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AFGL-TR-77-0007

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ANALYSIS OF CHEMICAL SMOKE RELEASES TO
CHARACTERIZE STRATOSPHERIC / THERMOSPHERIC
WIND FIELDS

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November 1976

Final Report for Period 1 January 1976 - 1 November 1976

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AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER AFGL TR-77-0007 ✓	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER 9
4. TITLE (and Subtitle) ANALYSIS OF CHEMICAL SMOKE RELEASES TO CHARACTERIZE STRATOSPHERIC/THERMOSPHERIC WIND FIELDS. ✓	5. TYPE OF REPORT & PERIOD COVERED Final <i>rept.</i> 1 Jan 1976 - 1 Nov 1976	
7. AUTHOR(s) Sheldon B. Michaels, Jeffrey S. Morris Otis/Philbrick	6. PERFORMING ORG. REPORT NUMBER	A. CONTRACT OR GRANT NUMBER(s) F19628-76-C-0139 NEW
9. PERFORMING ORGANIZATION NAME AND ADDRESS Information Design, Inc. Civil Air Terminal Bedford, Massachusetts 01730	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 82101F 66860501 12/8p.	15. 1705 16
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory Hanscom AFB, Massachusetts 01731 Monitor/Antonio Quesada	12. REPORT DATE Nov 1976	13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified	18a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.

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

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
**Wind fields
Stratospheric measurements
Thermospheric measurements
Smoke releases
Photogrammetry**

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
New interactive computer programs were used to measure the coordinates of smoke puff centers for a series of releases (Paradise Aeolus) in the thermosphere at Fort Churchill, Canada, in April 1975. Position data for triangulation of smoke trail releases at White Sands Missile Range (Stratospheric Winds) and Wallops Island (Winter Anomaly) were also measured, digitized and recorded on magnetic tape.

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PREFACE

The authors wish to thank Dr. Antonio F. Quesada of AFGL for his guidance and helpfulness during the development, testing, and operation of the film processing procedure.

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INTRODUCTION

Studies at AFGL on the movement of chemical smoke trails and puffs utilize photographs to define the trail or puff positions as a function of time. The chemical events are photographed at regular intervals with high resolution cameras from at least two separate sites.

This report is concerned solely with the techniques used for recovering and digitizing the two-dimensional trail or puff image from the photographic films of the events. We report here work done on improving existing computer/microdensitometer techniques, on improvements which allow determination of the center and Gaussian radius of puffs, and on the trail images actually digitized using these programs.

PROGRAMMING CHANGES

Program Improvements

Problems Protracted work with existing trail digitizing programs used at Information Design's Pictorial Analysis Facility showed two deficiencies:

1. A serious problem was operator fatigue, since fatigue and resultant stress can deteriorate the data reduction process. Fatigue was thought to be due to the requirement for carefully monitoring of a cathode ray tube (CRT) presentation of alphanumeric and pictorial information. Hardware and software considerations yielded a maximum flicker rate of about four frames per second.
2. Another problem was the rigid structuring of the program. The film analysis was performed as a series of operations which were executed primarily in a predetermined order. This implied that the operator was not free to perform ancillary tests or to check judgments except in prespecified ways.

Solutions The operator fatigue problem was attacked primarily by making hardware changes. A CRT Terminal with integral memory and a programmable cursor capability was made the device on which all alphanumeric information was displayed. Because this is a flicker-free display, much more information is now available to the operator at a glance. Messages indicating cursor x and y position, last recorded position, tracking limits, filter settings, and available program function instructions are now available at all times. Pictorial information is now supplied by a CRT controller which incorporates a bit-oriented instruction set. This makes it possible to display eight picture elements in the time formerly required to display one pixel.

The program has now been restructured in such a way that any subroutine can be called from any other subroutine. This allows the operator greater flexibility to make cross-checks, detailed examination of scanning areas, and so forth. Any errors he might make, such as scanning an area that doesn't include the entire smoke trail, can now be easily remedied by re-performing the required subroutine. Each subroutine presents its available set of function options on the alphanumeric CRT, and the operator selects among these with sixteen microswitch pushbuttons.

Results The only objective measure of the effect of these improvements would be a comparison of data reduction accuracy both before and after the changes. This comparison is not available. Subjectively, however, the results are dramatic. The operator now reports very little fatigue. The data reduction task has become much less stressful because error checks can easily be made, and ambiguous areas of trail pictures can be scanned at higher than normal magnification for more detailed analysis.

One non-programming consideration which has proved very useful is the preparation by AFGL of photographic prints of each of the films. These have proved useful during the course of making decisions about trail ambiguities in the areas of trail self-intersections.

Program additions

Requirements The repertoire of available subroutines in the analysis program has been expanded in order to accommodate smoke puff images. These images are diffuse in character and of an approximately elliptical shape. Their density cross-sections should be approximately Gaussian. The position of the center of the puff is of importance for determining wind velocities, while the Gaussian radius is related to diffusion characteristics.

Shape handling The diffuse, elliptical shapes have been accommodated by allowing the operator to scan rectangular areas of any desired aspect ratio. He controls the position, height, and width of a rectangular box displayed superimposed in the image of the entire frame. For each puff scanned, the box is adjusted to completely enclose the desired puff.

Centering Determining the center of puffs has been accomplished by defining the center to be the center-of-mass of the puff image. By "mass", of course, we mean the optical density of the image elements. To exclude neighboring images such as foreground objects, dust specks, streaks, adjacent puffs, etc. from the centroid computations, a medial axis transform (MAT) and inverse MAT have been implemented. These techniques allow the operator to

construct a mask which completely encloses large images, while totally excluding smaller images. See the Bibliography for references to a more detailed description of the MAT technique.

After using the MAT to isolate the puff, minimum optical density is found, assumed to be a background level, and is therefore subtracted from all remaining MAT-masked densities. These densities are now used to mathematically weight the corresponding x, y coordinates of each point within the masked area. The weighted average of the mask defines the centroid.

Limited experiments using a typical puff film have shown that even very large differences in MAT mask size yield small differences in resultant calculated centroid. Consistency on the order of plus-or-minus 50 to 100 microns has been observed for puffs of several millimeters image size. We may infer that the output consistency despite input variability indicates a high degree of accuracy.

Gaussian radius After the operator has determined the center of a puff, a major axis and a perpendicular minor axis are displayed superimposed on the puff image. Digital knobs can then be rotated to align these axes with the puff orientation as judged by the operator. As the axes are rotated, the program calculates the approximate Gaussian radius for both axes and displays these on the alphanumeric CRT. Simultaneously, axis density cross-sections are displayed pictorially. The radius is found by first determining the total area under the cross-section profile, minus background density, along the axis. Then, starting at the center, successive points on both sides of the center are added until the integrated area is $1 - 1/e$ times the total area. This is the Gaussian diameter, and is divided by two to yield the radius. Although this is an inelegant method, it has the advantage of being computationally rapid and thus allows real-time display of the results. Care has been taken to maintain spatial relationships properly, despite the differing distances between rectilinear raster elements during axis rotation.

PHOTOGRAPHIC ANALYSIS

For all events, at all sites, films were aligned on the scanner so that a line connecting a pair of points chosen on fiducials on opposite sides of the frame would be orthogonal with the axis of the scanner drum to a tolerance of 100 microns over the width of the frame.

Films processed and digitized for smoke trail triangulations are tabulated in the following table. Resolution on each frame was variable at the operator's discretion between 25 and 50 microns raster.

Name	Frames Processed
Project Paradise Aeolus	136
Winter Anomaly Program	19
July 1976 Stratospheric Trail	14

Trails, puffs, and starcals were sometimes taken from single films, and all data were submitted in the form of magnetic tapes in CDC-6600 compatible format.

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