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Weather Radar Research at M. I. T.*

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IT HAS BEEN KNOWN for several years that microwave radar may provide the meteorologist with an entirely new and uniquely valuable tool. It has already seen extensive use as such by the armed services. Several different groups now contribute to our fundamental knowledge of the subject while a number of observational programs keep pace with them. To concentrate most particularly on the meteorological aspects of the problem, the U. S. Army Signal Corps has placed with the Meteorology Department, Massachusetts Institute of Technology, a research contract to explore some of the basic physics associated with weather-radar phenomena. The resultant project is known as M.I.T.'s Weather Radar Research.

With organizational activities starting in March, 1946, the group has grown to include a total of eighteen individuals. Our laboratory is placed within the Meteorology Department with a good radar site on the roof of the building. The Signal Corps has provided two radar systems, a wealth of instruments and other equipment. In addition, the Army Air Forces have furnished a B–17 aircraft and crew to make possible airborne measurements and studies.

Emphasis will be placed on a study of the scattering of microwave radiation by water and ice particles in the atmosphere. This branch of radar is commonly called "storm detection." Our immediate aim is to measure all, or nearly all, of the significant variables with sufficient accuracy to check and advance both microwave and meteorological theory.

The characteristics of microwave scattering are such that we have, at a particular wavelength, three primary quantities to observe and measure:—(*1*) the location in space and relative intensity or appearance on the scope of any radar echoes from weather phenomena (*2*) the average value of the signal intensity returned from the region under observation; (*3*) the frequency spectrum of the fluctuating signal intensity from the region. The first of these quantities involves a study of the appearance of precipitation echoes as presented on the different scopes (PPI, RHI, etc.). Complete photographic records will be kept. The second requires measurements of returned power integrated over a long enough time to give a measure of the average. The entire radar and measuring system must be carefully stabilized and recalibrated at frequent intervals. When corrected for attenu-

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ation these measurements may be used to determine the "reflectivity" of the region from which the signal is returned. If we assume all the particles to be spherical and to have the same size, and if that size is small compared to the wavelength, the return signal will be proportional to the number of particles per unit volume times the sixth power of their diameter. This means that the returned power is a measure of both the number of particles and their size, but not a unique function of either. The third quantity (frequency spectrum) results from the fluctuating nature of radar echoes from precipitation. The fluctuations are caused by interference changes due to the relative motions of the large number of drops or particles illuminated by the radar pulse. Measurement of the frequencies of fluctuation, which are in the audio range, may give some clue to turbulence and possibly other characteristics of the region measured.

The most significant meteorological quantities are those directly associated with the scattering particles, namely their size, shape, state (liquid or solid), the number per unit volume, and their relative motion. These quantities will be measured with four instruments carried aloft by the project's aircraft. First, the total liquid water content per unit volume will be measured by catching all liquid and solid particles in a "capillary cup" or collector [1] which will be heated, if possible, to melt any particles of ice or snow. This instrument indicates, with negligible lag, the volume of liquid water being collected per unit time from a known volume of air. Second, the size and number of spherical particles will be recorded by a light-beam-photo-cell instrument carried on the aircraft in a manner which allows the particles to pass undisturbed through the light beam. The attenuation caused by each particle becomes an electrical pulse whose size and frequency of occurrence are measured and indicated by electronic means. Third, the size and shape of solid particles will be measured by a sampling process which involves catching representative samples [2] and making plastic replicas of them for later observation and measurement under the microscope [3]. Fourth, the relative motion of the particles will only be observed very indirectly. Vertical accelerations of the aircraft will be continuously recorded, and a correlation will be sought between the magnitude of these accelerations and the nature of the frequency spectrum of the radar echo.

In addition, temperature, humidity, and other commonly measured quantities will be recorded in flight, visual observations made, and so forth. One of the most difficult phases of the program is that of accurate space-time coordination between air and ground observations. Fundamental accuracy limits are set by the "optical resolution" of the radar systems which in turn is determined by pulse length and beam width. We are attempting to control the lags and sampling errors of our airborne instruments in such a manner as to keep their readings within the accuracy limits set by the radar. The coordination machinery, involving good communications, timing, and complex operational procedures, has required a large fraction of our total effort.

The program has now reached a point where we have made a number of interesting radar studies from the ground, and a point at which we are just starting on the more detailed quantitative ground and air measurements. The ground radar measurements are being made at two wavelengths, 3 and 10 centimeters, and for the past two months have included measurements of the returned power from selected parts of certain storms. Measurements of frequency spectra will not be made for several months more.

Quite an extensive file of scope photographs has accumulated since our first radar system (10 cm SCR 615–B) began operation last July. Most of these are PPI photographs. They include cold fronts, warm fronts, and other types of precipitation. A cold front generally appears as a linear array of sharply defined cells. A warm front rain echo is weaker, more general and less sharply defined. Horizontal sheets or layers are observed aloft quite often, with or without some precipitation reaching the ground.

The second system placed in operation

(3 cm, AN/TPS–10A) uses RHI presentation. With its antenna pointed in any particular azimuth direction, it scans vertically and plots a vertical section through the atmosphere, altitude against range in rectangular coordinates. These vertical sections are particularly interesting. If precipitation is falling through the freezing isotherm it usually shows as a layer of strong radar return extending from the freezing isotherm downward for about 2000 feet. The return from below this layer is usually stronger than from above, in fact often nothing can be detected above the layer. The condition is typical of warm front types of precipitation in the winter. These phenomena have been observed by others and appear to be due to transformation of fine, dry snow to large agglomerated flakes, then to melting flakes, and finally to large raindrops with associated changes in rates of fall, etc. J. W. Ryde has calculated the relative intensities of radar return which should result [4]. We have not yet made quantitative measurements with the TPS–10 but the general appearance of these echoes on the RHI scope shows intensity changes of the same sign as those called for by Ryde. Shower-type precipitation appears as tall vertical columns on the RHI scope. These columns often have a marked slope apparently due to wind shear. Sometimes the slope is as much as 70° from the vertical, indicating, presumably, that the precipitation is in the form of snow.

As our work progresses, and particularly when we have obtained and analyzed results from a number of coordinated air-ground studies, we hope to make contributions in the following directions: First through the routine operation of our radar systems, we can certainly add to the general fund of observational material. Second, our simultaneous, quantitative measurements of both radar parameters and actual meteorological factors aloft should yield more complete physical data than have been previously available. And finally, we hope that through this observational work and these coordinated, quantitative measurements, we can develop improved radar techniques and a further knowledge of precipitation processes in the atmosphere.

References

[1] "Instruments for Measuring Atmospheric Factors Related to Ice Formation on Airplanes." By Vonnegut, Cunningham and Katz, De-Icing Research Lab., M.I.T. Army Contract No. W33–038 ac–5443, April 1946.

[2] "An Air Decelerator for Use on De-Icing, Precipitation Static and Weather Reconnaissance Planes." By V. J. Schaefer, G. E. Research Lab., Jan. 1945.

[3] "A Method of Making Replicas of Snowflakes." By V. J. Schaefer, *The Museum News*, September 15, 1941.

[4] "The Attenuation and Radar Echoes Produced at Cm. Wavelengths by Various Met. Phenomena." By J. W. Ryde, Research Lab. of G. E. Co. Ltd., Wembley, England, April 8, 1946.

An Ancient Meteorological Treatise

The editor of the *Bulletin* recently was offered by a second-hand book dealer, a very old book titled as follows:

"A Prognostication everlasting of right good effect, fruitfully augmented by the author, containing plaine, briefe, pleasant, chosen rules to judge the weather by the Sunne, Moone, Starres, Comets, Rainbow, Thunder, Clowdes, with other extraordinary tokens not omitting the aspects of planets, with a briefe judgment for ever, of Plentie, Lacke, Sickness, Dearth, Warres, etc. opening also many naturall causes worthie to be Knowne, etc." By Leonard Digges. Printed by Felix Kyngstone, 1605.

At a cost of $125, ye editor could not afford to indulge his curiosity nor satisfy his thirst for the sort of knowledge contained in this book, but he is led to wonder why our modern text-book writers cannot produce such optimistic, helpful and omniscient handbooks as this one appears to be. Has there been no progress in meteorology these last 300 odd years?