AD-766 563

DETERMINATION OF THE INTEGRAL WATER
CONTENT OF RAIN CLOUDS AND DEPTH OF THE
RAIN LAYER BY SHF RADIOMETRIC METHOD

A. G. Gorelik, et al

Foreign Technology Division
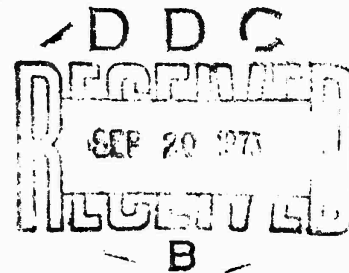Wrignt-Patterson Air Force Base, Ohio

14 August 1973

FOREIGN TECHNOLOGY DIVISION

DETERMINATION OF THE INTEGRAL WATER CONTENT
OF RAIN CLOUDS AND DEPTH OF THE RAIN LAYER BY
SHF RADIOMETRIC METHOD

by

A. G. Gorelik; V. V. Kalashnikov

DDC

SEP 20 1973

RECEIVED

B

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
Foreign Technology Division	UNCLASSIFIED
Air Force Systems Command	2b. GROUP
U. S. Air Force	

3. REPORT TITLE

DETERMINATION OF THE INTEGRAL WATER CONTENT OF RAIN CLOUDS AND DEPTH OF THE RAIN LAYER BY SHF RADIOMETRIC METHOD

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Translation

5. AUTHOR(S) (First name, middle initial, last name)

A. G. Gorelik; V. V. Kalashnikov

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
197	14	9

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. 3005	FTD-MT-24-700-73
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Foreign Technology Division
	Wright-Patterson AFB, Ohio

13. ABSTRACT

04

EDITED MACHINE TRANSLATION

FTD-MT-24-700-73

DETERMINATION OF THE INTEGRAL WATER CONTENT OF·
RAIN CLOUDS AND DEPTH OF THE RAIN LAYER BY SHF
RADIOMETRIC METHOD

By: A. G. Gorelik; V. V. Kalashnikov

English pages: 9

Source: Trudy Tsentral'noy Aerologicheskoy
Observatorii. Sputnikovaya
Meteorologiya, No. 103, 1972, pp. 31-41.

Country of origin: USSR

Requester: FTD/PDTW

This document is a SYSTRAN machine aided
translation, post-edited for technical accuracy
by: Sgt Frank C. Vaughn.

Approved for public release;
distribution unlimited.

All figures, graphs, tables, equations, etc. merged into this translation were extracted from the best quality copy available.

U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.
The use of diacritical marks is preferred, but such marks
may be omitted when expediency dictates.

DETERMINATION OF THE INTEGRAL WATER
CONTENT OF RAIN CLOUDS AND DEPTH OF
THE RAIN LAYER BY SHF RADIOMETRIC
METHOD

A. G. Gorelik and V. V. Kalashnikov

1.   The attenuation of the microradiowaves in clouds depends
on their meteorological parameters and can be found from the
value of the brightness temperature or directly by a decrease
in the signal from the extraterrestrial source of radio emission
[1, 2].   In the presence of clouds without precipitation the
absorption can be determined by the simplified procedure given
in [2, 3].   The connection between the radio brightness tempera-
ture and optical thickness of the radiation rain layer was
obtained as a result of the solution of the equation of the
transfer of microwave radiation in operation [4].   On the basis
of this dependence on the value of the measured brightness
temperatures a complete reduction in the clouds was determined
with precipitation in the form of rain (τ_k) which is equal to
the sum of the absorption in the light-droplet cloud layer (τ_0)
and the decrease in rain ($\tau_{\text{д}}$)

$$\tau_k = \tau_0 + \tau_{\text{д}}. \tag{1}$$

Absorption in the cloud layer is connected with the integral water content by relationship [2]

$$\tau_0 = k_\lambda(T)Q. \tag{2}$$

where Q is the integral water content of the clouds, k_λ is the specific absorption coefficient in the cloud, $\overline{T}$ is the effective cloud temperature.

The decrease in rain not allowing for the multiple dispersion also during known, distribution of the rain drops constant with height according to dimensions N(d) is equal to

$$\tau_д = \gamma_\lambda [\lambda; N(d)] h_д. \tag{3}$$

The specific attenuation factor in rain can be calculated according to formula

$$\gamma_\lambda = \frac{\pi}{4} \int_0^\infty d^2 K(m, \rho) N(d)\, \alpha d. \tag{4}$$

where $K(m, \rho)$ is the attenuation efficiency factor, the method and the results of the calculation of which for the microwave range are discussed in works [6, 7]. The equivalent depth of the rain layer $h_д$ is the parameter which characterizes the vertical extent of the rain layer, the drop spectrum in which remains invariable and the same as on the earth's surface.

$$h_д = \frac{\int_0^h \gamma[N(d; h)]\, dh}{\gamma[N(d; 0)]}.$$

Substituting in (1) relationships (2) and (3), we will obtain the system of equations for wavelengths λ_1 and λ_2

$$\tau_k(\lambda_1) = \gamma_{\rm a}(\lambda_1)\,h_{\rm a} + k(\lambda_1;\,\bar{T})\,Q,$$
$$\tau_k(\lambda_2) = \gamma_{\rm a}(\lambda_2)\,h_{\rm a} + k(\lambda_2;\,\bar{T})\,Q, \tag{5}$$

where the unknowns are the equivalent height of the formation of hydrometeors $h_{\rm д}$, and the integral water content of the light-droplet layer of rain clouds Q, from (5)

$$Q = \frac{A_2}{A}\,; \quad h_{\rm a} = \frac{A_1}{A}\,;$$

$$A_2 = \begin{vmatrix} \gamma_1 & \tau_1 \\ \gamma_2 & \tau_2 \end{vmatrix}; \quad A_1 = \begin{vmatrix} \tau_1 & k_1 \\ \tau_2 & k_2 \end{vmatrix}; \quad A = \begin{vmatrix} \gamma_1 & k_1 \\ \gamma_2 & k_2 \end{vmatrix}. \tag{6}$$

The analysis of the determinant |A| of system (5), carried out for all possible combinations of waves 0.8; 1.35; 2.5; 3.2 cm with the rainfall intensity 1-100 mm/h, showed that not only the absolute value |A| was not constant, but even the sign changed in a number of cases.

Calculations of the determinant were performed for the different spectra of drops with a concentration of 100-1000 m^{-3} and effective temperatures of the cloud layer changing within the limits - 20-20°C for every value of rainfall intensity. The spectra of drops were calculated in accordance with the procedure given in [8, 9].

The combination of waves 0.8-1.35 cm makes it possible to measure the integral water content of cloud layer and the depth of the rain layer in an interval of rainfall intensity of 1-5 mm/h during virtually all changes in the meteorological parameters. The pair of waves 2.5-3.2 cm is applied during rainfall intensity to 30 mm/h.

However, analysis of the determinant of the system of equations (5) does not give a complete representation of the possibility of the measurement of the integral water content and equivalent rain layer depth by the SHF-radiometric method, since the

numerators of formulas (6) $|A_1|$ and $|A_2|$ remain unknown due to the absence of experimental data on the interconnection of the water content of the cloud layer and intensity, the spectrum of the drops and rain layer depth. Final conclusions about the optimum combination of waves can be made according to the results of cooresponding experiments during the development of the method of the computation of the multiple scattering of microwave radiation by the rain drops.

2. The experimental work procedure and equipment were selected with the purpose of determination of integral water content of clouds not providing precipitation, or of clouds with precipitation in the form of rain. The measurements of the radio emission of cloudy atmosphere were conducted on a radiotelescope with an antenna 3 m in diameter, where the SHF-radiometric equipment of ranges 0.8 and 1.35 cm was established.

The basic technical specifications of equipment and the antenna feed circuit are given in Table 1.

Table 1.

λ cm	δT °K	Δf MHz	$\Delta\phi'$	α dB	$\eta(1 - \beta)$
0.8	2	30	8	2.05	0.70
1.35	1.2	30	9	2.01	0.75

In Table 1 δT is the fluctuation threshold of the equipment response with the time constant $\tau = 1$ s; Δf is the IF amplifer passband; $\Delta\phi'$ is the half-width of the radiation pattern of the half power level; α is the total losses in the wave guide tract; η, β are the efficiency factor and the isotropic scattering coefficient of the antenna.

The estimation of the effective temperature of the cloud layer was conducted by depth measurements of the upper boundary

4

of the clouds with the aid of the X-band R. S. and of the depth of the lower boundary with the aid of the IVO-1 device with the inclusion of the data on the vertical profile of the temperature, obtained from the results of radiosounding. The determination of the effective temperature with the known distribution of the water content w(h) with height of cloud and the vertical profile of the temperature can be conducted according to the formula

$$\overline{T} = \frac{\int_{h_1}^{h_2} T(h)\, k_\lambda(T)\, \omega(h)\, dh}{\int_{h_1}^{h_2} k_\lambda(T)\, \omega(h)\, dh}.$$

Precise estimation of the effective temperature of the cloud layer has great significance, since temperature dependence $k_\lambda(\overline{T})$ is clearly expressed [3] and the error in the determination of T_k at 1°K corresponds to the measurement error of the integral water content equal to 2%. The easiest method of the effective temperature estimation with the known height of zero isotherm, of the lower and upper boundaries of the cloud layer and with the vertical temperature profile consists of the measurement of the mean temperature of the cloud

$$T_{cp} = T_1 - \left| \frac{T_1 - T_2}{2} \right|.$$

where T_1 and T_2 are the temperatures at the lower and upper boundary levels of the clouds respectively.

A comparison of the values of mean T_{cp} and effective $\overline{T}$ temperatures in examples of clouds with the known two types of distribution of temperature and water content over the vertical extent of the cloud layer [5] shows that the greatest disagreements between T_{cp} and $\overline{T}$ reach 5°C with uneven distribution of the water content with height, and with a large drop in the temperatures

at the level of the upper and lower boundaries of the cloud layer (first type of distribution w(h) [5]). At the lesser vertical extent of stratus clouds and the more even distribution of water content with height (second type of distribution w(h) value $(T_{cp} - \overline{T})$ does not exceed 1°K.

Thus, during the determination of the integral water content of single-layer cloudcover the replacement of the effective temperature by the mean temperature is permissible; in this case the maximum errors of the single-wave measurements are found within the limits of 2-10% and can be decreased due to the estimations of the condensed moisture concentration with the height of the cloud during the known temperature distribution and the boundary height. With the presence of multilayer cloud-cover the problem of the determination of the effective temperature is complicated by the fact that the integral water content of the separate layers can vary greatly; therefore the estimation of the effective temperature of the drop moisture as the average between the separate layers can lead to more considerable errors than with single-layer cloudcover.

The distribution of the rain drops according to dimensions was measured by the trial and error method on filter paper. Samples were taken directly at the observation point. The exposure time of the samples was selected within the limits of 2-8 s. Radiothermal and radar surveillance were conducted in the regime of aircraft sounding. When selecting the radiotelescope antenna the effect of the width of the radiation pattern on the accuracy of the experimental results was considered during the comparison of these radiotelescope and ground-based measurements. With a wide radiation pattern (>1°) the comparison of the results becomes difficult due to both the large space averaging and as the result of the premature "lock-on" of meteorological objects

by the radiation pattern. So, with the antenna diameter of 0.6 m the time deviations of the ground-based and distance observations reached 40 s, whereas SHF-radiometric measurements were conducted with time constant of $\tau = 4$ s.

3. The results of the measurements of integral water content of clouds with precipitation in the form of rain, obtained by observations of waves of 0.8 and 1.35 cm with a simultaneous measurement of the distribution of the drops according to dimensions at the earth's surface, are represented in Table 2.

In Table 2 Q_0 is the integral water content of the cloud layer, $Q_д$ is the integral water content of rain, $h_д$ is the equivalent height of the formation of hydrometeors. The integral water content of rain was determined by measurements of the distribution of the drops of rain according to dimensions at the earth's surface and calculations of the equivalent rain layer depth.

The data in Table 2 show that the integral water content of the cloud layers in all cases exceeds the value of the integral water content of rain. The measurement accuracy of integral cloud water content with precipitation in the form of rain by the SHF-radiometric method is lower than the clouds not giving off precipitation, since in this case supplementary errors appear during the interpretation of the spectra of the rain drops, or as a result of wind deflection during the incidence time of the hydrometeors.

The 10% error during measurement of the radio brightness temperature of the attenuation factor in rain corresponds to the 15% determination error of the integral water content of the clouds. During the unfavorable combination of measurement errors of the attenuation factor and the radio brightness

temperature at 10% the error in the determination of integral water content can reach 25%. The greatest difficulty during the determination of the integral water content of the rain clouds appears as a result of the measurement error in the spectrum of the rain drops, and also as a result of the effect of the wind deflection of the drops.

The accuracy of the determination of integral water content depends also on the rainfall intensity during the measurements using fixed waves. For example, applying the combination of 0.8 and 1.35 cm waves it is necessary to keep in mind that with I > 10 mm/h the saturation of the radio brightness temperature is observed in the regime of vertical sounding on a wave of 0.8 cm. The rainfall intensity range in which the integral water content of the cloud layer can be measured is determined by the correct selection of the wavelengths at which the measurements of the radiothermal radiation of atmospheric formations are conducted. If in the combination of waves the minimum wavelength is selected equal to 1.35 cm, then the measurements are possible of the integral water content of the clouds with precipitation in the form of rain up to 30-40 mm/h intensity. In this case one keeps in mind the maximum intensity of rainfall which fell from a separate cumulonimbus cloud or with a source in nimbostratus clouds.

The determination of the integral water content of the light-droplet cloud layer with precipitation in the form of rain will make it possible to establish the interconnection between the quantity of water which is located in the cloud layer and that which precipitates to the earth in all stages of the development of the clouds both in the nucleus and in the peripheral areas of the cloud.

Table 2.

Q_0 kg/m²	$Q_д$ kg/m²	$h_д$ km	Q_0 kg/m²	$Q_д$ kg/m²	$h_д$ km.
1,1	0,49	1,5	1,6	0,18	1,5
1,8	0,55	1,7	2,2	0,10	0,7
1,2	0,50	1,9	1,3	0,22	1,8
0,9	0,58	2,6	1,3	0,18	3,3
1,2	0,53	2,0	1,2	0,13	1,7
1,3	0,59	2,2	1,4	0,09	0,8
2,7	0,20	0,6	1,1	0,14	2,5
0,5	0,72	4,0	1,5	0,09	1,0
2,4	0,26	1,0	1,1	0,16	1,6
2,7	0,09	0,5	1,9	0,16	1,3
2,5	0,17	0,7	1,7	0,10	0,8
1,1	0,72	3,0	1,9	0,08	0,6
1,5	0,54	1,8	2,0	0,14	0,5
2,0	1,27	2,9	1,1	0,29	1,0
0,9	0,67	2,4	1,4	0,27	0,3
0,6	0,26	1,7	2,6	0,18	0,6
1,4	0,24	2,1	2,3	0,29	0,8

BIBLIOGRAPHY

1. Кутуза Б. Г. Экспериментальные исследования ослабления и радиоизлучения дождя в СВЧ-диапазоне. Труды ГГО, 1968, вып. 222, 111—120.
2. Жевакин С. А., Троицкий В. С., Цейтлин Н. М. Радиоизлучение атмосферы и исследование поглощения сантиметровых волн. Изв. ВУЗов, радиофизика, 1958, т. 1, № 2.
3. Башаринов А. Е., Кутуза Б. Г. Исследование радиоизлучения и поглощения облачной атмосферы в миллиметровом и сантиметровом диапазонах волн. Труды ГГО, 1968, вып. 222, 100—110.
4. Волчок Б. А., Черняк М. М. Перенос микроволнового излучения в облаках и осадках. Труды ГГО, 1968, вып. 222, 83—99.
5. Боровиков А. М., Гайворонский И. И., Зак Е. Г., Костарев В. В., Мазин И. П., Минервин В. Е., Шметер С. М. Физика облаков. Гидрометиздат, Л., 1961.
6. Шифрин К. С. Рассеяние света в мутной среде. ГИТТЛ, М., 1951.
7. Шифрин К. С., Черняк М. М. Поглощение и рассеяние микрорадиоволн в осадках. Труды ГГО, 1968, вып. 222, 74—82.
8. Горелик А. Г., Смирнова Г. А. О связи водности и интенсивности осадков с радиолокационной отражаемостью метеособъекта при различных параметрах распределения капель по размерам. Труды ЦАО, 1963, вып. 48, 98—105.
9. Горелик А. Г., Гришкян И. В., Пеняз Л. А., Цыкунов В. В. Результаты совместных радиолокационных и наземных измерений микроструктуры осадков. Изв. АН СССР, сер. физ. атм. и океана, 1967, т. 3, № 9, 931—966.