Transport of Air in the Stratosphere as Revealed by Radioactive Tracers

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The available measurements on cosmogenic ^{7}Be and artificial tracers ^{109}Cd and ^{238}Pu in the atmosphere are discussed in terms of plausible circulation patterns in the stratosphere and across the stratopause. The ^{7}Be data in the northern hemisphere between 24 and 37 km, when integrated with the aircraft data from lower altitudes, suggest an equatorward transport of polar air above 25 km during the winter of 1965. Such a motion does not seem to be operative below 24 km. There are cyclic variations in the concentration of ^{109}Cd and ^{238}Pu in both hemispheres which are out of phase by about six months; in early spring through summer, the concentrations are repeatedly higher than in the fall and winter during 1962–1965 at 34°S and 31°N. These data indicate that the transport across the stratopause is strongly seasonal and probably takes place during an extended spring period. A detailed analysis of tracers injected in the mesosphere further suggests that the dispersion history of the debris injected in the mesosphere strongly depends on the time of injection.

Studies with natural and artificial radioactive tracers like cosmic-ray-produced ^{7}Be and bomb-produced ^{109}Cd and ^{238}Pu have yielded important information about circulation patterns in the atmosphere and the dispersion of radioactive debris. For example, it has been clearly demonstrated [*Telegadas and List*, 1964; *Bhandari et al.*, 1966] that at polar latitudes vertical mean motions are dominant in downward transport of radioactive debris to lower altitudes up to the tropopause. However, it has not been possible to ascertain, by using these artificial tracers [*Bhandari et al.*, 1966], whether such vertical motions are also responsible for the observed enhancements in radionuclide concentrations at middle or low latitudes or whether the debris first descends at the polar latitudes and then quickly moves to the lower latitudes. Also, very little information is available about the motion of air within the mesosphere and its transport across the stratopause.

We have made ^{7}Be measurements up to 20 km. In addition, the high-altitude balloon data reported by the Health and Safety Laboratory on ^{7}Be, ^{109}Cd, and ^{238}Pu are discussed in this paper.

^{7}Be

As a tracer, ^{7}Be has the important advantage that its source function is known fairly well [*Bhandari et al.*, 1966, Figure 3]. In the region above about 24 km the ^{7}Be production rate is expected to remain constant with altitude at any latitude in the range 30° to 70°. However, at any altitude the production rate changes rapidly from about 15 dpm/SCM at 30° to about 90 dpm/SCM at 70°. Thus, whereas any vertical motion of air above 24 km does not change the concentration profile of ^{7}Be, influx of a small amount of polar air significantly increases the concentration at lower latitudes. Therefore, for studying equatorward motion of polar air, ^{7}Be appears to be an ideal tracer.

In Figure 1, the observations at 20 km [*Bhandari*, 1965] and 24 to 37 km [*Health and Safety Laboratory*, 1966–1968] are shown for various latitude belts. The saturation activity of ^{7}Be, i.e., the concentration of ^{7}Be expected in air after an in situ local production over six months or more in various regions of the atmosphere, is also shown. It is clear that in all regions except (1) ~20 km, 65°N and (2) 24–37 km, 31°N the concentrations are close to those expected. The aircraft data [*Bhandari*, 1965] are accurate to within ±15%. Only those balloon data that are assigned an accuracy of ±20 to 50% are included in this figure. In three of the four blank runs made by HASL, ^{7}Be activity was too low to be detected; only in one run was there significant contamination (1100 dpm). Al-

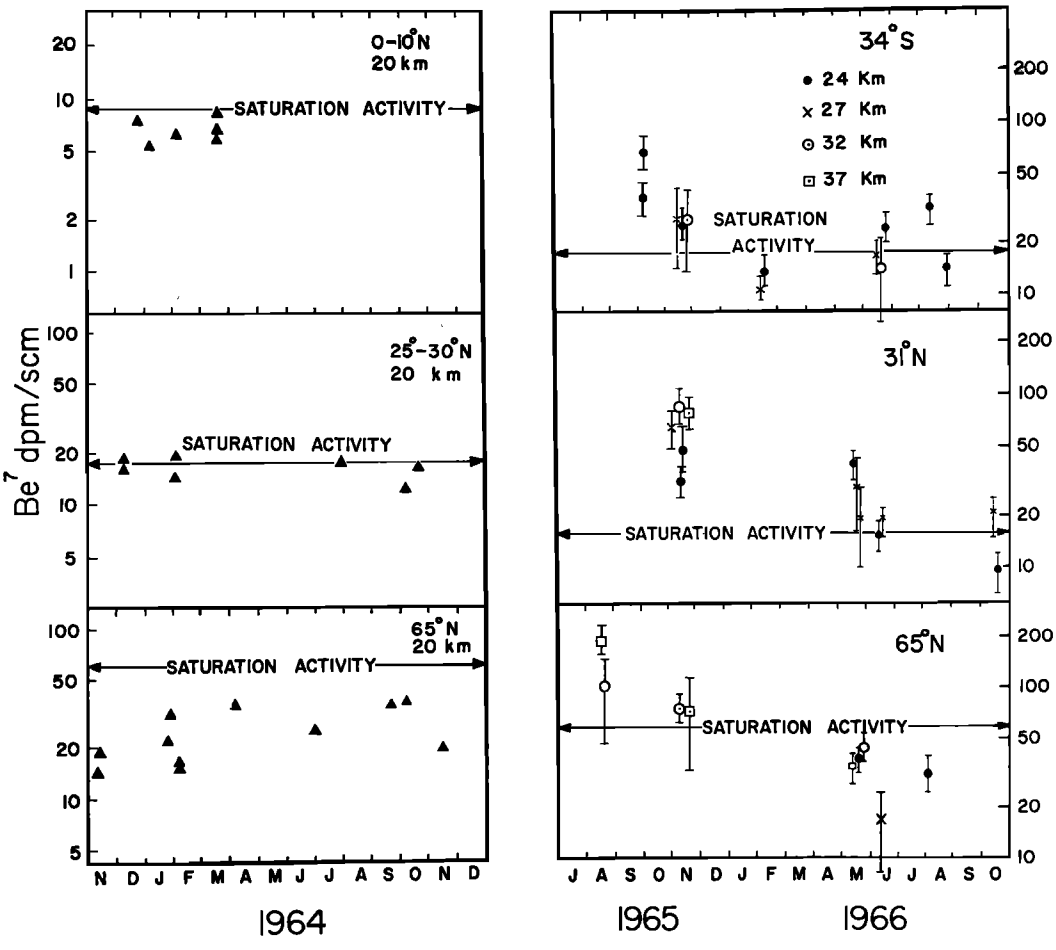

Fig. 1. Observed concentrations of ^{7}Be (dpm/m^3 STP) during 1963–1966 at various latitudes and altitudes. The levels of expected saturation activity are also shown.

though the ^{7}Be data look internally consistent, the contamination found in this blank prohibits us from attaching any significance to individual measurements. We shall therefore restrict our discussion to general features of the ^{7}Be profile and assume that these data are accurate to within a factor of 2.

At 20 km in the polar stratosphere, the concentrations are lower by a factor of 2 to 3 than the saturation concentration. Similar deficiencies have also been found up to 40°N [*Bhandari et al.*, 1966], although only a limited number of data are available there. This undersaturation could be brought about by vertical mixing of air from lower altitudes or meridional mixing of air from lower latitudes. It is difficult to decide between these two alternatives from ^{7}Be data alone. However, other tracer studies have indicated [*Bhandari et al.*, 1966] that probably both these processes are operative.

At higher altitudes, the situation is less ambiguous. The region at 31°N, 24–37 km, is the only region in the atmosphere where the ^{7}Be concentration is higher than the saturation value by a factor of 2 to 5. These high concentrations of ^{7}Be can result only from the influx of polar air at these latitudes at a rate faster than the decay rate of ^{7}Be. Thus we can say that, during November 1965, significant amounts of polar air were transported to lower latitudes to 31°N in the northern hemisphere. Outflux of polar air, associated with sudden polar warmings, is known to occur repeatedly during winter [*Labitzke*, 1968]. However, such an excess as was observed

during November 1965 was not observed again until October 1966; therefore, from the data presently available, it is difficult to establish whether such a transport occurs as a part of an annual cycle.

In the southern hemisphere, data are reasonably scattered throughout the year. Although minimum concentrations appear to occur during local summer, no large excesses have been observed during winter. Detailed and more accurate measurements are necessary to delineate the seasonal dependence and to estimate rate of transport. The isotope pair $^{7}Be/^{32}P$ would serve as a more sensitive parameter for such a study. Any errors in the estimation of volume of air sampled can also be thus eliminated.

^{109}Cd and ^{238}Pu

Measurements on these two tracers have been reported by HASL and *List et al.* [1966]. ^{109}Cd was injected in July 1962 at 17°N, 400 km, whereas the injection of ^{238}Pu resulted from the burn-up of a nuclear device, Snap 9A, at 40–60 km over the Indian ocean, at about 11°S during April 1964. The observed concentrations above 31 km, (mainly at 31–33 km) at 31°N and 34°S are shown in Figure 2. At these levels in both hemispheres, the two tracers show cyclic variations in concentration that are out of phase by about six months. This is best illustrated by ^{109}Cd in the southern hemisphere, for which three such cycles are observed. The amplitude of the pulse during the years 1962–1965 decreases successively as the mesospheric inventory is depleted and the stratospheric inventory increases with time. Still it can be clearly seen that the concentrations of both the tracers are repeatedly higher in early spring through summer than in fall and winter.

The total inventory of ^{238}Pu, seems to be too low (17 kc as compared to 250 kc for ^{109}Cd [*List et al.*, 1966] to give rise to a prominant peak during successive years. None the less, they confirm the trend shown by ^{109}Cd; the slight differences in the time of appearance during successive years is probably not significant and could be understood in terms of the variable nature of circulation patterns from year to year. Therefore, if the 31- to 33-km level can be considered to reflect concentrations at higher levels in the stratosphere, these observations suggest that the transport of air across the stratopause is strongly seasonal, taking place around spring.

It is known [*Feely et al.*, 1966; *List et al.*, 1966] that the debris from this level gradually descends to lower altitudes in the stratosphere. The sudden decrease in the tracer concentration encountered every year suggests that mixing

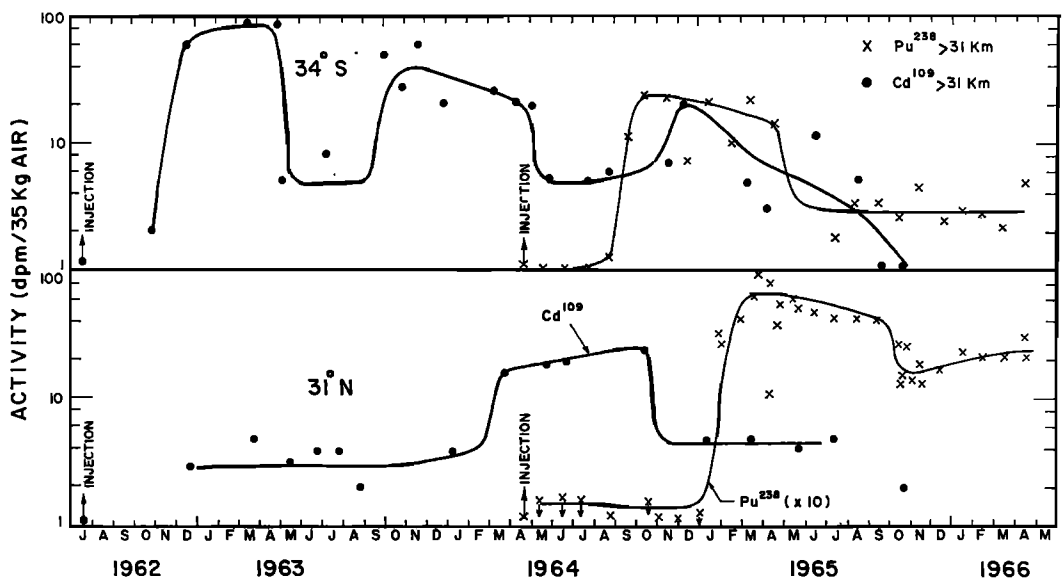

Fig. 2. Observed ^{109}Cd and ^{238}Pu concentrations at 34°S and 31°N during 1962–1966. The data are taken from HASL reports.

with the lower levels is quite sudden and strong.

Since both tracers happened to appear in the southern hemisphere about six months after their injection, *List et al.* [1966] concluded that in both the hemispheres the time histories for dispersion of debris injected in the mesosphere are identical and independent of the season of injection to a large extent. Our analysis suggests that this conclusion may not necessarily be valid. The delay of almost one year in the major appearance of ^{109}Cd in the northern hemisphere as compared to ^{238}Pu can be understood only in terms of seasonal variations in the mesospheric circulation and mesospheric-stratospheric exchange of air. The seasonal difference in periods of their injection might well be responsible for their different dispersion pattern in the northern hemisphere. The observed distribution of these isotopes can be reproduced if it is postulated that in the mesosphere air moves from the summer to the winter pole and away from the equator during equinox months. Although such a circulation pattern can explain the behavior of the two isotopes ^{109}Cd and ^{238}Pu in the upper stratosphere, further confirmation will be necessary to prove its existence.

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References

Bhandari, N., Studies of some physical processes occurring in the atmosphere based on radionuclides of natural and artificial origin, Ph.D. thesis, University of Bombay, 1965.

Bhandari, N., D. Lal, and Rama, Stratospheric circulation studies based on natural and artificial radioactive tracer elements, *Tellus, 18*(2), 391, 1966.

Feely, H. W., P. E. Biscaye, B. Davidson, and H. Seitz, Eleventh progress report on Project star dust, *DASA Rep. 1821, Isotopes, Inc.*, 1966.

Health and Safety Lab., U.S. Atomic Energy Commission, Reports 158, 171, 172, 173, 174, 182, 183, and 184, 1966–1968.

Labitzke, K., Midwinter warmings in the stratosphere and lower mesosphere, *Z. Geophys., 34*, 556, 1968.

List, R. J., L. P. Salter, and K. Telegadas, Radioactive debris as a tracer for investigating stratospheric motions, *Tellus, 18*(2), 345, 1966.

Telegadas, K., and R. J. List, Global history of the 1958 nuclear debris and its meteorological implications, *J. Geophys. Res., 69*(22), 4741, 1964.

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