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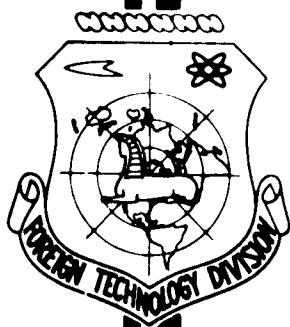
# TRANSLATION

ON THE ACCURACY OF RADAR MEASURING THE ALTITUDE OF CLOUDS

By

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## On the Accuracy of Radar Measuring the Altitude of Clouds

by

A. M. Borovikov, V. V. Kostarev

In this report are discussed results of comparative radar and aircraft observations of altitude boundaries of clouds. It was established, that with the aid of a radar station, developed at the TSAO, is possible a convenient for practical purposes altitude measurement of the upper boundaries of clouds with an accuracy of  $\pm 100$  m. The practical advisability of the employing the radar method for measuring the altitude of lower cloud boundaries is explained. This is due to the "masking" of lower boundaries of radar images of clouds on account of large particles falling out from the clouds.

Greater possibilities of the radar method in determining spatial position of clouds make it very alluring for practical employment, e.g. for meteorological services of aviation. It is therefore natural, that in recent years in the USSR as well as broad extensive research was conducted on the development of this method. But all or a predominant majority of radar systems used for that purpose detected not the clouds themselves, but the large droplet zone in them, which unconditionally considerably reduced the practical value of observation results, because the altitudes of clouds were measured with greater errors, and in some instances the clouds appeared to be generally locationally invisible.

In 1956-1958 in the radar lab of TSAO was developed a special radar set of meteorological application, offering the possibility of detecting not only large droplet zones, but also the clouds themselves. This station was constructed with the use of blocks and mechanisms of series apparatus, subjected to suitable modernization. Furthermore, <sup>for</sup> the mention set was especially developed a device for increasing the sensitivity of the receiver, based on the accumulation principle,

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the video amplifier circuit was changed and the antenna arrangement was enlarged.

As results of the adopted measures it was possible to increase the potential of the station to a value, assuring radar detection of clouds to necessary altitudes in a predominant majority of cases. It appears, that the realization of radar cloud observation on a 3 cm wave will increase the accuracy of obtained data in comparison with the use of a millimeter range, as result of lesser absorption, especially during propagation in precipitates.

To explain the possibilities of employing the developed radar system, and the accuracy of its measurement in the Fall of 1959 in the region of Krivoy Rog and in the Spring of 1960 in Vilno were carried out series of comparative aircraft and radar observations. In this report are given the results of these observations.

It is apparent, that to obtain reliable and comparable radar and aircraft data on the vertical distribution (altitudes of boundaries) of clouds it is necessary to fulfill certain basic requirements:

- maximum combination of these observations in time.

In this connection it became necessary to conduct a series of preliminary experiments for processing and defining the method of comparative aircraft and radar observations. As result was developed a suitable method of parallel observations, which later on, with certain variations was used in selecting comparative data.

Combining the measurements in space and time was attained in the following manner. The radar station was set up at the airfield directly in line with the homing station. At such an arrangement the beam of the radar system coincided practically with the beam of the radar homing station. The aircraft executed subsequent flights along the boundaries of clouds in the approach of homing stations. Between the aircraft and the locator was established direct UHF-radio communication. Thanks to this it was possible to warn the personnel of the location station about the approach of the aircraft to the homing station, around which

the locator station is located, and to transmit a signal at the moment it flew over the homing station.

It was established after a number of experiments that vertical radar sounding is most appropriate. At such a method the over flight of the aircraft over the location station was clearly noticed in form of a bright blip flying over the station of the aircraft on the radar nephogram, and in some instances also on the taps of the output register of the storing block in form of a sharp splash of the recording line. In addition, at vertical direction of the beam the accuracy of radar measuring cloud altitude increased<sup>1</sup>.

In view of the fact that the width of the radar beam was  $0.8^{\circ}$ , and the width of the beam of the homing radiostation about  $2^{\circ}$ , in some instances the passages of the aircraft over the radar homing station have not been noticed, and the passing moments were fixed upon the command from the pilot, transmitted over radio.

Basic measurements of cloud boundary altitude on the aircraft were carried out directly when passing the homing radar station. These measurements were later on used as reference measurements. But in connection with the fact that cloud altitude location measurements (gate passages) were carried out more frequently, than the passages of the aircraft along the boundary of the cloud directly through the locator beam (over the homing station), for the purpose of obtaining more numerical data and to compare the altitudes we used synchronous measurements of cloud boundary altitudes by the aircraft and locator directly in one point, as well as simultaneous altitude measurements by aircraft and locator at a certain distance - up to 1-2 km - at the time of approach or departure of the aircraft from the homing station along the boundaries of the clouds. In the first case were used direct cloud boundary altitude readings at the moment of approaching the

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1. Radar sounding not by vertical, but at a certain angle was done only in these sufficiently rare cases, when the upper boundary of the clouds appears to be situated too low (less than 300m).

homing station, in the second were taken into consideration the fluctuations of cloud boundary altitudes at the given moment on this section of the path. If the altitude, determined by radar, was within the limits of cloud boundary fluctuations, the altitude differential at this section was accepted as equalling zero.

During the second expedition observations of cloud altitudes were made in 18 flights. But suitable for comparison were only 13 flights (2 in first and 11 in second). The remaining could not be used neither because of the presence of precipitations under the cloud, having emitted a greater signal, masking the true position of cloud boundaries, or because the upper boundary was not reached, or, finally, of technical trouble of the station (which took place only in the first expedition). In these flights a total of 168 comparative measurements of upper cloud boundary altitude and 13 - lower altitude - were made.

Comparison results are given in fig. 1,2,3.

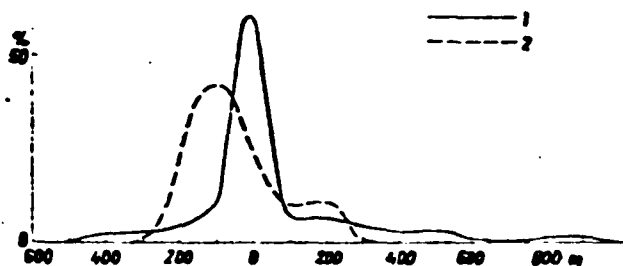


Fig. 1. Distribution  $\Delta N = N_r/1 - N_s$ . 1-upper boundary, 2-lower boundary.

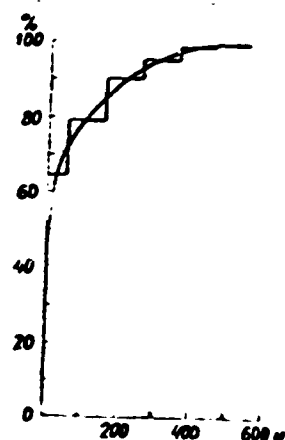


Fig. 2. Graph of stored repetition frequencies  $\Delta N$  for upper cloud boundaries.

As shown by comparison results, the accuracy of radar measuring the altitude of upper cloud boundary appears to be perfectly satisfactory. The mean arithmetic error of all comparative measurements equals only 8 m, and root-mean square - 135 m.

But these statistical parameters, even though they are sufficiently satisfactory in magnitude, yet they are still in our case very formal and insufficiently clearly defining the true accuracy of the method. Much more characteristic in this

respect are distribution graphs in fig. 1 and 2. As is evident, in 51% of all instances of comparative measurements the radar altitude coincided with the altitude according to the aircraft with an accuracy of  $\pm 50$  m, i.e. within measurement accuracy limits. Differences in 80% of instances do not exceed  $\pm 150$  m, i.e. the coincidence is satisfactory <sup>for</sup> practical purposes, e.g. for needs of aviation.

Nature of the distribution curve - sharp maximum at zero with steep drop to the right and left, considerable symmetry of right and left parts - clearly indicate, that considerable divergences ( $> 100$  m) in altitudes, measured by various methods, are not systematic, but bear a purely incidental nature and, apparently, appear to be the result of error in counting in visual estimation of magnitude of upper boundary altitude fluctuations, or errors of the radar operator.

True there is a certain prevalence in positive differences ( $N_R/1-N_S$ ), especially at greater magnitudes of these differences. Most likely, this is explained by the imperfectness of the system controlling the rate of motion connecting the strobepulse in the storage block, which requires accurate setting of the potentiometer and at an operator error results in overestimation of distances. It should be pointed out separately, that during the observations was not noticed the effect of precipitations under the clouds on the accuracy of radar data concerning the altitude of upper boundary. This is confirmed by an identical good conformity of parallel measurement results on the locator and the aircraft, and also by the identical nature of radar nephograms and storage recorder during the origination of discontinuation of precipitations along the distribution (propagation) path (i.e. between observed clouds and the radar). This circumstance is highly essential, because on an 8-mm wave should be anticipated considerable errors, caused by the absorption of energy of 8 mm radiation in clouds and precipitations.

Location measurements of upper cloud boundary altitude also allows to obtain data on the nature of upper cloud surface fluctuations and about the limits of

their fluctuations. To do this such observations should be carried out quite frequently—with an interval of 1–2 min. In fig. 3 are given schematic data of one such case of subsequent measurements. As is evident, a predominant majority of location altitudes (with the exception of two) lies within limits of upper surface altitude fluctuations, observed from the aircraft, and their end positions are in excellent conformity with analogous aircraft data.

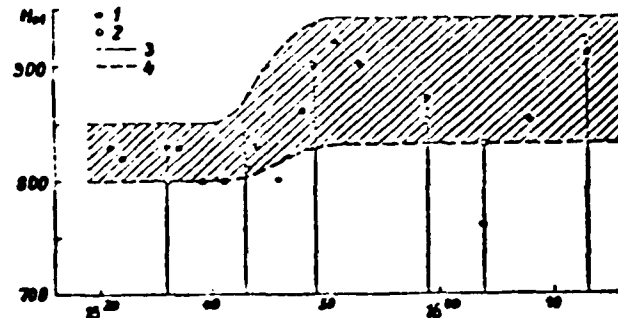


Fig. 3. Example of comparative observations on May 25, 1960; 1—altitude of upper boundary by radar; 2—altitude of upper boundary by aircraft; 3—moment the aircraft passes over the radar; 4—altitude fluctuation limits of upper cloud boundaries by aircraft observations.

As already mentioned before, in the carried out flights in addition to the observation of upper cloud boundaries a considerable number of comparative observations was made also over the lower boundary. But these observations have shown the inadvisability of employing the radar method in determining the altitude of lower boundary for the following reasons.

First of all radar determination of altitude of lower boundary is impossible when from the clouds are separated precipitations, because the latter issue a signal all the way down to earth. The repetition of such instances is high, especially in Fall–Winter season.

Secondly, data about the height of lower boundary of clouds by radar appear to be considerably distorted in these cases, when from clouds come out precipitations, which do not reach the Earth or visually invisible large particles. As shown by our data, such phenomena are observed quite frequently, whereby the large particles may fall out from the cloud at very great distances. Consequently, also in

these cases radar measurements of lower boundary altitudes are practically aimless.

In this way, suitable for measuring lower boundaries by radar methods are only the cases, when the cloud has absolutely no large particles, or when they do exist in the cloud, but do not fall out from it at greater distances.

The results of comparing lower boundary altitudes of such clouds are given in fig.1. It is evident, that the maximum of the distribution curve is shifted considerably to the left - in direction of lower location altitudes of the lower boundary. The reason for that is apparent, the dissemination of visually unseen large particles under the cloud. Consequently, also at such clouds the altitude of the lower boundary is in a large percentage determined with substantial errors. Furthermore, it is clear that the number of such clouds among all the clouds is small, and there are no methods for predicting whether the cloud has large particles or not.

But the above mentioned lack of perspectiveness of radar measuring lower boundary altitude should not be the cause for discontinuing efforts to reduce the lower altitude limit of location sounding, because such a reduction is necessary for measuring the altitude of upper boundaries of low clouds, lower than 0.6-0.7 km.

These causes considerably limit the possibility for radar determination of cloud boundaries at multilayer cloudiness and position of cloudless layers. The fact is, large particles falling out from higher situated layers may totally or partially mask the cloudless intervals between the layers.

Ordinarily at a relatively small vertical stretch of cloudless layers (to 400-500m) is observed total masking of same and multilayer cloudiness on the locator screen or on the storage attachment recording tape are fixed, as one solid layer. At a greater distance between the cloud layers, e.g. in presence of clouds of various formations, the cloudless layer between them is ordinarily spotted by radar, even though with distortion of the true vertical expansion of same depending upon the depth of fall out of large particles.

In this way, at present time with the aid of radar is possible to obtain only orientation data about the multilayer formation of clouds. If the radar does pick up cloudless layers, meaning such actually do exist, even if larger in magnitude. But the absence of these layers by radar data does not indicate that such layers do not truly exist.

The above given analysis of results of comparative aircraft and location (radar) observations allows to make a conclusion, that with the aid of aerological radar station is possible to measure upper boundary altitudes of clouds with an accuracy of  $\pm 100$  m in a range of from 0.8 to 6-7 km. and also to obtain orientation data on the presence of multilayer clouds. This in turn, indicates that the radar of given type is suitable for use for purposes of aviation meteorological services.

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