WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

REFERENCE NO. 66-50

DATA REDUCTION OF STORMFURY 1965 CLOUD OBSERVATIONS MADE FROM RESEARCH FLIGHT FACILITY AIRCRAFT

by

Joseph Levine

September 1966

FINAL REPORT

Submitted to Environmental Science Administration under Contract CWB 11255.

Approved for Distribution ______________________

Claes G. H. Rooth
Assistant Chairman

ABSTRACT

An outline of work done at the Woods Hole Oceanographic Institution with National Science Foundation support since 1963 on cumulus convection as related to larger scale atmospheric motions is given.

In addition a preliminary analysis of the meso-scale wind field as derived from aircraft Doppler wind observations taken during one day of the Stormfury 1965 operation is described. Such facts as scale and magnitude of meso-scale divergence and vertical velocity in the trades are inferred.

INTRODUCTION

Inasmuch as the atmosphere is an extremely complex physical system, we must lean heavily on observations as well as theory in endeavoring to understand its behavior. In keeping with this notion, the study of cumulus convection in the context of the atmosphere's larger scales of motion was started with a field trip during August 1963 based at Barbados.

Furthermore, since the atmosphere is so large a system and requires the observation of so many different physical quantities, comprehensive data coverage can only be achieved by the collaboration of many people and the use of considerable equipment. Therefore, in pursuing my work, I have tried to work with other people doing field work on an informal basis. In return for my cooperation, I have expected the people that I work for or with to supply me with supplementary information and assistance. By not becoming involved with the management of large numbers of people and large equipment such as aircraft, I am left free to think about the scientific details.

In particular, since August 1963, I have been doing field work under the supervision of Dr. Joanne Simpson, who has permitted me considerable latitude in the conduct of my work. For the August 1963 field trip to Barbados, I handled the details of preparing the Woods Hole Oceanographic Institution's C-54 and then took part in the observational work. During this field trip, we did some limited multiple aircraft work with the Weather Bureau's Research Flight Facility DC-6's. Because of the heavy work load, I was only able to analyze our own data. Also, the time available for preparing the C-54 was too limited to insure proper operation of all the instruments.

The data obtained during the Barbados expedition with the C-54 was combined with data obtained earlier with the C-47. Ever since I came to Woods Hole, I have been apalled by the stupefying amount of routine data reduction required after a field trip; and concurrently, I have always looked for ways to avoid it. The digital computer supplied a way to do it. Since all of these data were in the form of analogue records, I wasn't able to take full advantage of it. However, I did learn to use a digital computer in the process of analyzing the above data for the observational part of my Ph. D. thesis (1965).

Immediately after completion of my Ph. D. work, I took part in the Stormfury 1965 expedition also under Dr. Joanne Simpson's supervision. For this field trip we managed to have my hot wire instrument system installed on both the ESSA Research Flight Facility DC-6's. On this field trip, we were able for the first time to approach the desired comprehensive data coverage. The outputs from my cloud instrument, a vertical accelerometer, and the Rosemount instrument were recorded on oscillograph recorders. Pressure, altitude, pitch, roll, air speed, water vapor content, and vortex thermometer temperature were recorded on magnetic tape at one second intervals.

Handling such large masses of data by hand becomes so impossible a chore that one is forced to use a digital computer. Here my previous experience with the computer came in handy, but we were still faced with the problem of combining the oscillograph records with the magnetic tape data. A Benson-Lehner machine for converting analogue records to punched cards, available at Woods Hole, was used to digitize the records. Magnetic tapes compatible with the GE-225 and Fortran derived from the aircraft magnetic tapes were kindly supplied by the National Hurricane Research Laboratories. A program for combining the punched cards and magnetic tape data on a single tape was made. Then a program for computing the important cloud variables such as liquid water, content, volume median, drop diameter, and turbulent vertical velocity was made up to put the results on a final magnetic tape, from which a hierarchy of interpretative computations may be programed.

2. Some preliminary analysis of the Stormfury 1965 Doppler wind data.

A crucial aspect of the study of cumulus cloud interaction with larger scales of motion is observation of the wind field. An important incentive for joining forces with the ESSA Research Flight Facility was their Doppler wind system and their digital tape recording equipment. With their help we were able to observe the winds and other large scale variables along with the small scale cloud variables. Thus with these observations it is now possible to evaluate momentum, heat, and water vapor exchange with the large scale wind field. Also, the details of cloud motions and cloud liquid water content may be related to the meso-and synoptic scale horizontal divergence fields of motion and water vapor transport.

Since the Doppler wind system is a relatively new device, its precision limitations are not yet known. Actually, neither are the accuracies of the other aircraft instruments too well known. However, as these instruments are used in the field, their characteristics will become apparent. Some idea of wind accuracy may be obtained by seeing how reasonable the wind field looks.

Since winds and the other observations were recorded at intervals of 10 seconds or 1 second on the magnetic tape, the data are much too dense to be plotted unless spot samples or averages over a specified time interval are taken. Spot samples are not satisfactory, because errors or turbulent fluctuations tend to obscure the larger scale structure.

Fortunately, with the data on tape, it is easy to perform an averaging or smoothing process with a digital computer. For synoptic scale features the data were averaged at 1000 second intervals which yielded observations at intervals of 100 km of flight path. For meso-scale features, a 200 second interval (20 km distance) was found to be satisfactory. To eliminate periods with excessive flight path curvature intervals with a straight line distance between end points less than .7 of the maximum possible straight line distance were omitted. Thus, the best possible Doppler winds were used since the Doppler navigation system doesn't function too well during sharp turns.

Detailed consideration of the synoptic scale data has been deferred until a later date when Rawin and Pibal observations will be available, but the west to east (u) and south to north (v) meso-scale wind components have been plotted. In order to show meso-scale circulation features, I assumed as a first guess that they were probably being advected with the strong easterly current. Therefore, I established 1600Z as the reference time and moved each observation a distance equal to its time difference times the average over both levels of the easterly current velocity.

The results are given in figures 1 and 2 for August 5, 1966 at the 10,000 and 20,000 foot levels. Lines of equal u component (solid lines) and equal v component (dashed lines) have been drawn at intervals of 1 knot.

Some notion of the wind component accuracy may be inferred from paired values very close together in space and time (20 kilometers and 3 minutes, respectively). Several of them are contained in Table I.

Table 1

Paired values of 200 second averages of (u,v) near each other in space and time

At 10,000'	At 20,000'
(-8.4, 2.2), (-8.6, 2.7)	(-13.1, -1.1), (-1k.4, -1.1)
(-10.2, 1.9), (-8.7, 1.7)	(-16.3, -1.4), (-9.9, -.8)
(-7.8, .3), (-10.8, -.4)	(-8.0, -.7), (-13.7, -1.1)
(-12.5, -.6), (-10.1, -1.3)	(-10.6, -.9), (-12.8, -1.1)

An attempt to plot the wind field around a cloud at the 10,000' level showed a fictitious drift of a .1 of a degree in position between the first and last cloud run. Therefore, this work was temporarily abandoned. It is possible that by proper corrections something could be gleaned from the winds and related to a particular cloud grove or line.

There is no obviously distinct relation of the patterns at the two levels. There are two distinct maxima and one minimum in the easterly wind component at the 10,000' level. At the 20,000' level there is one distinct maximum and two minima in the easterly wind component. A case could be made for minima at the 20,000' level matching roughly the maxima at the 10,000' level. Then regions of divergence at one level roughly tend to match regions of convergence at the other.

The horizontal scale of separation of maxima and minima is about 150 km. The distance over which the easterly wind component slows down or speeds up is therefore about 75 km. In a region of convergence at the 10,000' level centered roughly at latitude 14. 6 and longitude 65. 4W the velocity difference is 3 knots, so that the convergence is about 2×10^{-5} sec.$^{-1}$ At the 20,000' level a center of divergence at about latitude 14. 8 and longitude 65. 7W has an easterly velocity component difference of 9 knots or a divergence of 6×10^{-5} sec.$^{-1}$. The corresponding estimated magnitudes of the vertical velocities are 6 and -36 cm sec.$^{-1}$, respectively, if these convergent and divergent circulations extend down to the surface. However, the divergence could be associated with the convergence at the lower level, which could be indicative of a much smaller negative or even positive vertical velocity at 20,000'.

In conclusion the above results appear encouraging enough to justify more work with the Stormfury 1965 data. Also a case can now be made for more systematic flight patterns covering regions of the tropics to establish the synoptic and meso-scale wind field because the data analyzed here were only obtained incidentally in the course of looking for seedable clouds.

The relation of the cloud and wind data is yet to be done. The details of the cloud data reduction are covered in my final report to ESSA (1966). There is also the possibility of relating the cloud fields as given in aircraft and satellite cloud photographs.

3. Publications.

A brief article on "Cloud Physics" has been published in the "Encyclopedia of Physics" edited by Besancon (1966). I have submitted two papers to the Journal of Atmospheric Sciences based on Parts II and III of my Ph.D. thesis (1965). One of these papers has been returned for revision and the other is still being reviewed.

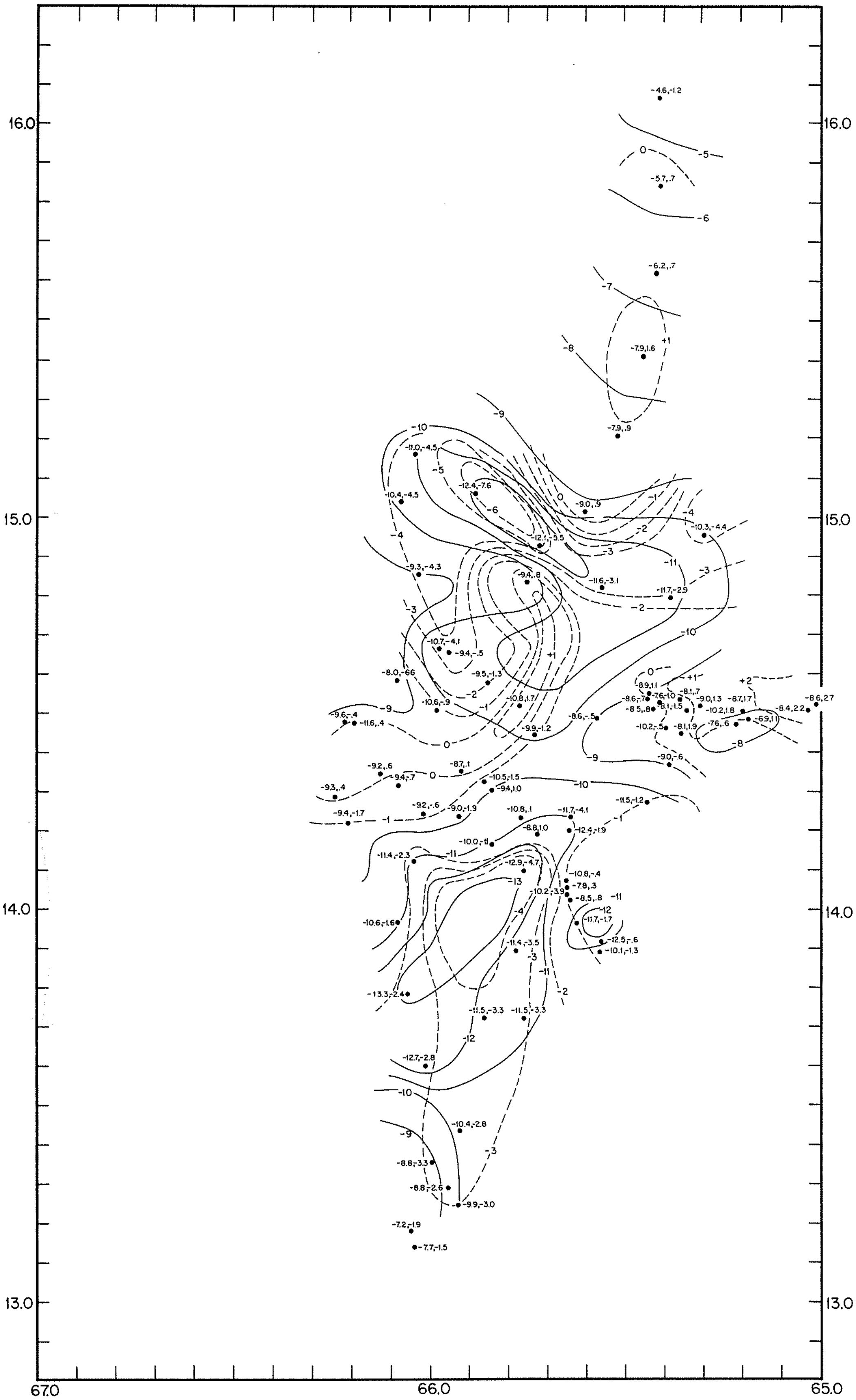

Figure 1. Mesoscale circulations at 10,000' at 16$\underline{00}$Z August 5, 1965.

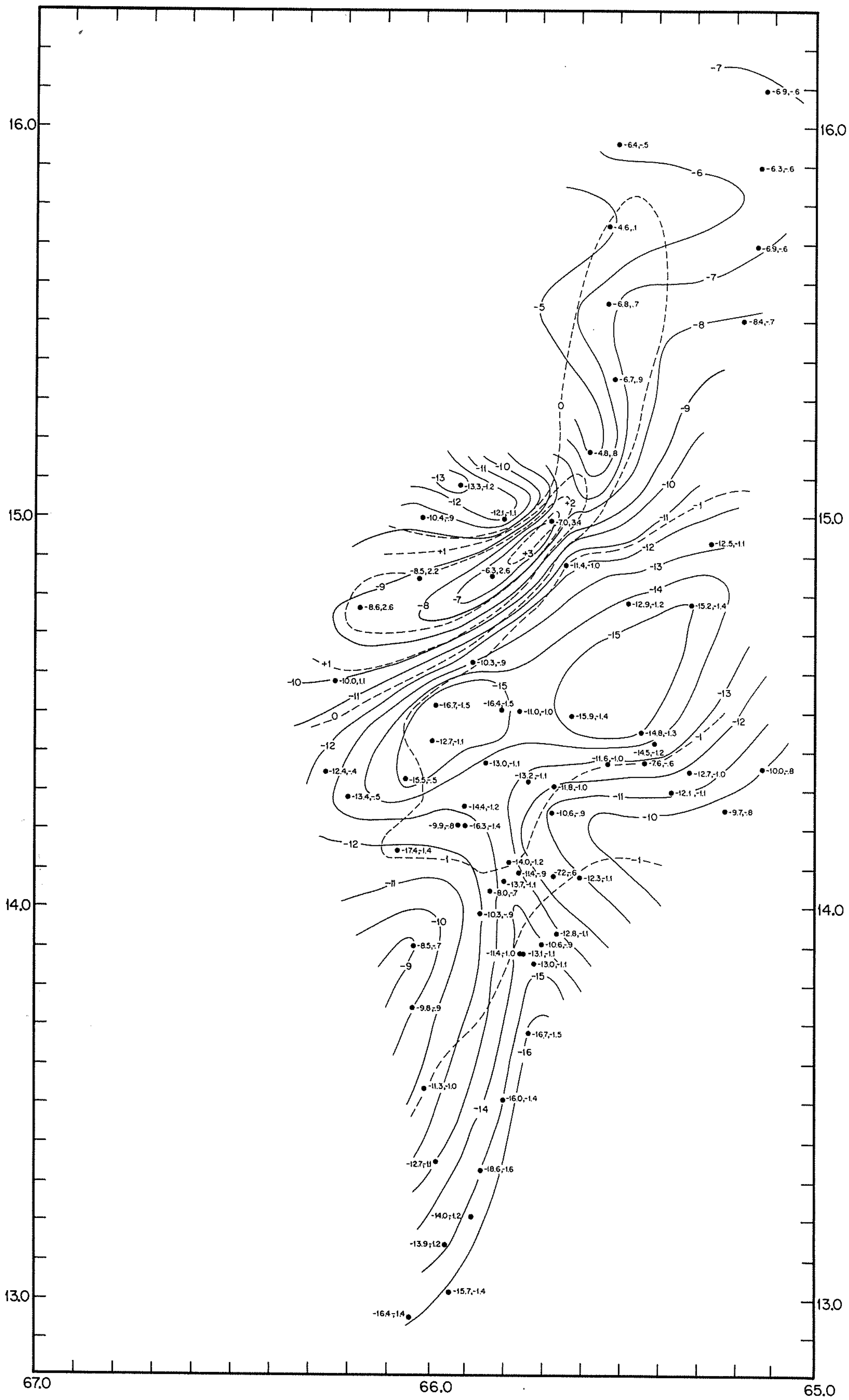

Figure 2. Mesoscale circulations at 20,000' at 16$\underline{00}$ Z August 5, 1965.

REFERENCES

Levine, J., 1966: Data reduction of Stormfury 1965 cloud observations made from Research Flight Facility aircraft. Woods Hole Oceanographic Institution, unpublished manuscript, Reference No.

ACKNOWLEDGEMENTS

The observational basis of my work would not have been possible if Dr. Joanne Simpson had not made my participation in Stormfury 1965 possible. I am also indebted to the personnel of the National Hurricane Research Laboratory who made data on magnetic tape available to me in the proper format. We also succeeded in getting good complete cloud data because of the extensive cooperation of Dr. Gerry Conrad and the ESSA Research Flight Facility.

No. of Copies	Addressee
1	Director, U. S. Naval Weather Service Office of the U. S. Naval Weather Service Washington Navy Yard Washington, D. C. 20390
1	Officer in Charge U. S. Navy Weather Research Facility U. S. Naval Air Station Norfolk, Virginia 23511
1	Officer in Charge U. S. Fleet Weather Facility U. S. Naval Air Station, North Island San Diego, California 92135
1	Commanding Officer U. S. Naval Air Development Center NADC Library Johnsville, Pennsylvania 1874
2	Department of Meteorology & Oceanography U. S. Naval Postgraduate School Monterey, California 93940
2	Officer in Charge Fleet Numerical Weather Facility U. S. Naval Postgraduate School Monterey, California 93940

AIR FORCE

1	ARCRL (CRZF) L. G. Hanscom Field Bedford, Massachusetts

ARMY

1	Army Research Office Environmental Sciences Division Washington, D. C.

OTHER U. S. GOVERNMENT AGENCIES

20	Defense Documentation Center Cameron Station Alexandria, Virginia 22314

No. of Copies	Addressee
1	National Research Council Committee on Oceanography 2101 Constitution Avenue, N. W. Washington, D. C.
1	Director of Meteorological Research U. S. Weather Bureau Washington, D. C.
1	Director Coast & Geodetic Survey Office of Oceanography U. S. Department of Commerce Washington, D. C.
2	Library, U. S. Weather Bureau Washington, D. C.
1	Chief, Marine Science Center Coast & Geodetic Survey U. S. Department of Commerce Lake Union Base 1801 Fairview Avenue East Seattle, Washington 98102

RESEARCH LABORATORIES

2	Director Woods Hole Oceanographic Institution Woods Hole, Massachusetts 02543
3	ONR Scientific Liaison Officer Woods Hole Oceanographic Institution Woods Hole, Massachusetts 02543
1	Library Narragansett Marine Laboratory University of Rhode Island Kingston, Rhode Island
1	Bingham Oceanographic Laboratories Yale University New Haven, Connecticut
1	Gulf Coast Research Laboratory Librarian Ocean Springs, Mississippi

No. of Copies	Addressee
1	Chairman, Department of Meteorology & Oceanography New York University New York, New York
1	Library Lamont Geological Observatory Columbia University Palisades, New York 10964
1	Director Hudson Laboratories 145 Palisade Street Dobbs Ferry, New York
1	Great Lakes Research Division Institute of Science & Technology University of Michigan Ann Arbor, Michigan
1	Director Chesapeak Bay Institute Johns Hopkins University 121 Maryland Hall Baltimore, Maryland
1	Director, Marine Laboratory University of Miami #1 Rickenbacker Causeway Miami, Florida 33149
2	Head, Department of Oceanography & Meteorology Texas A & M University College Station, Texas
1	Director Scripps Institution of Oceanography La Jolla, California
1	Head, Department of Oceanography Oregon State University Corvallis, Oregon
1	Head, Department of Oceanography University of Washington Seattle, Washington

No. of Copies	Addressee
1	Director Hawaiian Marine Laboratory University of Hawaii Honolulu, Hawaii
1	Department of Engineering University of California Berkeley, California
1	Applied Physics Laboratory University of Washington 1013 NE Fortieth Street Seattle, Washington
1	Documents Division - ml University of Illinois Library Urbana, Illinois
1	Director Ocean Research Institute University of Tokyo Tokyo, Japan
1	Central Library Lockheed-California Company Dept. 72-25, Bldg. 63-1, Plant A-1 Burbank, California
1	New Zealand Oceanographic Institute Department of Scientific and Industri[al] Research Librarian P. O. Box 8009 Wellington, New Zealand
1	Institue of Geophysics University of Hawaii Honolulu, Hawaii
1	Division of Engineering & Applied Phys[ics] Harvard University Cambridge, Massachusetts 02138
1	Howell Associates Hanscom Field Terminal Bedford, Massachusetts

No. of Copies	Addressee
1	Dr. Gerry Conrad Research Flight Facility P. O. Box 2235 Airport Station Miami, Florida 33159
2	Prof. Roscoe R. Branham, Jr. Department of the Geophysical Sciences University of Chicago Chicago 37, Illinois
2	Dr. Cecil Gentry National Hurricane Research Laboratory P. O. Box 8265 Miami, Florida 33124
2	Mr. Jack Warner CSIRO, Division of Radiophysics University Grounds Sydney, N. S. W. Australia
1	Prof. Michael Garstang Department of Meteorology Florida State University Tallahassee, Florida
1	Prof. Charles L. Hosler Department of Meteorology Pennsylvania State University 322 Mineral Industries Bldg. University Park, Pennsylvania
1	Dr. Charles E. Anderson Office of Federal Coordinator for Meteorological Services and Supporting Research 1666 Connecticut Avenue, N. W. Washington, D. C.
1	Prof. Morris Neiburger Department of Meteorology University of California Los Angeles, California
2	Mr. Bennett (FDTR) Air Force Flight Dynamics Laboratory Wright Patterson Air Force Base Ohio 45433

No. of Copies	
1	Prof. Charles L. Jordan Department of Meteorology Florida State University Tallahassee, Florida
1	Prof. Wendell A. Mordy Desert Research Institute University of Nevada Reno, Nevada 89507
1	Mr. Paul B. MacCready, Jr. Meteorology Research, Inc. 2420 N. Lake Avenue Altadena, California
1	Dr. Robert M. Cunningham Air Force Cambridge Research Laboratories L. G. Hanscom Field Bedford, Massachusetts
1	Prof. B. J. Mason Department of Physics Imperial College of Science and Technology 10 Princes Gardens London S. W. 7, England
1	Prof. Louis J. Battan Institute of Atmospheric Physics University of Arizona Tucson, Arizona
1	Prof. H. G. Houghton Meteorology Department Massachusetts Institute of Technology Cambridge, Massachusetts 02139
1	Dr. Sigmund Fritz Meteorological Satellite Laboratory U. S. Weather Bureau ESSA Washington 25, D. C.
1	Prof. Frank H. Ludlam Department of Meteorology Imperial College of Science and Technology London S. W. 7, England

No. of Copies	Addressee
1	Dr. Patrick Squires Laboratory of Atmospheric Sciences NCAR Boulder, Colorado
1	Dr. Douglas K. Lilly Laboratory of Atmospheric Sciences NCAR Boulder, Colorado
1	Prof. Yoshimitsu Ogura Ocean Research Institute University of Tokyo Nakano-Ku Tokyo, Japan
1	Mr. Clement J. Todd U. S. Navy Weather Research Facility Naval Air Stations, Bldg. R-48 Norfolk, Virginia
1	Mr. Walter Hitschfield Department of Meteorology McGill University Montreal 2, Canada
1	Library National Center for Atmospheric Research Boulder, Colorado
6	Dr. Joanne Simpson Experimental Meteorological Branch ESSA 8060 13th Street Silver Spring, Md. 20910
1	Dr. Fred D. White National Science Foundation Washington, D. C.

Woods Hole Oceanographic Institution
Reference No. 66-50

DATA REDUCTION OF STROMFURY 1965 CLOUD OBSERVATIONS MADE FROM RESEARCH FLIGHT FACILITY AIRCRAFT by Joseph Levine. 14 pp. September 1966. Contract No. CWB 11255.

The data reduction procedures used on the observations obtained from the ESSA Research Flight Facility aircraft during the Stormfury 1965 operation is described. The results to be obtained eventually are cloud liquid water content, volume median drop size, turbulent vertical velocity, and buoyancy fluctuations in cloud passes made by the aircraft.

1. Clouds cumulus, trade winds
2. Liquid water in clouds
3. Drop size in clouds
4. Turbulent vertical velocity in clouds
5. Buoyancy fluctuations in clouds

I. Levine, Joseph

II. CWB 11255

This card is UNCLASSIFIED

Woods Hole Oceanographic Institution
Reference No. 66-50

DATA REDUCTION OF STROMFURY 1965 CLOUD OBSERVATIONS MADE FROM RESEARCH FLIGHT FACILITY AIRCRAFT by Joseph Levine. 14 pp. September 1966. Contract No. CWB 11255.

The data reduction procedures used on the observations obtained from the ESSA Research Flight Facility aircraft during the Stormfury 1965 operation is described. The results to be obtained eventually are cloud liquid water content, volume median drop size, turbulent vertical velocity, and buoyancy fluctuations in cloud passes made by the aircraft.

1. Clouds cumulus, trade winds
2. Liquid water in clouds
3. Drop size in clouds
4. Turbulent vertical velocity in clouds
5. Buoyancy fluctuations in clouds

I. Levine, Joseph

II. CWB 11255

This card is UNCLASSIFIED

Woods Hole Oceanographic Institution
Reference No. 66-50

DATA REDUCTION OF STROMFURY 1965 CLOUD OBSERVATIONS MADE FROM RESEARCH FLIGHT FACILITY AIRCRAFT by Joseph Levine. 14 pp. September 1966. Contract No. CWB 11255.

The data reduction procedures used on the observations obtained from the ESSA Research Flight Facility aircraft during the Stormfury 1965 operation is described. The results to be obtained eventually are cloud liquid water content, volume median drop size, turbulent vertical velocity, and buoyancy fluctuations in cloud passes made by the aircraft.

1. Clouds cumulus, trade winds
2. Liquid water in clouds
3. Drop size in clouds
4. Turbulent vertical velocity in clouds
5. Buoyancy fluctuations in clouds

I. Levine, Joseph

II. CWB 11255

This card is UNCLASSIFIED

Woods Hole Oceanographic Institution
Reference No. 66-50

DATA REDUCTION OF STROMFURY 1965 CLOUD OBSERVATIONS MADE FROM RESEARCH FLIGHT FACILITY AIRCRAFT by Joseph Levine. 14 pp. September 1966. Contract No. CWB 11255.

The data reduction procedures used on the observations obtained from the ESSA Research Flight Facility aircraft during the Stormfury 1965 operation is described. The results to be obtained eventually are cloud liquid water content, volume median drop size, turbulent vertical velocity, and buoyancy fluctuations in cloud passes made by the aircraft.

1. Clouds cumulus, trade winds
2. Liquid water in clouds
3. Drop size in clouds
4. Turbulent vertical velocity in clouds
5. Buoyancy fluctuations in clouds

I. Levine, Joseph

II. CWB 11255

This card is UNCLASSIFIED