THE USE OF SOUND SCATTERING FOR STUDYING TEMPERATURE STRATIFICATION OF THE ATMOSPHERIC BOUNDARY LAYER

M.A. Lokoshchenko and M.S. Pekur

M.V. Lomonosov State University, Moscow
Institute of Atmospheric Physics of the Russian Academy of Sciences, Moscow
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The results of continuous observations of temperature stratification of the atmospheric boundary layer are derived from the facsimile record of the acoustic radar (sodar) return. For the first time in the USSR simultaneous sodar measurements have been carried out at two stations over a large city.

Continuous observations of stratification of the atmospheric boundary layer have been carried out in the Institute of Atmospheric Physics of the Academy of Sciences of the USSR and in the Meteorological Observatory of the Moscow State University in a large city (Moscow) during 1989–1991 with the help of an acoustic radar (sodar). The sound backscattering providing the basis for monostatic sodar operation is known to be determined by turbulent temperature fluctuations,[1] whose intensity and spatial structure are closely related to the temperature stratification of the atmospheric boundary layer (ABL). As a result, the facsimile record of a sodar return may be interpreted in terms of the ABL stratification.[2,3]

An acoustic radar EKHO–1 was placed at the atation of the Meteorological Observatory of the Moscow State University 8 km apart from the center of the city in the region of uncompacted building with a large number of parks (Botanic garden of the Moscow State University and others). This system provided a continuous facsimile record at operating frequency of 1666 Hz. Its sounding range was 800 m and duration and power of a sounding pulse were 75 ms and 75 W, respectively. Its specifications and method for interpreting the facsimile records are presented in more detail in Refs. 4 and 5.

The statistical processing of data arrays provided for diurnal variations of recurrence of different types of stratification for every month and season, recurrences and heights of inversions (surface and elevated), and neutral and unstable stratifications for every month, season, and year (Figs. 1–4). The annual behavior of these characteristics (Fig. 1) reveal that the surface inversions are rarer encountered during intermediate seasons (in March–April and September–October they are encountered in about 20 % of observations) than in the rest of months of the year (they are encountered less than in 40 % of observations). The stratification close to neutral on the contrary, is most often encountered in spring and autumn (less than in 60–65 % of observations). The convection is most often encountered in summer (less than in 35 % of observations performed from May to August) and is rarest encountered in late autumn and in winter (in about 1 % of observations). The recurrence of elevated inversions is not high (in about 10 % of observations) in all seasons, the only exception is the late autumn when it increases up to 20 %. During 1990, the average probability of occurence of surface inversions (Fig. 2) was 33 % and the clear–cut convections was in all 14 % at the station of the Moscow State University. Based on the data of long–standing balloon sounding over Moscow (the station was located outside the city), the probability of occurence of surface inversions was about 30 % and that of elevated inversions (with in the 0.01 – 0.25 km layer) was 9 % (Ref. 6).

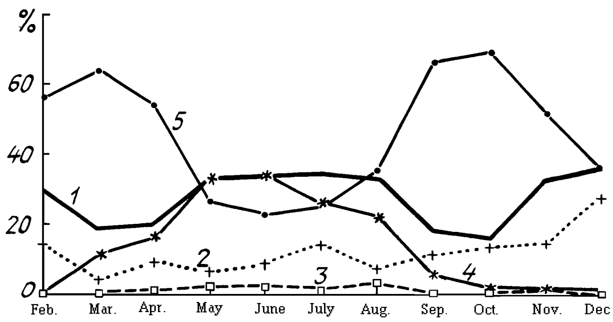

FIG. 1. Annual behavior of recurrence of different types of stratification derived from sodar observations at the station of the Moscow State University in 1990*: 1) surface inversion (single), 2) stable and neutral stratifications with elevated inversion, 3) convection capped with the elevated inversion, 4) developed convection, and 5) stratification close to neutral.*

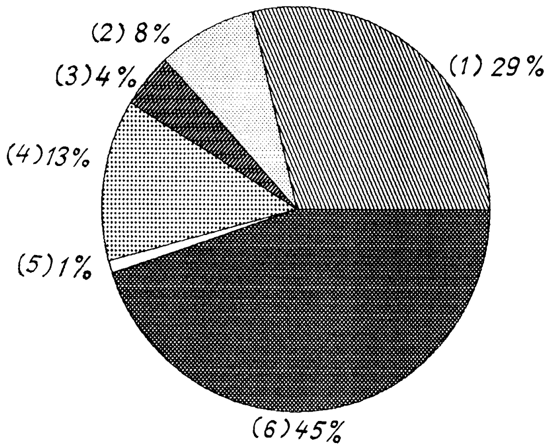

FIG. 2. Polar diagram for recurrence of different types of stratification derived from sodar observations, at the station of the Moscow State University in 1990*: 1) surface inversion (single, i.e., without the elevated inversion), 2) low–stable or neutral stratification with elevated inversion, 3) surface and elevated inversions simultaneously, 4) developed convection, 5) convection capped with the elevated inversion, and 6) stratification close to neutral.*

A comparison of the obtained data with analogous results of other sodar observations is difficult due to disagreement in the criterion of the type of stratification used by the authors. In particular, in Ref. 7 the authors classify the absence of facsimile images as a neutral stratification while we include weakly pronounced disordered surface structures of different morphology which encompass a number of low–stable and neutral stratifications too. Nevertheless, the relative contribution of elevated inversions in the general sample (12 %) is close to the analogous quantity for New–Delhi[7] (11 %) in spite of the aforementioned difference of criteria as well as different climatic conditions.

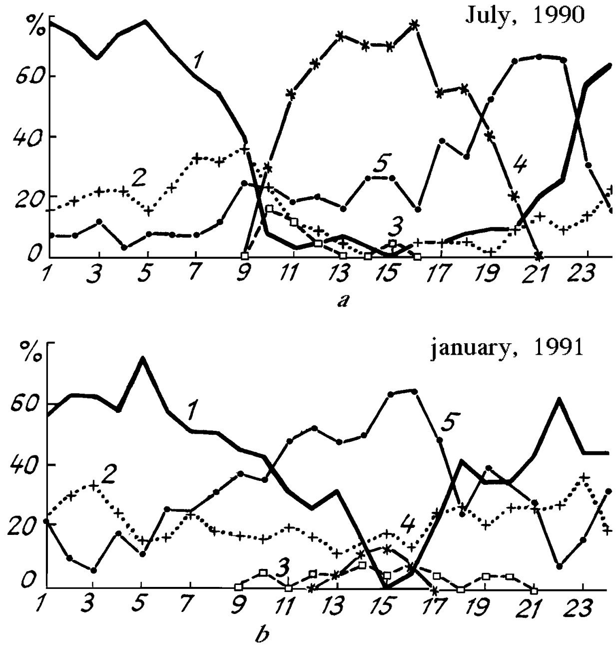

FIG. 3. Average daily recurrence of different types of stratification derived from sodar observations at the station of the Moscow State University: a) July 1990 and *b) January* 1991. *1) Surface inversion, 2) elevated inversion, 3) convection capped with the elevated inversion, 4) developed convection, and 5) stratification close to neutral.*

In winter and summer, the diurnal variations of recurrences of different stratifications are shown in Fig. 3. Classical diurnal variation of stratification of the lower atmospheric layer in summer is well known. At nighttime, surface inversion is found to occur in 70–85 % of observations due to radiative cooling. After sunrise, this inversions starts to rise, while the convective structure becomes gradually pronounced under the inversion. It should be noted that the elevated inversion may exist above the developed convection layer for some hours. The daytime recurrence of unstable stratification, according to our data, reaches 75–90 %. By the evening, the conversion decays being superceded first by neutral conditions and then by a newly formed inversion layer. A cloud cover, variations in the average wind velocity, and other meteorological parameters modify the typical behavior. In particular, nighttime evolution of radiative inversion can proceed differently depending on synoptic factors. In winter the developed convection is rare encountered, and in daytime the neutral stratification predominates.

The average thickness of the surface inversion layer is subjected to seasonal trends. Histograms of the inversion height (thickness) distribution H_i in winter and summer (Fig. 4) show that the winter inversion occurs, on the average, much higher. The maximum values of H_i are reached, according to our data, in November–February (300–320 m), and the minimum ones are recorded in summer and early autumn (180–200 m). The maximum height of the surface inversion is also recorded in winter (slightly above 600 m).

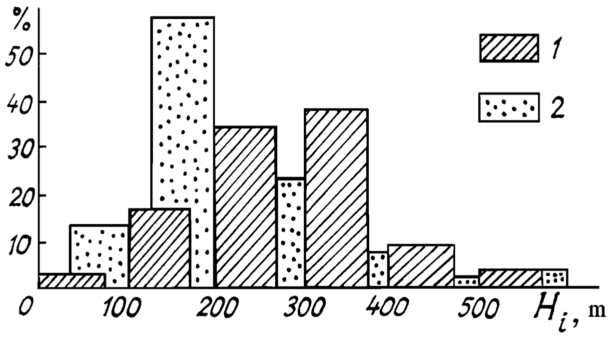

FIG. 4. Histograms of the surface inversion thickness distribution derived from sodar observations at the station of the Moscow State University in winter and summer: 1) December 1989 *– February,* 1990*; 2) June – August* 1989.

We have been carried out, for the first time in the USSR, the simultaneous sodar measurements at two stations in a large city. In addition to the station of the Moscow State University, the second station was used. An acoustic radar was placed on the roof of the building of the Institute of Atmospheric Physics at the center of the city at an altitude of about 10 m. The sodar specifications were given in Ref. 8. An analysis of the data reveals that there are differences in dynamics and structure of the ABL between these stations. Shown in Fig. 5 is the comparison of the types of stratification recorded during synchronous observations on May 15 and June 15, 1990. The numbers indicate the hours during which we observed each type of stratification at the stations of the Institute of Atmospheric Physics and of the Moscow State University, and at these two stations simultaneously.

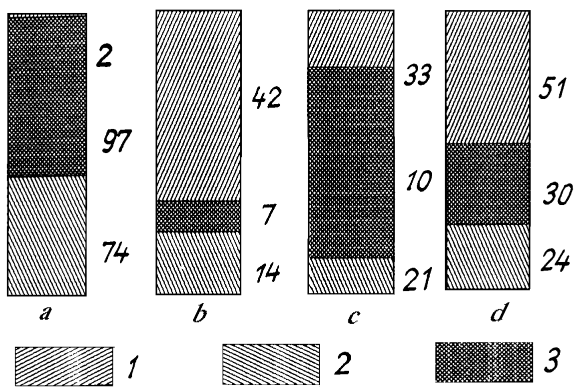

FIG. 5. Comparison of the types of stratification of the atmospheric boundary layer: a) surface inversion, b) elevated inversion, c) developed convection, d) stratification close to neutral. 1) Observed only at the station of the Institute of Atmospheric Physics, 2) observed only at the station of the Moscow State University, and 3) observed simultaneously at the stations of the Institute of Atmospheric Physics and of the Moscow State University.

It should be noted that though for neutral and convective stratifications a pattern of "coincidences" is practically symmetric, a pronounced asymmetry is recorded under the inversion conditions. The surface inversions at the center of the city are recorded by a factor of approximately one and a half rarer and are practically always (in more that 90 % of cases) accompanied by inversions at the station of the Moscow State University. This is obviously due to the effect of an urban "island of heat" which reduces the duration and decreases the thickness of nighttime radiative inversions at the center of the city compared with its outskirts. This very effect may probably explain the fact that elevated inversions are more often encountered over the station of the Institute of Atmospheric Physics than over the station of the Moscow State University.

The obtained data can be used to work out the recommendations for the height of the plant stacks as well as for the level of overheating of the plumes required for removing the pollutants out of the mixing layer. The results of synchronous measurements at two stations are indicative of the fact that more than a single station is required to perform observations in such a large city as Moscow. Therefore, monitoring of the meteorological conditions influencing the pollutants concentration would call for the use of several stations.

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