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STORMY WEATHER RESEARCH

# PRECIPITATION STUDIES BY RADAR AND OTHER TECHNIQUES


**J. S. Marshall**

McGILL UNIVERSITY
STORMY WEATHER GROUP


## FINAL REPORT

**January 1962 to August 1965**


Contract No. AF 19(628)-249
Project No. 8620
Task No. 862004


**OCTOBER 1965**


Prepared for
Air Force Cambridge Research Laboratories
Office of Aerospace Research
United States Air Force
Bedford, Massachusetts

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ABSTRACT

This Final Report covers the period January 1962 to August 1965. In this period the first study of profiles derived from the stepped grey scale radar maps was completed. The profiles, which are plots of the distribution of area and/or flux of precipitation with intensity as a function of height for a total area of 20,000 $nmi^2$, give useful data for relation to synoptic meteorology. The results of measurements of snowfall rate by measuring depth increments on the ground by optical attenuation in the falling snow are reported.

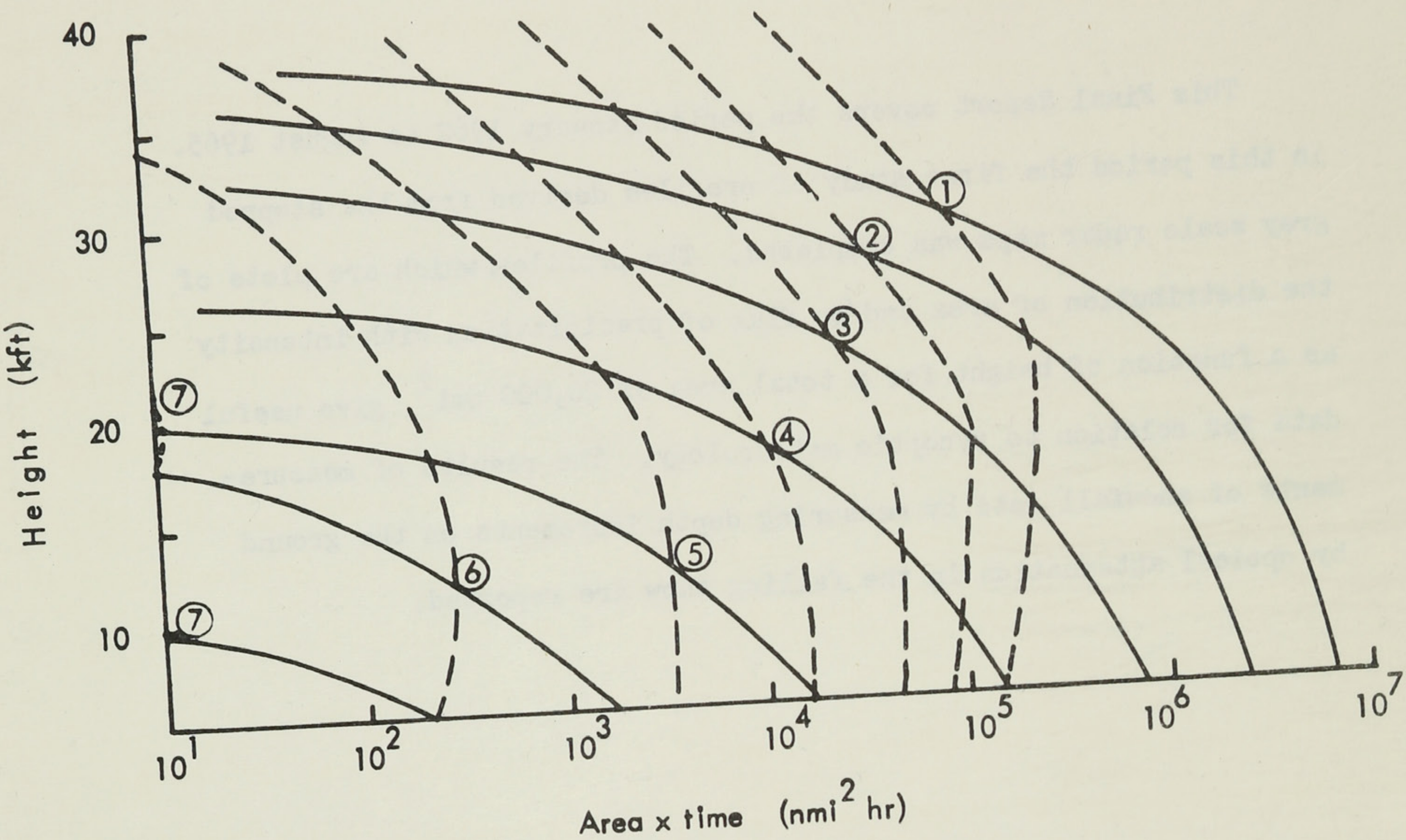


Figure 1: The variation of area x hours with height for sets of maps in which precipitation reached 40 kft (broken lines) and those in which it did not (solid lines). In the broken lines, area x time remains constant or increases slightly with height up to 15 or 20 kft, then decreases gradually up to the top of the diagram. In this they resemble similar single-time "profiles" for items of severe weather (Hamilton, MW-37). The solid line curves that do not go to 40 kft (the much more usual case at Montreal) drop back with increasing height, and so resemble single-time profiles for situations without severe storms.

# PRECIPITATION STUDIES BY RADAR AND OTHER TECHNIQUES

The first major use of CAPPI records for research has been through "profiles". From a CAPPI map at a given height the area of precipitation is obtained, and its distribution with target-intensity, for an area of 20,000 nmi$^2$ centered on the radar. The process is repeated at several heights; then by interpolation this distribution for a large area in plan is obtained as a function of height. Advantages: (i) Variations due to wind-shear are averaged out, so that (notably for the small updraughts of continuous precipitation) the enhancement of precipitation with distance fallen can be studied. (ii) A summer precipitation pattern contains individual showers at various rates of development, each with its own meso-meteorological circulation. Summation over areas large compared with individual showers and their areas of influence should make it possible to relate the shower activity to the circulation on a synoptic scale.

Item (i) is only now being exploited, but possibilities under (ii) have been demonstrated amply by Hamilton (MW-37). (An operational device for effecting the summations is ready for use now; all work to date has depended on a temporary system.)

Hamilton found (quoting from the abstract to MW-37) that "Profiles for summer shower situations commonly show an accumulation of precipitation aloft. Its height is observed to increase with the available energy of convection. This observation has been combined with calculations by other researchers to give a three-fold relation among mean updraught speed, height of accumulation and energy of convection. Profiles for continuous rain are quite distinct from those of showers, generally showing the greatest amount of precipitation at the base of the storm".

Summations over an area of 20,000 nmi$^2$ give data for relation to synoptic meteorology, and average over several meso-scale systems. It appears possible to single out individual meso-scale systems and to obtain profiles for them

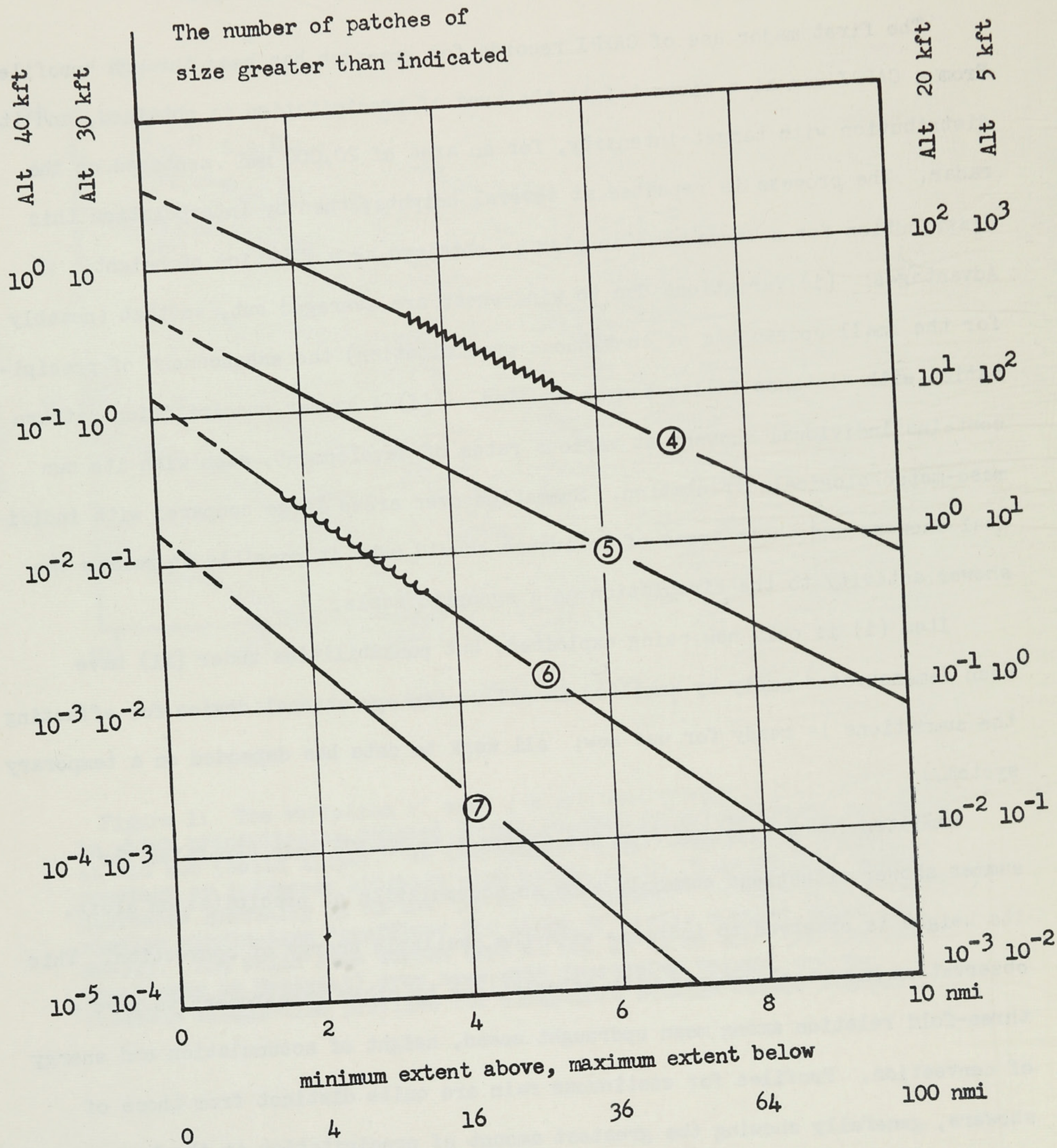


Figure 2: The number of patches Y larger than given size (X) as viewed by a pilot flying in a corridor of width 100 nmi for a total distance of $10^6$ nmi, in summer weather. It is assumed that the climate throughout is equivalent to that of Montreal. The encircled numbers denote radar thresholds. For storm avoidance they might be interpreted as follows: 4 weak 5 moderate 6 strong 7 extreme.

individually; this possibility is being exploited now.

In MW-48* summation was extended, from 20,000 $nmi^2$ at one instant to 20,000 $nmi^2$ over a whole summer season (Figure 1). Occasions when echo extended above 40,000 ft show considerably more evidence of storage aloft (at about 20,000 ft) than the remaining storms of the summer.

Report MW-48 also studied the size and shape of patches (intensity-contours of individual storms), and Figure 2 summarizes this study. The dual scales of abscissae indicate how shape varies with size, the ratio of max to min extent equalling the min extent in miles. The multiple ordinate scales imply that the distribution of patches with size is roughly the same at all heights, and only the total number and area vary with height.

Work in cloud physics under other auspices has been reported throughout the contract. With support from the National Research Council, extensive studies of new-fallen snow were made (MW-44). The primary purpose was to obtain rate-of-snowfall data, and to develop techniques therefore. The following paragraphs in quotes are from Gunn's abstract:

"The rate of accumulation of snow at the ground has been recorded by photographing the snow surface against a wire grid. The records have provided useful data about amounts and rates of snowfall at Montreal. Of 101 snowstorms considered, half deposited less than 2 mm of water (mmw). During a winter there are only half a dozen storms that deposit more than 10 mmw (4 inches of snow). Half the amount of snow in a season comes at rates of 1.2 mmw $hr^{-1}$ and less. The highest rate measured in two winters was 7.4 mmw $hr^{-1}$ over a period of one-half hour.

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* Report MW-48 was a report to the Air Transport Association during the period when our Air Force Contracts had been extended without additional funds. Part II of this report applies itself to the ATA problem; Part I producing prerequisite meteorological information has broader relevance, and on account of it the report will be distributed in some form to the addresses that normally receive our MW-reports.

"The snow surface is continually subsiding at a rate generally less than 1 mm of snow per hour. The subsidence is due to the compacting of the snow cover presumably as the crystals become modified in their new environment. The rate of compacting of any layer in the new snow is found to be about 1 per cent per hour, independent of the snow density.

"Many measurements of the snowfall rate R and the average mass per crystal $\bar{m}$ have provided values of $R/\bar{m}$, the number of snow crystals reaching unit area of of the surface per unit time. A typical number is 1 per $cm^2$ per sec. Over a whole season's data, the flux is proportional to the snowfall rate. Specifically, two thirds of the measurements lie within a factor two of a locus $R/\bar{m}$ $(cm^{-2}\ sec^{-1}) = 1.5\ R^{1.0}$ where R is in mmw $hr^{-1}$."

Further steps toward measuring rate of snowfall have been taken. Heated rain-gauges and the measurement of wide-angle scattering of light by falling snow will be reported late this year (MW-45), although the work has been going on for several years. The most likely way to measure snowfall rate, we think, is by optical attenuation, as was done by Lillesaeter (MW-43), whose abstract follows. (Lillesaeter's work was our serious attempt to make use of lasers. We never did use them, but we did learn about snow, and our techniques are readily adaptable to lasers.)

"A pulsed light has been used in a conventional optical system with a nearly-parallel beam of light: divergence less than 0.1°. Attenuation measurements over a 123-m path were made in Montreal in the early months of 1964. Attenuation by falling snow appeared to be proportional to the rate of snowfall, and is obviously proportional to distance. The value found was approximately 18 (db $km^{-1}$)/(mmw $hr^{-1}$), using mmw to denote the millimetres of water to which the snow would melt. This value dropped from 18 to 10 for wet snow and snow pellets. Attenuation by rain was only 0.25 (db $km^{-1}$)/(mmw $hr^{-1}$). Observed visual

range in snow varied inversely as the rate of snowfall, and was 1 km when the rate was 1 mmw $hr^{-1}$."

The freezing of raindrop-sized water samples has been under observation in the laboratory (MW-41).

"The dependence of heterogeneous nucleation of supercooled water drops on temperature and the duration of supercooling has been studied. The rain-sized drops were placed on an oiled aluminium surface and thermoelectric refrigeration was used to provide constant cooling-rates and to maintain constant temperatures. Once-distilled tap-water and melted snow and hail were investigated. Only the first two of these showed definite time-dependent properties.

"The experimental results are inconsistent with the hypothesis that all drops have equal probability of nucleation (stochastic hypothesis), and also with the hypothesis that the freezing temperature of a drop is the characteristic temperature of one of the impurities contained in the drop ("singular" hypothesis). The results can be explained if the existence of a variety of nuclei is recognized, each of which is most likely to cause nucleation in a different range of temperatures, and if the nucleation probability associated with each impurity is a function of the temperature of the sample."

The Alberta Hail Studies have been the subject of scientific reports MW-36, MW-38 and MW-42. These combine data-analysis with theoretical syntheses. The unique observational contribution relates to the distribution with size of hailstones arriving at the ground. On the theoretical side, our concept of a great concentration of rainwater aloft, resulting from a rough balance between fallspeed and updraught-speed, increasing until it kills the updraught or generates faster-falling hailstones or does both, seems to be gaining some measure of respect nowadays.

# P E R S O N N E L

The work summarized in this report has involved the following scientists and engineers:

| | | |
|---|---|---|
| J.S. Marshall | Project Director | 1/6-time |
| K.L.S. Gunn | Physicist | 1/10-time (on leave 64-65) |
| W. Hitschfeld | Physicist | 1/12-time |
| E.J. Stansbury | Physicist | 1/12-time |
| O. Lillesaeter | Physicist | NRC Post-doctoral Fellow (63-64) |
| P. Hamilton | Research Asst. | 2/3-time |
| G. Vali | Research Asst. | 3/4-time |
| M. Weiss (Miss) | Research Asst. | 1/2-time (64-65) |

Funds from the contract have also contributed to the support of scientific and secretarial assistants.

SCIENTIFIC REPORTS OF THE PRESENT SERIES

MW-1: Effect of particle shape and secondary scattering on microwave reflections from clouds and precipitation, by Milton Kerker and Walter Hitschfeld, March 1951.

MW-2: Measurement of snow parameters by microwaves, by J.S. Marshall and K.L.S. Gunn, May 1951.

MW-3: The modification of rain with distance fallen, by E. Caroline Rigby and J.S. Marshall, January 1952.

MW-4: Interpretation of the fluctuating echo from randomly distributed scatterers: Part I, by J.S. Marshall and Walter Hitschfeld, October 1951.

MW-5: Scattering and absorption of microwaves by a melting ice sphere, by M.P. Langleben and K.L.S. Gunn, March 1952.

MW-6: Interpretation of the fluctuating echo from randomly distributed scatterers: Part II, by P.R. Wallace, December 1951.

MW-7: The microwave properties of precipitation particles, by J.S. Marshall, T.W.R. East and K.L.S. Gunn, July 1952.

MW-8: Precipitation trajectories and patterns, by J.S. Marshall, M.P. Langleben and E. Caroline Rigby, August 1952.

MW-9: A theory of snow crystal habit and growth, by J.S. Marshall and M.P. Langleben, July 1953.

MW-10: The modification of rain in showers with time, by E. Caroline Rigby and J.S. Marshall, March 1953.

MW-11: A mathematical treatment of random coalescence, by Z.A. Melzak and Walter Hitschfeld, March 1953.

MW-12: Errors inherent in radar measurement of rainfall at attenuating wavelengths, by Walter Hitschfeld and Jack Bordan, June 1953.

MW-13: Radar evidence of a generating level for snow, by K.L.S. Gunn, M.P. Langleben, A.S. Denis and B.A. Power, July 1953.

MW-14: Initiation of showers in cumuli by snow, by A.S. Denis, July 1953.

MW-15: Turbulence in clouds as a factor in precipitation, by T.W.R. East and J.S. Marshall, July 1953.

MW-16: The terminal velocity of snow aggregates, by M.P. Langleben, January 1954.

MW-17: Development during fall of raindrop size distributions, by E. Caroline Rigby, K.L.S. Gunn and Walter Hitschfeld, January 1954.

MW-18: The effect of wind shear on falling precipitation, by K.L.S. Gunn and J.S. Marshall, December 1954.

MW-19: The convection associated with release of latent heat of sublimation, by R.H. Douglas and J.S. Marshall, December 1954.

MW-20: A: Size distribution generated by a random process, by Walter Hitschfeld.
B: The distribution with size of aggregate snowflakes, by K.L.S. Gunn and J.S. Marshall, September 1956.

MW-21: Pattern in the vertical of snow generation, by R.H. Douglas, K.L.S. Gunn and J.S. Marshall, July 1956.

MW-22: Precipitation mechanisms in convective clouds, by T.W.R. East, January 1956.

MW-23: Measurement and calculation of fluctuations in radar echoes from snow, by Walter Hitschfeld and A.S. Dennis, July 1956.

MW-24: The plan pattern of snow echoes at the generating level, by M.P. Langleben, February 1956.

MW-25: A possible role of hail information of tornadoes, by Walter Hitschfeld and J.S. Marshall, March 1957.

MW-26: Growth of precipitation elements by sublimation and accretion, by R.H. Douglas, May 1957.

MW-27: Studies of Alberta hail storms 1957, by R.H. Douglas and Walter Hitschfeld, May 1958.

MW-28: Electronic constant altitude plan position indicator for a weather radar, by T.W.R. East, November 1958.

MW-29: The motion and erosion of convective storms in severe vertical wind shear, by Walter Hitschfeld, July 1959.

MW-30: Alberta hail, 1958, and related studies. Parts I and II by R.H. Douglas, Part III by R.H.D. Barklie and N.R. Gokhale, July 1959.

MW-31: The quantitative display of radar weather patterns on a scale of grey, by T.H. Legg, June 1960.

MW-32: Weather-radar attenuation estimates from raingauge statistics, by P.M. Hamilton and J.S. Marshall, January 1961.

MW-33: Improvements in weather-radar grey scale, by F.T. Barath, July 1961.

MW-34: Interim account of hail studies - November 1960, by R.H. Douglas, J.S. Marshall and R.H.D. Barklie. Reprinted in April 1962.

MW-35: Alberta Hail Studies, 1961, by A.E. Carte, R.H. Douglas, C. East, K.L.S. Gunn, Walter Hitschfeld, J.S. Marshall, E.J. Stansbury, December 1961.

MW-36: Alberta Hail Studies, 1962/63, by A.E. Carte, R.H. Douglas, R.C. Srivastava and G.N. Williams, August 1963.

MW-37: Precipitation profiles for the total radar coverage, by P.M. Hamilton, September 1964.

MW-38: Two studies of convection, by R.C. Srivastava and C.D. Henry, October 1964.

MW-39: Interpretation of the fluctuating echo from randomly distributed scatterers: Part 3, by Paul L. Smith, Jr., December 1964.

MW-40: Facsimile and areal integration for weather radar, Vols. I and II, by Marceli Wein, April 1965.

MW-41: Time-dependent characteristics of the heterogeneous nucleation of ice, by Gabor Vali and E.J. Stansbury, April 1965.

MW-42: Alberta Hail Studies, 1964, by J. Derome, R.H. Douglas, W. Hitschfeld, M. Stauder, July 1965.

MW-43: Attenuation of a parallel beam of light, particularly by snow, by Olav Lillesaeter, April 1965.

MW-44: Measurements on new-fallen snow, by K.L.S. Gunn, August 1965.

MW-45: Measurements on falling snow, by K.L.S. Gunn and M. Wein (to be published December 1965).

MW-46: Experiments on the nucleation of ice, 1961-63, by G. Vali and E.J. Stansbury, August 1965.

MW-47: Number in reserve for the future.

MW-48: Part I of Air Transport Association Report "Parameters for airborne weather radar" by J.S. Marshall, C.D. Holtz and Marianne Weiss will be issued with this number, December 1965.

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13. ABSTRACT

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