NOTES AND CORRESPONDENCE

Storage of Radioactive Debris in the Polar Vortex

J. R. BARCUS

University of California, Berkeley

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In recent years there have been a number of balloon observations in the lower stratosphere of radioactive layers which had originated from nuclear explosions at great distances. For example, Mantis and Winckler (1960) and Anderson (1962) have observed such layers beneath the base of the stratosphere. In these cases the debris was encountered within several days after the explosions, and the delay times and spatial distributions at the various sites have been reasonably well accounted for in terms of known meteorological processes at and below the tropopause. An early fallout pattern generally results from such material in the troposphere as the lifetime of the debris is relatively short there (20-30 days) owing to rapid scavenging and precipitated in rainfall.

Many more similar observations in the stratosphere have also been reported (Anger and Brown, 1960; Anderson, 1962; Keppler *et al.*, 1964; Conforto *et al.*, 1964). Again, enhancements above normal radiation levels were encountered within several days following the detonations and thus pertain to the early phases of the debris dispersal. The significance of these observations has not been adequately developed as the transport, distribution, and lifetime of the debris in the stratosphere are much less well understood.

This letter presents several observations of the storage of radioactive debris in the polar stratosphere. The measurements were made incidentally to a series of high altitude balloon flights primarily intended for auroral zone research and released from Point Barrow, Alaska, during March 1963. This period followed by some months an intensive high latitude series of atmospheric nuclear tests which had been conducted by the USSR from 5 August to 25 December 1962.

Fig. 1 summarizes the observations showing the counting rate versus pressure relationship up to 10 mb ($\sim 100,000$ ft) for energy losses greater than 25 keV in an NaI scintillator (2.54 cm dia., 2.54 cm ht.). Similar measurements at 50 and 100 keV were also made on each flight. The smooth curve illustrates the normal atmospheric transition which is largely due to secondaries produced by the primary cosmic radiation; this curve was obtained from the ascents of more than 60 similar balloon borne detectors released from central Alaska in the summer of 1962, some months before the

tests, and again in the autumn of 1963, approximately one year after the series. The figure shows that a considerable and nearly constant excess was repeatedly encountered in the polar atmosphere during the spring of 1963. Departures from normal began to appear somewhat above the tropopause (~ 10 km), attained a maximum near 20 km, and essentially returned to zero below 30 km. The differences in the profiles from flight to flight and the "lumpiness" on individual flights are significant and probably indicate real spatial structure.

Except for the sporadically occurring auroral events which involve the precipitation of soft electrons, the geophysical and solar circumstances were otherwise quiet. This fact and the unusual intensity profile for the excess radiation at the observed depth in the atmosphere make it highly probable that this relatively stable layer was due to radioactive debris which had been injected into the stratosphere in the autumn and early winter of 1962 and subsequently stored in the polar vortex.

It is possible to make some crude estimates of the specific and total activities in the vortex. Consideration of the sensitivity of the detector for various types of radiation together with the additional energy measurements at 50 and 100 keV indicate the excess was largely degraded γ rays whose energies were approximately 100 keV. Application of the usual method utilizing an absorption in air appropriate for γ rays in this energy range leads to a specific activity of the order of 1 disintegration per second per gram in the neighborhood of the maximum. The vortex winds were such that a given parcel of air in the lower stratosphere at these latitudes would circle the pole in a few days. Thus, a large portion of the vortex would have been sampled over a period of two weeks, and the observations then indicate a relatively uniform distribution in longitude. One can only guess at the distribution in latitude; however, it seems reasonable to suppose the debris at this time was still largely contained to polar latitudes. Assuming then the observed profile is representative above a belt-like region some 10^9 cm circumference by 10^8 cm width, a total activity of the order of 10^2 to 10^3 megacuries of mixed gamma activity results. This appears to be a respectable order of magnitude estimate as the fission yield of mixed gamma activity some 4 to 6 months following the deto-

FIG. 1. Comparison of balloon ascents through the atmospheric transition region showing evidence of radioactive debris in the polar stratosphere.

nation of a one megaton device would be of the order of a few megacuries, and the 1962 USSR test series yielded some 150 megatons (*Supplement to Effects of Atomic Weapons*, 1964). In view of large uncertainties, even this order of magnitude agreement might be considered somewhat fortuitous; nevertheless, it is sufficiently accurate to illustrate the enormous quantity of debris stored in the vortex.

These *in situ* observations of vortex storage have an important bearing on stratospheric circulation systems and their relevance to the residence time of radioactive debris. A very promising approach to these problems has been offered by Libby and Palmer (1960) in their analysis and interpretation of world-wide radioactive fallout. They suggest the essential controlling factors are a combination of meridional circulation cells, the annual evolution of the polar vortex, and the geographical location of the injections with respect to these systems. The present observations lend considerable support to their viewpoint regarding the important role played by the polar vortex. This is made especially clear by summarizing the following sequence of events: (1) Balloon probes during the summer of 1962 showed the polar stratosphere was largely "clean" at this time. (2) An intensive series of atmospheric nuclear tests at high latitudes took

place from August through December, 1962; this period largely coincided with the formative and mature phases of the polar vortex in the northern hemisphere. (3) Over a two week period in March 1963 several observations of radioactive debris in the polar stratosphere were made; consideration of the existing meteorological conditions indicated a relatively uniform longitudinal distribution throughout the vortex. (4) Summaries of the upper air profiles of temperature and wind showed that the vortex gradually broke-up in late April (Palmer, 1964, private communication). (5) Shortly thereafter radioactive fallout in rainfall exhibited large increases at all latitudes in the northern hemisphere; fallout continued at a high level throughout the summer but finally declined to a low value by September 1963 (Libby, 1964, private communication). (6) Balloon probes during September and October 1963 showed that radiation levels in the polar atmosphere had essentially returned to normal. This is exactly the spatial and temporal sequence which had been proposed for polar injections.

It thus appears that the effects of circulation systems on the transport and residence time of radioactive debris in the lower stratosphere are better established. It will be of great interest to follow the progress of radioactive tracers injected by the equatorial tests whereby the zonal and meridional circulations in the high stratosphere may also be better understood.

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REFERENCES

- Anger, C. D., and R. R. Brown, 1960: Observations of the temporary presence of radioactive matter in the atmosphere. *J. Geophys. Res.*, **65**, 3502-3503.
- Anderson, K. A., 1965: Thin atmospheric layers of radioactive debris during September 1961 and 1962. *J. Geophys. Res.*, **70**, 1139-1153.
- Conforto, A. M., F. Mariani, S. Cantarano, A. Egidi and Mr. Terenzi, 1964: Balloon observations of very intense artificial

- radioactivity in autumn 1962. *J. Geophys. Res.*, **69**, 1658–1662.
- Keppeler, E., G. Pfozter and W. Riedler, 1964: Radioactive debris from nuclear explosions in high altitudes. *J. Atmos. Terrest. Phys.*, **26**, 429–436.
- Libby, W. F., and C. E. Palmer, 1960: Stratospheric mixing from radioactive fallout. *J. Geophys. Res.*, **65**, 3307–3317.
- Mantis, H. T., and J. R. Winckler, 1960: Balloon observations of artificial radioactivity at the base of the stratosphere. *J. Geophys. Res.*, **65**, 3515–3520.