant environment and in verifying cloud edge definitions, or visual range, along with the Multispectral Imagery Digital Acquisition System (MIDAS).

Two sets of data were obtained from the US Army Atmospheric Science Laboratory (ASL). One consisted of the Multispectral Imagery Digital Acquisition System (MIDAS) cloud dimensional analysis data, while the other consisted of the visioceilometer and human observer data. The MIDAS data was compared with the visioceilometer data for the analysis of visual range. The human observer data was compared to the visioceilometer to analyze density levels. Thirty-four smoke clouds were employed during the seven day test at Eglin Air Force Base, Florida. Thirty of these were used in this analysis. The remaining four clouds contained insufficient data for meaningful comparisons.

The test grid was located on flat sandy terrain. The test grid layout was as depicted in Figure 1. The MIDAS system video cameras/imagers were located at points A and B. The visioceilometer and the human observer were located at point A, adjacent to one of the MIDAS cameras. The height difference between the MIDAS and the visioceilometer is considered insignificant for this analysis. The visioceilometer and the human observer shared approximately the same line of sight (LOS) as the MIDAS camera. The maximum visibility range along the LOS was 1.28 km to the target, a line of trees. A reference light was located at the end of the LOS.

Fach obscurant smoke munition was detonated approximately at the center of the test grid, point C. The types of obscurants used during the test and their codes are listed below.

0 = Hexachloroethane (HC)

2 = High-explosive (HE)

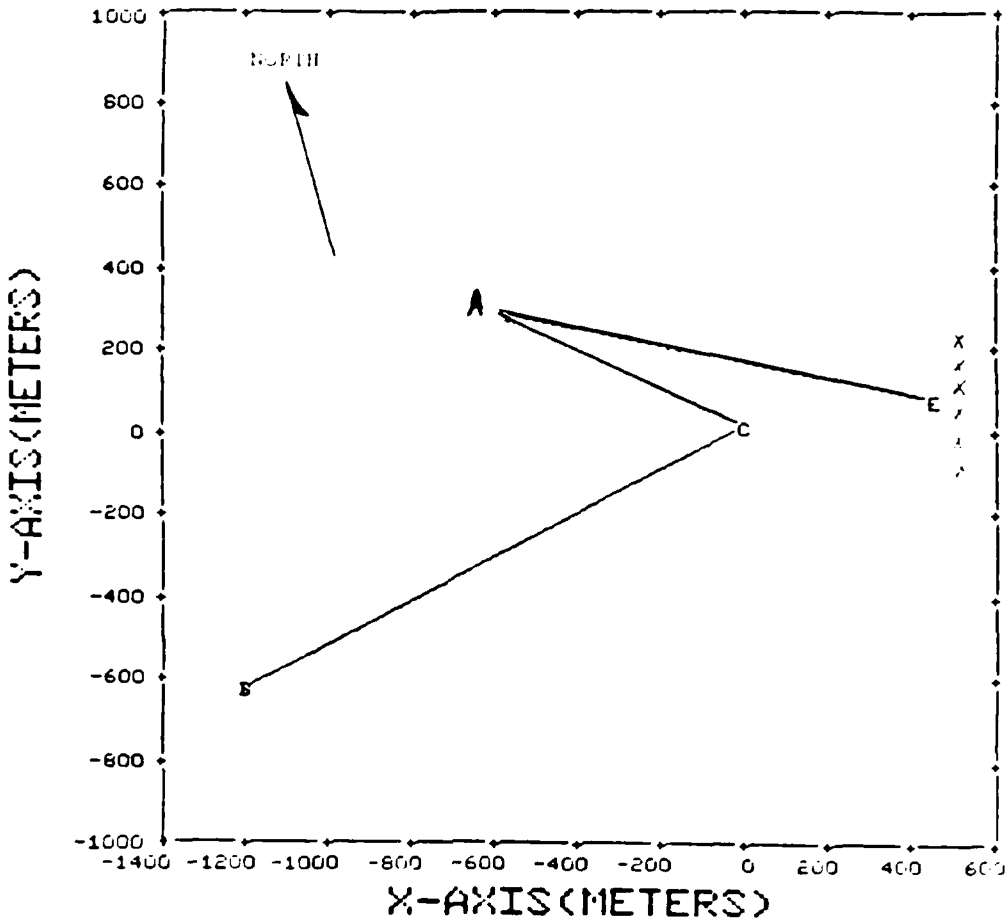
3 = Fog Oil (FO)

4 = Graphite (GP)

5 = Natural Dust (DT)

6 = EA5763 (EA)

7 = Aluminum (AL)




Point A is the location of one of the MIDAS system cameras, the visioceilometer, and the human observer. Point B is the location of the other MIDAS system camera. Point C is the center of the test grid. Line A-E is the line of sight (LOS) for the visioceilometer and the human observer. The target, a line of trees, is indicated by the X's. A reference light is located at the end of the LOS in front of the line of trees.

Figure 1. Test Grid Layout

## B. MULTISPECTRAL IMAGERY DIGITAL ACQUISITION SYSTEM (MIDAS) DATA

The multispectral imagery digital acquisition system (MIDAS) provided data on the location of the smoke clouds and their growth for each obscurant. The system's function during the test, that related to the visioceilometer, was to provide a generalized representation of obscurant cloud growth, and transport and diffusion rates as a function of time. The MIDAS system cloud growth, transport, and diffusion data for each obscurant was recorded one time per second for the first 10 seconds after detonation and five seconds thereafter until either the smoke cloud stabilized or the test grid was screened out by smoke. The smoke cloud graphical dimensional representation was in the form of ellipsoids. The ellipsoids were computed at prescribed time intervals. Two views of the ellipsoids were computed, the top-down view and the side view. Figure 2 displays the graphical representation of a graphite smoke cloud. Data from the MIDAS system had to be transformed into visual range measurements to facilitate the comparison with the visioceilometer measurement readings. The top-down view of the ellipsoids was used to transform MIDAS data into visual range measurements.

In order to determine the MIDAS measurements of visual range, from the system to the edge of the obscurant, the graphical location of the MIDAS system camera at point A, it's X and Y coordinates on the grid layout, had to be

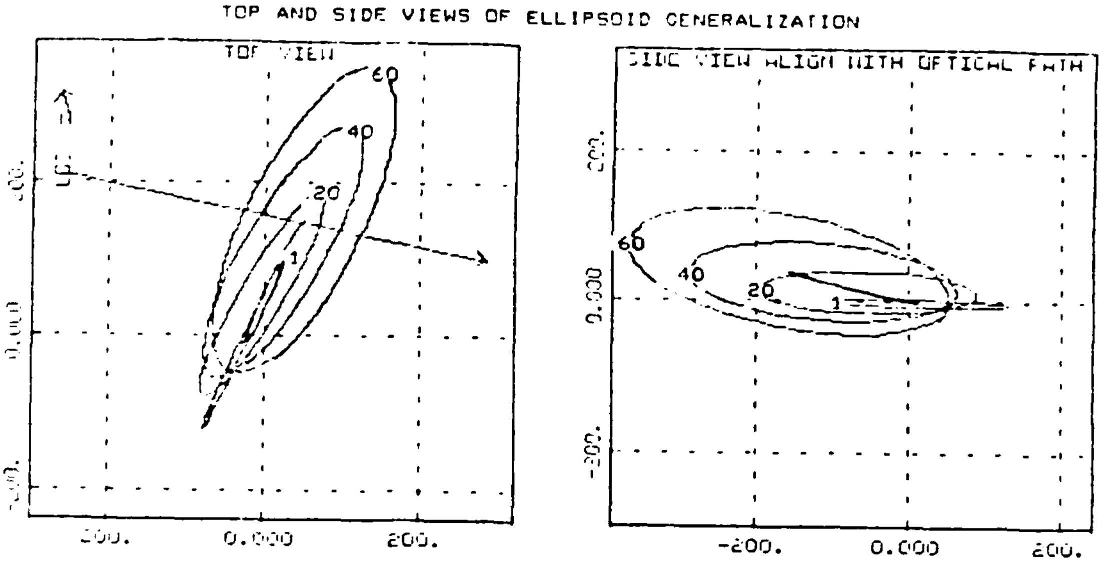



Figure 2. Graphite Smoke Cloud 348

determined. The system remained in the same location throughout the testing. Using these coordinates, visual range was then determined for the distance from the MIDAS system to where LOS intersected the outer edge of the ellipsoid. This was done by using the Pythagorean relationship to compute slant distance or visual range. The equation used was:

$$C = \sqrt{A^2 + B^2}$$

Here 'A' is the horizontal distance along the X-axis and 'B' is the vertical distance along the Y-axis on the test grid layout. 'C' is the computed visual range. The MIDAS system visual range was computed at time instants that corresponded to the time of the visioceilometer lidar shots. For most cases the MIDAS generation of ellipses started on an average approximately six minutes 30 seconds after the visioceilometer lidar measurements.

In instances where an ellipsoid was not computed for a time that corresponded to a visioceilometer reading, linear interpolation was used to compute the size and location for this prescribed time. Calculating the MIDAS system measurements of visual range in this manner resulted in obtaining 100 data points for the 30 smoke clouds analyzed.

## C. THE VISIOCEILOMETER AND HUMAN OBSERVER DATA

Data collected from the visioceilometer was in the form of graphs and numerical lidar return readings for the 30 smoke clouds used for the analysis. A standard test sequence was followed to evaluate the performance of the visioceilometer. At the start of each test trial, several "clear air" shots were taken as calibration references for the visioceilometer. Lidar shots were then fired approximately every minute and a half, after detonation until the smoke cloud dissipated. At the end, "clear air" shots were taken again. All data from the visioceilometer were entered into the data processing unit for future evaluation.

The number of lidar shots per smoke cloud ranged from 20 to 9, with an average of approximately 13 shots. These readings measured the range from the visioceilometer to the first encounter of an obscurant, and the total visibility range (as far as it could see through the obscurant's smoke) along the line of sight. Each visioceilometer reading was recorded by date and time and given a three digit trial code. The trial code identified the time of day, the type of obscurant, and the replication number. Time of day was indicated by 0 = night trial, 1 = morning trial (0600-1000 hours), 2 = mid day trial (1000-1400 hours) and 3 = afternoon trial (1400-1800 hours).

Table 2 displays smoke cloud summary data for the visioceilometer. Recorded are the date of each smoke cloud, the obscurant type (i.e., hexachloroethane (HC), high-explosive (HE), fog oil (FO), graphite (GP), dust (DT), EA5763 (EA), and aluminum (AL)), the smoke cloud identification number, the time of the first and last visiceilometer measurement reading, the total time for the smoke cloud, and the number of lidar shots taken. The average number of lidar shots per smoke cloud was 13. Table 3 contains similar data for the MIDAS system. It displays the start time of the MIDAS recordings and the time delay between the visioceilometer start time and the MIDAS start

TABLE 2

VISIOCEILOMETER SMOKE CLOUD DATA SUMMARY

| DATE | OBSCURANT | SMOKE CLOUD | START TIME | END TIME | TOTAL TIME | LIDAR SHOTS |
|---|---|---|---|---|---|---|
| 5/27 | HC | 201 | 10:27:50 | 10:44:33 | 16:43 | 14 |
| 5/27 | HC | 202 | 12:09:30 | 12:21:07 | 11:30 | 12 |
| 5/23 | HE | 220 | 11:42:37 | 12:02:24 | 6:23 | 17 |
| 5/19 | FO | 331 | 16:21:53 | 16:41:31 | 19:38 | 16 |
| 5/21 | FO | 333 | 15:29:44 | 15:47:22 | 17:38 | 11 |
| 5/24 | FO | 135 | 08:52:11 | 09:40:01 | 47:50 | 20 |
| 5/21 | GP | 241 | 10:30:28 | 10:44:19 | 2:37 | 10 |
| 5/21 | GP | 242 | 22:44:52 | 12:02:31 | 17:39 | 13 |
| 5/23 | GP | 343 | 16:08:56 | 16:28:40 | 19:44 | 12 |
| 5/24 | GP | 244 | 10:59:05 | 11:12:31 | 13:26 | 10 |
| 5/24 | GP | 245 | 11:43:10 | 11:58:20 | 15:10 | 11 |
| 5/26 | GP | 246 | 11:26:32 | 11:52:08 | 15:46 | 13 |
| 5/26 | GP | 247 | 12:20:25 | 12:34:44 | 14:19 | 12 |
| 5/26 | GP | 348 | 14:15:20 | 14:30:13 | 14:53 | 13 |
| 5/21 | DT | 351 | 14:33:13 | 14:51:47 | 18:34 | 13 |
| 5/23 | DT | 352 | 15:19:23 | 15:37:13 | 17:50 | 14 |
| 5/24 | DT | 354 | 14:17:35 | 14:30:08 | 12:33 | 10 |
| 5/24 | DT | 253 | 12:25:19 | 12:41:25 | 16:06 | 13 |
| 5/26 | DT | 355 | 14:51:22 | 15:15:22 | 24:33 | 13 |
| 5/26 | DT | 356 | 15:34:29 | 15:50:53 | 16:24 | 12 |
| 5/20 | EA | 163 | 09:42:39 | 09:59:01 | 16:22 | 14 |
| 5/24 | EA | 366 | 14:46:25 | 15:02:14 | 16:49 | 13 |
| 5/26 | EA | 267 | 10:19:30 | 10:34:56 | 15:26 | 11 |
| 5/26 | EA | 268 | 10:57:39 | 11:08:54 | 11:15 | 9 |
| 5/20 | AL | 371 | 15:25:19 | 16:06:26 | 41:07 | 16 |
| 5/21 | AL | 172 | 08:20:17 | 08:37:31 | 17:14 | 14 |
| 5/21 | AL | 173 | 09:19:56 | 09:35:50 | 15:54 | 12 |
| 5/23 | AL | 374 | 16:57:28 | 17:11:13 | 14:45 | 12 |
| 5/27 | AL | 375 | 17:18:15 | 17:33:23 | 15:08 | 14 |
| 5/27 | AL | 376 | 17:52:20 | 18:08:38 | 16:18 | 15 |

TABLE 3

MIDAS SMOKE CLOUD SUMMARY DATA

| DATE | OBSCURANT | SMOKE CLOUD | MEASURE-MENTS | START TIME | TIME DELAY |
|---|---|---|---|---|---|
| 5/27 | HC | 201 | 3 | 10:32:00 | 4:50 |
| 5/27 | HC | 202 | 3 | 12:09:02 | (.28) |
| 5/23 | HE | 220 | 3 | 11:47:00 | 6:23 |
| 5/19 | FO | 331 | 4 | 16:36:01 | 4:08 |
| 5/21 | FO | 333 | 4 | 15:34:01 | 4:17 |
| 5/24 | FO | 135 | 4 | 09:26:01 | 34:50 |
| 5/21 | GP | 241 | 2 | 10:33:05 | 2:37 |
| 5/21 | GP | 242 | 3 | 11:51:05 | 6:13 |
| 5/23 | GP | 343 | 4 | 16:18:05 | 9:09 |
| 5/24 | GP | 244 | 3 | 11:02:02 | 2:57 |
| 5/24 | GP | 245 | 4 | 11:48:03 | 4:53 |
| 5/26 | GP | 246 | 2 | 11:41:02 | 4:40 |
| 5/26 | GP | 247 | 3 | 14:18:03 | 2:43 |
| 5/21 | DT | 351 | 3 | 14:40:46 | 7:33 |
| 5/23 | DT | 352 | 3 | 15:24:01 | 4:38 |
| 5/24 | DT | 354 | 4 | 14:22:01 | 4:26 |
| 5/24 | DT | 253 | 4 | 12:30:02 | 4:43 |
| 5/26 | DT | 355 | 3 | 15:04:01 | 12:39 |
| 5/26 | DT | 356 | 4 | 15:39:01 | 4:32 |
| 5/20 | EA | 163 | 3 | 09:46:52 | 4:13 |
| 5/24 | EA | 366 | 4 | 14:51:01 | 8:37 |
| 5/26 | EA | 267 | 4 | 10:24:02 | 4:06 |
| 5/26 | EA | 268 | 3 | 11:02:02 | 4:23 |
| 5/20 | AL | 371 | 3 | 15:56:05 | 30:46 |
| 5/21 | AL | 172 | 4 | 08:24:02 | 3:45 |
| 5/21 | AL | 173 | 5 | 09:24:03 | 4:07 |
| 5/23 | AL | 374 | 3 | 17:01:02 | 3:34 |
| 5/27 | AL | 375 | 4 | 17:23:02 | 8:47 |
| 5/27 | AL | 376 | 3 | 17:57:02 | 4:42 |

time. The average delay is approximately six minutes and 30 seconds. There are few data points for comparing visual range between the visioceilometer and the MIDAS system because of this delay. The hexacholoroethane smoke cloud 202 was the only MIDAS system recording that occurred before the first visioceilometer lidar shot was fired.

Comments by a human observer on the density level of the obscurant were given for each visioceilometer measurement. The same observer was used throughout the tests. The comments indicated the density level along the line of sight (LOS) at the time the lidar was fired, categorized as heavy, moderate, and light smoke clouds. A reference light was located at the end of the line of sight, in front of the lines of trees. The observer also commented on whether this light was visible when he indicated the density level of the obscurant. These observer comments, along with the visioceilometer visibility readings were used to measure the degree of agreement between the two in determining density levels of the obscurants. Table 4 displays the type of data obtained from a single lidar shot. For this example, an afternoon lidar shot was fired through a graphite smoke cloud. The lidar first encountered the cloud at 0.56 Km along the line of sight and could see through it out to 1.25 Km. The observer's comment of 'moderate smoke' was the density level he recorded for this visioceilometer reading. The observer's comment of 'light visible' refers to the

TABLE 4

VISIOCEILOMETER AND OBSERVER DATA [Ref. 1]

| | |
|---|---|
| Record: | 506 |
| Date: | 05-26-1986 |
| Time: | 14:18:16 |
| Trial Code: | 348 |
| Obscurant: | 0.56 Km |
| Visibility: | 1.25 Km |
| Observer Comments: | |
| Light visible, Moderate smoke | |

reference light at the end of the line of sight path. Everytime the observer identified the smoke as being heavy, he also indicated that the light was not visible. Likewise everytime the observer identified the smoke as being light, he always indicated that the light was visible. However, when a moderate density level was identified the observer would in some instances indicate that the light was visible, barely visible, or not visible.

## D. ASSUMPTIONS

A few assumptions were made about the data obtained from Smoke Week VIII data. They are:

1. The human observer comments are true accounts of the obscurant density level at the time of the visioceilometer measurement reading.
2. The MIDAS system cloud transport and expansion rates, and ellipsoid shape remained constant for interpolated ellipsoids.

# IV. DATA ANALYSIS

There are two objectives for this analysis. One is to compare the visioceilometer range measurements with those provided by the MIDAS system and determine the relationship between the two. The second is to compare the visioceilometer visibility range measurements with the descriptions of density given by the human observer to determine the amount of agreement between the two.

## A. VISUAL RANGE ANALYSIS

The relationship between the visioceilometer and the MIDAS system measurement of visual range is investigated first by examining the consistency of agreement between the measurements provide by both systems. This is accomplished by plotting the visual range measurements produced by each system for all smoke clouds. On the plots, X is defined as the MIDAS system measurement of visual range to the cloud edge and Y is defined as the visioceilometer measurement of visual range to the edge of the cloud, for any given smoke cloud.

If there is perfect agreement between the two measurements of visual range, then the plotted data points should lie on the line Y = X, with zero intercept and slope of one. Because of the differences in the two systems, perfect agreement was not expected, nor was it observed when the data is plotted. However, linearity was expected, so the equation $\hat{y} = \hat{a} + \hat{b}X + \hat{e}$ is estimated for each smoke cloud. The plotted data can be used to gauge the agreement between the MIDAS system and the visioceilometer.

Two different aspects of the MIDAS system and visioceilometer agreement may be observed from these plots. "Accuracy" of agreement is indicated by the slope of the fitted line, if $b = 1$, then a 100 meter change in the MIDAS reading corresponds to a 100 meter change in the visioceilometer reading. If $b < 1$, then a 100 meter change in the MIDAS system reading translates into a $100b < 100$ meter change in the visiocilometer and if $b > 1$, then a 100 meter change in the MIDAS system reading translates into a $100b > 100$ meter change in the visioceilometer. "Consistency" of agreement between the two systems can be judged by the scatter of the data about the line. If all the observed data values fall on the line (regardless of the slope), then the MIDAS system and the visioceilometer readings are consistent: a given change in range from the MIDAS system always translates into the same change in the visioceilometer. The greater the scatter of the points about the line, the less consistency there is between the two systems.

As indicated in Tables 2 and 3, seven types of obscurants were detonated over a total of seven different days; in addition these detonations can be grouped into time of day, morning (0600-1000), midday (1000-1400), and afternoon (1400-1800). This allows rough comparisons of the MIDAS system and the visioceilometer agreement between smoke clouds, between day and times of day, as described below. One must keep in mind several facts regarding these data:

1. The visioceilometer presumably directly measures range to the edge of the cloud.

2. The MIDAS system uses cathode ray tube (CRT) data to fit ellipsoids of cloud shape. The computed MIDAS system range used here is the distance from the MIDAS camera to the "top down" two dimensional projection of the ellipsoid onto the ground. This may not accurately represent the true range along the line of sight.

3. Because of time delay between the first visioceilometer measurement and the first MIDAS computed ellipsoid, there are very few data points available for each smoke cloud.

1. Smoke Cloud Analysis

All the available data for the thirty smoke clouds analyzed are plotted in Figures 3 through 9A. Table 5 identifies the schemes used in these plots.

Variability in the smoke clouds and obscurants did not always display a good relationship between the visioceilometer and the MIDAS system. Out of the 30 smoke clouds examined only seven or 23 percent displayed a good consistency of agreement between the MIDAS system and the visioceilometer measurement of visual range. These smoke clouds are 201, 244, 247, 348, 355, 163, and 374. The accuracy of agreement for five of the seven smoke clouds displaying good agreement is measured by slopes of less than

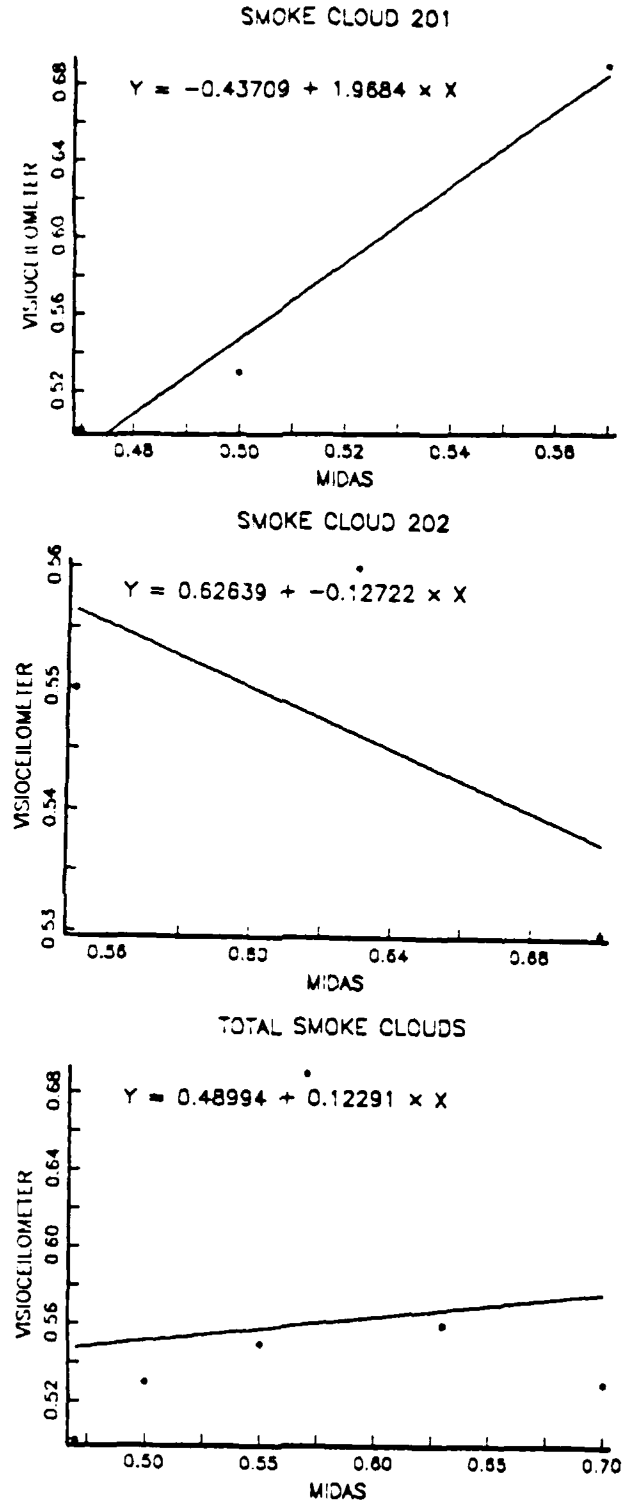



Figure 3. Hexachloroethane Data Graphs, Visioceilometer versus MIDAS

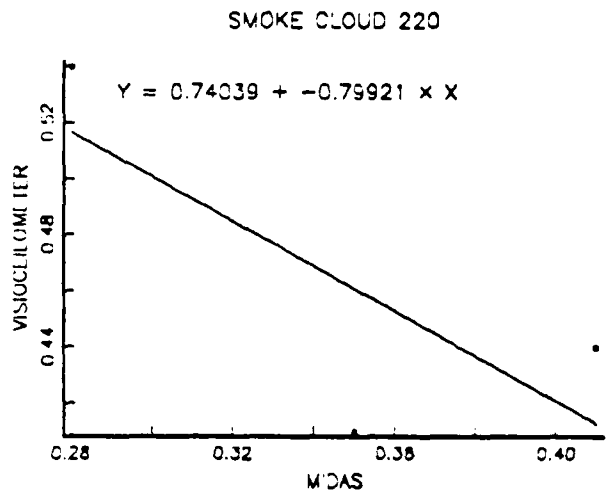



Figure 4. High-Explosive Data Graph, Visioceilometer versus MIDAS

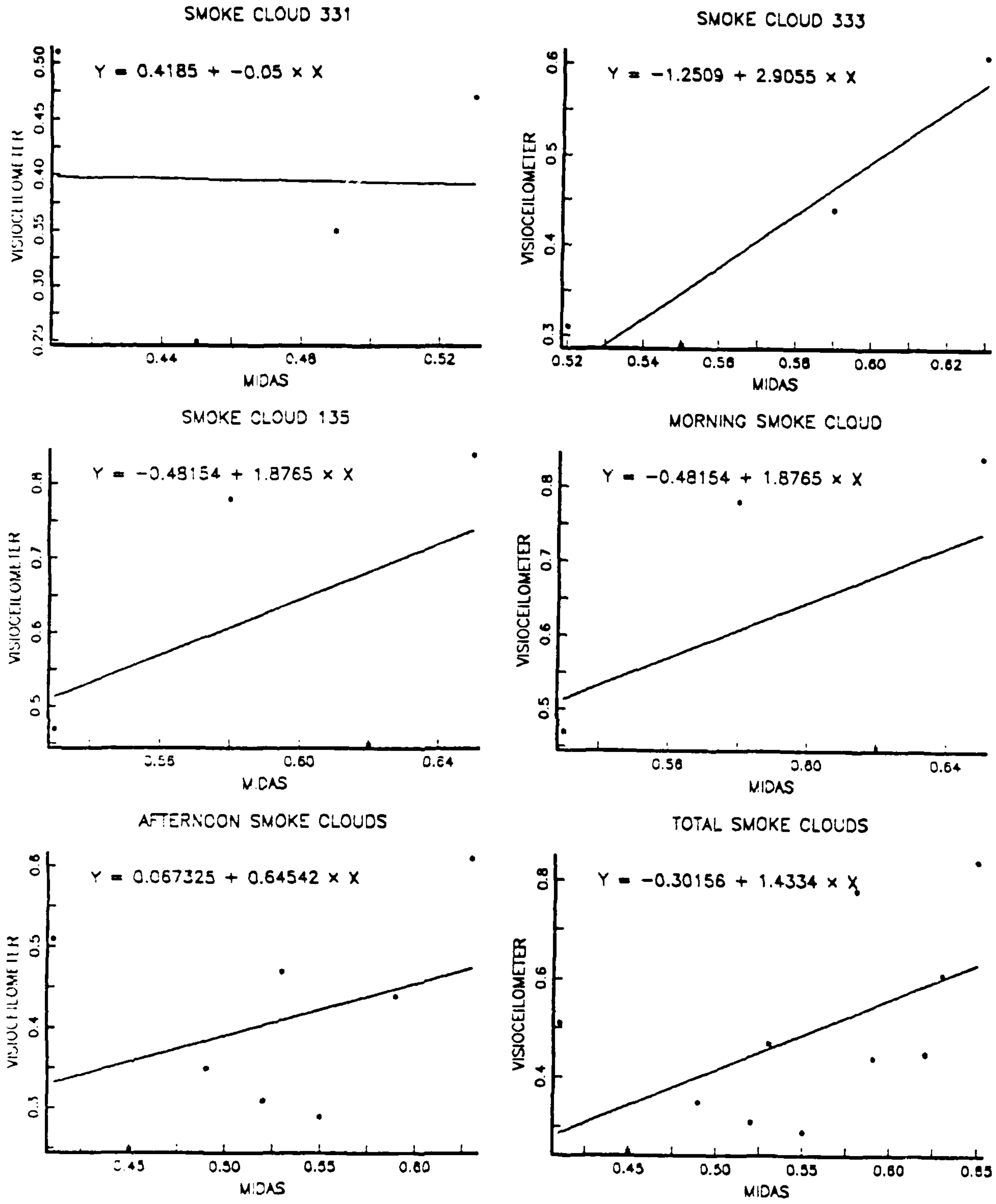



Figure 5. Fog Oil Data Graphs, Visioceilometer versus MIDAS

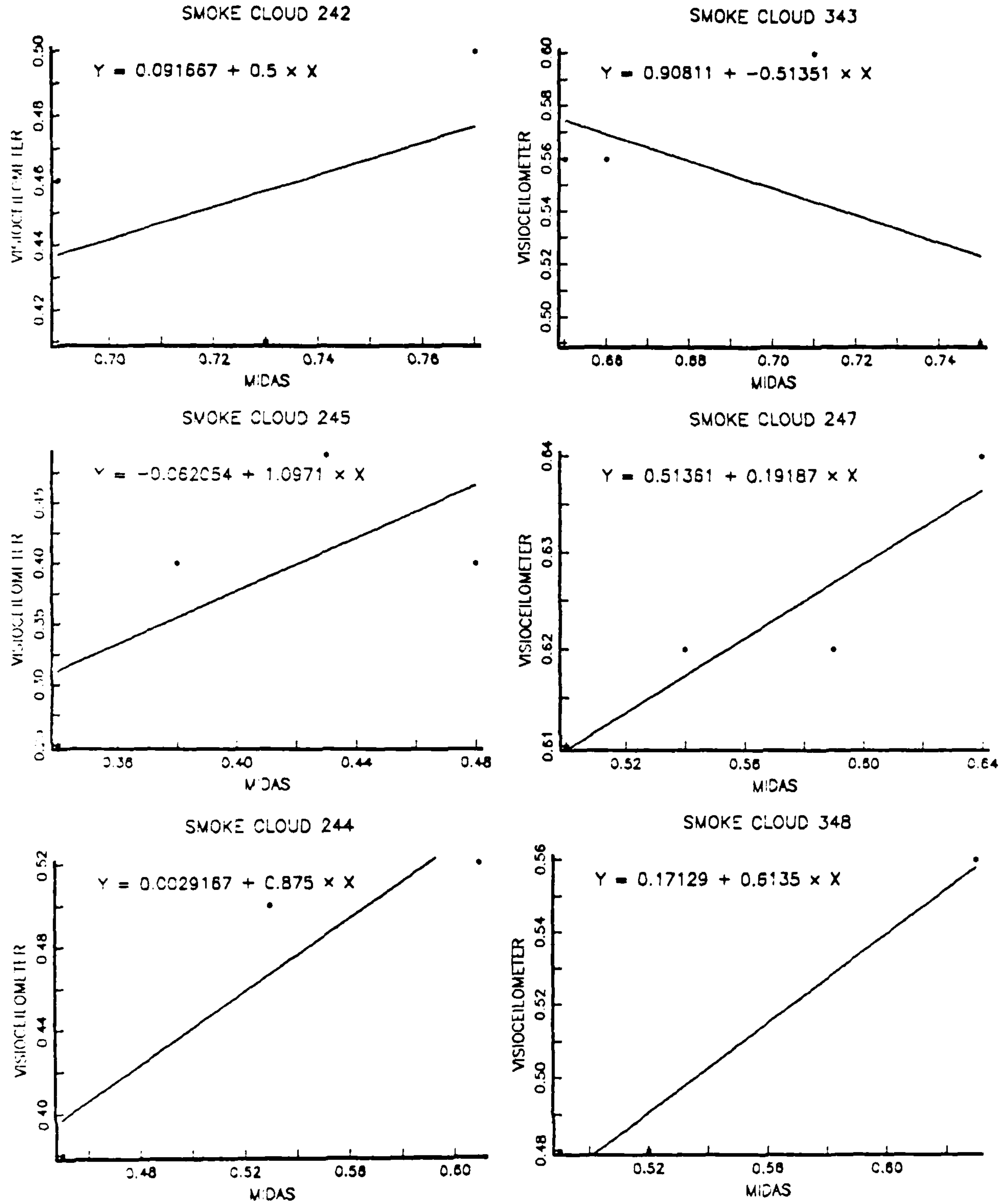
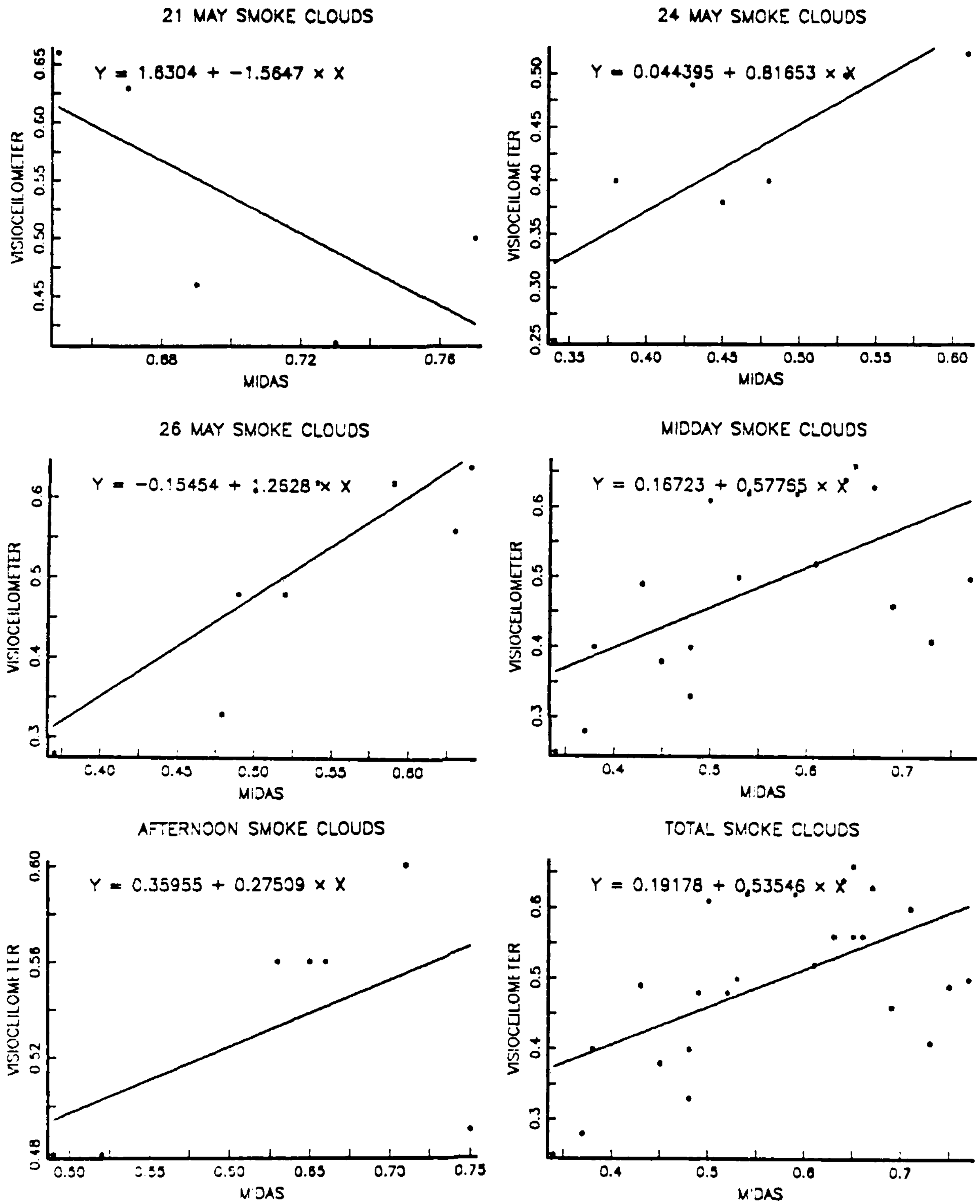



Figure 6. Graphite Data Graphs, Visioceilometer versus MIDAS



21 MAY SMOKE CLOUDS
Y = 1.8304 + −1.5647 × X
VISIOCEILOMETER
MIDAS
24 MAY SMOKE CLOUDS
Y = 0.044395 + 0.81653 × X
VISIOCEILOMETER
MIDAS
26 MAY SMOKE CLOUDS
Y = −0.15454 + 1.2528 × X
VISIOCEILOMETER
MIDAS
MIDDAY SMOKE CLOUDS
Y = 0.16723 + 0.57765 × X
VISIOCEILOMETER
MIDAS
AFTERNOON SMOKE CLOUDS
Y = 0.35955 + 0.27509 × X
VISIOCEILOMETER
MIDAS
TOTAL SMOKE CLOUDS
Y = 0.19178 + 0.53546 × X
VISIOCEILOMETER
MIDAS


Figure 6A

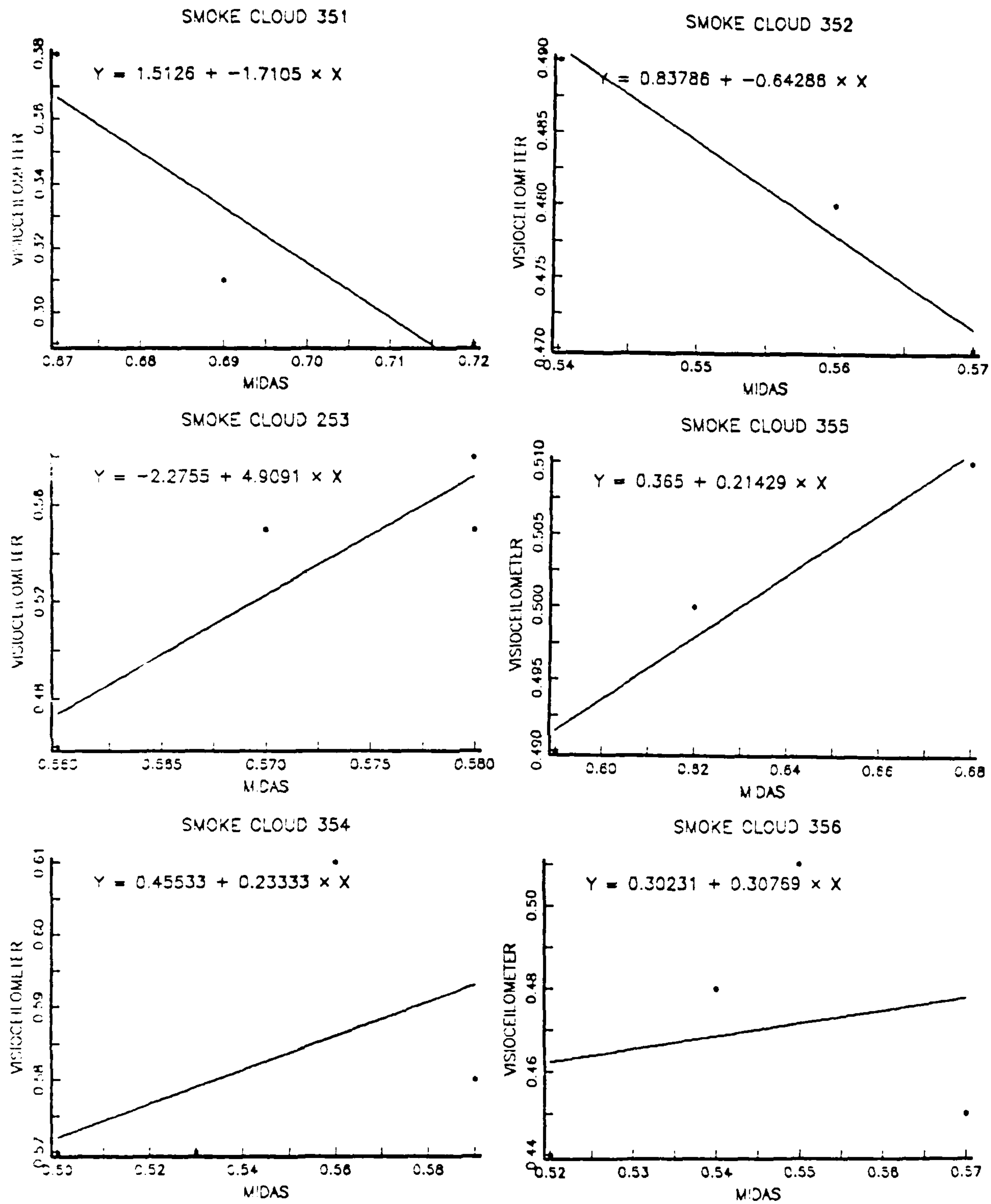



Figure 7. Dust Data Graphs, Visioceilometer versus MIDAS

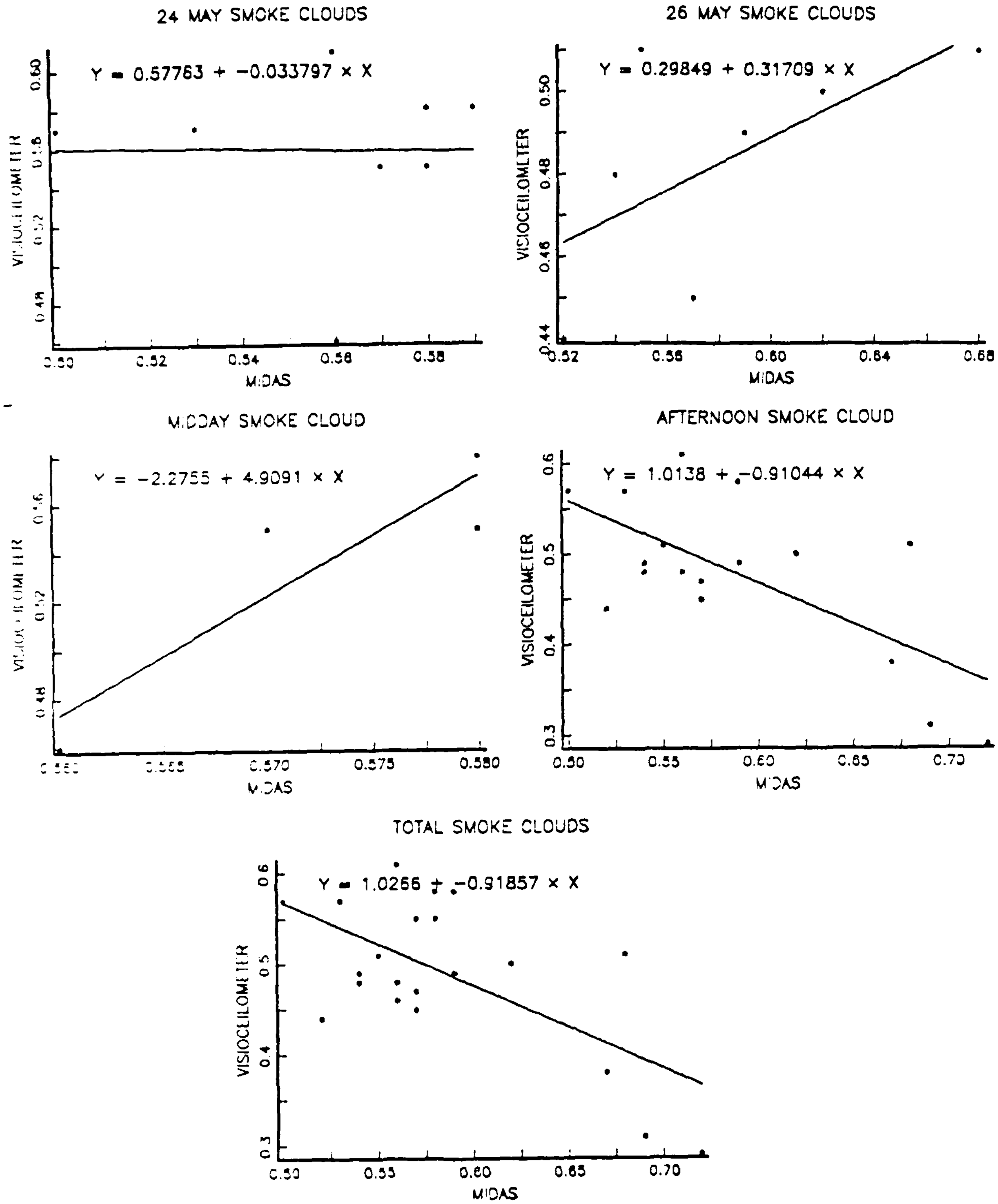

24 MAY SMOKE CLOUDS
Y = 0.57763 + -0.033797 × X
MIDAS
26 MAY SMOKE CLOUDS
Y = 0.29849 + 0.31709 × X
VISIOCEILOMETER
MIDAS
MIDDAY SMOKE CLOUD
Y = -2.2755 + 4.9091 × X
MIDAS
AFTERNOON SMOKE CLOUD
Y = 1.0138 + -0.91044 × X
VISIOCEILOMETER
MIDAS
TOTAL SMOKE CLOUDS
Y = 1.0266 + -0.91857 × X
VISIOCEILOMETER
MIDAS

Figure 7A

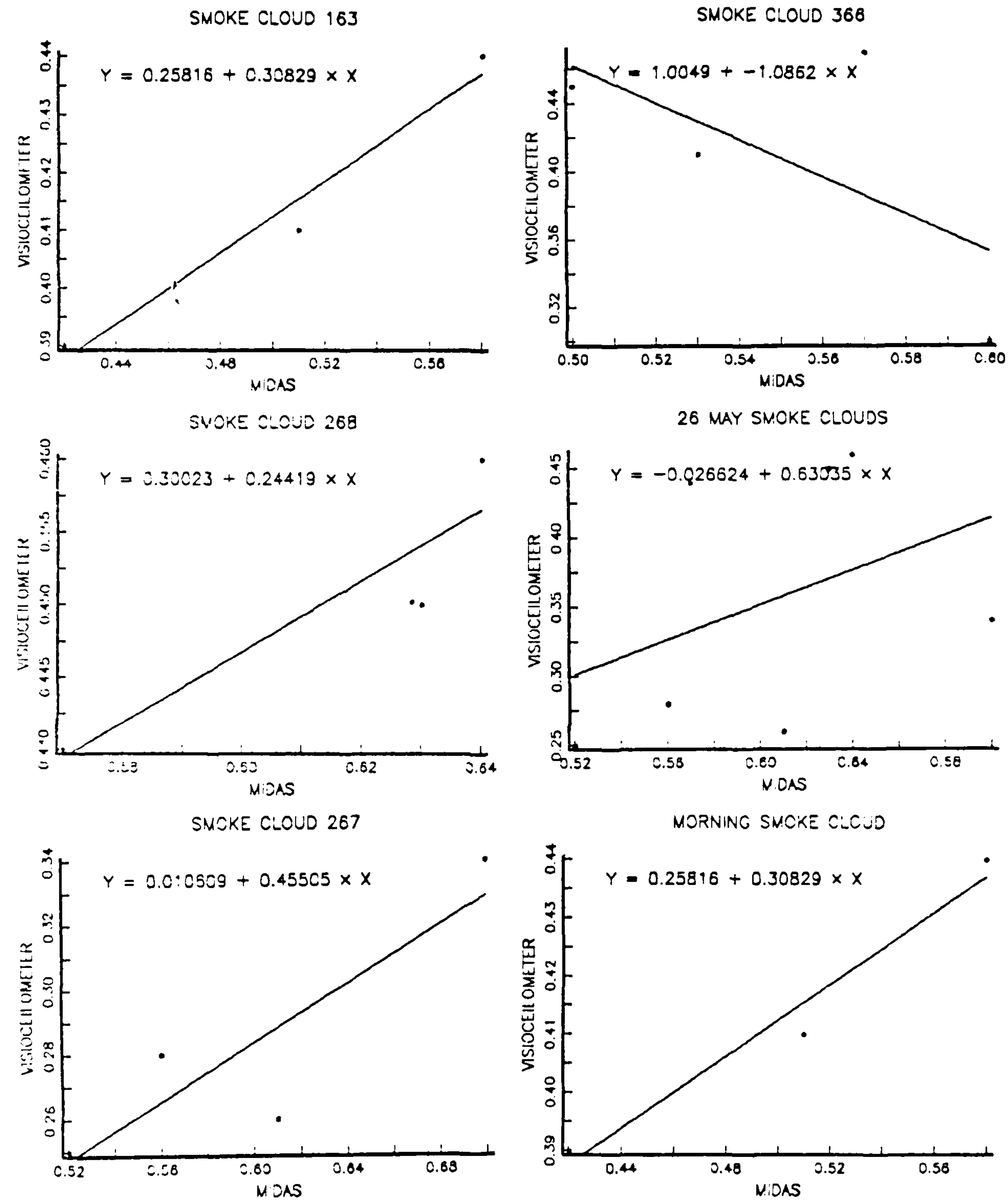



Figure 8. EA5763 Data Graphs, Visioceilometer versus MIDAS

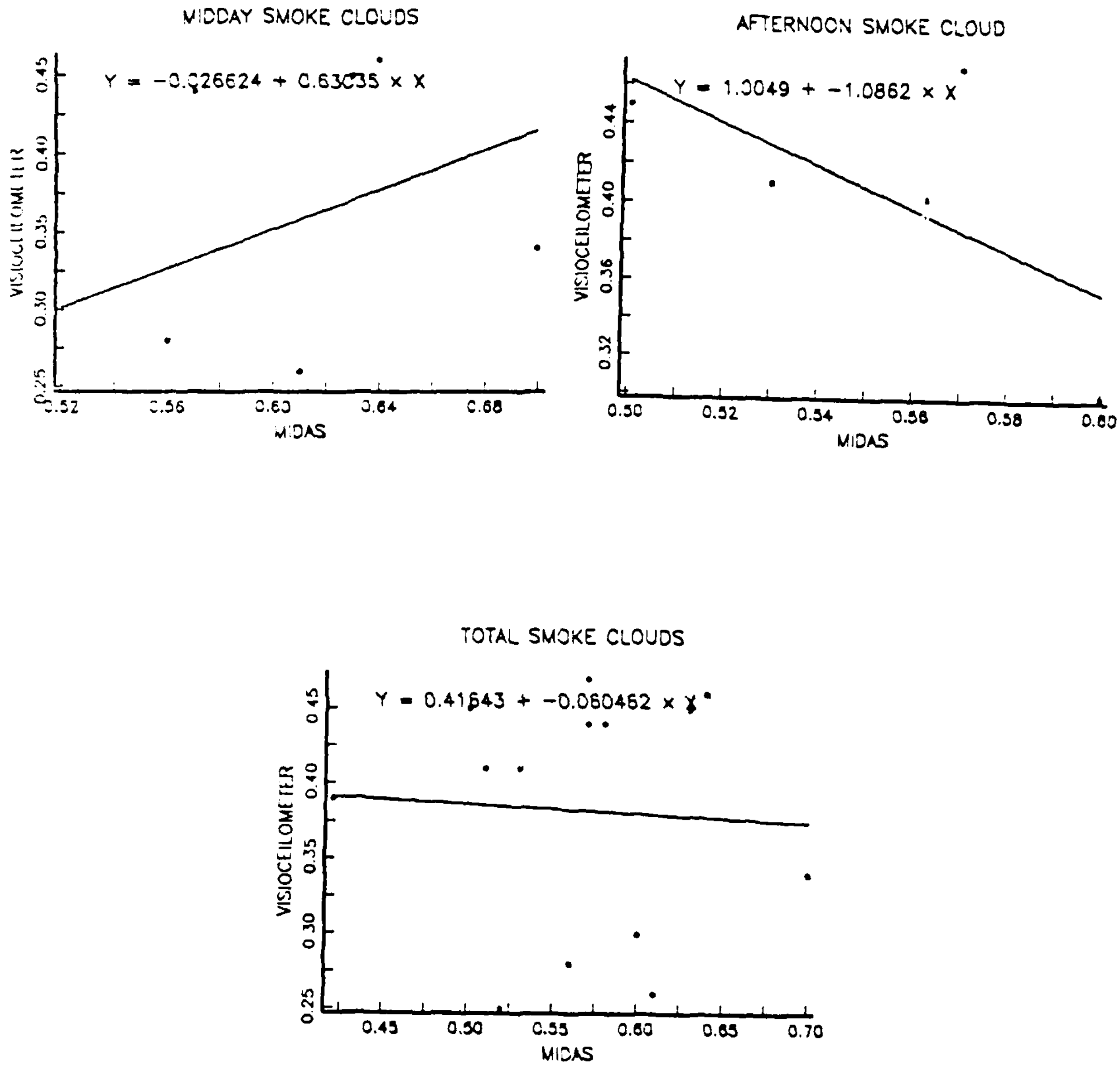

MIDDAY SMOKE CLOUDS
Y = -0.026624 + 0.63035 x X
VISIOCEILOMETER
MIDAS
AFTERNOON SMOKE CLOUD
Y = 1.0049 + -1.0862 x X
VISIOCEILOMETER
MIDAS
TOTAL SMOKE CLOUDS
Y = 0.41643 + -0.060462 x X
VISIOCEILOMETER
MIDAS

Figure 8A

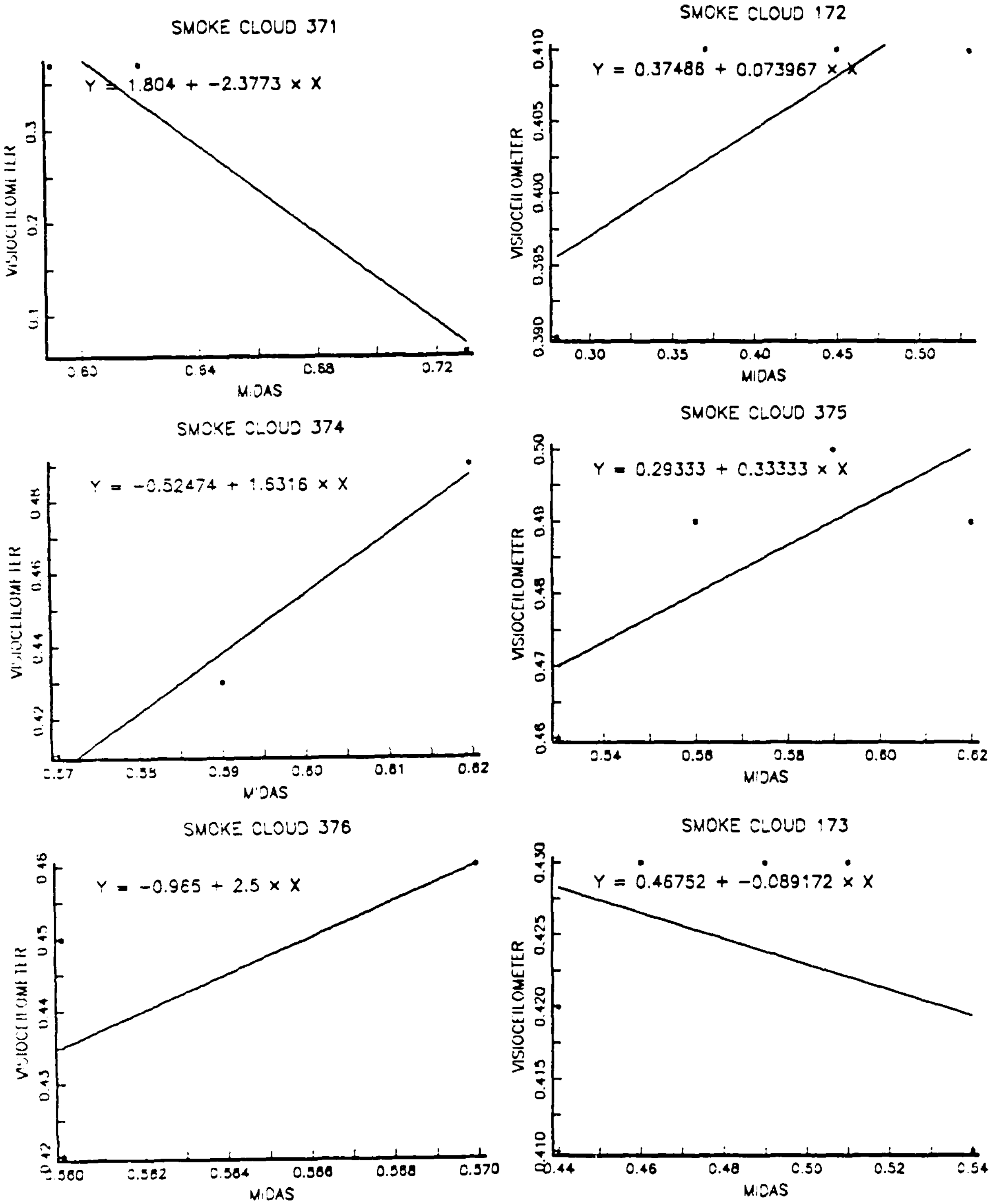
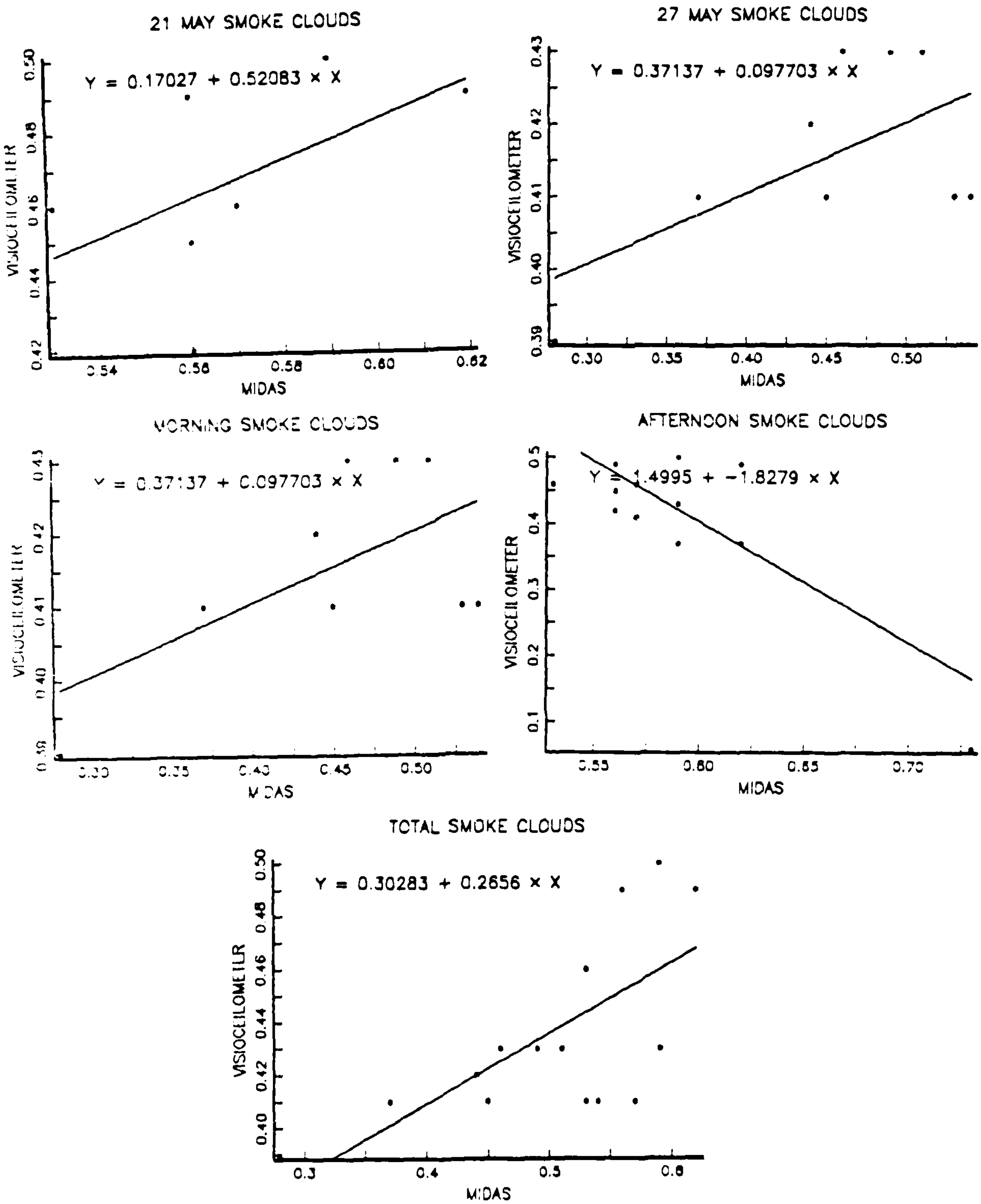



Figure 9. Aluminum Data Graphs, Visioceilometer versus MIDAS



21 MAY SMOKE CLOUDS
Y = 0.17027 + 0.52083 × X
VISIOCEILOMETER
MIDAS
27 MAY SMOKE CLOUDS
Y = 0.37137 + 0.097703 × X
VISIOCEILOMETER
MIDAS
MORNING SMOKE CLOUDS
Y = 0.37137 + 0.097703 × X
VISIOCEILOMETER
MIDAS
AFTERNOON SMOKE CLOUDS
Y = 1.4995 + −1.8279 × X
VISIOCEILOMETER
MIDAS
TOTAL SMOKE CLOUDS
Y = 0.30283 + 0.2656 × X
VISIOCEILOMETER
MIDAS


Figure 9A

TABLE 5

PLOT SCHEME

| FIGURE | SMOKE CLOUD | PLOTS |
|---|---|---|
| 3 | Hexachloroethane | 2 individual smoke clouds and the combination of the two |
| 4 | High-explosive | One smoke cloud with 3 data points |
| 5 | Fog Oil | 3 individual smoke clouds, 1 morning, 2 afternoon and the combination of 3 |
| 6 | Graphite | 6 individual smoke clouds |
| 6A | Graphite | Graphite smoke clouds combined by day, times of day, and overall |
| 7 | Dust | 4 individual smoke clouds |
| 7A | Dust | Dust smoke clouds combined by day, times of day, and overall |
| 8 | EA5763 | 4 individual smoke clouds and 2 combined for day, time of day |
| 8A | EA5763 | EA5763 smoke clouds combined for time of day and overall |
| 9 | Aluminum | 6 individual smoke clouds |
| 9A | Aluminum | Aluminum smoke clouds combined for day, time of day, and overall |

one, indicating that a 100 meter change in MIDAS reading translates into a 100b < 100 meter change in the visioceilometer reading. Two of the seven smoke clouds accuracy was measured by slopes of greater than one, indicating a 100 kilometer change in the MIDAS system reading translates into a 100b > 100 meter change in the visioceilometer. One smoke cloud, 333, or three percent of the total examined displayed a fair consistency. Only on two occasions did time of day display better than poor consistency. This occurred for dust at midday and EA5763 morning reading. The agreement displayed for the remaining time of day for the other obscurants was poor. Day effects observed displayed a poor relationship for all days except 24 and 26 May for graphite smoke clouds, which was fair. The overall relationship between the MIDAS system and the visioceilometer measurement of visual range is poor.

The conclusion made is that the two systems do not provide similar or consistent measurements of visual range. The poor agreement is possibly caused by a number of factors affecting the data used for the analysis and the method in which it was obtained. The small size of data set could have omitted information that could have been useful in the analysis. Also, visual range measurements for the MIDAS system were computed from the ellipsoidal representation of the smoke cloud computed by the system. The assumption that the smoke clouds were ellipsoidal could be incorrect, which would in turn cause the MIDAS system visual range measurements to also be incorrect and therefore affect the agreement between the two systems measurements. Another important factor is the height of the two systems from the ground when measurements were taken. This information is not known, but was assumed to be equal. If the difference between the two systems height is substantial, this could have an impact on the agreement between the two systems measurement.

## B. DENSITY LEVEL

Density level is investigated by comparing the visioceilometer visibility range readings (how far it could see through the smoke cloud) with the human observer density level identification at the time of the visioceilometer reading. The length of the visibility measurement is used to determine the density level for the visioceilometer, i.e., a short length would indicate a heavy smoke cloud. The density level analysis compared the visibility range measurements of the visioceilometer with the level of density identified by the human observer. For every visioceilometer lidar measurement of visibility, a human observer, who shared the same line of sight with the visioceilometer, indicated the level of the smoke cloud (heavy, moderate or light). He also indicated whether or not a reference light located in front of the target could be seen. It was noted that everytime the human observer identified the density level as heavy he never saw the light, whenever he judged the level as light he always saw the light, and for moderate densities the comment was mixed; sometimes the light was visible, barely visible, or not visible at all. Out of the 97 times the moderate density level was identified, on 58 he could see the light, on 31 he could barely see the light and on 8 he did not see the light.

Range boundaries identifying density levels had to be established for the visioceilometer for comparison with the human observer. Consideration is given to the fact that the visioceilometer provides continuous measurements, while the human observer provides discrete accounts of the density level at a point in time. After a careful examination of the data set, the continuous measurement scale of the visioceilometer was broken into three non-overlapping segments in an attempt to provide perfect agreement when compared with the human observer.

Initially, data from smoke clouds were examined by type of obscurant and individual range boundaries established according to that type. For example, if an obscurant was characteristically dense, such as fog oil, the heavy-moderate density bound was set lower on the measurement scale, and the moderate-light bound adjusted accordingly. However, after examining the other obscurants the range bounds found were very similar to each other, so one set was used for all obscurants. These range boundaries are identified as the original range boundaries. Sensitivity analysis is then performed by shifting the original range boundaries to determine if a better agreement between the visioceilometer and the human observer can be obtained.

1. Original Range Boundaries

Range boundaries were established for each category of density level after carefully examining the data set and taking into consideration that the continuous visioceilometer measurements are compared to the discrete human observer identification of the smoke cloud density level. A short visual range implies that the smoke cloud density level is heavy while a long visual range indicates that the smoke cloud is light. The moderate range falls in between the two. The originally established range boundaries were

ORIGINAL BOUNDARIES

| | |
|---|---|
| Heavy | 0 to .99 km |
| Moderate | 1.00 km to 1.23 km |
| Light | 1.24 km to 1.28 km |

A matrix was used to record the comparisons of the human observer identification of density level with that indicated by the visioceilometer. Once the range boundaries were established a count of heavy, moderate, or light as identified by the visioceilometer and the observer was made. These results are investigated by obscurant and by time of day.

a. Obscurant

Each obscurant was investigated to determine the agreement between the visioceilometer and the human observer identification of visual range. Agreement between the two is represented by the counts falling on the diagonal of the matrix. If the visioceilometer measurement did not agree with the human observer, they were recorded in the appropriate density level category column. The percentage of agreement is computed by dividing the visioceilometer count, the number on the diagonal, by the human count, the number in the total column. The result of these measurement counts and percentage of agreements is found in Table 6. A total count was made combining all obscurants. The results of the agreement between the human observer and the visioceilometer was 84 percent for heavy (82 of 98), 36 percent for moderate (35 of 97), and 77 percent for light (97 of 126). The overall result for total obscurants was 67 percent (214 out of 321).

b. Time of Day

As stated before, time of day was examined for morning (0800-1000), midday (1000-1400), and afternoon (1400-1600).

Morning. Three obscurants were tested during the morning period. They were fog oil, EA5763, and aluminum. The human observer recorded 31 for heavy while the visioceilometer recorded 30 or 98 percent in agreement with the human observer. In the moderate category the human observer recorded 15 while the visioceilometer recorded only 3 or 20 percent of the human observer. The light category recorded a 75 percent agreement between the two, that is

TABLE 6

OBSCURANT DENSITY LEVEL RESULTS

HEXACHLOROETHANE

VISIOCEILOMETER

| | LEVEL | 0-.99 km | 1.00-1.23 km | ≥1.24 km | TOTAL | % |
|---|---|---|---|---|---|---|
| | Heavy | 11 | 2 | 3 | 16 | 69 |
| Obs. | Moderate | 1 | 4 | 2 | 7 | 57 |
| | Light | 0 | 0 | 0 | 0 | 100 |
| | Total | 12 | 6 | 5 | 23 | 65 |

HIGH-EXPLOSIVE

VISIOCEILOMETER

| | LEVEL | 0-.99 km | 1.00-1.23 km | ≥1.24 km | TOTAL | % |
|---|---|---|---|---|---|---|
| | Heavy | 0 | 1 | 0 | 1 | 0 |
| Obs. | Moderate | 0 | 0 | 1 | 1 | 0 |
| | Light | 1 | 0 | 11 | 12 | 92 |
| | Total | 1 | 1 | 12 | 14 | 79 |

FOG OIL

VISIOCEILOMETER

| | LEVEL | 0-.99 km | 1.00-1.23 km | ≥1.24 km | TOTAL | % |
|---|---|---|---|---|---|---|
| | Heavy | 21 | 4 | 0 | 25 | 84 |
| Obs. | Moderate | 1 | 1 | 3 | 5 | 20 |
| | Light | 0 | 4 | 13 | 17 | 77 |
| | Total | 22 | 9 | 16 | 47 | 75 |

TABLE 6 (CONTINUED)

GRAPHITE

VISIOCEILOMETER

| | | | | | | |
|---|---|---|---|---|---|---|
| | Heavy | 20 | 3 | 1 | 24 | 83 |
| Obs. | Moderate | 7 | 6 | 7 | 20 | 30 |
| | Light | 1 | 6 | 23 | 30 | 77 |
| | Total | 28 | 15 | 31 | 74 | 66 |

DUST

VISIOCEILOMETER

| | | | | | | |
|---|---|---|---|---|---|---|
| | Heavy | 3 | 0 | 0 | 3 | 100 |
| Obs. | Moderate | 2 | 8 | 12 | 22 | 36 |
| | Light | 0 | 0 | 29 | 29 | 100 |
| | Total | 5 | 8 | 41 | 54 | 74 |

EA5763

VISIOCEILOMETER

| | | | | | | |
|---|---|---|---|---|---|---|
| | Heavy | 5 | 0 | 0 | 5 | 100 |
| Obs. | Moderate | 9 | 1 | 1 | 11 | 9 |
| | Light | 6 | 10 | 16 | 32 | 50 |
| | Total | 20 | 11 | 17 | 32 | 50 |

ALUMINUM

VISIOCEILOMETER

| | | | | | | |
|---|---|---|---|---|---|---|
| | Heavy | 22 | 2 | 0 | 24 | 92 |
| Obs. | Moderate | 11 | 15 | 4 | 29 | 52 |
| | Light | 1 | 0 | 6 | 8 | 75 |
| | Total | 34 | 17 | 10 | 61 | 71 |

TABLE 6 (CONTINUED)

TOTAL SMOKE CLOUDS

VISIOCEILOMETER

| | | | | | | |
|---|---|---|---|---|---|---|
| | Heavy | 82 | 12 | 4 | 98 | 84 |
| Obs. | Moderate | 31 | 35 | 31 | 97 | 36 |
| | Light | 9 | 20 | 97 | 126 | 77 |
| | Total | 122 | 67 | 132 | 321 | 67 |

the human observer recorded 12 while the visioceilometer recorded 9. The overall percentage of agreement for morning was 64. Using these range boundaries, heavy and light gave a better agreement with the human observer. Table 7 lists the morning density level recorded count and percentage of agreement between the visioceilometer and the human observer.

TABLE 7

MORNING DENSITY ANALYSIS

VISIOCEILOMETER

| | LEVEL | 0-.99 km | 1.00-1.23 km | ≥ 1.24 km | TOTAL | % |
|---|---|---|---|---|---|---|
| | Heavy | 30 | 1 | 0 | 31 | 84 |
| Obs. | Moderate | 8 | 3 | 4 | 15 | 2 |
| | Light | 1 | 2 | 9 | 12 | 75 |
| | Total | 39 | 6 | 13 | 58 | 64 |

Midday. During the afternoon period five obscurants were tested. They were hexachloroethane (HC), high-explosive (HE), graphite, dust, and EA5763. The agrement between the human observer and the visioceilometer were recorded as 77 percent of heavy (34 of 44), 27 percent for moderate (6 of 22), and 75 percent for light (36 of 48). Overall agreement for afternoon was 67 percent. Table 8 lists the recorded density level counts and the percentages of agreement between the visioceilometer and the human observer.

TABLE 8

MIDDAY DENSITY LEVEL

| | | VISIOCEILOMETER | | | | |
|---|---|---|---|---|---|---|
| | LEVEL | 0-.99 km | 1.00-1.23 km | ≥ 1.24 km | TOTAL | % |
| | Heavy | 34 | 6 | 4 | 44 | 77 |
| Obs. | Moderate | 6 | 6 | 10 | 22 | 27 |
| | Light | 6 | 6 | 36 | 48 | 75 |
| | TOTAL | 46 | 18 | 50 | 114 | 67 |

Afternoon. Five obscurants were tested during the afternoon period. They were fog oil, aluminum, graphite, dust, and EA5763. The visioceilometer had 78 percent (18 of 23) agreement with the human observer for the heavy density level category, 43 percent (25 of 58) for moderate, and 79 percent (54 of 68) for light. The overall agreement between the two for afternoon was 65 percent. Table 9 gives the recorded counts and percentages for density levels in the afternoon.

2. <u>Sensitivity Analysis</u>

Sensitivity analysis was performed on the original range boundaries by shifting them upward and downward to see if a better agreement between the visioceilometer and the human observer could be obtained. Two approaches were

TABLE 9

AFTERNOON DENSITY LEVELS

| | | VISIOCEILOMETER | | | | |
|---|---|---|---|---|---|---|
| | LEVEL | 0-.99 km | 1.00-1.23 km | $\geq$ 1.24 km | TOTAL | % |
| | Heavy | 18 | 5 | 0 | 23 | 78 |
| Obs. | Moderate | 17 | 25 | 16 | 58 | 43 |
| | Light | 0 | 14 | 54 | 68 | 79 |
| | TOTAL | 35 | 44 | 70 | 149 | 65 |

considered for the sensitivity analysis. The first approach involved shifting the original range boundaries of the moderate density level, which in turn affected the heavy or light bounds, but not both at the same time. When the upper bound of the moderate density level is shifted upward to increase the moderate segment length, the light segment length decreases. Likewise when the lower bound of the moderate density level is shifted downward the upper bound of the heavy density is also shifted downward.

The second approach involved forcing perfect agreement between the visioceilometer and the human observer for as many density levels as possible. The heavy and light density levels were chosen for this method. Range boundaries are established by setting the range boundaries for heavy in such a way that every heavy measurement identified by the human observer would agree with the range measurements made by the visioceilometer. This is also done for the light density measurement. The restriction in this approach is that there can not be any overlapping of boundary range values and a set of range boundaries must be included for moderate density level. This method was not used because meaningful information could not be obtained from it. Graphite is used to demonstrate how this method works. The highest visioceilometer range value for the heavy density level identified by the human observer 1.24 km. Therefore the upper range bound for heavy is set at 1.24 km to include all the measurements and get perfect agreement between the two systems. Next the lowest visioceilometer range value identified by the human observer for the light density level is 1.04 km. The lower bound on the light density level is then set at 1.04 km. So to force perfect agreement between the two density levels, heavy upper bound would be set at 1.24 km and light lower bound would be set at 1.04 km. Since both of these segments include range values between 1.04 km and 1.24 km and no range boundaries can be set for the moderate density level, this method could not be used. After examining the data, in all cases except one the boundaries overlapped.

The method of changing the original range boundaries for the moderate density level is used for the sensitivity analysis. The first change for this method is to shift the upper (U) range bound of the moderate density level to include point 1.24 km. This had an impact on the light level by deleting point 1.24 km, but did not affect the heavy density level. These changes to the original range boundaries are listed below in the upper table.

UPPER

| | |
|---|---|
| Heavy | Less than 1.00 km |
| Moderate | 1.00 to 1.24 km |
| Light | 1.25 km and above |

The second change affected the lower range bound of moderate level and the upper range bound of heavy density level. There was no effect on the light density level. The new range boundaries are called lower and listed in the table below.

LOWER

| | |
|---|---|
| Heavy | Less than .71 km |
| Moderate | .71 to 1.23 km |
| Light | 1.24 km and above |

The upper (U) and lower (L) shifts of the original range boundaries were combined to get a third set of range boundaries for comparison of the visioceilometer and the human observer. They are listed below as combination range boundaries.

COMBINATION

| | |
|---|---|
| Heavy | Less than .71 km |
| Moderate | .71 to 1.24 km |
| Light | 1.25 km and above |

An example of this sensitivity analysis is demonstrated by using the hexachloroethane (HC) obscurant. The information recorded on the counts and percentages of agreement between the visioceilometer and the human observer is listed below.

HEXACHLOROETHANE

ORIGINAL BOUNDARIES

VISIOCEILOMETER

| | LEVEL | 0-.99 km | 1.00-1.23 km | $\geq$ 1,24 km | TOTAL | % |
|---|---|---|---|---|---|---|
| | Heavy | 11 | 2 | 3 | 16 | 69 |
| Obs. | Moderate | 1 | 4 | 2 | 7 | 57 |
| | Light | 0 | 0 | 0 | 0 | 100 |
| | TOTAL | 12 | 6 | 5 | 23 | 65 |

UPPER BOUNDARIES

VISIOCEILOMETER

| | | | | | | |
|---|---|---|---|---|---|---|
| | Heavy | 11 | 3 | 2 | 16 | 69 |
| Obs. | Moderate | 1 | 6 | 0 | 7 | 86 |
| | Light | 0 | 0 | 0 | 0 | 100 |
| | TOTAL | 12 | 9 | 2 | 23 | 74 |

LOWER BOUNDARIES

VISIOCEILOMETER

| | | | | | | |
|---|---|---|---|---|---|---|
| | Heavy | 10 | 4 | 2 | 16 | 63 |
| Obs. | Moderate | 1 | 6 | 0 | 7 | 86 |
| | Light | 0 | 0 | 0 | 0 | 100 |
| | TOTAL | 11 | 10 | 2 | 23 | 70 |

COMBINATION BOUNDARIES

VISIOCEILOMETER

| | | | | | | |
|---|---|---|---|---|---|---|
| | Heavy | 10 | 4 | 2 | 16 | 63 |
| Obs. | Moderate | 1 | 6 | 0 | 7 | 86 |
| | Light | 0 | 0 | 0 | 0 | 100 |
| | TOTAL | 11 | 10 | 2 | 23 | 70 |

The results of the boundaries changes for hexachloroethane, indicate that the upper set of boundaries provide the best agreement between the visioceilometer and the human observer. The overall percentage of agreement for the upper set of boundaries is 74.

Summary results of the percentage of agreement between the visioceilometer and the human observer are listed in Table 10. The original range boundaries percentages of agreement are also listed in Table 10. For each obscurant the result of all the boundaries changes are listed. The column headings in the table are O, U, L, and C indicating original (O), upper (U), lower (L), and combination (C) range boundaries changes.

TABLE 10

DENSITY LEVEL ANALYSIS RESULTS

VISIOCEILOMETER

| | Hexachloroethane | O | U | L | C |
|---|---|---|---|---|---|
| | HEAVY | 69 | 69 | 63 | 63 |
| OBS. | MODERATE | 57 | 86 | 86 | 86 |
| | LIGHT | 100 | 100 | 100 | 100 |
| | TOTAL | 65 | 74 | 70 | 70 |

| | HIGH-EXPLOSIVE | O | U | L | C |
|---|---|---|---|---|---|
| | HEAVY | 0 | 0 | 0 | 0 |
| OBS. | MODERATE | 0 | 100 | 0 | 100 |
| | LIGHT | 92 | 8 | 92 | 8 |
| | TOTAL | 79 | 14 | 79 | 14 |

TABLE 10 (CONTINUED)

| FOG OIL | | O | U | L | C |
|---|---|---|---|---|---|
| | HEAVY | 84 | 84 | 44 | 44 |
| OBS. | MODERATE | 6 | 4 | 6 | 4 |
| | LIGHT | 77 | 59 | 77 | 59 |
| | TOTAL | 76 | 7 | 53 | 49 |

| GRAPHITE | | O | U | L | C |
|---|---|---|---|---|---|
| | HEAVY | 83 | 83 | 63 | 63 |
| OBS. | MODERATE | 30 | 50 | 35 | 70 |
| | LIGHT | 77 | 40 | 80 | 40 |
| | TOTAL | 66 | 57 | 66 | 55 |

| DUST | | O | U | L | C |
|---|---|---|---|---|---|
| | HEAVY | 100 | 100 | 100 | 100 |
| OBS. | MODERATE | 36 | 59 | 36 | 59 |
| | LIGHT | 100 | 72 | 100 | 72 |
| | TOTAL | 74 | 69 | 74 | 69 |

| EA5763 | | O | U | L | C |
|---|---|---|---|---|---|
| | HEAVY | 100 | 100 | 80 | 80 |
| OBS. | MODERATE | 09 | 18 | 36 | 46 |
| | LIGHT | 50 | 25 | 50 | 25 |
| | TOTAL | 46 | 31 | 50 | 35 |

TABLE 10 (CONTINUED)

| | ALUMINUM | O | U | L | C |
|---|---|---|---|---|---|
| | HEAVY | 92 | 92 | 92 | 92 |
| OBS. | MODERATE | 52 | 52 | 45 | 48 |
| | LIGHT | 75 | 50 | 75 | 50 |
| | TOTAL | 71 | 67 | 67 | 66 |

| | TOTAL | O | U | L | C |
|---|---|---|---|---|---|
| | HEAVY | 84 | 84 | 66 | 66 |
| OBS. | MODERATE | 36 | 51 | 44 | 57 |
| | LIGHT | 77 | 43 | 69 | 43 |
| | TOTAL | 67 | 58 | 61 | 54 |

A couple of rules are considered to select the range boundaries to obtain the closest agreement between the visioceilometer and the human observer. The first rule is to select the range boundaries that maximize the proportion correct agreement between the visioceilometer and the human observer for the heavy density level. The heavy density level is chosen because it is considered the worst possible that can occur. Therefore we would want to know when a heavy density obscurant is present a greater percentage of the time than moderate or light. The second rule is to select the range boundaries that provide the best overall agreement between the visioceilometer and the human observer.

The range boundaries selected as a result of the first rule are listed below.

| OBSCURANT | RANGE BOUNDARIES |
|---|---|
| Hexachloroethane | Upper |
| High-explosive | Original or Lower |
| Fog Oil | Original |
| Graphite | Upper |
| Dust | Upper |
| EA5763 | Upper |
| Aluminum | Original |
| Total | Upper |

Four out of the seven obscurants selected upper range boundaries, 2 selected the original range boundaries and one used the same results for either the original or lower range boundaries. When the obscurants are combined the upper range boundaries are selected. Most of the obscurant selecting the upper range boundaries indicate that the moderate density level visibility range is longer than that identified by the original range boundaries, which also implies that the light density level is shorter. Therefore the range boundaries should be set with the upper bounds. Note, however, that for the heavier or denser obscurants, such as fog oil and aluminum, best agreement obtained is with the original range boundaries.

If the second rule, to select range boundaries based on overall agreement between the visioceilometer and the human observer, is used the results are as listed below.

| OBSCURANT | RANGE BOUNDARIES |
|---|---|
| Hexachloroethane | Upper |
| High-explosive | Original or Lower |
| Fog Oil | Original |
| Graphite | Original or Lower |
| Dust | Original or Lower |
| EA5763 | Lower |
| Aluminum | Original |
| Total | Original |

Using the second rule, the best agreement between the visioceilometer and the human observer was as follows; two selected the original range boundaries, three selected the original or lower to provide the same overall results, one selected the lower range boundaries, and one selected the upper range boundaries. Total obscurants selected the original range boundaries. All obscurants that selected the upper range boundaries for the first rule changed to another set of range boundaries for the second rule, except Hexachloroethane.

If the obscurant type is known then range boundaries can be set accordingly. Otherwise, the range boundaries that provided the best agreement between the visioceilometer and the human observer by combining the obscurants, should be used, i.e., from the test, upper or original.

## C. RESULTS OF PREVIOUS CLOUD CEILING HEIGHT TESTS

Several earlier tests were conducted utilizing the visioceilometer as a cloud ceiling height measuring device. In 1978 the first of these tests was conducted at Otis Air Force Base, MA. The first generation of the visioceilometer, was compared with the rotating beam ceilometer (RBC). These results were encouraging. However, the visioceilometer did not provide good results during rain. It had a tendency, in some cases, to indicate a cloud, when no cloud was present. The electronics and basic algorithm of the system were refined to minimize such false identifications. The second generation model of the visioceilometer was developed as a result of these refinements.

The second test of the visioceilometer as a cloud ceiling height measuring device was conducted in Meppen, Germany in 1980. This test compared the visioceilometer with a particle spectrometer carried aloft by a balloon (balloon-borne particle counter or weather balloon). The particle spectrometer is an instrument that measures cloud ceiling height by actually going into the cloud. Particle counts are taken as the balloon ascends and descends. Based on the number of particles found a determination of the cloud height is made. The visioceilometer measurement readings obtained from lidar returns of cloud height were found to be in good agreement.

In 1983 the visioceilometer was compared again with the rotating beam ceilometer in Cardington, England. The agreement between the two systems were good.

# V. CONCLUSIONS, SUMMARY AND RECOMMENDATIONS

## A. CONCLUSIONS

The intent of this thesis was to determine if the visioceilometer could provide measurements of visual range and identify the density level of obscurants and smoke clouds. Visual range was examined by investigating the agreement between the visioceilometer and the MIDAS system measurements of visual range. Density level identification was examined by comparing the visioceilometer range readings with the observation of density levels made by a human observer.

### 1. Visual Range Analysis

Overall poor agreement between the visioceilometer and the MIDAS system was found after examining the 30 smoke clouds. All obscurants displayed poor agreement. The poor agreement between the two systems could have resulted from a number of factors. The method in which the MIDAS system measurements of visual range were obtained, the height of the two systems, and the small data set used for the analysis could have adversely effected the results.

The MIDAS system measurements of visual range were obtained from the graphical representations of the smoke clouds. The MIDAS system assumed that the shapes of the smoke clouds were ellipsoidal. Computations made to obtain visual range measurements were based on this assumption. If the ellipsoidal assumption is not entirely true, then the visual range measurements computed for the MIDAS system may not be accurate, which could possibly cause the poor agreement between the two systems.

The MIDAS system range readings were computed as the linear distance to the two-dimensional projection of the [illegible] on the ground. This may differ from the range to the [illegible] of the cloud along the line of sight of the visioceilometer.

The MIDAS system averaged six and a half minutes delay in starting after the first visioceilometer measurement was made. Because of this delay, very few data points were obtained for comparing the two systems.

### [illegible] Density Level Analysis

Four range boundaries for comparing the visioceilometer and the human observer identification of density levels were examined. The range boundaries are identified as original, upper, lower, and a combination. These range boundaries were subjectively established for each density level. Based on the boundaries established, overall results for each obscurant were good. The heavy density level provided the best overall results, while the moderate density level provided the worst. The moderate density level was most difficult to set range boundaries for because it contained many overlapping measurement readings, i.e., many high and low values. The moderate comment from the observer did not appear to be very selective, relative to the visioceilometer.

The results of the analysis indicated that density level range boundaries can be set for the visioceilometer in two ways depending on the desired results. If the user is interested in obtaining the best possible agreement for the worst density level, heavy smoke, then this is found by setting upper range boundaries at heavy (0-.99), moderate (1.00-1.24), and light (greater than 1.25). On the other hand, if the user is interested in the overall results providing the best agreement between the visioceilometer and the human observer, then the original range boundaries are best.

3. Cloud Ceiling Height

The visioceilometer has demonstrated in previous cloud ceiling height tests that it can remotely measure cloud ceiling height with results in agreement with other available measuring devices. The last cloud ceiling height comparison was conducted in 1983. The result of this test was good and indicated that the visioceilometer measured cloud ceiling height equally as well as the rotating beam ceilometer system. Nothing was observed in the Smoke Week VIII test to either confirm or deny these results.

## B. SUMMARY

This thesis involved the analysis of test data to examine the use of the visioceilometer, a system of measuring obscurants as a tactical device in the battlefield. The system required for tactical use has to be light weight, rugged, simple to use and be able to remotely measure cloud ceiling height, visibility, and be able to identify the density level of an obscurant.

The test data obtained from the US Army Atmospheric Science Laboratory, White Sands Missile Range, NM, was first analyzed to investigate how the visioceilometer fared when measuring visual range as compared to the MIDAS system. The results from this analysis showed the agreement between the two systems to be poor. A number of factors were pointed out that could possibly be the cause of this poor agreement. When the visioceilometer was compared with a human observer for identifying heavy, moderate, or light density levels, the results were good. Results from previous cloud ceiling height tests have indicated that the visioceilometer may perform this function well. The overall performance of the visioceilometer as a range finding device is uncertain at the conclusion of this analysis. It is not clear whether the disagreement between the visioceilometer and the MIDAS system measurements of the range to a cloud's edge is cause for alarm or not. The MIDAS system initially appeared to be a good system to compare to the visioceilometer, but that may not be the case.

However, overall results are promising. More testing should be accomplished to obtain accurate visual range data to analyze the visioceilometer range finding capabilities.

C. RECOMMENDATION

Recommend that an in-depth test be conducted comparing the visioceilometer with another system specifically designed to measure visual range. The transmissonmeter is one such system that when compared with the visioceilometer should more accurately demonstrate its visual range measuring abilities.

Recommend that visibility range boundaries be investigated and established for identifying the density level of an obscurant. This information could be part of the visioceilometer logic algorithm allowing the quantification of an obscurant density level at a push of a button.

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