Daily fluctuations of radioactive fallout particles in ground-level air

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ABSTRACT

Long-range 500 mb and 300 mb air trajectories were computed in an attempt to interpret the daily variation of the number of fallout particles in the ground-level air observed at Fayetteville (36°N, 94°W), Arkansas, after a nuclear weapon was tested at Lop Nor (40°N, 90°E), China, December 24, 1967. The dates of occurrence of peak concentrations of fallout particles generally coincided with (*a*) the arrival times of air masses at 500 mb and/or 300 mb after completing a cycle around the world, and (*b*) the passage of 500 mb troughs at Fayetteville. A significant deviation from the above rule occurred on January 20, 1968, when the highest concentration of fallout particles in air was observed at Fayetteville. According to the computed air trajectories, such a maximum should have occurred 3 days earlier on January 17, 1968. The discrepancy was explained as due to local meteorological conditions: the occurrence of positive vorticity transport at 500 mb followed by the formation of slow-moving cut-off low during January 17 through January 19, 1968.

1. Introduction

A study on the atmospheric transport processes of radioactive isotopes can perhaps be best performed by collecting air samples directly, using aircraft, balloons and rockets. Such an approach is costly, however, and requires a well organized effort of many investigators. On the other hand, much can be learned about the behavior of radioisotopes in the atmosphere by observing a day-to-day variation of the radioactive fallout particles in the ground-level air at one locality of the earth and following the paths of air masses by computing air trajectories.

Radiochemical data recently secured in this laboratory and elsewhere (Kuroda et al., 1965; Cooper et al., 1966; Baugh et al., 1967; Thein et al., 1967, 1968, 1969; Beck et al., 1969) have demonstrated the cycling effect of radioactive isotopes injected into the atmosphere by a number of Chinese nuclear explosions during the past few years. Yoshikawa et al. (1968) showed that the day-to-day variation of the concentrations of fallout particles in the ground-level air was also profoundly affected by local-meteorological conditions, such as the passage of 500 mb troughs. The results obtained by the above investigators clearly demonstrated the need for a long-range air trajectory study, which enables us to trace the paths of fallout particles, while they circle the earth more than once. Such a long-range air trajectory was prepared by Chen et al. (1970) and was shown to be useful in the interpretation of the day-to-day fluctuation of the fallout particle concentrations in the ground-level air, after the third Chinese nuclear explosion of May 9, 1966.

A long-range air trajectory study at 500 mb such as carried out by Chen et al. (1970), however, is not expected to yield sufficient informations, if radioactive fallout particles are injected simultaneously into the lower stratosphere and troposphere. Under these circumstances, the fallout particles would circle the earth at different velocities at different altitudes. The day-to-day variation of the number of fallout particles in the ground-level air would then reflect a superimposed cycling effect of the particles at higher and lower altitudes. Such a

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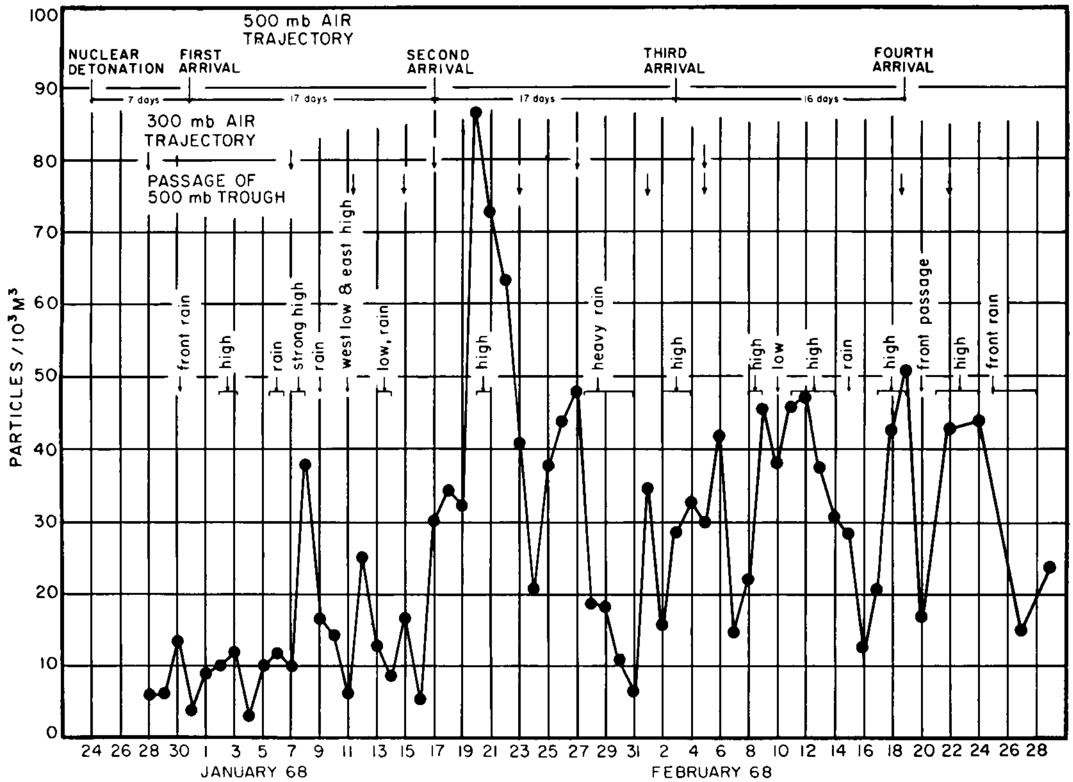

Fig. 1. Daily variation of the number of single fallout particles in the ground-level air at Fayetteville (36°N, 94°W.), Arkansas, observed after the December 24, 1967 Chinese nuclear explosion. Some meteorological situations are also given.

situation seems to have occurred after the seventh Chinese nuclear explosion of December 24, 1967 and the cyclic patterns of variation of the radioisotope ratios in rain and single particle concentrations in the ground-level air observed at Fayetteville, Arkansas, were such that the computed 500 mb air trajectories were not sufficient to explain the complex patterns of variations of the radioisotope ratio and fallout particle concentration data (Thein et al, 1969).

We have computed in this work both 500 mb and 300 mb air trajectories for the period from December 1967 through February 28, 1968, following the December 24, 1967 Chinese nuclear explosion, and attempted to interpret the day-to-day fluctuation of the fallout particle concentration in the ground-level air. It appears that the data can be interpreted satisfactorily on the basis of the computed 300 mb and 500 mb air trajectories and in terms of local meteorological conditions.

2. Experimental data

300 mb and 500 mb air trajectories were prepared based on the conventional isobaric method. The isobaric trajectories were constructed all from the observed winds. The distance traveled within one day was made equal to the product of a 24 hour interval and the linear mean of the initial and final wind speeds. No cross-contour flow was assumed along the path of the isobaric trajectory, so that the displacements were always made parallel to the contour. The fallout particle data were obtained in this laboratory by Baugh (Baugh, 1969; Baugh et al., 1969) and were taken from the report of Thein et al. (1969).

3. Results and discussion

Fig. 1 shows the daily variation of the number of single fallout particles in the ground-level air at Fayetteville, measured by Baugh (Baugh, 1969; Baugh et al., 1969; Thein et al., 1969). The number of hot particles on the filter paper was visually counted after the radiographic exposure was made of each air-filter sample. The data are expressed in terms of number of particles counted per 1000 m^3 of air, and the confidence levels of the indivudual peaks are better than 95%.

The computed 500 mb trajectory suggests that fresh debris arrived at Fayetteville on December 31, January 17, February 3, and February 19 after the Chinese nuclear explosion of December 24, 1967. The major peaks in the ground-level air particle concentration that occurred on December 30, February 4, and February 19 agree within one day with the calculated 500 mb trajectory. However, no apparent peaks of particle concentration were observed on January 17 as suggested by the calculated air trajectory. A more detailed discussion on this point will be given later. The ground-level air particle concentration in Fig. 1 is an average value of measured large (> 2–3 μ diameter) and small (< 1–2 μ diameter) fallout particles (Thein et al., 1969). Since different size particles may enter different altitudes after a nuclear explosion, and the particles fall at different speeds subject to gravitational settling and atmospheric motion, the cycling of the particles may, therefore, follow air trajectories at different levels. The 300 mb air trajectory therefore seems to be a logical level to be included in this air trajectory study since it represents the westerly jet stream. The calculated 300 mb air trajectory suggests the arrival of fresh debris on December 28, January 7, January 17, January 27, and February 5. The peaks on January 8, January 27, and February 6 are most likely due to the arrival of smaller particles carried by 300 mb air in the upper troposphere. This statement is partially supported by the data in Table II of Thein et al. (1969). The time lag between the dates of the calculated air trajectory and the measured peaks, one day in this case, presents an interesting physical problem related to the settling process of fallout particles from higher altitudes. More information is needed to estimate how much of this time lag is due to the meteorological processes. Nevertheless, the human errors involved in the computation of air trajectories

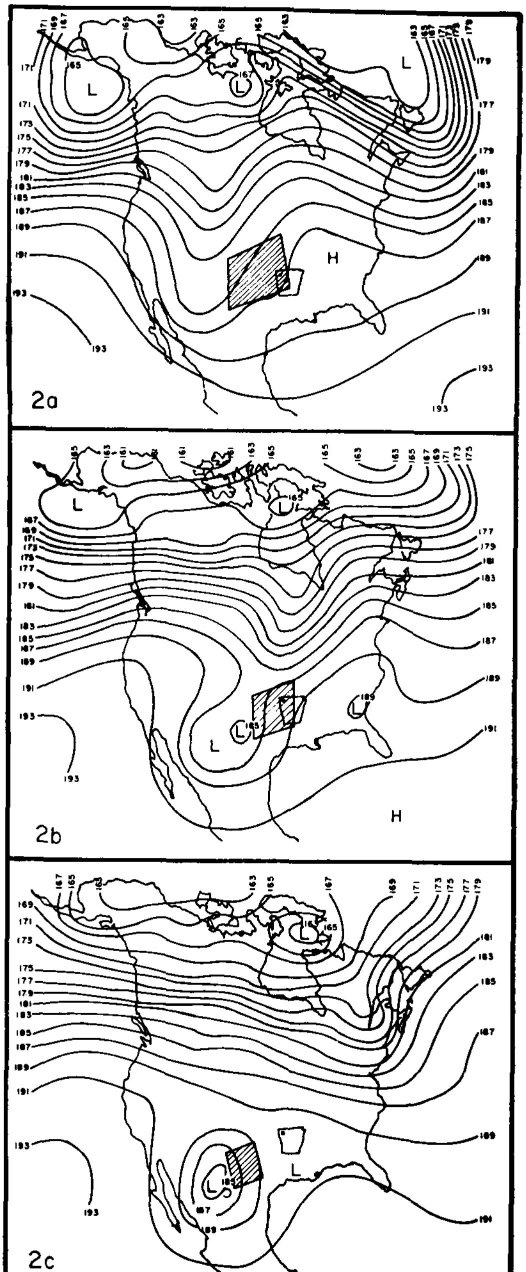

Fig. 2. (*a*) 500 mb height contours at 1900 EST., January 17, 1968, showing the favorable location for low-level ascending motion (hatched box) due to 500 mb positive vorticity transport (heights in hundreds of feet). (*b*) 500 mb height contours at 1900 EST., January 18, 1968, showing the formation of cut-off low and its related location to the low level ascending motion. (*c*) 500 mb contours at 1900 EST., January 19, 1968, showing the southwestward drifting of cut-off low and its related location to the low-level ascending motion.

cannot be completely discounted for portion of such discrepancy.

The second arrival date for the calculated 500 mb trajectory coincides exactly with the third arrival at 300 mb on January 17. This seems to indicate that both large and small particles arrived at Fayetteville on the same date, and thus a pronounced particle concentration is to be expected. At first glance, it appears that both 500 mb and 300 mb air trajectories have failed to give an explanation for the maximum particle concentration of January 20. However, a close check of 500 mb weather maps indicated a very strong upward motion, as shown by the hatched box in Fig. 2*a*, took place in the lower atmosphere on February 17 due to positive vorticity transport. On the following day an intensifying slow-moving cut-off low developed to the southwest of Oklahoma (Fig. 2*b*), and continued to strengthen the upward motion and thus may have acted to sustain and trap particles in this system. This cut-off low slowly drifted in a southwesterly direction and finally the updraft motion weakened over our area on February 19 (Fig. 2*c*). As a result of the diminishing upward motion coupled with the increasing subsidence motion caused by a surface high pressure system formed on January 20, the sustained particles were released and created the maximum particle concentration on January 20.

The day to day small scale fluctuations of ground-level air particle concentration is related to the complex system of changing weather. One of the factors which influence the variation of the concentration of fallout particles is the washout process by atmospheric precipitations. A typical example was the heavy rainfall that occurred between January 27 and January 31, which coincides with the occurrence of a minimum particle concentration as shown in Fig. 1. Other minima due to washout processes occurred on January 6, 9, 13, February 15, and February 26 right after frontal rains. The variation of surface pressure is always affected by the vertical motion of air parcels. Large scale subsidence of air is expected whenever a surface anticyclonic system approaches. This phenomena is demonstrated by our collected air samples. On several occasions increasing particles concentration, such as on January 2, 8, 21, February 3, 9, 12, 18, and 24, are all correlated with the observed surface high pressure systems. The low concentration on January 11 is due primarily to the upward motion caused by the 'west low and east high' situation.

Several other pronounced increases in particle concentrations were measured on January 12, 15, 23, February 1, 19, and 22. All these peaks have a direct correlation with the passage of the 500 mb trough. The dynamic explanation of this process is that to the immediate west of the upper-level trough, we usually find low-level divergence and upper-level convergence with descending motion. It is this descending motion that brings down upper air and thus tends to increase the particle concentration. Miyake et al. (1960) also reported that similar meteorological conditions play an important role in the transport of radioisotopes from the stratosphere to the troposphere. They noted that the Sr^{90} concentration in the ground-level air showed an increase after the passage of a 500 mb trough.

From the air trajectory study, it appears that at 500 mb heights, the number of days required for one complete global cycle is 17, while at 300 mb heights the particles move much faster, requiring only 10 days for a complete cycle. If the radioisotopes are to be carried by air currents at these different rates, it is justified to believe that some of the measured ground-level fallout data have to agree with the 500 mb trajectory, while the 300 mb trajectory should fit other measured peaks. This would lead us to believe that the 400 mb air trajectories may perhaps add a valuable dimension to the interpretation of the fallout data, but such attempt was abandoned for lack of data at that particular level. Our study suggests that the 300 mb trajectory provides a very good interpretation of the small particle concentration, while the 500 mb trajectory seems to agree better with the cyclic behaviour of larger particles. The validity of the conclusions in this report rest upon the validity of the calculated air trajectories, and their reliability is possible to estimate only by adding the result from a number of other case studies. Chen et al. (1970) computed the long range air trajectories at 500 mb and found a good correlation existed between the arrival dates of air mass and the measured peak concentrations of single particles in the ground-level air measured after the third Chinese nuclear explosion of May 9, 1966. Therefore despite the belief that isobaric trajectories permit only an order-of-magnitude estimate of the track of radioactive debris, because vertical motions are not taken into account to a sufficient degree, our study, however, showed these trajectories provided a good support to the interpretations of radioactivity fluctuations measured at the ground.

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СУТОЧНЫЕ ВАРИАЦИИ ВЫПАДЕНИЯ РАДИОАКТИВНЫХ ЧАСТИЦ В СЛОЕ ВОЗДУХА НА УРОВНЕ ЗЕМЛИ

В попытке интерпретации суточных вариаций выпадения частиц в Файетвилле (36° с.м., 94° з.д.), Арканзас, после испытаний ядецного оружия в црстыне Лобнор (40° с.м., 90° в.д.) в Китае 24 декабря 1967 г. были вычислены на длительные сроки траектории воздушных частиц на поверхностях 500 и 300 мб. Времена появления максимальных значений концентрации выпадающих частиц обычно совпадают с а) временами прибытия воздушных масс на поверхностях 500 и/или 300 мб после цикла их прохождения вокруг земного шара и б) прохождением через Файетвилль ложбин на поверхности 500 мб. Значительное отклонение от этих правил произошло 20 января 1968 г., когда в Файетвилле была наблюдена наивысшая концентрация выпавших частиц. Согласно вычисленным траекториям воздушных частиц, такой максимум должен был бы наблюдаться тремя днями раньше 17 января 1968 г. Расхождение было объяснено локальными метеорологическими условиями; наличием переноса положительной завихренности на поверхности 500 мб, сопровождавшегося образованием изолированной области низкого давления в период с 17 по 19 января 1968 г.