APPLICATION OF SODAR SOUNDING TO STUDYING INFLUENCE OF SYNOPTIC CONDITIONS ON THERMAL STRATIFICATION

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Influence of synoptic conditions on stratification of the lower 800 m *air layer over Moscow is studied on hourly data basis using routine sodar sounding during* 7 *months. We propose a technique for parallel analysis of pressure fields and geographic types of prevailing air masses (when the type can be determined unambiguously). The salient feature of the analysis is high discreteness in time up to* 2–3 *hours. This makes it possible to study short-time variations of temperature stratification in detail for the first time. The colder is the air mass, the more often thermal convection and surface inversions take place in warm and cold period of the year, respectively. However, surface inversions are observed rarely in cyclone rears in winter during the hours of air mass invasion. In summer, no synoptically caused distinctions in recurrence of surface inversions were detected. Elevated inversions are always observed more often in centers of anticyclones and at ridge axes; in cold period, they are observed in warm air masses too. Besides the main task of this study, some peculiarities in the air mass transformation over Moscow in different months of the year are discussed.*

Thermal structure of the atmospheric boundary layer (ABL) over towns is rather complicated and highly variable. Synoptic conditions also show an appreciable influence on it. The aim of this study was to accurately reveal certain fine regularities in this influence. Among the variety of synoptic connections, we consider here the variations of the vertical temperature gradient depending on the type of prevailing air mass and position of relatively large baric formations and atmospheric fronts.

The novelty of this paper is that the problem is for the first time solved by use of a vast archive of sodar observations that enables one to comprehensively follow up very fine details in the stratification variations. Analysis of sodar data, if they are interpreted correctly, promises to be very accurate, as the data are detailed and possess high resolution both along the vertical (about 10 m) and in time (sound pulses are sent to the atmosphere every 10 s). The conclusions drawn may be useful in improvement of forecasting air pollution levels, including synoptic conditions.

Sounding of the lower 800 m atmospheric layer over Moscow with the vertical sodar «EKhO-1» was performed at Moscow State University jointly with the Institute for Atmospheric Physics of the Russian Academy of Sciences continuously during more than 3 years. The sodar used was operated at 1666 Hz sound frequency, duration and power of the sounding pulse being 75 ms and 75 W, respectively. Every hourly interval of a continuous facsimile record of an echo signal in «time-height» coordinates (the record demonstrated the view of the ABL turbulent structure) was analyzed separately. Based on the technique from Ref. 12 complemented by the author, the type of thermal stratification and the heights of the boundaries of feather-like images and horizontal layers of the echo signal were determined, being in turn connected with the convective thermal conditions and thermal inversions, respectively. The reliability of this interpretation and its experimental validation have been considered in detail in Refs. 7 and 8.

It is evident that stratification of the near-ground layer of the atmosphere varies from day to day, mainly due to the advective processes followed by transformation of the invading air mass.[1] So we assume advective variations of T as a basis of our synoptic analysis. At least two approaches to make this analysis are possible. They can be based both on pressure field or on the air mass type. We use them both in parallel. Seven months of sodar observations carried out in 1991 are chosen for the study. From January to March, in August, September, and November, soundings were performed at Moscow State university, and from 24.04 to 25.07 in Ostankino, in the northern part of Moscow. The preliminary results are presented in Refs. 9 and 15.

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[1] Synoptic regularities of elevated inversions in the Ekman layer are even more complicated what will be discussed below.

ANALYSIS OF THE PRESSURE FIELD

For this part of analysis, synoptic conditions were classified by the presence and sign of thermal advection

	Synoptic condition	Main process
1.	Weak-gradient pressure field in a saddle, at the center of an anticyclone, ridge, or near the ridge axis.	Transformation, formation of the local air mass; no perceptible advection
2.	Center of a cyclone, secondary cyclone, or the trough axis	As a rule, this is the front zone, active front processes
3(a).	Rear zone of an anticyclone or ridge	Advection with respect to a warm air mass
3(b).	Forepart of a cyclone or trough before a warm front	
4(a).	Forepart of an anticyclone or ridge	Advection with respect to a cold air mass
4(b).	Rear zone of a cyclone or trough behind a cold front	
5.	Warm zone of a cyclone	Advection with respect to a warm air mass

The proposed classification is easy-to-interpret and simple, and the number of classes in it is reduced to a minimum. It is based on confinement of the advective processes to definite parts of the pressure field. Such a correspondence is very well fulfilled in summer when air masses quickly transform over dry land in the middle latitudes. As for cold period, it happens not always. For instance, on the 19th of November, invasion of a cold continental Polar air (*cP*) occurred through the western periphery, in the rear of a ridge over Southern Ural. Here, in each concrete case, one must take into account the type of the invading air mass and the site of its formation.

The boundaries of classes 3, 4, and 5 are usually fronts and lines of zero advection at the ridge axes. The differentiation is normally easy to do with only rare exceptions. Usually, class 4(b) gradually transforms to class 4(a). At the axes of moving ridges separating the cyclones, the class 4(a) is changed by the 3(a) one, on reaching the maximum in pressure behavior and the wind rotation. Class 3(a) is followed by 3(b) under already cyclonic curvature of isobars, and then by class 5 after the passage of a warm front. Class 5 (or 3(b) in the case of occlusion front) is usually changed by the 4(b) class. In the vast anticyclones closing cyclone families, the situation behind a cold front can also be characterized by a weak-gradient field (class 1).

To distinguish among the classes, we propose a generalized criterion: zero or very small pressure trend ($\le |0.2\text{–}0.3|$ hPa per 3 h); calm or $v \le 2$ m/s near the Earth's surface; weak geostrophic wind at the 850 hPa baric surface ($\le 10\text{–}15$ m/s); small geostrophic component of thermal advection $(\partial T/\partial t)_a$, that is no more than a few tenth of degree Celsius per 12 h. Charts of relative baric topography are also useful as a help in the analysis. However, one should not rely upon them completely because we are interested in the absence of advection not in the entire layer from 1000 to 500 hPa, but only within the ABL.

Taking into account these properties as a whole, it is usually easy to determine the boundaries of class 1 accurate to 3–4 h. Although the class 2 does exhibit these properties, it is only rarely discerned on the background of low pressure especially with the allowance for pronounced frontal weather processes.

The similarity of advective changes in the T sign makes it possible to unite the related subclasses (a) and (b). Sometimes the adjacent peripheries of neighboring baric formations are distinguished by the isobar curvature.[13]. But now we are interested only in the most general regularities. So we use 5 main classes without further dividing them into subclasses.

ANALYSIS OF AIR MASSES

As it has already been said above, analysis of the pressure field is not sufficient to understand synoptic regularities in the ABL stratification. It is needed to recognize the type of an air mass separately, with as large number of specific features as possible. Such analysis has been performed on the basis of their geographic classification. First, the type of a mass was supposed to correspond to the site of its formation. The site was determined by back trajectories of air particles at the levels of 850 and 700 hPa. Then it was corrected with allowance for daily average $T_{\rm da}$, maximum $T_{\rm max}$, minimum $T_{\rm min}$, and pseudopotential $\theta_{\rm ps}$ temperatures, °C; water vapor partial pressure e, hPa; absolute humidity a, g/m^3; specific humidity q, g/kg; saturation deficit d, hPa; minimum relative humidity $f_{\rm min}$, %; visual range D, km; aerosol optical thickness of the atmosphere τ; type of clouds and atmospheric effects. The ranges of meteorological elements that are characteristic of different types of air mass are well studied in classical climatology.[1,5,6,14]

The analysis is performed using the charts of surface analysis, absolute and relative baric topography, and data of meteorological observations at Moscow State University. The values of $\theta_{\rm ps}$ were determined from radiosonde profiles acquired at the Central Aerological Observatory, $(\partial T/\partial t)_a$ using AT_{850} charts. The data on τ have kindly been presented by E.V. Yarkho. It should be noted that the author not always had the complete set of necessary data at his disposal.

PECULIAR FEATURES OF THE METHOD USED

Hourly coding of sodar data requires highly detailed analysis in time. So the boundaries of all the classes and types of masses were determined accurate to 2–4 hours. Regarding the air masses, only the periods with doubtless type corresponding to most of characteristic values were considered. Times of dominance of a mass with intermediate properties and gradual change of type under transformation were ignored. Since the characteristic values of meteorological quantities in the hours when Moscow was in zones of stationary fronts (class 2) were not representative, and the mass type was not determined for these hours either. So the total number of observation hours involved in analysis of air masses is always less than those involved in analysis of synoptic situations.

The problem of such a detailed separation in time is not usually considered in climatology. Skeptical attitude to compiling of air mass calendars is also well-known.[10] It is assumed that the possibility of making a reliable recognition of their geographic types is too problematic. If in Ref. 14 the types are confidently correlated with ranges of meteorological elements, the attitude to their determining shown in Ref. 6 is more cautious. Of course, the variety of circulation processes and active transformation, especially in summer, cause many mixed and transient forms, but in some periods the type of air mass manifests itself very clearly and unambiguously. The author is sure that careful analysis of synoptic charts, data of surface observations and radio soundings enables one to reveal such periods reliably.

Thus, the novelty of the approach proposed is to consider not a complete temporal series but only the hours chosen so that the type of an air mass can be determined objectively and unambiguously.

In Refs. 10 and 11, concrete regions of the air mass invasion are used in the study of regional climate. However, while obtaining a more detailed information, one looses, at the same time, the objective criterion of differentiation between the conditions. It is not clear to what extent the regions must be «divided» in practice. Objectivity of the consideration of the main geographical types of air masses depends on the global atmospheric circulation and on the ratio of oceanic and dry land areas.

On the other hand, the catalogs of known classifications of synoptic processes (L.V. Klimenko et al.) characterize separate days as a whole. This could be justified if we deal with a many-year observation series. The peculiarities of sodar observations (their climatically short series and detailed structure in time) require a special approach. In that case we already cannot neglect the errors that may be caused by the change of synoptic situation during a day. So the choice of the method for making synoptic analysis accepted here was caused by specific features of the remote sounding data. It is close to analysis of weather types during short periods proposed in Ref. 4 and performed there for a single month, as an example.

However, Ref. 4 again deals with separate days, although the change of synoptic conditions rarely falls exactly on the beginning of a day. Employment of only two quantities, T and e, makes analysis of weather types poorer as compared with the consideration of air masses. For instance, in winter, the difference in conditions of maritime Arctic air (mA) and cP is clearly manifested only in D, while other meteorological elements being close.

Besides, no objective criterion is seen in the basis of the weather type classification («relatively warm», «moderately cold, moist»). Qualitatively characterizing the hydrothermal effect makes generalizing of this analysis for other places difficult since every place has its own threshold values of T and e. Note that the series of these types presented in Ref. 4 does not contain «normal» weather with conditions close to the climatic norm. It should also be noted that many-year data on four types of weather in Moscow have been summarized in Ref. 3.

Let us briefly consider synoptic conditions in some months of 1991 chosen for analysis. The conclusions drawn here by way of the discussion might be of a certain climatological interest. Besides, the description demonstrates how many times one or other air mass type was observed during a month, that means, how representative the calculated results, given in the Table I, are.

1) On the whole, **January**, especially its first ten days, was very warm (by 3.3°C above the norm) and humid because of a strongly developed Iceland depression and weakened Siberian maximum. The increase of western transfer determined 6 cases of the maritime Polar air (mP) invasion into the European Part of the Country (EPC). On the 11th of January, T_{da} and $T_{\max}$ reached, near Moscow university, their record values +3.4 and +5.2°C that are characteristic even for the tropical air![5] But, other values remained typical for mP and confirmed the general rule: cyclones of Polar front in winter are almost always occluded in Moscow.[1] A very deep cyclone spread over the whole EPC on the 26th of January. The quick change of three air masses when T decreased by 20°C (!) during a day was connected with the complicated front system of the cyclone. The Ultra Polar invasion of continental Arctic air (cA), which was clearly observed near the Earth from 27.01 to 04.02 with two short (≈145 h) intermissions, occurred in the cyclone rear.

2) Synoptic conditions in **February** were also quite variable. The cold first days were followed by usual T in the middle of the month when cP prevailed during almost 9 days. The third ten days were very warm due to two mP invasions in succession (the second one was returning). Temporary invasions of mA were observed twice (for 30 h each time).

3) **March** was moderately warm and very dry. During the first ten days, Moscow was in a diffuse

pressure field in the center of a blocking anticyclone (Fig. 1*a*). Long absence of advection near the Earth and at heights allows one to treat the values of meteorological elements as practically standard for the local air mass (*cP*) in the beginning of March. Those were as follows: $T_{\text{da}} = -4{-}5$°C; $T_{\max} = +1{+}3$°C; $e = 2{-}3$ hPa; $q = 1{-}2$ g/kg; $a = 1{-}3$ g/m^3; $D = 15$ km. By the middle of month, western transfer and cyclone activity connected with it have restored. The classes were changing by the scheme $3 \Rightarrow 5 \Rightarrow 4$, being sometimes interrupted by weakening of pressure gradients at ridge axes. In saddles the scheme $4 \Rightarrow 1 \Rightarrow 3$ worked. It is interesting that the same situation in the cyclone rear (class 4) was accompanied in March by the invasion of three types of masses: *cP*, *mA*, and even Atlantic *mP*. Behind the cold front the latter one replaced the warmer Mediterranean *mP* that was filling the warm sector of the anticyclone on March 22–24. This demonstrates insufficiency of analysis based only on the pressure field without the study of the air mass type.

4) **The period from 24.06 to 25.07** can be divided into two intervals. Hot weather before 03.07 was caused by the *cT* advection from Middle Asia through the southwest periphery of the anticyclone (Fig. 1*b*). The period of *cT* transformation into the local mass is considered separately. It is interesting that, on the completion of the transformation on 02.07, when the decrease in T_{da} almost ended, under conditions a weak-gradient field and $(\partial T/\partial t)_a \approx 0$, the formed *cP* kept values typical for tropical air in many quantities: $T_{\max} = 29$°C; $T_{\min} = 20$°C; $a = 13{-}15$ g/m^3; $q = 11{-}13$ g/kg; $e = 18{-}21$ hPa. We see that *cT* transformation does not end completely even at 56th parallel due to high insolation in the middle of summer. In other words, the properties of the local mass that formed here from the tropical air occupy this time an intermediate position in the types' classification. During the following, rather cold three weeks, in the rear of Atlantic cyclones, four invasions occurred of *mP* and *mA*. Those quickly transformed into *cP* over the warmed continent. The single

TABLE I. Results of synoptic analysis of sodar sounding data on thermal stratification in Moscow in 1991: cold period (a); warm period (b).

	Synoptic situation				Air mass type					
Frequency of occurrence*, %	5	3	1	4	*mP*	*mA*	*cP*	*cA* ⇒ *cP*	*cA*	Ambiguous or intermediate
a						November 2–30				
Surface inversions**	68	51	48	53	49	–	70	79	–	–
Elevated inversions	35	35	53	19	47	–	20	4	–	–
Convections	5	2	5	5	4	–	2	–	–	–
Weakly stable and neutral stratification	27	47	47	42	47	–	28	21	–	–
Number of hours of sodar observations***	44	347	159	49	389	–	57	24	–	129
						January 3–31				
Surface inversions	62	57	62	41	43	50	46	–	76	–
Elevated inversions	3	33	53	19	15	6	15	–	16	–
Convections	–	4	7	4	1	–	4	–	5	–
Weakly stable and neutral stratification	38	39	31	55	56	50	50	–	19	–
Number of hours of sodar observations***	88	173	40	235	215	45	79	–	83	114
						February				
Surface inversions	44	65	75	56	50	48	62	–	94	–
Elevated inversions	37	22	22	17	30	29	13	–	19	–
Convections	2	–	5	3	2	10	5	–	–	–
Weakly stable and neutral stratification	54	35	20	41	48	42	33	–	6	–
Number of hours of sodar observations	68	173	165	174	135	63	206	–	54	122
						March				
Surface inversions	69	64	59	35	57	53	57	–	–	–
Elevated inversions	23	28	31	9	28	9	25	–	–	–
Convections	4	14	25	31	5	31	27	–	–	–
Weakly stable and neutral stratification	27	22	16	34	38	16	16	–	–	–
Number of hours of sodar observations	103	190	204	206	162	59	347	–	–	135

TABLE I (continued).

Frequency of occurrence*, %	Synoptic situation					Air mass type						
	2	5	3	1	4	*cT*	*cT* ⇒ *cP*	*cP*	*mP*	*mA*	*cA*	Ambiguous or intermediate
b						June 24 – July 25						
Surface inversions	55	35	38	31	36	40	32	35	37		37	–
Elevated inversions	23	15	11	18	16	17	28	17	15		4	–
Convections	2	36	30	47	46	30	46	45	49		42	–
Weakly stable and neutral stratification	43	29	32	22	18	30	22	20	14		21	–
Number of hours of sodar observations	40	88	49	181	298	99	66	157	120		26	188
						July 29 – August 31						
Surface inversions	44	65		50	52	–	60		53	50	–	–
Elevated inversions	29	15		16	18	–	18		16	8	–	–
Convections	8	23		35	29	–	26		25	41	–	–
Weakly stable and neutral stratification	48	12		15	19	–	14		22	9	–	–
Number of hours of sodar observations	119	115		207	316	–	178		228	44	–	307
						September						
Surface inversions	–	62		45	54	62	–	50	63	61	54	–
Elevated inversions	–	20		25	19	28	–	30	18	13	10	–
Convections	–	13		17	18	8	–	8	11	31	31	–
Weakly stable and neutral stratification	–	25		38	28	30	–	42	26	8	15	–
Number of hours of sodar observations	–	244		87	239	78	–	95	85	40	69	203

* In calculations of the frequency of occurrence, the sum of hours with three possible stratification types in the low air layer ($\gamma < 0$, $0 \le \gamma \le 1$, and $\gamma > 1$°C/100 m) is taken as 100%; the occurrence of elevated inversions is calculated with respect to the sum.

** Inversions: $\gamma < 0$, where $\gamma = -\partial T/\partial z$, °C/100 m; weakly stable and neutral stratification: $0 \le \gamma \le 1$; convection: $\gamma > 1$.

*** Observation hours that fall on the period of strong and moderate precipitation are excluded from the consideration as they impede reliable interpretation of sodar facsimile records.

invasion of *cA* into the EPC on 09–10.07 was represented by an air mass partially transformed in temperature.

5) **August** was close to the normal in T while being humid. Up to the sixth, there were three short (from 12 to 24 h) invasions of fresh *mA* at the periphery of the anticyclone over the Baltic Sea. With weakening of meridian flows, the values of e, q, and then D quickly become intermediate between *mA* and *cP*. Later on, the situations of stagnation with frequent stationary fronts in immobile depressions on the background of a diffusion pressure field (Fig. 1*c*) were only twice changed by an increase in regional transfer and *mP* advection. Stagnation of air is typical for summer in Moscow.[2] It is interesting that in the end of August, with already low insolation, *mA* is transformed into the local mass very slowly: it took almost 60 h for Moscow to be at the ridge axis on 24–26.08, so that the values of q and a had finally exceed the typical ones for maritime air in August.

6) **September** in this year almost exactly corresponded to the norm both in temperature and precipitation. At the same time, it was extremely different from the viewpoint of synoptic conditions. Periods of prevalence of *cA* were observed twice; *mA* prevailed three times; *mP* and *cP* four times.

Analysis of the first days is presented in Fig. 2. Invasion of *mA* from the region of Greenland and the Norwegian Sea took place on September the 1st, 2nd, and 5th. On the 3rd of September, *mP* invaded with the regional flows from the Central Atlantic. If the type of the latter was confirmed by all its properties, the first two, very transparent and dry masses, were warmer than the usual *mA* in September. Note that the final change of types comes, on the average, half-day later than the set of the corresponding circulation near the Earth. For instance, the main branch of

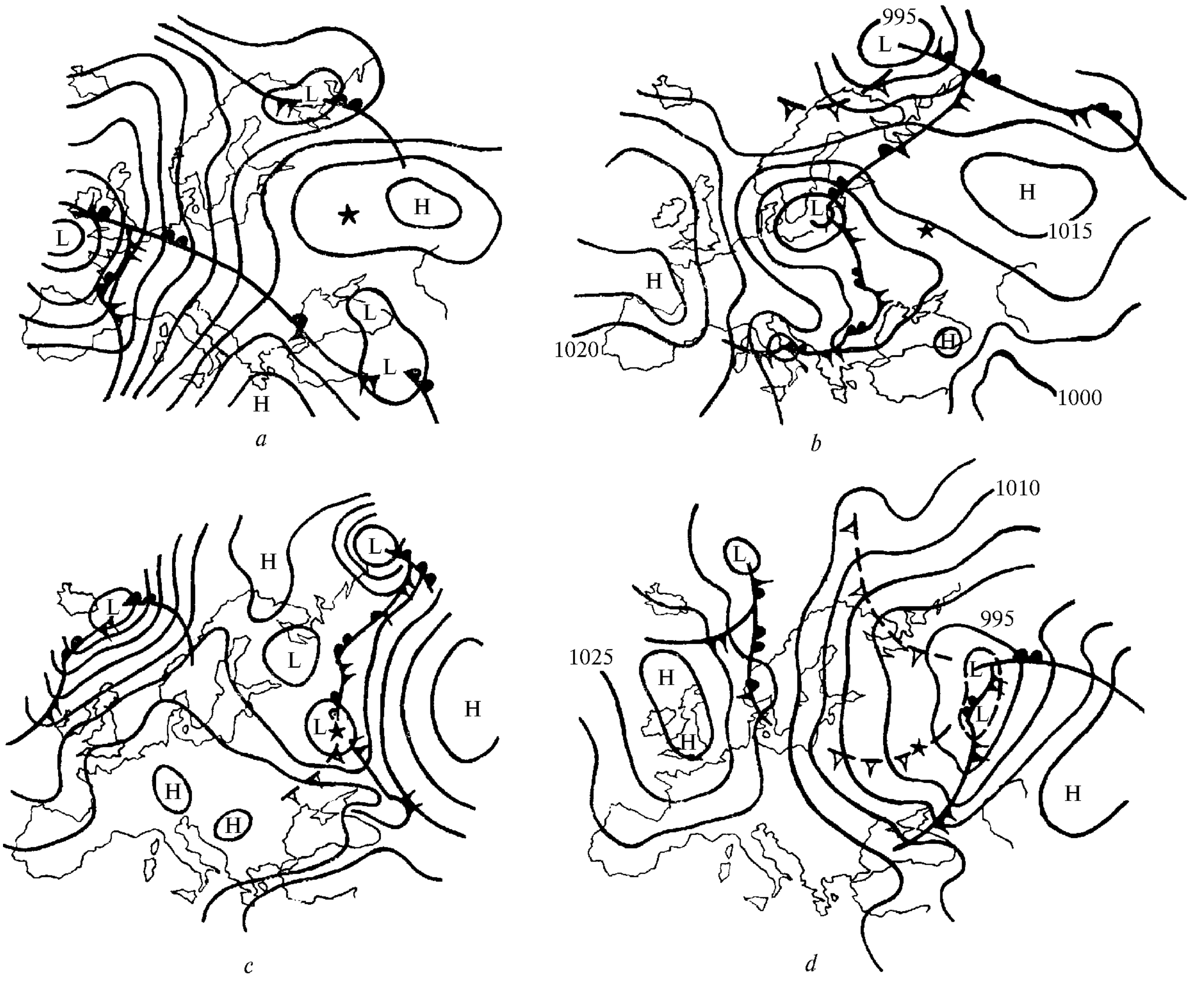

FIG. 1. Fragments of synoptic charts: AT_{850} *chart for* 12 h, *March 8, 1991, class 1, cP (a); surface chart for* 12 h, *June 28, 1991, class 3, cT (b); surface chart for* 6 h, *August 21, 1991, class 2 (c); surface chart for* 6 h, *September 7, 1991, class 4, cA (d). Moscow is marked with asterisk.*

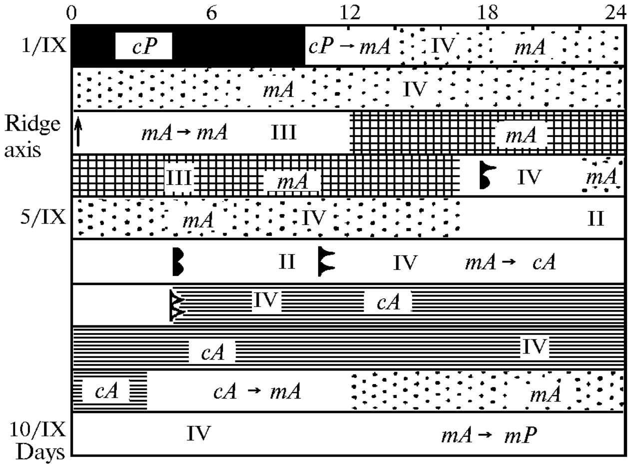

FIG. 2. An example of synoptic analysis with high temporal resolution during the period from 1 to 10 of September, 1991. Roman numbers denote the classes of synoptic situations. The arrow means the ridge axis; the designations of atmospheric fronts are standard.

the Arctic front passed about the noon on 06.09 but the values of meteorological elements near Moscow University even at midnight on 07.09 remained at best to be intermediate between the maritime air and the *cA*. Only by 6 a.m. the value of *e* sharply decreases from 9 to 6–7 hPa, *q* from 5.9 to 3.9–4.7 g/kg, *a* from 7.1 to 4.7–5.7 g/m^3 during the day. According to all the characteristics in the following 45–48 h, the type of this mass which was formed earlier over the Kara Sea (Fig. 1*d*) has become unambiguously Arctic.

In the last days of the month, a very warm air mass (T_{da} = 16–17°C and $T_{\max}$ up to 23°C) with extremely high humidity (*e* up to 15–17 hPa; *q* up to 10–11 g/kg) and low *D* settled. By the whole set of properties, it was determined as *cT* although its origin site was not clear: at the level of 850 hPa, the invasion occurred from the Eastern part of the Mediterranean region, near the Earth, may be from Iran and Middle Asia along the southern periphery of the anticyclone with the center over the Caspian Sea.

7) **November** was by 2.2°C warmer than the norm. The beginning of observations fell within the period of

cA transformation into the local mass. The period is highlighted here separately. Ignoring it and three short invasions of *cP* from the West of the EPC, this month was characterized by intensive western and southwestern transfers, that is by domination of Mediterranean and Atlantic cyclones. Eighteen full and not full days are classified as periods with a clearly *mP*, and it is this type of data that are statistically most reliable.

RESULTS OF ANALYSIS

Let us first consider those for separate months. All the calculations presented in the Table are reduced to equal fractions of every hour of a day. Thus, the main regularity of the warm season of a year is that **convective sodar images** are more frequently recorded when cold air masses prevail and, correspondingly, zero or cold advection occurred. For instance, in June and July convection was observed in 45–50% of all hours in classes 1 and 4, that is with the prevalence of both local and relatively cold air masses. Much rarely, only in every third case, convection is observed in classes 3 and 5, that is in warm *cT*. On the whole, this same regularity was also revealed in September. The peculiar features characteristic of separate months are as follows:

1) In a weak-gradient field, convection was developed in August even more frequently than under clear cold advection; in the middle of summer and in September, classes 1 and 4 exhibited almost similarly high occurrence of convection. Under warm advection, convection was always observed less frequently.

2) When considering air masses, convection was observed in June and July almost similarly frequent both in *cP* and cold types of masses; in August and September, convection took place more frequently in cold Arctic air masses.

Most seldom, convection was observed in summer in zones of stationary fronts (class 2) with frequent precipitation and solid cloudiness of the lower level, that is when the surface is not warmed up. In that case the stratification was usually neutral or weakly stable.

During the cold period, the number of hours with convection is very low everywhere, so the statistical data are unreliable. However, already in March one can see the same regularity: the disposition of both the classes and mass types from cold to warm ones corresponds to sequential increase in the occurrence frequency of convective stratification. Note that in March *mA* is already colder than *cP*, especially after the early thawing of snow in 1991.

As to the **surface inversions**, their occurrence in warm months is either the same everywhere or exhibits a weak reverse trend with respect to convection. This is seen from the consideration of circulation conditions in August and September (surface inversions were observed more frequently at warm advections) and air masses in June-July and August (more frequent in the warmest masses). However, surface inversions were observed most seldom not under cold advection, but in a weak-gradient pressure field.

During the cold months, the situation is different. Surface inversions are more frequently observed at the heat advection (the trend is the same as in summer but better expressed) as well as in the absence of advection. In the cyclone rears, their occurrence is always seldom, and in January and March it is the least of all the classes. However this is only true until the underlying surface is warmer than the invading air. As soon as the invasion ends and the cold mass is settled over Moscow, occurrence of surface inversions in class 1 sharply increases, by 20–25%, as compared with the class 4.

When considering air masses, the same effect is clearly seen by an example with *cA*. In winter its domination is usually accompanied by fine, low-wind, and very frosty weather. As to the heat transfer from deep soil layers to the surface, it is weak due to small heat conductivity of snow. As a result, snow surface is strongly chilled, and extremely stable inversions are being formed. The inversions sometimes last through two or three days. So their occurrence in the coldest masses is 75–80% in winter and even 94% in March. It is just the effect that demonstrates the influence of synoptic conditions in cold time of the year most clearly.

The regularities of **elevated inversions** are more complicated what is caused by the diversity of their nature. On the whole, they depend on the dynamic causes to a greater degree. For instance, during a cold period, elevated inversions were observed more frequently in the region of the center of an anticyclone or on a ridge axis (class 1) due to, obviously, more frequent subsidence inversions. Besides, frequency of occurrence of the elevated inversions is higher in a warm advection than in a cold advection. In that case the influence of advective conditions is indirect. It seems to be manifested in an increase of the number of inversions connected with the boundaries of fog layers and *St* clouds which are typical for the warm invasions.

In summer, elevated inversions are observed almost as frequently under both the warm and cold invasions. Their occurrence is the largest in the zones of stationary fronts, due to both frontal inversions at the surfaces of air mass separation and more frequently observed inversions above and under the clouds.

Now let us turn to the general results averaged separately for the warm and cold periods of the year (Fig. 3). Here we exclude the contingencies connected with deficient statistics of some monthly samples. However, the peculiar features of conditions in some months are also lost in this approach. One can see that the disposition of air mass types in a row from warm to cold ones corresponds to the sequential increase of the fraction of surface inversions in them from November to March (horizontal hatching: from 49% in *mP* to 82% in *cA*); from June to September, the disposition corresponded to the increased convection (points: from 22% in *cT* to 33% in *cA*). Thus both main regularities have clearly manifested themselves in the averaged data. In general, no differences in the occurrence frequency of the surface inversions are seen during the warm period. As to the elevated inversions, they were observed most frequently (33%) in maritime Polar air which is the warmest from November to March. In other types of air masses, their occurrence was only 15–20% during four months.

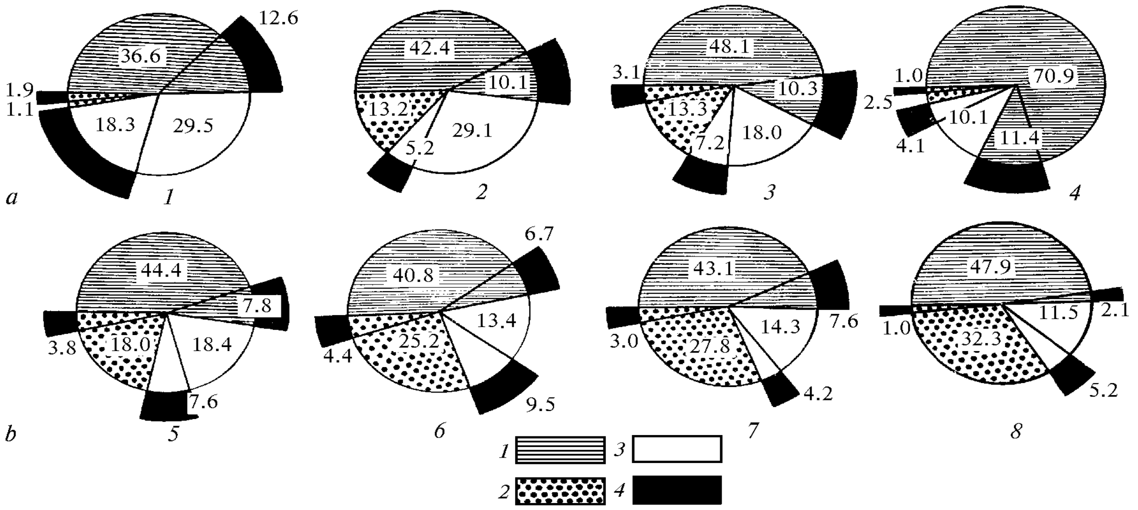

FIG. 3. Frequency of occurrence of the types of thermal stratification in Moscow during the hours of domination of different air masses: cold period (from January 3 to March 31, 1991 and from 2 to 30 of November, 1991) (a); warm period (from June 24 to July 25 and from July 29 to September 30, 1991) (b). Air masses (from left to right): mP (1), mA (2), cP (3), cA (4); cT (5), cP (6), mP and mA (here together) (7), cA (8). Horizontal hatching denotes surface inversions, black sectors are elevated inversions, dots are thermal convection, light sectors are weakly stable and neutral stratification. The figures are given in %.

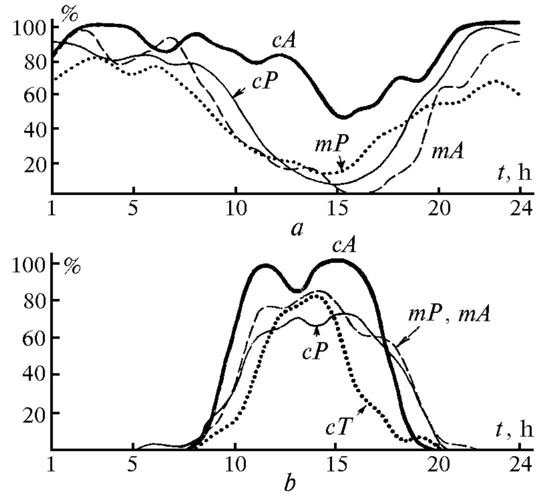

FIG. 4. Diurnal behavior of the occurrence of the types of thermal stratification in different types of air masses: total frequency of occurrence of the surface inversions (both single and covered by elevated ones in cold period of the year) (a); the occurrence of convection in the absence of elevated inversion layers up to the height of 800 m *during the warm period of the year (b).*

The diurnal behaviors of the frequency of occurrence of surface inversions in the cold period and that of convection in the warm period are presented in Fig. 4. As seen from the Figure, frequent observation of the surface inversions in domination of *cA* in winter is connected mainly with the light time of the day: at night their occurrence is not much higher here as compared to other air masses. Convection is developed more frequently in summer in maritime and local masses as compared with the tropical air due to morning and especially evening hours. In the continental Arctic air, the occurrence of convection is still higher even in the middle of the day.

CONCLUSIONS

Thus, it may be stated that synoptic conditions in Moscow considerably influence the regime of thermal stratification of the atmosphere. In summer, in cold advection and cold air masses, thermal convection is developed more frequently (mainly in the morning and evening hours; in the day-time, the differences are expressed weaker). As to the occurrence of surface inversions, no synoptic regularities are seen here in warm periods. This result is unexpected and requires further comprehension. The cause seems to be in the presence of a clearly expressed diurnal behavior on the background of which the advective processes are too weak to produce any effect upon the lifetime of nocturnal surface inversions.

In winter, surface inversions were observed more frequently in colder air masses over Moscow. These were comparatively seldom just during the hours of the invasion of cold air. After all, elevated inversions in the 800 m layer are always observed more frequently in a weak-gradient field with high background of pressure, and, in winter and late autumn, also in maritime Polar air.

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