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On the Feasibility of Precisely Measuring the Properties of a Precipitating Cloud with a Weather Radar

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- Full Text

In this paper the results of an investigation are presented that are concerned with the feasibility of employing a weather radar to make precise measurements of the properties of a precipitating cloud. A schematic cloud is proposed as a model for interpreting the interaction of the radar energy with the cloud. Point values of the liquid-water concentration are estimated from measurements of the received power. The measurements were made under conditions which minimized errors arising from attenuation of the radar signal and a radar beam which is not completely filled with raindrops.

A continuity equation for liquid-water concentration is developed. The vertical speeds at the core of convective clouds are related to the spatial and temporal variations of the liquid-water content by means of this equation. The version of the continuity equation developed in this study represents an improvement over forms used previously. The new version accounts for the downward development of a radar echo at speeds faster than the fall speed of raindrops. This echo development is caused by the coalescence mechanism.

An error analysis is performed and it indicates that the percentage error of the measurements of the liquid-water concentration may be as much as 102.4%. The fractional error of the vertical speeds is + 1391.4% which results from the compounding of the experimental errors of the terms in the continuity equations.

To check the estimated magnitudes of the experimental errors a case study was performed. The echoes of 23 convective clouds were studied and 695 observations of liquid-water concentration were obtained. The observed magnitudes indicate that these estimates are of the correct order. The values of vertical speeds also indicate that the estimated error of this quantityis indeed large.

Possible methods for reducing the experimental errors are considered. This examination indicates that reasonably accurate measurements of liquid-water concentration can be made if high experimental standards are maintained. The use of calibrating instruments which are very accurate together with good experimental control may permit a reduction of the percentage error to less than 2O%. However, this study indicates that attempts to measure vertical speeds accurately by use of the continuity equation may not be too successful.

Introduction

Nature of the Problem

Before the meteorologist can attempt sagaciously to modify rainfall from clouds or before he can predict with any degree of certainty the distribution of unmodified rain over a geographical area, he must gain an understanding of the thermodynamic and kinematic principles that describe the formation and subsequent evolution of this rain. In the study of the physical processes of precipitation, an important consideration is the delineation of the spatial distribution of water in the cloud and the variations of this distribution with time.

The primary purpose of this study was to investigate the feasibility of using a weather radar to obtain precise measurements of the formation of rain in cumulus clouds. A secondary objective was the accurate measurement of the vertical velocities in a cloud that are related to the process of rain formation. Convective clouds form as the result of the expansion and consequent cooling of ascending air. Cloud droplets will form by the condensation or sublimation once a sufficiently high relative humidity is reached. In the case of clouds which extend to heights in the atmosphere where temperatures are much less than OC, an important mechanism for the formation of rain is one in which drops begin their life as ice crystals and then grow rapidly at the expense of surrounding water drops. When the ice crystals attain a sufficient size, they fall from the upper regions of the cloud and melt upon falling through the isothermal surface whose temperature is OC. To account for rain which falls from clouds that do not reach the height of the OC-isothermal surface, another mechanism appears to be operative. In these so-called "warm" clouds, drops form initially as small droplets by condensation and a small proportion of their number grows further by colliding with the remaining droplets. Growth of the droplets to raindrops will occur if there are adequate collisions and coalescence between the smaller cloud droplets. The probability of a collision is enhanced by vertical velocities that are strong enough to support the droplets and maintain a relatively high concentration in the cloud. Since the time for precipitation to appear at the ground is dependent on the vertical air speeds, the measurement of the rate of ascent was deemed to be important. The technique used to measure the vertical velocities was an extension of the method used by Runnels [1962] and Clark [1964]. The measurements of the water content of a cloud (and the changes of this water content) were made by using a weather radar in the Department of Meteorology of Texas A&M University. The technique used to measure the water content of the cloud was a special case of the general scattering problem in which electromagnetic waves interact with a collection of particles and a portion of the scattered energy is measured. From the spatial distribution of the scattered energy it is possible to deduce some of the physical properties of the scattering particles. The weather radar irradiates a portion of a cloud and measures the energy scattered in the direction of the radar set. The energy received at the radar site is proportional to the concentration of particles in the irradiated volume. An advantage in using a weather radar to measure the properties of a cloud is that the sampling may be performed without disturbing the sampled volume.

Conclusions

The results of this study indicate that reasonably accurate measurements of the liquid-water content in a cloud can be achieved with a radar operating at a wavelength of 1O cm if high experimental standards are maintained. The theoretical equation which relates the liquid-water content to the power received from a precipitating volume is expressed by Equation (47), viz.,

This equation has a systematic error that is small and can be accounted for if attenuation is negligible and the radar beam is completely filled. Use of the lO-cm wavelength assured the former while selection of convective echoes at ranges of less than 40 mi minimized the beam-filling error.

An error analysis of the experimental apparatus and technique was made. This indicated that the fractional error of measurements of liquid-water content is 1.O24. It was surmised that a part of this error may be compensated for if careful measurements are made of the variables in Equation (47). Twenty-three echoes were studied and 695 measurements of liquid-water content were obtained from them. The grouping of these data showed that the magnitudes of many of the values were reasonable, but a number of them were too large to be accepted. The gross-features of the scalar fields of liquid-water appeared to be physically reasonable.

A continuity equation for liquid-water content was developed in an effort to compute point values of the vertical speed in a cloud. This equation has an advantage over the continuity equation employed by Runnels [l962] and Clark 51964]. In the previously-used version it was assumed that the condensation of water vapor immediately produced large rain drops (lO0microns and larger in diameter). An integral expression for droplet growth by coalescence was used in the present equation in place of the condensation term. The use of a term for growth of drops by coalescence is more appropriate for a radar study since drops are not detected until their diameters are approximately 1OO microns. To reach this size, growth is assumed to be by the coalescence mechanism. The coalescence term also makes it possible to account for the downward development of an echo at a speed that is faster than the fall speed of raindrops. ... as being a typical one [Byers, 1965]. The point values of the vertical speeds computed from the continuity equation were vitiated by the compounding of the experimental errors. The scalar fields of w, for each echo, were quite unrealistic.

A study of the reduction of the errors of measurement indicated that reasonably accurate values of M (+ 16%) can be obtained through the use of better experimental control of day-to-day variations and accurate instruments to measure the parameters affecting the measured quantities. The use of accurate test instruments would permit the reduction of the semi-objective estimates of the errors used in this study by ascertaining systematic corrections for a part of the error. The remaining random component will be much smaller.

This study also indicates that attempts to measure vertical speeds accurately by use of the continuity equation may be frustrated because of the compounding of the experimental errors. An analysis of the errors associated with the derivatives of the scalar field of M will have to be performed before a definite answer can be given to the question of the usefulness of the continuity equation as a measuring relation.

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