Program of the Tenth Weather Radar Conference,
April 22–25, 1963, Washington, D. C.

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GENERAL INFORMATION
The Tenth Weather Radar Conference will be held at the International Inn, Thomas Circle. The meeting will be under the joint sponsorship of the U. S. Weather Bureau and the American Meteorological Society and will be hosted by the District of Columbia Branch of the Society.

Rooms have been reserved at the International Inn for conferees and their guests. Single room rates range from $12 to $18 per day, double rooms from $15 to $24 per day. Reservations should be made early since a number of other conferences and conventions and a large number of tourists should be in town at that time. Limousine service is available from Washington National, Dulles International, and Friendship (Baltimore) Airports.

A dinner will be held Wednesday, April 24, at 7:30 p.m. at the Inn. A social hour will precede the dinner. Tickets will be available at the registration desk.

The registration desk at the Inn will be open on Sunday evening from 6 to 9 p.m. and at 8 a.m. Monday, April 22. The registration fees are $14 for Society members and $24 for non-members. As with previous weather radar conferences, a printed copy of the Proceedings will be available at the registration desk. Text of papers to be read by title only will be included in the Proceedings. Cost of the Proceedings is included in the registration fee.

PROGRAM

Monday Morning, 22 April, 9–12 a.m.
USE OF RADAR IN FORECASTING
Chairman: Dr. Edwin Kessler, III
The Travelers Research Center
Hartford, Conn.

Radar precipitation echo motion and suggested prediction techniques. Roland J. Boucher, Aracon Laboratories. (15 min)

Some studies on the shape and movement of a weather echo. Kazuo Watanabe, Japan Meteorological Service. (15 min)

A radar study of shower activity associated with the sea breeze. Paul L. Moore, U. S. Weather Bureau. (10 min)

Cloud distributions within areas of thunderstorms. Roland E. Nagle and Roy H. Blackmer, Jr., Stanford Research Institute. (15 min)

Statistical properties of weather-radar echoes. Edwin Kessler, III, and John A. Russo, The Travelers Research Center. (15 min)

Applied research at Weather Bureau WSR-57 radar stations. Paul L. Hexter, Jr., U. S. Weather Bureau. (10 min)
WSR-57 and lake effect snow. B. L. Wiggin, U. S. Weather Bureau. (Title only)
Comparisons of time integrated radar detected precipitation with satellite observed cloud patterns. Roland E. Nagle, Stanford Research Institute. (Title only)

**Monday Afternoon, 22 April, 1:30-5 p.m.**

**THUNDERSTORM STUDIES**

Chairman: R. J. Donaldson
Air Force Cambridge Research Laboratories
Sudbury, Mass.

- Characteristics of hailstorms in the high plains as deduced from 3-cm radar observations. Richard A. Schleusener, Colorado State University. (10 min)
- On the relation between radar echo tops, the tropopause and severe weather occurrences. F. Doloresco and M. E. Pautz, U. S. Weather Bureau. (10 min)

**Tuesday Morning, 23 April, 9-12 a.m.**

**SHOWER STRUCTURE**

Chairman: Harry V. Senn
University of Miami
Coral Gables, Fla.

- Role of microphysical processes in shaping vertical profiles of precipitation and cloud. Edwin Kessler, III, Peter J. Feteris and Edward A. Newburg, The Travelers Research Center. (15 min)
- Kinematical relations between radar-observed water concentrations and vertical motions in convective clouds. Robert C. Rummels, A. and M. College of Texas. (15 min)

**Tuesday Afternoon, 23 April, 2-5 p.m.**

**(A) SCATTERING AND ATTENUATION**

Chairman: Kenneth E. Wilk
U. S. Weather Bureau
Norman, Okla.

- Radar observations of melting ice spheres during free fall. John T. Willis, K. A. Browning and David Atlas, Air Force Cambridge Research Laboratories. (15 min)
- On the backscatter cross-sections of ice spheres. Kenneth M. Glover and David Atlas, Air Force Cambridge Research Laboratories. (10 min)
- Raindrop-size distributions and their variation with height. Kenneth R. Hardy, The University of Michigan. (15 min)
- The scattering coefficient of rain from forward scatter measurements. Lorne H. Doherty, National Research Council, Ottawa, Canada. (15 min)

**(B) MESOSCALE STUDIES**

Chairman: Rex Inman
University of Oklahoma
Norman, Okla.

- Orographic effects on radar echo characteristics and distributions. L. D. Mendenhall, New York University, and Fred W. Decker, Oregon State University. (10 min)
- Radar and mesoscale analysis of a cold front. Ryozo Tatehira and Hayashi Fukatsu, Nagoya Local Meteorological Observatory. (10 min)
Radar observations of the clear atmosphere between 10,000 and 30,000 feet. R. J. Wagner and L. C. Conant, Radio Corporation of America. (10 min)

Tuesday Evening, 23 April, 7:30—9 p.m.
HURRICANE STUDIES
Chairman: Prof. H. W. Hiser
University of Miami
Coral Gables, Fla.

The accuracy of center positions of hurricanes as determined by the spiral overlay technique. C. L. Jordan, Florida State University. (15 min)
Radar composites of Hurricane Carla. H. E. Foster, U. S. Weather Bureau. (15 min)
Filling of a typhoon eye over land. I. Imai, Meteorological Research Institute, Tokyo, Japan. (15 min)

Wednesday Morning, 24 April, 9—12 a.m.
PRECIPITATION MEASUREMENT
Chairman: Dr. Louis J. Batten
Institute of Atmospheric Physics
University of Arizona
Tucson, Ariz.

Evaluation of the AN/FPS-36 radar as a precipitation measuring device. Douglas M. A. Jones, Illinois State Water Survey. (10 min)

A comparison between radar and ground areal rainfall. Jiro Aoyagi, Meteorological Research Institute, Tokyo, Japan. (15 min)

Relationship between gage measured precipitation rates and radar echo intensities. James Wilson, The Travelers Research Center. (15 min)

Radar measurements of the distribution of precipitation in New England storms. Pauline M. Austin, Massachusetts Institute of Technology. (15 min)

Digitized X band radar echo in a ten-mile square and the occurrence of precipitation. Roland J. Boucher, Arcon Laboratories. (10 min)

Rainfall determination from 0.86 and 1.87 cm radar measurements. C. W. C. Rogers and Raymond Wexler, Arcon Laboratories. (15 min)

Rainfall rate measurement by radar using two radar sets of different wavelengths. Robert Hashbrouck Cartmill, Southwestern Power Administration. (5 min)

Monthly variations of precipitation echo occurrences across the United States. Lawrence E. Truppi, U. S. Weather Bureau. (10 min)

Project report on the Weather Bureau’s radar hydrology program. Allen F. Flanders, U. S. Weather Bureau. (Title only)

A preliminary analysis of a grid method of determining precipitation amounts by radar over the upper portion of the Columbia Basin. The Missoula Radar Staff and Hydrologic Services Division. (Title only)

Wednesday Afternoon, 24 April, 2—5 p.m.
DOPPLER RADAR APPLICATIONS
Chairman: Dr. K. L. S. Gunn
McGill University
Montreal, Canada

Wind velocity measurement with Doppler radar. R. J. Pililé, J. E. Jiusto, and R. R. Rogers, Cornell Aeronautical Laboratories. (15 min)

The measurement of wind and convergence by Doppler radar. P. G. F. Caton, Royal Radar Establishment, Malvern, England. (10 min)

Precipitation vertical velocities and their significance. Roger M. Lhermitte and David Atlas, Air Force Cambridge Research Laboratories. (15 min)

Some observations of vertical velocities and precipitation sizes in a thunderstorm. Louis J. Batten, University of Arizona. (10 min)

The vertical velocities of an edge echo. Louis J. Batten, University of Arizona. (10 min)

On the possibility of radar detection of clear-air turbulence. P. L. Smith, Carnegie Institute of Technology, and R. R. Rogers, Cornell Aeronautical Laboratory. (15 min)

Weather echo signals in Doppler and conventional radars. Roger M. Lhermitte, Air Force Cambridge Research Laboratories. (Title only)

Wednesday Evening, 24 April, 6:30 p.m.

International Inn
Social Hour and Banquet

Toastmaster: Alan Bemis
Massachusetts Institute of Technology
Cambridge, Mass.

Speaker: Dr. Joachim P. Kuettner
Director, Saturn-Apollo Program
NASA, Marshall Space Flight Center
Huntsville, Ala.

Thursday Morning, 25 April, 9—12 a.m.
WEATHER RADAR DESIGN AND DISPLAY TECHNIQUES
Chairman: R. T. H. Collis
Stanford Research Institute
Menlo Park, Calif.

On the method of quantitative echo intensity measurement used for the WSR-57 radars. S. G. Bigler and M. W. Brooks, U. S. Weather Bureau. (15 min)

Vertical echo protrusions observed by WSR-57 radar. Robert L. Smith, U. S. Weather Bureau. (10 min)

Radar parameters for airborne weather reconnaissance. H. V. Senn and H. W. Hiser, University of Miami. (10 min)
Fundamental limitations on precipitation observations from satellites. Arnett S. Dennis, Stanford Research Institute. (15 min)

A new pulsed-Doppler radar for cloud observations. John B. Theiss and A. Richard Kassander, Jr., University of Arizona. (15 min)

Tube-face filters for line-space compensation. K. L. S. Gunn, McGill University, Montreal, Canada. (10 min)

Facsimile output for weather radar. Marcell Wein, McGill University, Montreal, Canada. (10 min)

A signal level quantizer for weather radar. Charles W. Niesen and Spiros G. Geotis, Massachusetts Institute of Technology. (5 min)

A new Air Force weather radar set. Wilbur H. Paulsen, Air Force Cambridge Research Laboratories. (Title only)

Constant height antenna scan. Ralph J. Donaldson, Jr., Air Force Cambridge Research Laboratories. (Title only)

Thursday Afternoon, 25 April, 2–5 p.m.

DATA PROCESSING

Chairman: To be announced


A processor for weather radar data. Mario Schaffner, Massachusetts Institute of Technology. (15 min)

A radar precipitation integrator. Ronald T. H. Collis, Stanford Research Institute. (15 min)

Some uses of a storage tube in weather radar. Nobuhiko Kodaira, Meteorological Research Institute, Tokyo, Japan. (15 min)

Use of a direct view dark trace storage tube in a weather radar. Wilbur H. Paulsen, Air Force Cambridge Research Laboratories. (10 min)

A scan-converter for weather radar applications. C. A. Martin-Vegue and H. W. Hiser, University of Miami. (15 min)

Papers Given by Title Only

Status of weather radar observations in Japan. S. Ohta and T. Shinohara, Japan Meteorological Agency. (Title only)


Use of the M33 radar for meteorological studies. D. Ray Booker and L. G. Davis, Pennsylvania State University. (Title only)

Some characteristics of trackable radar angels. D. B. Rai and T. H. Rollofs, Cornell University. (Title only)

The detection of radar echoes from the clear atmosphere. R. J. Wagner and L. C. Conant, Jr., Radio Corporation of America, Defense Electronic Products Div. (Title only)

Use of Radar in Forecasting

Radar Precipitation Echo Motion and Suggested Prediction Techniques

Roland J. Boucher

Three modes of radar precipitation echo: lines, edged sheets and amorphous fields, have been investigated. The lines advance in a direction within 90 deg to the right of the 700-mb wind with approximately the component speed. The forward edges of echo sheets advance with a persistent direction and speed which bears no apparent relation to the wind at any level while the motion of the amorphous echo fields can be characterized by the motion of their centroids.

For predicting onset of precipitation at a point for periods of up to three hours, the best technique appears to be the extrapolation of the motion of the echo leading edge for lines and sheets, and the extrapolation of echo element motion for amorphous fields.

Some Studies on the Shape and Movement of a Weather Echo

Kazuo Watanabe

It is widely accepted that the movement of a small precipitation area as observed on a radar scope shows good agreement with the wind velocity near the 700-mb level. More detailed discussions on the relation between a given wind profile and the resultant shape and movement of a weather echo are made in this report.

A Radar Study of Shower Activity Associated with the Sea Breeze

Paul L. Moore

Based on tabulations of radar echoes observed at stations in peninsular Florida, the effect of the interaction of the sea breeze and the general wind on shower distribution is examined. Significant space and time variations in shower activity are found to be associated with changes in general wind regimes. The echo patterns are compared with theoretical distributions of vertical motion within the sea breeze circulation.

Cloud Distributions within Areas of Thunderstorms

Roland E. Nagle and Roy H. Blackmer, Jr.

U-2 photographs of cloud cover have been examined to determine the distributions of clouds within areas of thunderstorms. The dimensions and concentrations of clouds were compared with the distributions of radar echoes as shown by hourly RADU plotting charts. Special emphasis was given to the relative heights of clouds as determined by radar and by photogrammetry.
from the film. The areal extent of cloud cover as compared with the areal extent of radar echoes is also discussed.

Statistical Properties of Weather-Radar Echoes

Edwin Kessler, III, and John A. Russo, Jr.

Statistical characterizations of a digitized weather echo pattern are provided by computer analyses of the distribution in lag space of the coefficients of pattern autocorrelation. A quadratic polynomial fitted to the distribution about zero lag of the autocorrelation coefficients defines an ellipse whose major and minor axes, orientation, and ellipticity provide objective criteria for pattern bandedness, orientation of bands, and characteristic length of pattern elements.

The lag location of the maximum cross-correlation coefficient between patterns observed at different times is a measure of pattern displacement. The magnitude of the maximum cross-correlation decreases as the time interval between observations increases; the rate of decrease measures the rate of pattern development and is related to the scale of pattern elements as defined by the axes of the autocorrelation ellipse. The computer also determines the average echo intensities and intensity variances, and tabulates frequency distributions and contingency tables. The statistical parameters are to be applied to the development of improved techniques for radar weather analysis and forecasting, and air traffic control. The parameters may also find use as predictors in generalized programs for probability forecasting.

Applied Research at Weather Bureau
WSR-57 Radar Stations

Paul L. Hexter, Jr.

The objectives and scope of the Weather Bureau applied radar research program are given. Studies completed and currently underway at the thirty-one stations are grouped into categories by general subject type and examples are given. Future expectations are discussed in the light of equipment improvements and new experience gained by the radar personnel.

WSR-57 and Lake-effect Snow

B. L. Wiggin

The problem of lake-effect snow is stated and illustrative examples cited. Forecasting techniques and models used prior to WSR-57 are described. Use of WSR-57 in snowstorms of December 1961, January 1962, and December 1962 is explained. Plans for 1963-64 snow season are outlined.

Comparisons of Time Integrated Radar Detected Precipitation with Satellite Observed Cloud Patterns

Roland E. Nagle

Radar precipitation echo patterns integrated over extended periods of time by a procedure which (1) simulated moving the radar station along with the precipitation system and (2) allowed the precipitation to move across the radarscope were compared with cloud forms as viewed by the TIROS I meteorological satellite. Examples of these comparisons are presented showing precipitation-to-cloud relationships in varying synoptic situations and in different climatic regions of the world. The results indicate that not only is this technique a powerful method for interpreting cloud forms as viewed by satellites, but may also find application in other fields of meteorology.

Thunderstorm Studies

Characteristics of Hailstorms in the High Plains As Deduced from 3-cm Radar Observations

Richard A. Schleusener

Measurements were made of thunderstorm reflectivity structure in eastern Colorado from 15 May to 1 August 1962.

Using a CPS-9 3-cm radar at Lowry Air Force Base which was equipped with a stepped-gain system, measurements were made of RHI tops, elevation of maximum reflectivity, maximum reflectivity, and reflectivity at 20, 30, and 40 thousand feet msl. An analysis of variance was performed to determine whether significant seasonal differences occurred. In addition, an analysis of variance was performed to determine the significance of differences in these factors for non-hail cases and for hail cases, categorized either by maximum size of stone reported at the ground within 30 min of the radar observations, or “impact energy” values estimated for the hailstorms.

Using another 3-cm radar at New Raymer, Colo., the angles of “tilt” of the radar echoes were determined from PPI position of the tops of echoes and the position of the point of maximum reflectivity at the base of the echoes. The mean azimuth angle of the tilt was found to be clockwise from the wind shear vector between 14 and 35 thousand feet for hail cases, and counterclockwise for non-hail cases. There was no significant correlation between the horizontal distance between the top and the base of the radar echo and the magnitude of the wind shear vector between 14 and 35 thousand feet.

Using a vertical-scanning radar, equipped with a stepped-gain system, thunderstorms were examined for differences in reflectivity between sectors (front, middle, back and north, central, south). The results indicate higher reflectivities in the front and middle sectors than in the back, and weaker reflectivities in the north than in the central and south sectors.

Three-Dimensional Analysis of a Thunderstorm Cell Structure

G. E. Stout and K. E. Wilk

Radar sampling at 10-min intervals of gain-reduced echo patterns at various elevation angles over a 40-min period provided data for a detailed study of an intense thunderstorm on 8 September 1960 in east central Illinois. Strong outflow produced 75 per cent of the damage to crops and property. Maximum hail size was less than
one-half inch. Aerial and ground surveys of the time of occurrence, areal extent and intensity of the damaging weather assisted greatly in relating the radar intensity measurements to the resulting weather. Within the thunderstorm, cells of reflectivity, $Z$ in excess of $8 \times 10^3$ mm$^3$m$^{-4}$, varied in number from two to five. Small cores of higher reflectivity, $Z$ in excess of $5 \times 10^3$ mm$^3$m$^{-4}$, with a life history of less than 3 min, were present during the dissipation stage. The complexity of the thunderstorm cells and cores will be illustrated with three-dimensional drawings.

**ON THE RELATION BETWEEN RADAR ECHO TOPS, THE TROPOPAUSE AND SEVERE WEATHER OCCURRENCES**

F. Doloresco and M. E. Pautz

Radar echo tops and their apparent penetration of the reported tropopause have been correlated with severe weather occurrences. The period February through August 1961 was investigated using data from Weather Bureau radars east of the Rocky Mountains.

The primary purpose of this investigation was to determine if a reasonable estimate of severe weather occurrences could be made using current radar data and the latest tropopause chart available. Nearly six thousand individual echo tops were investigated relating tornadoes, hailstorms and thunderstorms without reported hail to tropopause height. Geographical, diurnal, seasonal, as well as hail versus tornado comparisons are tabulated.

**SYNOPTIC AND RADAR ANALYSIS OF A TORNADO AT CHARLTON, MASS., 12 OCTOBER 1962**

Raymond Wexler and Ruth Wexler

Remarkable radar echoes of the Charlton, Mass., tornado, 12 October 1962, have been obtained with the CPS-9 radar at Maynard, Mass. The structure of the storm is followed through its peak and decay, the maximum height being about 50,000 ft. The tornado shows up as a square cloud at 1631E close to, but detached from, an extensive squall rain area. Six minutes later the circulation associated with the funnel is readily seen. Just south of a meso-high, probably formed by the outflow of cold air beneath the thunderstorm area, the tornado is located along an instability line ahead of a cold front.

**A SQUALL LINE VORTEX**

J. M. Pike, R. E. Rinehart and J. G. Traylor

During a squall line passage on 1 May 1962, radar observations revealed a small circulatory system evidenced by dual spiral bands similar to typical hurricane bands. The radar was operating on the 4-mi range, and a photograph was taken with the system nearly centered on the PPI. Since the diameter of the spiral echo pattern is about 5 mi, considerable detail of the system is evident. Characteristics of the spiral structure, relevant synoptic data, and comparisons with other spiral systems will be discussed.

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**BULLETIN AMERICAN METEOROLOGICAL SOCIETY**

**AN OBSERVATION OF ANTICYCLONIC HOOK-SHAPED ECHO IN AN AREA OF KNOWN TORNADIC ACTIVITY**

F. E. Wells

An echo with an anticyclonic hook-shaped appendage occurred during the time of known tornadic activity over south-central Kansas during the early evening hours of 24 May 1962. A series of radarscope photographs of the WSR-57 radar at Wichita, Kans., shows that this phenomenon persisted for 12 min and suggests that the appendage underwent anticyclonic rotation. These photographs show that the anticyclonic hook was located in the right rear quadrant (characteristic of cyclonically-curved hooks) of the echo with respect to its motion. Position of the protuberance in this quadrant of the echo during the time of known tornadic activity also suggests that it was associated with this activity.

**GROUND PATTERNS OF HAILSTORMS**

David J. M. Proctor and Spiros G. Geotis

The 10-cm reflectivity patterns of several sustained hailstorms are compared with detailed maps of hail sizes as reported by ground observers. Information on the vertical structure of the storms is included where available.

**RAIN GUSHES AFTER LIGHTNING**

B. Vonnegut, E. A. Vrablik and C. B. Moore

Additional observations are presented of echo intensification in clouds immediately after lightning strokes. The drop charging and accelerating mechanism proposed by Vonnegut is developed further. The velocities computed as possible for charged drops in the vicinity of a lightning channel are compared with the apparent mean velocities estimated from the rates of echo intensification observed.

**500-KC SFERICS INTERPRETATIONS OF SEVERE STORM RADAR ECHOES: A PRELIMINARY INVESTIGATION**

Douglas A. Kohl, John E. Miller and Neil B. Ward

Directional sferics analyzing equipment was used to obtain a continuous record of average count rate produced in 5.6-deg azimuth sectors during all thunderstorm periods occurring in a 48-day survey. Although only 43 per cent of maximum sensitivity WSR-57 radar cloud area produced sferics, 98 per cent of those sectors with sferics activity also contained radar evidence of cloud formation. The region of maximum radar reflectance, $Z$, and site of maximum sferics count rate were located near each other within the growing storm. However, variations in $Z$ and count rate are apparently unrelated. Severe weather events were found to occur during the increasing trend in sferics count rate and a decreasing trend in sferics preceded the dissipation of cloud echoes.

**THE ESTIMATION OF CLOUD TO GROUND LIGHTNING BY RADAR**

Charles Reeve Shackford

PPI radar reflectivities of different levels of thunderstorms provide information about horizontal and vertical precipitation structure of the storms at different times in
the life cycle. A correlation of such information with nearly simultaneous surface observations of the location and amount of lightning occurring in the immediate vicinity of the radar echoes reveals that cloud to ground lightning production is related to the development of radar reflectivity in the layer between 15,000 and 25,000 ft and that an estimate of the amount of cloud to ground lightning likely to take place in a given thunderstorm up to about 10 strokes per minute can be made from its three dimensional CPS-9 radar echo structure. Radar echo height alone is not considered an adequate measure of lightning activity.

Substitution of radar observed precipitation values for the layer 15,000-25,000 ft in a thunderstorm charging rate equation of Latham and Mason show these values were at least if not actually more than adequate to produce the amount of associated lightning according to the process of charge generation and separation suggested by them.

Comparisons of Atmospherics and Equivalent Radar Reflections for Some Texas Thunderstorms

Tom E. Sanford

Simultaneous observations of radar and sferics parameters are obtained for north-central and central Texas thunderstorms. Atmospherics are expressed by an index which includes relative amplitudes and stroke rates obtained from the histograms of a four-channel spectrum analyzer, and azimuths are obtained by direction-finding loops. Values yielded by the index are compared with constant altitude equivalent radar reflectivities of five storms. Results indicate a reasonable association between these parameters in both phase and magnitude and further support the contention that sferics may be used as a measure of storm intensity.

Shower Structure

Role of Microphysical Processes in Shaping Vertical Profiles of Precipitation and Cloud

Edwin Kessler, III, Pieter J. Feteris and Edward A. Newburg

A one-dimensional formulation of relationships among updrafts, condensation, conversion of cloud to precipitation, and collection of cloud by precipitation is examined to interpret associations between the vertical profiles of precipitation and cloud and the magnitude of parameters which model, for example, the shape of drop-size distributions and the cloud collection efficiency. The shape in steady updrafts of transient features of the solutions, is related to cloud conversion and collection rates, which control the onset of precipitation. Solutions of a pair of simplified equations whose terms model cloud conversion and collection illustrate one of the considerations attending interpretation of empirical data in terms of the relative strengths of these processes. If one of the processes is relatively rapid, precipitation development is quite insensitive to the magnitude of the other process. After precipitation is initiated, precipitation and cloud profiles approach a steady state in all cases where the maximum updrafts are not in excess of typical precipitation fall speeds. It appears that the steady state is independent of initial conditions, weakly dependent on the microphysical parameters, and strongly related to the updrafts. Order of magnitude variations of the microphysical parameters are usually necessary to alter significantly the steady precipitation and cloud profiles in a particular updraft, since the complete equations are a model system whose reaction to changes of the microphysical processes is almost always in a direction to minimize the effects of the changes.

Kinematical Relations between Radar-Observed Water Concentrations and Vertical Motions in Convective Clouds

Robert C. Runnels

A simple convection cell is selected as a model to represent convective cloud motions suitable for analysis using radar-measured parameters. A one-dimensional (vertical) continuity equation for water substance is considered. Atmospheric values of parameters which appear in the continuity equation are determined from radar reflectivity measurements taken by an AN/CPS-9 radar located at College Station, Tex. Empirical equations are employed to relate a particular parameter to reflectivity values. In the continuity equation, the generation term that accounts for the change of phase of water is found to be important when considering the center of a convective cloud. This model incorporates a linear decrease of generation with height. The results of this investigation indicate that the mean vertical speeds of convective clouds can be determined with some confidence from cloud parameters measured by a weather radar.

Air Flow within a Tornadic Storm

K. A. Browning and C. R. Landry

The detailed structure of the radar echo from a tornadic mid-west thunderstorm is analysed in conjunction with nearby soundings to give a model of the associated airflow. Many features of its structure and airflow resemble those observed in an English hailstorm studied by Browning and Ludlam [1962: Airflow in convective storms. Quart. J., R. meteor. Soc., 88, 117-135]. Both storms travelled within a strongly sheared environment, and both comprised a rather steady updraft inclined into the shear which entered and left on the downshear side. However, certain differences in organization are revealed. These are due mainly to the much greater veer in wind direction with height in the environment of the mid-west storm. The wind veer was especially large within the layer of potentially warm air near the ground. A theory is proposed which makes this at least partly responsible for the development of the tornadoes.

Development of a Cumulonimbus under the Influence of Strong Vertical Wind Shear

T. Fujita and J. E. Arnold

A cumulonimbus which developed over the NSSP network on 21 April 1961 was well-documented by aircraft
at three levels, three ground located radars, and the surface network. Combined analyses of these data revealed that the storm developed rapidly in the form of several towers which merged into a large cumulonimbus with its anvil extending over 100 mi downstream in a few hours. A marked low level convergence below the cloud base, middle level flow around the cloud, and divergence at the cloud top level was quantitatively obtained. Although, to a certain extent, the Doppler winds were considered unreliable, the results were found to be realistic. A number of aerial photographs were used in determining cloud heights and volumes as a function of time in an attempt to compare them with those obtained by ground located radar.

**Pretcipitation Profiles for Operations and Research**

P. M. Hamilton

Plots of areal coverage of echo or of average precipitation rate as a function of height and intensity form a useful digest for the synoptic meteorologist and provide new methods of studying the precipitation process. Profiles of summer showers tend to show a growth of precipitation at all heights, the rates of growth covering a wide range of values. They also indicate that at any one height the relative areas of given intensities remain in the same proportion throughout a storm. Basic data for the profiles are accumulated on film at the radar from an A-scope display. One frame of film records the signals from all ranges and ice-simulating Stycast spheres are considered both theoretically and experimentally. Calculations of the individual contributions from the front and rear surface reflections. The

**Distortions in Reflectivity Patterns by Antenna Side Lobes**

Ralph J. Donaldson, Jr., and Richard T. Tear

Measurement errors caused by antenna side lobe distortion are computed for seven model reflectivity distributions observed over various ranges by CPS-9 and WSR-57 radars. Particular attention is paid to errors in echo top height, maximum reflectivity, and reflectivity measured at 0 deg antenna elevation angle. The detectability of an echo-free hole surrounded by intense precipitation is also considered. Methods are suggested for minimizing the distortion errors with optimum reliability in a wide variety of reflectivity structures.

**Quantitative Estimations for Measuring Echo Top Heights**

Jiro Aoyagi

The estimation of echo top height has been studied for the case where the radar beam (the main lobe has a Gaussian pattern) illuminates a part of the target whose radar cross section has a uniform or an exponential distribution. The elevation angle of a vertically uniform target may be represented by subtracting a certain value from the angle of the center of the beam axis. This specified value of the angle depends on the ratio of $P_{min}$ to $P_r$, where $P_{min}$ is the minimum detectable signal of the radar receiver and $P_r$ is the intensity of the reflected power from the target which fills the beam perfectly. If $10 \log (P_{min}/P_r) = -13$ db, then the specified value becomes half the beam width.

The height of the echo top of a vertically exponential target decreases in inverse proportion to $r^2$ up to a certain range ($70 \sim 100$ km). Beyond the range, on the other hand, the indicated radar height increases.

**Scattering and Attenuation**

**Radar Observations of Melting Ice Spheres during Free Fall**

John T. Willis, K. A. Browning and David Atlas

Simultaneous high precision measurements of the fall speed and the radar cross section of ice spheres descending in the free air have been obtained using a C-band missile tracking radar, the AN/FPS-16. An ice sphere, 5.1 cm in diameter, with a frosted surface was observed to decelerate from an initial terminal velocity of approximately 50 m per sec to a lower terminal velocity of approximately 32 m per sec. The deceleration and the lower terminal velocity occurred at temperatures above the 0C wet bulb temperature. The decrease in fall speed is attributed to a smoothing of the surface of the ice sphere as a result of the melting of the frost coat. Contrary to intuitive expectation, spheres at certain fall speeds have very much higher drag coefficients when they are smooth than when they have slightly roughened surfaces. Initially, when the sphere was dry, the radar cross section was within 3 db of the theoretical value and before reaching the ground decreased by approximately 5 db, or half the change expected in transition from all ice to all water. This confirms that wetting of large hailstones in free fall may account for significant decrease in their radar cross section.

Important implications for the growth of hailstones are involved, if further observations reveal that a similar reduction in fall speed takes place when the surfaces of small hailstones become wet. The observed behavior of the 5.1-cm ice sphere implies a mechanism to explain the common occurrence of hailstones with onion-like structure. Thus a hailstone growing dry in a super-cooled cloud has a rough surface, a high fallspeed and a high rate of accretion. If this causes the hail to become wet, its surface will become smooth decreasing its fallspeed and rate of accretion so that it becomes dry once more. The resultant alternation between wet and dry growth gives rise to the onion-like structure.

**On the Back Scatter Cross-Sections of Ice Spheres**

Kenneth M. Glover and David Atlas

The back scatter cross-sections of large ice spheres and ice-simulating Stycast spheres are considered both theoretically and experimentally. Calculations of the cross-sections are made using a modified geometrical optics approach which considers the individual contributions from the front and rear surface reflections. The
results of this approach are in good agreement with the exact Mie solution over the range of diameter to wavelength ratio of about 1.7 to 7.

The simplified theory is extended to cover dielectric spheres whose surface is partially covered by a highly reflective coating. Backscatter data for ice-simulating Stycast spheres with small metallic caps and melting ice spheres at 3.2-cm wavelength are presented to illustrate the interaction between the individual contributions to the total back scatter. It is demonstrated that the reflection from the rear surface makes the major contribution to the back-scatter.

RAINDROP-SIZE DISTRIBUTIONS AND THEIR VARIATION WITH HEIGHT
Kenneth R. Hardy

Computations of the changes of the raindrop-size distributions with distance fallen are made, using an electronic digital computer. For a steady mass flux of raindrops just below the melting level, changes brought about in the distribution through coalescence among raindrops, by accretion of cloud droplets, and by evaporation are considered. It is found that an initial exponential distribution having a relatively large negative slope is considerably modified as the rain falls and a distribution with a relatively small negative slope is only slightly modified by the above three processes.

Assuming steady-state conditions, a procedure is presented whereby the raindrop-size distribution at the melting level can be deduced. This is possible by combining the information obtained from the computations of the change in the distribution below the melting level with the observed distribution at the ground. One study of this type for the light and prolonged rain on 31 July 1961 at Flagstaff, Ariz., shows that at the melting level 1.) more large drops must be present than is indicated by the Marshall and Palmer distribution, and 2.) the concentration of the larger drops must not be substantially different from their concentration observed at the ground.

THE SCATTERING COEFFICIENT OF RAIN FROM FORWARD SCATTER MEASUREMENTS
Lorne H. Doherty

Measurements of the scattering coefficient of rain have been made at 9400 mc sec\(^{-1}\) over a 2800 ft scatter link. The radio system responds to the power in the spectrum of Doppler frequencies due to the vertical velocities of the falling raindrops and a measure of the drop size is obtained simultaneously. The radio data has been compared with rainfall rate values obtained from tipping bucket rain gauges. Values of the parameters in the familiar relationship \(2D^2 = AR^2\) have been obtained by an analysis technique which is believed to be more than usually accurate. It has been found that \(\alpha\) varies between 1.4 and 2.2 with some correlation with rainfall types. The value of \(\"A\"\) is as much as 10 db less than the commonly accepted values. The possibility of improving the accuracy of radio measurements of rainfall rate by utilizing the Doppler frequency data has also been considered.

THE EFFECTS OF MULTIPLE SCATTERING ON THE ATTENUATION AND BACKSCATTER OF MICROWAVES BY LARGE ICE SPHERES
Benjamin M. Herman

The single-scatter pattern of large ice spheres is known to exhibit an extremely large peak confined to a small solid angle about the forward direction. This forward-scattered energy is practically indistinguishable from the incident beam and represents a considerable portion of the total scattered energy. Calculations of attenuation by standard means, based on the total attenuation cross-sections computed from the Mie theory, assume that all energy absorbed or scattered by the sphere is lost to the incident beam. This assumption might lead to errors in calculations of attenuation and backscatter. To evaluate the importance of multiple scattering, the equation of radiative transfer has been solved numerically, taking into account the effects of all significant orders of scattering, as well as polarization effects. The transmission and backscatter of a beam incident upon a hypothetical hail shaft is computed, and the results are compared to those obtained by standard techniques.

Mesoscale Studies

OROGRAPHIC EFFECTS ON RADAR ECHO CHARACTERISTICS AND DISTRIBUTION
L. D. Mendenhall and Fred W. Decker

Case studies of data collected during fall, winter, and spring months reveal echo characteristics that relate to the precipitation anomaly in coastal, mountain and valley zones of western Oregon. Also discussed are changes in echo intensity, size and shape resulting from effects of various types of topography as the echoes move inland from the Pacific and the relation of these changes to the observed orographic anomaly. The studies also discuss the apparent effect of the presence or absence of certain physical and synoptic parameters on the resulting precipitation anomalies.

RADAR AND MESOSCALE ANALYSIS OF A COLD FRONT
Ryozo Tatehira and Hayashi Fukatsu

Mesoscale structure of a cold front is analyzed, using the data from radar and surface meteorographs. The principal results obtained from this analysis are as follows:

1.) This cold front is accompanied by many line echoes having a definite orientation (ca. 35 —215 deg).

2.) There are many generation areas of echo cells along the surface cold front, where convective cells are generated successively. The generated cells move leeward (NE), increasing in number gradually. Thus many line echoes are formed, which extend from the cold front toward a definite direction, and the line echoes become parallel to the difference vector between the cell velocity and the velocity of generation area. As the echo cells seem to move with the 600-700 mb wind and the genera-
3.) As a result, when the cold front runs nearly meridionally, the line echo is situated on the warm-air side of the cold front and is considered to be a so-called prefrontal squall line. The line echoes are arranged on the cold-air side and compose the mesoscale pattern of precipitation behind the cold front, when the front runs nearly zonally.

4.) The mechanism of generation area is not studied in detail. However, the small low formed on the cold front is accompanied by several generation areas and is considered to be a large generation area of cells as a whole.

5.) In order to discriminate between the cold front and the prefrontal squall line, pseudo-wet-bulb potential temperature is analyzed.

Hurricane Studies

The Accuracy of Center Positions of Hurricanes as Determined by the Spiral Overlay Technique

C. L. Jordan

Spiral overlay positions of hurricane centers as reported during the years 1959–1962 have been extracted from the radar reports appearing on the teletype circuits. Verification of these reported positions have been made against positions read from the official hurricane tracks prepared by the U. S. Weather Bureau. The differences were somewhat larger than those obtained by Senn and Hiser, based on a study of radar films, but small enough to be of operational value in the absence of other data. Certain systematic features in the differences were noted which might prove useful in modifying the overlays.

Radar Composites of Hurricane Carla

H. E. Foster

Hourly radar composite photographs were prepared for the period during which Carla was under radar observation. The movement of echoes was studied in relationship to an irregularity in the storm trajectory.

Filling of Typhoon Eye over Land

Ichiro Imai

Some case studies were made of the deformation of typhoon eye as it moved inland. In general, the eye began to shrink a couple of hours before it reached the coastline. Upon entering the coast, complete filling occurred within an hour or so. In one case, the path of the typhoon eye turned to the left, as had already been described by Dunn et al. (1955). But some observations made at higher elevation angles seem to show that the upper portion of the eye was open and moved almost straight without turning.
Radar Measurements of the Distribution of Precipitation in New England Storms
Pauline M. Austin

Data in the form of range-corrected iso-echo contours as displayed on the PPI have been converted to numerical maps with digits representing equivalent rainfall rates in 5 by 5 mile squares. The data, which cover 85 storms and 530 hr of observations, include a variety of storm types: warm frontal and cold frontal precipitation, occluded fronts, coastal storms, squall lines and air-mass showers. Storms are grouped according to synoptic type, intensity of precipitation, and pattern on the radar scope. Spatial distributions and temporal variations in intensity are compared for the various groups of storms. Dependence of total precipitation amounts on large scale lifting and on convective activity, as indicated on the RHI, is also considered.

Digitized X Band Radar Echo in a Ten-Mile Square and the Occurrence of Precipitation
Roland J. Boucher

The probability of precipitation at the ground at a point within a ten mile square has been found to range from 0.6 to 0.7 for an echo coverage of $\frac{1}{3}$ to $\frac{2}{3}$ of the square to a probability of 0.8 to 1.0 for a completely covered square at ranges of 50 to 70 mi from the radar.

When no echo is observed within the square but is found within 100 mi of the radar, there is still a 0.25 probability that precipitation will be occurring at the point. The probability of occurrence of heavier hourly rates of precipitation also increases with density of echo coverage. Determining the onset of precipitation at a point from the arrival of echo in a square appears to be more reliable at inland locations where the incidence of very light precipitation is low.

Rainfall Determination from 0.86 and 1.87 cm Radar Measurements
C. W. C. Rogers and Raymond Wexler

Radar measurements of showers and thunderstorms were made at two wavelengths: 0.86 and 1.87 cm near Flagstaff, Ariz., during the summer of 1961. From these measurements, it is theoretically possible to determine rainfall rates from differential attenuation. However, difficulties arise because measurements are not simultaneous. Techniques require the evaluation of radial gradients of received power at the two wavelengths. The method appears feasible only during quasi-steady state conditions at points near the maximum rain intensity where the rainfall rate does not change appreciably with distance.

Rainfall Rate Measurement by Radar Using Two Radar Sets of Different Wave Lengths
Robert Hasbrouck Cartmill

This technique employs two radar sets of different wave lengths located side by side and requires that they range on identical volumes at the same time. The raindrops attenuate the average power received by each set at different rates as the beams traverse a precipitation area. This difference in attenuation rate, as measured by the change in range required to change the difference of the logarithms of the average power received a special amount, is used as an index of rainfall rate. With the present equipment performance capability, this procedure is applicable only to very high rates of rainfall. As the power resolution capability improves, lower rates of rainfall may be accurately determined.

Monthly Variations of Precipitation Echo Occurrences Across the United States
Lawrence E. Trappi

The U.S. Weather Bureau's network of weather radar stations provides a source of hourly data which indicate the presence or absence of detectable precipitation in the atmosphere within range of the radar. This paper is concerned with variations of precipitation echo occurrences as reported on hourly RAREPS by six WSR-57 radars along a line running from New York City to Sacramento, Calif. Monthly percentage frequencies of precipitation echo occurrences were computed for each station and compared to variations of precipitation amount.

Project Report on the Weather Bureau's Radar Hydrology Program
Allen F. Flanders

A resume will be provided of the various approaches and techniques being used at the Weather Bureau WSR-57 radar stations to measure and observe rainfall for hydrologic application. This will include reports on the progress being made to estimate rainfall using the yes-no db method as well as information on the stepped db multiple exposure and photo-integration procedures for determining heavy rainfall areas.

A Preliminary Analysis of a Grid Method of Determining Precipitation Amounts by Radar over the Upper Portion of the Columbia Basin
The Missoula Radar Staff and Hydrologic Services Division

Large portions of the Upper Columbia River Basin are in remote mountainous regions from which there are reports from very few precipitation measuring stations. The mountain top WSR-57 radar at Missoula, Mont., has under surveillance, within 100 n mi, most of northern Idaho and western Montana. By using the attenuators of the radar, attempts were made to measure quantitatively the precipitation amounts within 100 n mi of the radar. Some difficulties were encountered due to the blocking of the mountains, either partially or completely. Seasonal
variations in precipitation types gave varying correction factors which seem to show a pattern. Indications are that precipitation amounts can be determined with some accuracy in mountainous regions and this will result in a better determination of water available for run-off into the major river drainages.

**Doppler Radar Applications**

**Wind Velocity Measurement with Doppler Radar**

R. J. Pilié, J. E. Jiusto and R. R. Rogers

A wind measurement concept was formulated in which two Doppler radars are used to sense the motion of mafch introduced into the atmosphere. In determining the feasibility of this concept, exploratory field experiments were conducted with a single Doppler radar of modest performance characteristics. Comparative wind data obtained from the radar technique, by smoke trail photography, and by standard radiosonde methods are presented. Results of an error analysis, which includes specialized interpretation of Doppler spectra, are given to indicate appropriate radar methods for making wind measurements.

**The Measurement of Wind and Convergence by Doppler Radar**

P. G. F. Caton

A method is presented for the measurement of upper winds in precipitation conditions by Doppler radar. Although fundamentally similar to the techniques described recently by Lhermitte and Atlas, it appears to give certain additional useful information. By combining wind components at 10-deg intervals of azimuth over a wide sector, mean wind speed and direction may be measured at a number of heights simultaneously and the variation of wind both in space and time may be investigated. Results obtained during the advance of two warm-type fronts are presented.

The application of the Doppler technique to the measurement of convergence is examined and preliminary results are given.

**Precipitation Vertical Velocities and their Significance**

Roger M. Lhermitte and David Atlas

A C-band Doppler radar was used in vertically pointing mode to map the field of vertical particle motions in both stratiform and convective storms. The RMS velocity of the Doppler spectrum is mapped in time-height coordinates. Since velocity is virtually independent of reflectivity in the snow regions, snow trails imbedded in a general field of snow no longer appear clearly. Only anomalies associated with fast falling graupel and snow aggregates, or imbedded convective cells stand out. The transition to rain in the melting band is as expected, although occasional oscillations in velocity across the average melting band suggest either a fluctuating 0°C level or convective motions. Cellular convective motions are also implied in the layer 1 to 2 km below the 0°C level by a cellular stratum of alternating high and low fall velocities. In convective storms, occasional fall speeds up to 15 m sec⁻¹ are observed.

**Some Observations of Vertical Velocities and Precipitation Sizes in a Thunderstorm**

Louis J. Battan

Observations were made of a thunderstorm which formed over a vertically-pointing X-band pulsed-Doppler radar set. They show details of the vertical velocity field in the storm and yield information about the growth of the precipitation particles. It is shown that the maximum quantities of liquid water are associated with the updraft maximum. A downdraft starts early in the life of the cloud and is accompanied by precipitation particles which break up and evaporate under the cloud base.

**The Vertical Velocities of Angel Echoes**

Louis J. Battan

Observations of angel echoes have been made by means of an X-band vertically-pointing pulsed-Doppler radar set. Two types of echoes have been detected. Most of them appear to be discrete volumes of air whose vertical velocity is mostly upwards at speeds of 0.5 to 1.0 m sec⁻¹. It appears that they are buoyant bubbles of air having diameters of the order of tens of meters. The second type of angel echo was in the form of a shallow layer about 1000 ft thick. It lasted for more than one hour and was associated with a stable layer through which the humidity decreased rapidly with height. The signal intensity from the layer varied with time with maxima occurring at intervals of about 0.5 to 1.0 min. Vertical velocities in the layer varied from extremes of −3 to +3 m sec⁻¹ but were most often at −1 and +1 m sec⁻¹. Positive velocities were more frequent than negative ones. The observations suggest the existence of a wave motion in the layer.

**On the Possibility of Radar Detection of Clear-Air Turbulence**

P. L. Smith and R. R. Rogers

The potential usefulness of a radar system capable of detecting clear-air turbulence makes the design of such a system a problem of great interest. A theoretical analysis of the possibility of radar detection of atmospheric turbulence has been made, based on current turbulence theory and on reasonable radar system parameters. This paper presents the results of that analysis.

The scattering of electromagnetic waves from a turbulent region in the atmosphere is related to the Fourier spectrum of the spatial variations of refractive index within that region. Periodic variations of surprisingly small amplitude (less than 0.1 N-unit) would give a detectable radar target. In the atmosphere, however, the refractive index will vary in a random way because of turbulent mixing. The random fluctuations in refractive index will be significant in magnitude only when the
vertical gradient of the mean potential refractive index is large.

On the basis of presently available data, the results of the analysis indicate that in favorable cases the gradient of the mean index can be large enough to permit detection of atmospheric turbulence with pulsed radar. The greater sensitivity attainable with coherent radar techniques would make detection of turbulence possible in a larger number of cases. However, in the absence of a large gradient of the mean index, turbulence would not create a detectable radar target. Extensive radar observations of refractive index irregularities in the atmosphere are needed to determine whether radar detection of turbulence is possible on an operational basis.

**Weather Echo Signals in Doppler and Conventional Radars**

Roger M. Lhermitte

A comparison is made between echoes received by phase-coherent (Doppler) and conventional pulse radars from distributed targets such as precipitation or clouds. It is shown that a complete knowledge of the signals given by conventional radars can be derived readily from the Doppler power density spectrum, which is deduced directly from the radial speed distribution of the radar reflectivity density in the scattering medium. A theoretical treatment of signals for both types of radars as well as experimental tests of the theory are presented. Extension of this treatment is made to the case of scattering of light pulses (i.e., lasers) by media such as clouds or air molecules.

**Weather Radar Design and Display Techniques**

**On the Method of Quantitative Echo Intensity Measurement Used for the WSR-57 Radar**

S. G. Bigler and M. W. Brooks

Proper application of modern weather equipment requires performance calibration routines that are reproducible among stations. Quantitative echo intensity measurements for rainfall estimation, hail and severe weather identification, and coordinated network operation require careful calibration as well as standardized procedures to be followed by radar operators. The method adopted by the Weather Bureau for its WSR-57 radars is described.

**Vertical Echo Protrusions Observed by WSR-57 Radar**

Robert L. Smith

During periods of thunderstorm and anomalous propagation detection by the WSR-57 radar at Apalachicola, Fla., narrow vertical protrusions have been observed up to 70,000 ft on the RHI scope. Before these were observed with anomalous propagation, they were reported as heights of thunderstorm echoes. When they were observed with anomalous propagation, it became apparent that some serious errors in echo height reporting had been made. Observations of these protrusions in typical thunderstorm, shower, and anomalous propagation cases are discussed. This study points to the cause as being that of side lobe radiation. A case of the displacement and change in orientation of a bright band presentation is discussed as supporting evidence to the side lobe argument.

**Radar Parameters for Airborne Weather Reconnaissance**

H. V. Senn and H. W. Hiser

With the limitations of size, weight, and power requirements for radar equipment used in aircraft, the important radar characteristics are examined on a theoretical basis. Based upon this study, an attempt is made to determine optimum parameters for airborne weather reconnaissance radars for several different aircraft configurations and flight conditions. Particular attention has been devoted to radar equipment necessary in gathering radar meteorological data for research purposes.

**Minimum Requirements for a Meteorological Satellite Radar**

Arnett S. Dennis

During the past few years, a variety of systems have been suggested for adding weather radar to satellite instrumentation. In the present study, data from weather radars and other sources have been examined to determine the minimum requirements for a system which would provide a useful input to operational analysis and forecasting, and/or provide significant data for meteorological research. The results suggest a need for sensitivity corresponding to a minimum detectable rainfall rate of 1 mm per hr for a full beam, horizontal resolution of 4 mi and vertical resolution of 1 mi for the detection of a reasonable fraction of the precipitation scanned by the system.

The coverage requirements must be considered both in space and time. For polar orbits, a given region is scanned only once each 24 hr, and so the system would be useful in observing synoptic-scale, rather than meso-scale, precipitation areas. Proper identification of these requires coverage of a strip some 200 mi wide. Even this would not ensure detection of all such areas by a single satellite, as successive orbits would be over 1000 mi apart at the equator. An examination of proposed systems has shown none capable of fulfilling even the minimum requirements listed.

**A New Pulsed-Doppler Radar for Cloud Observations**

John B. Theiss and A. Richard Kassander, Jr.

A coherent pulsed-Doppler X-band radar for recording the vertical-velocity spectra of precipitation particles has been constructed at the University of Arizona. The basic operational principles of the system are illustrated, and the operation of the single sideband demodulator, which is used to separate the radar return from falling and rising reflectors, is discussed in some detail.

The original recording system consisting of audio
filters, a facsimile recorder, and a decimal printer is described and photographs of the radar output data are shown. It was found that the amount of data collected during a few hours operation was of such magnitude that a more automated recording and data reduction system was required. To meet this need, a four-track magnetic tape recording system was developed to record Doppler frequencies, time, range, and integrated video signals.

The tape system is briefly described along with the flow of information from the tape recording through the digital computer to its final form.

Performance capabilities of such a pulsed-Doppler radar are outlined and some fundamental limitations noted.

**Tube-Face Filters for Line-Space Compensation**

K. L. S. Gunn

The polar coordinates in which a PPI picture is painted makes line-spacing proportional to range. Thus, a constant video signal is mapped with brightness inversely proportional to range. Compensation can be achieved by a half-tone filter over the face of the tube, of least possible density at the edge. With it a constant video signal is mapped with uniform brightness. Several years' experience with filters of this sort supports their practicality. Production in quantity of the filters makes it appropriate now to compare their merits with those of electrical compensation.

**Facsimile Output for Weather Radar**

Marceli Wein

Use of facsimile paper for weather radar display permits a montage of several hours' CAPPI maps. Electrolytic paper is available with grey scale sufficient to carry the intensity information. The facsimile signal is obtained by rectangular scanning of fast-processed film at a rate of a few lines per second with a spot size of one square mile. This scanning provides helpful areal integration. As a result, the boundaries between successive shades of the stepped grey scale are enhanced, and so is the apparent contrast. The facsimile signal has a secondary use: it can be processed by counting circuits to yield the total mapped area covered by precipitation within each discrete intensity interval.

**A Signal Level Quantizer for Weather Radar**

Charles W. Niessen and Spiros G. Geotis

A device which provides the simultaneous display of several levels of signal intensity is described and some results with weather echoes shown.

**A New Air Force Weather Radar Set**

Wilbur H. Paulsen

The Air Force has under procurement a new C-band weather radar set that has a number of novel features in addition to being a low cost set. The use of a radome to eliminate wind loading and the placement of the RTM unit in a shelter at the base of the tower rather than on the back of the antenna has permitted a lightweight antenna, pedestal and drive system that has reduced costs considerably. Use of a direct view storage tube as the PPI indicator enables the set to be used in a well lighted room. Built-in test facilities provide for easy maintenance and assure high performance. Iso-echo circuits are provided and an alarm circuit actuated by intense echoes makes continual observance of the set unnecessary. Grouping of the indicators results in a console requiring much less floor space.

**Constant Height Antenna Scan**

Ralph J. Donaldson, Jr.

A technique is described for controlling the antenna elevation angle of a PPI-scan radar in such a manner that targets located along a line will be scanned at a constant, pre-selected height. The method should be particularly valuable for observation of a squall line at a rapid cycling rate. It could also be applied usefully in any situation where the width of the interesting part of an echo feature is small compared with its length, as, for example, an outer rain band of a hurricane.

**Data Processing**

STRADAP (STorm Radar Data Processor) Performance

David Atlas and Hugh J. Sweeney

This is an initial report on the performance of the digital STorm RaDar DaTa Processor (STRADAP) which has been in operation at the AFCRL Weather Radar Field Station since October 1962. During this period it has operated satisfactorily in one severe storm situation and a number of stratiform storms. Reliability is excellent with only minor breakdowns experienced. Operation is now virtually routine. Rendition of storm patterns is generally very good with only occasional errors. Storm reflectivities and heights are accurately reproduced; errors rarely exceed one class (6 db in reflectivity; 10,000 ft in height). Very few errors occur in stratiform storms. Sources of error will be discussed. The digital patterns are consistent both internally and sequentially, and check closely with those obtained by manual data reduction of conventional elevation-gain series. In the tornadic storm of 12 October 1962 the development and persistence of strong reflectivity and high storm tops correspond well with the region of severity at the ground. The STRADAP print-outs for a stratiform storm will also be discussed in relation to the storm's meso-scale structures. Although tests are not yet complete and certain deficiencies are apparent, STRADAP fulfills its primary objectives. The time is ripe for operation at least on a limited network-wide basis.

**A Processor for Weather Radar Data**

Mario Schaffner

A processor is described which will digitalize quantitative weather radar and print out the result by teletype-writer. It can also perform certain computations in various coordinate systems.
The heart of this device is a storage tube which stores one PPI (or RHI) representation at a time. The digitalization can be performed with different resolutions in space and in the number of signal intensity levels. The computations are: quantized representations, area covered by precipitation, total equivalent rainfall, intensity distribution, space correlations.

The processor will receive averaged range-corrected signals directly from the radar. It can be programmed to print out automatically, at preset intervals of time, routine sequences of analysis on the explored space. It may also be controlled directly by an operator for special types of analysis on particular areas.

A RADAR PRECIPITATION INTEGRATOR
Ronald T. H. Collis

A prototype precipitation measuring system is described. This system, which is installed at the U. S. Weather Bureau's experimental radar facility at Norman, Okla., operates with a WSR-57 radar. Using a stepped gain approach, weather echoes at each point of a grid of 141 points, regularly disposed over a circle of 200-mi diameter are quantized and recorded in pulsed digital form on punched tape. This record, which can be transmitted to remote points by standard teletype equipment, is processed by a simple relay computer to derive total accrued precipitation since reset at each point. This data is presented (directly in inches) on a series of electromechanical counters set out in a five-foot square map in positions corresponding to the grid.

The primary objective of the system is to provide operational data for river and flood forecasting from weather radar observations. The practical, operational aspects of this problem have determined the approach followed.

SOME USES OF A STORAGE TUBE IN WEATHER RADAR
Nobuhiko Kodaira

The characteristics of the storage tube will allow us to convert PPI scanning weather echoes into X-Y scanning pictures. By using this technique, the frequency component of the video signals can be reduced to voice bandwidth and also the areal measurements of weather echoes can be made very easily.

This paper describes the radar picture transmitting system through the voice channel line and the areal rainfall measurement equipment. Some examples of these systems will be shown.

USE OF A DIRECT VIEW DARK TRACE STORAGE TUBE IN A WEATHER RADAR
Wilbur H. Paulsen

Direct view dark trace storage tubes used as PPI indicators in the new Air Force Weather Radar Set AN/FPS-77 offer new and improved features in data presentation. The storage capabilities of the tube will enable the determination of the course and speed of a storm system and its component parts through generation of target trails. Integration of a weak return is possible by storage of successive scans thus enhancing the detectability of the signals. A weather pattern may also be stored indefinitely enabling an observer to make discrete RHI scans without necessitating reconstitution of a PPI pattern. Various techniques for Dark Trace PPI operation are developed so that its features are optimally utilized. The use of the Dark Trace Tube in simplifying the task of the observer will be stressed.

A SCAN-CONVERTER FOR WEATHER RADAR APPLICATIONS
C. A. Martin-Vegue and H. W. Hiser

A scan-converter system for electronically converting a radar PPI type presentation to a standard 525 line interlaced television signal is described. This system, while similar to existing storage tube type scan-converters, has been specifically designed to meet the requirements for using weather radar for pilot briefing in a weathervision system. Other applications for the scan-converter as a weather research or observation tool are discussed.

PAPERS GIVEN BY TITLE ONLY

STATUS OF WEATHER RADAR OBSERVATION IN JAPAN
S. Ohta and T. Shinohara

The basic idea of establishing a weather radar network, present radar locations, instrumentation and some operational uses in Japan will be outlined.

THE METEOROLOGICAL USE OF AIR DEFENSE COMMAND RADAR
John A. Mayer and Clyde P. Thomas

Under joint agreement between the Air Defense Command and the United States Weather Bureau, meteorological information from the Air Defense Command Radar Installation at Guthrie AFS, W. Va., has been made available to the Weather Bureau since September 1960. Despite problems inherent in such an operation, this radar has filled a major gap in Weather Radar Coverage. Meteorological capabilities of the FPS 67 and FPS 6 radars are discussed and evaluated; use of information obtained from the WBRU at Guthrie AFS is discussed.

USE OF THE M33 RADAR FOR METEOROLOGICAL STUDIES
D. Ray Booker and L. G. Davis

Several years of experience with the M33 radar have led us to believe that this excess military equipment is a valuable and versatile tool for meteorological research. The major components include a 1000-kw, 10-cm search radar with PPI presentation, a 250-kw, 3-cm tracking radar with A scope presentation and an analog computer with plotboards. The tracking radar can easily be made to track any passive target such as an aircraft or balloon and automatically plot the positions and velocities on various scales up to 50 mi. We have used this feature...
to investigate the undulations in an airstream caused by mountain waves, the buildup of localized convection over ridges, and the structure of winds surrounding showers and through cold fronts by tracking various types of balloons. We have also used the 3-cm radar pointed vertically to gather detailed, quantitative data for constructing time-height cross sections of precipitation. The range of the search radar has been extended to 200 mi and used in step-gain mode for quantitative observation of precipitation systems.

Other uses of the M33 system are described, including almost instantaneous reflectivity profiles in thunderstorms.

**Some Characteristics of Trackable Radar Angels**

D. B. Rai and T. H. Roelofs

Angel observations from a 5-cm tracking radar at Wallops Island during the period 1961-62 have been analyzed. The echoes have been observed and tracked in different meteorological situations ranging from fine weather to overcast skies and at heights up to 17000 feet. A comparison of these echoes with those from birds shows their character to be markedly different. Some of the points brought out by the analysis of these observations are presented and discussed. The horizontal velocities of the angel sources are in fair agreement with the air flow expected from the available upper wind observations. The height variations also show some interesting features which are quite consistent with the existing knowledge of vertical air motion associated with mesoscale systems. This suggests the possibility of utilizing such angel observations in studying small scale features of atmospheric flow.

**The Detection of Radar Echoes from the Clear Atmosphere**

R. J. Wagner and L. C. Conant, Jr.

During March, April and May of 1962, a "C" band radar with a peak transmitter power of 3 megawatts, an antenna gain of 47 db, and a receiver noise figure of less than 4 db, was used to sound the troposphere between 10,000 and 30,000 ft. Correlation was obtained between the observed radar backscatter power, the profile of windshear, and the gradient of the refractive index. This is believed to be the first time that consistent radar returns from clear air have been observed. The technique should have application to determination of wind fields and rapid analysis of the atmosphere at high altitudes.

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**The American Meteorological Society announces**

**a new Meteorological Monograph:**

**STATISTICAL PREDICTION BY DISCRIMINANT ANALYSIS**

**BY ROBERT G. MILLER**

with a Foreword by Thomas F. Malone

The limited amount of information contained in a set of meteorological predictors precludes any precise statement concerning which one of a number of possible future events will occur. For purposes of operational decision making the probability distribution over the possible events for given values of the predictors is required. The mathematical exposition of a technique for obtaining this distribution is presented. An objective procedure is proposed for excluding from the analysis any redundant or nonsignificant information.

Two numerical examples are provided which illustrate the application of the technique where the predictors are selected using the proposed procedure.—Robert G. Miller

... an important milestone along a tortuous path that has been followed by a number of investigators during the half a century ... advances during recent years in multivariate analysis, nonparametric methods, matrix techniques, decision theory and in developing the applications of probability theory, coupled with an almost explosive increase in the speed and capacity of electronic computers, have opened up attractive avenues or the application of statistics to meteorological prediction ... Miller's skillful extension and synthesis of these developments should do much to establish the framework within which some extremely interesting and productive work can be done ... Important groundwork has been laid for dealing with the kinds of distributions which must be reckoned with, sooner or later, in dynamical prediction.—Thomas F. Malone.

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All inquiries should be directed to the Society Headquarters,
45 Beacon Street, Boston 8, Massachusetts.
Training Courses in Air Pollution Presented by Public Health Service

The Public Health Service, through its Division of Air Pollution, will conduct a 1-week training course, "Meteorological Aspects of Air Pollution," 22-26 April 1963, in Cincinnati, Ohio. The course is designed for meteorologists, engineers, and other professional personnel responsible for or interested in the measurement and evaluation of the meteorological parameters affecting the concentration and diffusion of pollutants in the atmosphere. Particular stress is given to the methodology available for estimation of pollutant concentrations.

Three related training courses will be conducted from 29 April to 24 May 1963, also at Cincinnati. “Community Air Pollution” (1 week) opens the series. It is a broad technical course for supervisory technical personnel from public health, educational, and control groups and provides complete coverage of the air pollution problems that affect a growing community.

Following (6-17 May) is “Atmospheric Survey,” designed for engineers and other professional people engaged in the planning, conduct, and interpretation of atmospheric surveys. Emphasis here is on the economics of survey techniques. A 3-day survey is conducted by the trainees.

Concluding the series is the course “Source Sampling for Atmospheric Pollutants,” 20-24 May. This is designed for personnel concerned with the sampling of a gaseous effluent for the measurement of concentration of potential atmospheric pollutants. Emphasis is placed on the basic principles of source sampling and on the practical techniques required for the collection of a representative sample suitable for accurate analysis.

These courses are described in the Training Program Bulletin, which is available on request. Trainees may register for single courses or for a series. Address applications for the courses or requests for information to the Chief, Training Program, Robert A. Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati 26, Ohio, or to a Public Health Service Regional Office.

Opportunities for Graduate Study in Oceanography and Meteorology at the University of Michigan

Programs leading to the master’s or doctor’s degree in oceanography or meteorology-oceanography are being offered by The University of Michigan. Research assistantships and fellowships for graduate study in these fields are available.

The programs in oceanography and meteorology-oceanography at The University of Michigan are concerned with all aspects of water bodies, from the earth of their basins to the air above them. Many of the research efforts in these fields are conducted through the Great Lakes Research Division of The University of Michigan Institute of Science and Technology. The Division is primarily concerned with, but not restricted to, investigations of the Great Lakes, the largest source of fresh water in the world. Students will normally conduct their research aboard one of the research vessels operated by the Great Lakes Research Division. The Institute now operates a 114-foot research vessel, the “Inland Seas” (pictured), for mid-lake investigations and a 34-foot vessel, the “Naiad,” for inshore investigations. It is also building a 50-foot vessel to supplement the work of the other two. In addition the Institute maintains a complete oceanographic laboratory. Other facilities available for research are the Meteorological Laboratories, the Meteorological Field Station at the Willow Run Airport, and the Computing Center housing an IBM 7090 and analogue computers designed for meteorological and oceanographical problems.

The Division conducts an intensive research program aboard its vessels during the summer months and also undertakes investigations during the academic year, weather conditions permitting. The “Inland Seas” is equipped with all types of oceanographic gear, oceanographic laboratories, an electronics laboratory and an automatic recording meteorological system. Students may conduct a large portion of their research directly aboard the vessel.

Requests for information regarding the program or the assistantships and fellowships in oceanography should be addressed to Prof. John C. Ayers, 1069 North University Building, The University of Michigan, Ann Arbor, Mich. Students whose main specialization will be in the field of meteorology should address their requests to Professor E. Wendell Hewson, Department of Engineering Mechanics.

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