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RESEARCH TRANSLATION

Vertical Thickness and Structure of Cloud Cover in Frontal Zones Over the Ukraine During Various Synoptic Processes

I.N. PONOMARENKO
A.M. KOSHENKO
T.N. ZABOLOTSKAIA

OFFICE OF AEROSPACE RESEARCH
United States Air Force

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AMERICAN METEOROLOGICAL SOCIETY
45 BEACON STREET
BOSTON, MASSACHUSETTS
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VERTICAL THICKNESS AND STRUCTURE OF CLOUD COVER IN FRONTAL ZONES OVER THE UKRAINE DURING VARIOUS SYNOPTIC PROCESSES

Translation of

Vertikal'naia moshchnost' i struktura oblachnosti v zonakh frontov nad Ukrainoi pri razlichnykh sinopticheskikh protsessakh

by

I. N. Ponomarenko, A. M. Koshenko, and T. N. Zabolotskaia

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L. G. HANSCOM FIELD
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VERTICAL THICKNESS AND STRUCTURE OF CLOUD COVER IN FRONTAL ZONES OVER THE UKRAINE DURING VARIOUS SYNOPTIC PROCESSES

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Data on the vertical thickness and detail of the spatial structure of frontal cloud systems during various processes were obtained by analyzing 650 aircraft flights in atmospheric frontal zones.

Frontal clouds have been treated in a great many papers [1, 2-12, 14, 16-22, et al.], but many questions still remain unanswered. Most of the papers have not related the spatial structure of cloud cover to synoptic processes, and their conclusions have been based on very limited data of aircraft soundings; consequently, many of the well-known general schemes of cloud-cover distribution in fronts [2,4,17,18, etc.] are unrealistic.

The present paper gives some results of a study of the spatial structure and fundamental characteristics of cloud systems in frontal zones over the Ukraine during various synoptic processes. The work is based mainly on data obtained by the authors jointly with their colleagues from the Department of Experimental Research of the Ukrainian Hydrometeorological Research Institute in 1961-62, during experimental flights with IL-14 flying laboratories in frontal zones over the steppe region of the Ukraine. A series of closely-spaced vertical soundings was made at three-hour intervals, or else vertical-horizontal soundings were made in flight around the cloud systems. The former were coordinated with temperature-wind radar soundings in the Dnepropetrovsk-Krivoy Rog region, while the latter were made mainly over the southern, western, and eastern parts of the Ukraine. In addition, data from a network of aircraft sounding points (Kiev, Khar'kov, L'vov, and Odessa) for the same time interval were combined with these data to obtain a number of characteristics.

A total of 650 aircraft flights were studied: 560 for 1961-62 and 100 for previous years (1956 through 60). The survey covered 208 fronts in the cold half of the year and 255 in the warm half.

Most investigators studying frontal cloud cover [1, 2, 4, 6, 7, 8, 13, 19] were seeking general schemes to relate the spatial distribution of the cloud cover to the type of front. This was of considerable interest to us as well; but we also wanted to obtain detailed characteristic data on the following: stratification of cloud systems, frequency of various cloud types and their characteristic associations in various processes, the height of the tops and bases of clouds, and the total thickness of the cloud systems and individual types most suitable for modification by coolants.

To obtain such data for various sections of a front, one must have considerably more material than we had at our disposal. Hence, we limited ourselves in the initial stage of the investigation to an analysis of data relating to the frontal zone ±(100-150)km from the frontal line at ground level. Therefore, all the characteristics are presented for the Ukraine as a whole, without division into separate areas.

The properties of frontal cloud systems during various synoptic processes are definitely related to differences in moisture content and its distribution in large-scale airflows, as well as to the redistribution of moisture as a result of cyclogenesis and anticyclogenesis, and frontogenesis and frontolysis. Hence, a classification of synoptic situations with respect to a given problem must foresee the selection of synoptic situations that correspond to the basic types of circulation and take into account the properties of atmospheric fronts for characteristic types of pressure topography. Proceeding from this, we have defined six characteristic synoptic situations:

1. Polar outbreaks. These processes are associated with the movement of cold fronts over the Ukraine from northeast or east along the southwestern or western edges of anticyclones.

2. Northwestern cold outbreaks are associated with several synoptic situations. They are characterized by the movement, from the northwest, of sections of cold fronts that are distant from cyclone centers and disposed along the southeastern edge of large anticyclones.

3. Northwestern cyclones. In the overwhelming majority of cases, these involve the passage over the Ukraine of sections of occluded, warm, and cold fronts*) along the eastern edge of stationary anticyclones over Western Europe. More rarely, portions of occluded fronts were observed close to a cyclone center.

4. Western cyclones. Sections of cold, warm, and occluded fronts, associated with cyclones moving across the northern Ukraine from west to east, pass over the Ukraine. During the cold half of the year, as a rule, they move along the northernedge of a high pressure zone above southern Europe.

5. Southwestern cyclones. Sections of warm, cold, and occluded fronts, located close to the centers of cyclones, pass over the Ukraine, moving from the central Mediterranean across the Carpathians to the northwestern Ukraine and on to the northeast.

6. Southern cyclones. Sections of warm and occluded fronts located close to the centers of cyclones, move across the Ukraine from the Black Sea toward the north or northeast. The small number of cases precluded the examination of the cloud cover of cold fronts in this process.

Tables 1, 2, and 3 give data on the structural details of frontal cloud systems by the individual processes.

The data in table 1 show that in both halves of the year, the most developed cloud systems are observed in the fronts of southern cyclones with tops at an average height of 4.5 to 4.7 km and bases at 1.3 to 1.6 km. The frequency of cloud tops at the 4 to 6 km level and more is 73 to 74%. Fronts of polar processes have very weakly developed cloud cover: on the average,

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*) The small number of cold fronts precluded their consideration.

Table 1

Height of Bases and Tops of Frontal Clouds and Their Frequency under Various Conditions

Process	Type of front	Cold half of the year: Mean height, km		Cold half of the year: Frequency (%) of height gradations of top, km			Cold half of the year: No. of fronts	Warm half of the year: Mean height, km		Warm half of the year: Frequency (%) of height gradations of top, km			Warm half of the year: No. fronts
		Base	Top	<2	2–4	>4		Base	Top	<2	2–4	>4	
Polar outbreaks	cold	1,36	2,31	64	21	15	14	1,85	3,13	11	71	11	7
Northwestern cyclones	warm	1,45	3,20	30	43	26	23	1,36	3,77	21	29	50	11
	occluded	1,41	3,64	25	31	42	12	—	—	—	—	—	—
Northwestern cold outbreaks	cold	1,05	3,44	26	44	29	27	1,51	3,65	29	29	43	28
Western cyclones	warm	1,91	3,78	27	27	47	15	1,57	4,17	28	28	44	18
	occluded	1,09	2,63	31	62	8	13	1,61	4,10	10	20	70	10
	cold	1,32	3,37	38	22	40	40	1,85	3,95	25	25	50	105
Southwestern cyclones	warm	1,81	4,16	29	34	37	38	2,59	4,55	—	41	59	22
	occluded	—	—	—	—	—	—	0,96	5,05	—	25	75	4
	cold	1,46	3,79	33	27	40	15	2,13	4,16	9	30	61	23
Southern cyclones	warm	1,31	4,71	18	9	73	11	1,58	4,51	5	21	74	19
	occluded	—	—	—	—	—	—	1,54	3,60	—	50	50	1

Table 2

Thickness of Frontal Clouds under Different Conditions

Process	Type of front	Cold half of the year: Average cloud thickness km	Cold: Frequency (%) of gradations of thickness, km <2	Cold: 2–4	Cold: >4	Cold: No. of fronts	Warm half of the year: Average cloud thickness km	Warm: Frequency (%) of gradations of thickness, km <2	Warm: 2–4	Warm: >4	Warm: No. of fronts
Polar outbreak	cold	0,49	100	—	—	11	1,13	86	11	—	7
Northwestern cyclones	warm	1,18	91	4	4	23	1,13	86	14	—	11
	occluded	1,14	75	17	8	12	—	—	—	—	—
Northwestern cold outbreaks	cold	1,06	89	7	4	27	1,15	82	14	4	28
Western cyclones	warm	0,95	87	13	—	15	0,89	94	6	—	18
	occluded	0,74	100	—	—	13	1,52	70	30	—	10
	cold	1,07	90	5	5	40	1,23	82	16	2	105
Southwestern cyclones	warm	1,10	87	11	3	38	1,38	77	14	9	22
	occluded	—	—	—	—	—	2,92	25	50	25	4
	cold	1,56	80	7	13	15	1,53	70	26	4	23
Southern cyclones	warm	2,24	55	36	9	11	1,62	74	21	5	19
	occluded	—	—	—	—	—	1,40	75	25	—	4

Table 3

Structure of Frontal Cloud Cover under Different Conditions

Process	Type of front	Cold half of the year: Frequency (%) of cloud cover: Cont. from 1-6km	Occupying part of the layer	Two-layer	three-layer and more	No. of fronts	Warm half of the year: Frequency (%) of cloud cover: Cont. from 1-6km	Occupying part of the layer	Two-layer	three-layer and more	No. of fronts
Polar outbreaks	cold	—	100	—	—	14	—	71	—	29	7
Northwestern cyclones	warm	5	69	17	9	23	—	72	21	7	11
	occluded	10	73	17	—	12	—	—	—	100	1
Northwestern cold outbreaks	cold	—	82	11	7	27	4	75	7	14	28
Western cyclones	warm	—	67	26	7	15	—	61	6	33	18
	occluded	—	92	—	8	13	—	50	30	20	10
	cold	2	78	2	18	40	1	76	5	18	105
Southwestern cyclones	warm	—	66	21	13	38	—	45	14	41	22
	occluded	—	—	—	—	—	25	—	50	25	4
	cold	7	60	26	7	15	4	65	14	17	23
Southern cyclones	warm	9	46	9	36	11	5	37	26	32	19
	occluded	—	—	—	—	—	—	50	25	25	4

their cloud systems do not extend above 2.5 to 3.1 km, while the layer they occupy is approximately 1 km thick.

The fronts of western and southwestern cyclones have weakly developed cloud cover, associated mainly with their passage over the Carpathians [15,16]. The considerable mean height of the cloud bases (without Frnb, Fr Cu, or Fr St) during these processes is striking: 1.81 to 1.94 km in the cold half of the year and 2.13 to 2.59 km in the warm half.

Inasmuch as frontal cloud cover is quite rarely continuous with height, it is interesting to treat the actual thickness of the cloud cover as the sum of the thicknesses of the cloud layers. This characteristic must be taken into account in calculating the water storage of frontal cloud systems and in determining their suitability for artificial modification.

The data in table 2 show the total cloud layer thickness in fronts in both halves of the year to be ≤ 1.5 km on the average; the latter figure increases somewhat (to 2.24 to 2.92 km) in the fronts of southern and southwestern cyclones. Thicknesses of 2 to 4 and 4 to 6 km are not encountered in more than 25% of the cases during the cold half of the year, increasing to 45% only in the fronts of southern cyclones. The frequency of these thickness gradations is somewhat greater in the warm half of the year, but rarely exceeds 50%. Polar outbreaks and western cyclones have the smallest total cloud thicknesses (0.49 to 1.13 and 0.74 to 1.52 km, respectively). Thicknesses of 2 to 4 km were not recorded in polar outbreaks during the cold half of the year.

Frontal cloud cover above the Ukraine is generally stratified during all processes (table 2). Insufficient data from instrument measurements of cloud boundaries have precluded much investigation of this feature of frontal cloud systems, and the stratification of the clouds of cold and occluded fronts have been particularly neglected. The stratification of warm frontal clouds has been investigated to a somewhat greater extent: already in 1934, Bergeron indicated that conditions for cloud-cover stratification exist in a warm front, basing his conclusions on the nature of the upgliding of warm air. Several authors later proposed schemes for the stratification of warm frontal clouds, generally separating high Ns-As clouds from the main frontal cloud system.

The studies by L. T. Matveev and P. I. Smirnov [11, 18] occupy a rather special position. Proceeding from a qualitative-theoretical analysis of the distribution of vertical velocities, these authors presented diagrams of the spatial structure of frontal clouds, anticipating several cloud layers.

Baranov [2] obtained the basic characteristics of the stratification of frontal clouds for the entire European USSR and for several individual points, based on a synoptic-statistical analysis of aircraft sounding data. The synoptic situation was not taken into account in analyzing the data, so that the characteristics obtained differed very little for the different types of fronts. Non-stratified cloud cover was observed in 40 to 44% of the cases in warm and occluded fronts, and in 52 to 53% of the cases in cold fronts.

The data in table 3 indicate a less developed stratification of cloud cover. Nonstratified cloud cover predominates in all types of processes; it is relatively thin and occupies part of the 1 to 6 km layer. The obvious discrepancies of the data are probably due to more than our failure to consider the high clouds. The cloud cover is most stratified on the periphery of frontal cloud systems; several investigators [4-6, 17] attribute this to unequal distribution of advection and vertical motions with height. Stratification is not as frequent directly on the frontal line or strictly within the frontal zone. Hence, analysis of the data with and without allowance for the distance from the frontal line can produce completely different results. It is clear from the data of table 3 that the spatial structure of the cloud cover differs markedly in sections of the frontal zones at different distances from the frontal line. In the overwhelming majority of cases, a two-layer cloud system is observed directly above a frontal line: the lower layer may consist of Ns-As, Ns, or Sc, the upper layer of Ci, Cs, or Ac.

Unlike the characteristics already considered, cloud cover stratification is less dependent on synoptic conditions (table 3), increasing slightly (33 to 34%) only in fronts crossing the Carpathians in western processes [cyclones] and in the movement of southwestern cyclones; the differences are less marked in other processes.

The characteristics of the basic cloud system of Ns and Ns-As fronts are of the greatest interest for solving problems connected with the meteorological safeguarding of aircraft flights and with artificial modification. In the cold half of the year, the spatial distribution of Ns and Ns-As in polar outbreaks and northwestern cold outbreaks is analogous to the distribution presented in the general characteristics (table 1). The thickness of the layer containing the cloud system increases by an average of 1.5 km with motion of southern cyclones when Ns-As are present. On the other hand, the thickness decreases and the Ns-As layer rises in fronts crossing the Carpathians. During the warm half of the year, the position of the top nearly agrees with the data given in table 1, but the bottom rises sharply (1.0 to 1.5 km). In this regard, the thickness of the layer where Ns-As occur is noticeably less in the warm half of the year. This is most noticeable in polar outbreaks, northwestern cold outbreaks, and the motion of southern cyclones.

The total thickness of Ns and Ns-As compared with the data in table 2 is considerably more in the cold half of the year and less in the warm. Thicknesses of 1 to 2 km prevail in all synoptic situations, while thicknesses of 2 to 4 km are more frequent (67%) only in the fronts of southern cyclones during the cold half of the year. Thicknesses of 4 to 6 km are not observed in all synoptic situations during the cold half of the year and are completely absent in the warm half of the year.

According to table 4, which presents data on the frequency of continuous (vertical) and stratified Ns and Ns-As cloud cover, two-layer and three-layer structures occur noticeably more often in the presence of Ns and Ns-As. In the cold half of the year, depending on the synoptic situation, cloud cover can be observed in 12 to 63% of the cases; three-layer

Table 4

Frequency of Continuous (Vertical) and Stratified Cloud Cover in Fronts with Ns and Ns-As

Process	Type of front	Frequency (%) of cloud cover							
		Cold half of the year				Warm half of the year			
		Cont. 1-6 km layer	Occupied part of the layer	Two-layer	Three-layer and more	Cont. 1-6 km layer	Occupied part of the layer	Two-layer	Three-layer and more
Polar outbreaks	cold	—	100	—	—	—	—	—	—
Northwestern cyclones	warm	9	73	18	—	—	80	20	—
	occluded	12	75	12	—	—	100	—	—
Northwestern cold outbreaks	cold	—	83	17	—	—	86	11	—
Western cyclones	warm	—	37	63	—	—	40	20	40
	cold	—	72	21	7	—	57	14	29
	occluded	—	100	—	—	—	67	—	33
Southwestern cyclones	warm	—	62	31	8	—	69	—	31
	cold	12	63	25	—	—	75	—	25
	occluded	—	—	—	—	—	25	50	25
Southern cyclones	warm	17	33	33	17	—	43	43	14
	occluded	—	—	—	—	—	100	—	—

cloud cover, however, occurs only in the movement of fronts from the south and west (7 to 17%). Ns-As cloud cover is most characteristic of warm fronts in western cyclones (63%) and the movement of cyclones from the south (50%) and southwest (39%).

Stratified Ns and Ns-As are much more frequent in the warm half of the year, especially during western, southwestern, and southern cyclones, and are more frequent (75%) than single-layer Ns-As in occluded fronts moving from the southwest. Three-layer Ns-As also characteristically outnumber two-layer in western and southwestern cyclones during the warm half of the year.

The data in table 4 apparently lead to an unexpected conclusion: fronts with Ns-As have a thicker and more stratified cloud system, or, in other words, stratified cloud cover is more characteristic of active fronts. However, the general limitation of stratification to fronts crossing the Carpathians is indicative of the regional nature of this feature of the spatial structure of clouds over the Ukraine [15, 16].

Cloud formation and other details of the spatial structure of cloud systems are definitely associated with stratification of the air, the distribution of vertical motions, turbulence, the distribution of advection with height, etc. Since the predominance of a particular cloud type or cloud complex in frontal zones is indicative of certain conditions for cloud formation, it is interesting to examine their frequency in various synoptic processes.

The basic cloud system of Ns-As fronts does not predominate even in the cold half of the year (table 5), but is characteristic only of warm and occluded fronts associated with northwestern (52 to 67%) and southern (50 to 57%) cyclones. Ns-As and Sc-Ac are nearly equiprobable in other synoptic situations, while St and Cu-Cb cloud types are rarely encountered. The cold fronts of southwestern cyclones, in which Cu-Cb are quite frequent (21%), constitute an exception. Ns-As never predominate in the warm half of the year, except for occluded fronts of southwestern cyclones, warm fronts, and the occluded fronts of southern cyclones, in which the frequency of this cloud system reaches 83, 55, and 50%, respectively.

Hence, it appears that cloud systems of atmospheric fronts differ considerably from general systems. The presence of a particular cloud complex is only slightly dependent on the type of front, being determined mainly by the macrosynoptic situation. Regardless of the type of front, the Ns-As cloud system is mainly characteristic only of sections of fronts located close to cyclone centers. Ns-As and Sc-Ac cloud systems are equiprobable in fronts passing along the southeastern and eastern edges of anticyclones or merely remote from the cyclone centers. Subfrontal Sc clouds and the Sc-Ac system are characteristic of the cold fronts of polar outbreaks moving from the northeast or east. The Cu-Cb convective cloud system of the warm half of the year is more definitely associated with cold fronts, but is also mainly characteristic of sections of fronts close to cyclone centers. Sc-Ac and Sc are equiprobable in sections of fronts remote from cyclone centers.

Conclusions

The spatial structure of frontal cloud systems and the predominance of a particular complex of cloud types is slightly dependent on the type of front, but mainly dependent on the macrosynoptic situation, thus explaining the sharp differences in vertical extent and spatial structure of cloud systems in frontal zones with different synoptic situations.

1. The most developed cloud systems in both halves of the year are observed in the fronts of southern cyclones, with their tops at an average height of 4.5 to 4.7 km and their bases at 1.3 to 1.6 km. Fronts of polar outbreaks have very weakly developed cloud cover: their cloud systems do not extend above 2.5 to 3.1 km, and the average thickness of the cloud cover layer is approximately 1 km. Passage across the Carpathians weakens the cloud systems of western and southwestern cyclone

Table 5

Frequency of Fronts with Various Types of Clouds

Process	Type of front	Cold half of the year: Frequency (%) of clouds: Ns–As	St	Cu–Cb	Sc	Sc–Ac	High clouds only	No. of clouds	Warm half of the year: Frequency (%) of clouds: Ns–As	St	Cu–Cb	Sc	Sc–Ac	High clouds only	No. of clouds
Polar outbreaks	cold	15	–	–	51	31	–	13			43	11	43	–	7
Northwestern cyclones	warm	52	–	–	26	17	1	23	38		15	23	23		13
	occluded	67	–	–	11	11	11	9	–		–				–
Northwestern cold outbreaks	cold	38	3	–	24	35	–	29	26	–	26	22	26	–	27
Western cyclones	warm	47	7	7	27	13		15	33	–	11	6	39	11	18
	occluded	29	–	–	29	36	7	14	30	–	20	20	30	–	10
	cold	38	13	3	21.	26	–	39	23	1	36	7	32	1	90
Southwestern cyclones	warm	38	6		24	32	–	31	33		19	–	43	5	21
	occluded	–	–	–	–		–	–	83	17	–		–		6
	cold	57	–	21	7	14		11	27	–	45	5	23		22
Southern cyclones	warm	50	7	–	29	14	–	14	55	–	9	5	32	–	22
	occluded	–	–	–	–	–	–	–	50	–	–	–	50	–	4

fronts, but the average height of their cloud base is characteristically high: 1.81 to 1.94 km in the cold half of the year and 2.13 to 2.59 km in the warm.

2. The total thickness of the cloud layers in frontal zones above the Ukraine is relatively small: in neither half of the year does it exceed 1.5 km on the average, increasing to 2.24 to 2.92 km only in the fronts of southern and southwestern cyclones. The average total thickness of the basic frontal cloud system (Ns or Ns-As) is markedly higher than the total thickness of the cloud system in the cold half of the year and lower in the warm half of the year. In the cold half of the year, thicknesses of 2 to 4 km occur in 67% of southern cyclone fronts, while thicknesses of 4 to 6 km are not observed in the warm half of the year.

3. Frontal cloud systems are stratified primarily in the peripheral portions of frontal zones. In most cases, a two-layer cloud appears directly above the frontal line; its lower layer may be Ns-As, Ns, or Sc, while the upper may be Cs, Ci, or Ac. The stratification of the cloud cover is less dependent on the synoptic situation. Slightly increased stratification (33 to 55%) is observed only in frontal zones passing over the Carpathians in western processes and in the motion of cyclones from the southwest and west.

Literature Cited

1. Baranov, A. M. Frontal Clouds and Flying Conditions in Them (Frontal'nye oblaka i usloviia poletov v nikh). Leningrad, Gidrometeoizdat, 1964. 236 p. [MGA, 16.1-8.]

2. Baranov, A. M. "The stratification of frontal clouds" (O rassloennosti frontal'nykh oblakov), Meteorologiia i Gidrologiia, No. 8, 11-15, 1962.

3. Borovikov, A. M., I. I. Gaivoronskii, et al. The Physics of Clouds (Fizika oblakov). Leningrad, Gidrometeoizdat, 1961. 458 p. [MGA, 13.8-12.]

4. Zak, E. G. "Frontal cloud systems" (Frontal'nye oblachnye sistemy), Russia. Glavnoe Upravlenie Gidrometeorologicheskoi Sluzhby, Nauchno-Issledovatel'skoe Uchrezhdenie, Trudy, Series II, Sinopticheskaia Meteorologiia, No. 14, 1946 [MAB, 6F-382, 1955].

5. Zak, E. G. and A. M. Borovikov. "The evolution of the horizontal structure and phase state of frontal clouds" (K voprosu ob evoliutsii prostranstvennoi struktury i fazovogo sostoianiia frontal'nykh oblakov), Moscow. Tsentral'naia Aerologicheskaia Observatoriia, Trudy, No. 7: 22-38, 1952 [MAB, 8.9-253].

6. Zak, E. G. "Experimental investigation of the cloud systems of a warm front" (Eksperimental'noe issledovanie oblachnykh sistem teplogo fronta), ibid., No. 15, 1956.

7. Zubian, G. D. Synoptic-Aerological Investigation of Atmospheric Fronts (Sinoptiko-aerologicheskoe issledovanie atmosfernykh frontov). Leningrad, Gidrometeoizdat, 1955. 120 p. [MAB, 8.10-26.]

8. Zubian, G. D. "Some characteristics of cloud systems of stable fronts" (Nekotorye osobennosti oblachnykh sistem malopodvizhnykh fronto), Meteorologiia i Gidrologiia, No. 11, 1952.

9. Zverev, A. S. Synoptic Meteorology (Sinopticheskaia meteorologiia). Leningrad, Gidrometeoizdat, 1957. 558 p. [MAB, 9.9-8.]

10. Kozharin, V. S. "Role of turbulent exchange in the formation of the spatial and internal structure of stratiform clouds" (Rol' turbulentnogo obmena v formirovanii prostranstvennoi i vnutrennei struktury oblakov sloistykh form), Meteorologiia i Gidrologiia, No. 2: 3-9, 1957 [MAB, 10.3-293].

11. Matveev, L. T. "Some problems of the theory of the formation and evolution of stratified cloud cover" (Nekotorye voprosy teorii obrazovaniia i evoliutsii sloistoobraznoi oblachnosti), Leningrad. Arkticheskii i Antarkticheskii Nauchno-Issledovatel'skii Institut, Trudy, 228(1), 14-37, 1959.

12. Matveev, L. T. and V. S. Kozharin. "The role of turbulent mixing in the formation of the structure of stratiform clouds, I" (Rol' turbulentnogo peremeshivaniia v formirovanii struktury sloistoobraznykh oblakov, I), Akademiia Nauk SSSR, Izvestiia, Seriia Geofizicheskaia, No. 11, 1338-1353, 1956 [MAB, 9.6-209].

13. Matveev, L. T. "Conditions for the formation and evolution of clouds under the influence of vertical currents and turbulent exchange" (Usloviia obrazovaniia i evoliutsii oblakov pod vliianiem vertikal'nykh tokov i turbulentnogo obmena), ibid., No. 1, 130-140, 1961.

14. Niukhnia, O. V. and I. N. Ponomarenko. "Spatial structure and cloud cover of fronts above the southern part of the European USSR during polar outbreaks" (Prostranstvennaia struktura i oblachnost' frontov nad iugom ETS pri ul'trapoliarnykh protsessakh), Kiev. Ukrainskii Nauchno-Issledovatel'skii Gidrometeorologicheskii Institut, Trudy, No. 43, 1964.

15. Ponomarenko, I. N. and L. I. Basanets. "The influence of the northern part of the Carpathians on the evolution of frontal cloud cover over the Ukraine" (Vliianie severnoi chasti Karpat na evoliutsiiu frontal'noi oblachnosti nad Ukrainoi), ibid., No. 43, 1964.

16. Ponomarenko, I. N. and L. I. Basanets. "The orographic evolution of frontal clouds in the northern Cis-Carpathians" (Orograficheskaia evoliutsiia frontal'noi oblachnosti v Severnom Prikarpat'e). Akademiia Nauk SSSR, Mezhduvedomstvennyi Geofizicheskii Komitet, Biulleten, No. 6, 1963.

17. Pchelko, I. G. Flying Conditions in Frontal Zones over the European USSR (Usloviia poletov vo frontal'nykh zonakh nad Evropeiskoi chast'iu Soiuza). Moscow, Gidrometeoizdat, 1941.

18. Smirnov, I. P. "The problem of upglide and the type of cloud cover of a warm front" (K voprosu o voskhodiashchem skol'zhenii i forme oblachnosti teplogo fronta), Leningradskii Gidrometeorologicheskii Institut, Trudy, No. 2, 1950.

19. Sovetova, V. D. "The effect of the Ural Ridge on the evolution of frontal clouds, " (Vliianie Ural'skogo khrebta na evoliutsiiu frontal'noi oblachnosti), Moscow. Tsentral'nyi Institut Prognozov, Trudy, No. 79, 12-24, 1959.

20. Sawyer, J. S. and F. E. Dinsdale. "Cloud in relation to active warm fronts near Bircham Newton, 1942-46," Great Britain. Meteorological Office Professional Notes, 7(115), 1955 [MAB, 6.10-149].

21. Sawyer, J. S. "Temperature, humidity, and cloud near fronts in the middle and upper troposphere," Royal Meteorological Society, Quarterly Journal, 84(362): 375-388, 1958.

22. Matthewman, A. G. "A study of warm fronts," Great Britain. Meteorological Office Professional Notes, 7(114): 1955 [MAB, 6.10-149].