Artificial radio-activity, ozone and volcanic dust as atmospheric tracers in the Southern Hemisphere[1]

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(Manuscript received November 1, 1965)

ABSTRACT

The use of artificial radio-activity measurements to study atmospheric transfer processes is particularly attractive in the Southern Hemisphere because of the absence of atomic testing at other than equatorial regions.

Observations of volcanic dust at Aspendale (38° S) following the Bali eruption of 1963 show that the bulk of the material arrived in these latitudes after about six months at a height of 20 km. Simple diffusion theory would imply a horizontal transfer coefficient of 4×10^9 cm^2 sec^{-1}. A similar value would be inferred from the initial appearance of artificial radio-activity in rainfall following the 1962 series of atomic tests at the equator.

However, stratospheric sampling carried out at Mildura (35° S) indicate the poleward transfer of fission products to be rather complex. The first arrival after about six months is well demonstrated at a height of 18 km; but other, stronger centres of activity appeared at 33 km after 6–9 months, and at 25 km after 12 months.

Seasonal effects are observed in all tracers, but with the various maxima occurring at slightly different times of the year, presumably due to the different heights involved in transfer from an equatorial reservoir.

1. Introduction

In recent years there has been considerable interest in attempting to document the large-scale transfer processes in the stratosphere by means of various tracers. Some definite patterns are now emerging although individual studies occasionally appear to yield contradictory results. Most of these investigations have been confined to the Northern Hemisphere.

The need to extend this type of research to the Southern Hemisphere can be advanced for a number of reasons. There is a distinct possibility that the circulations in the two hemispheres are not identical. Some experimental evidence of this is already available from ozone observations. Where artificial radio-activity is used as a tracer the Southern Hemisphere offers unique opportunities in that no large atomic bombs have been exploded south of the Equator at any time. Thus the ambiguity regarding the source of fission products which exists in the Northern Hemisphere does not arise. Furthermore, although interaction between the two hemispheres is generally considered to be very small, there have been recent suggestions of a very definite link at heights of the order 50–60 km (GOLDSMITH, 1962).

The present paper summarises recent information which has been obtained in a series of investigations by members of the C.S.I.R.O. Division of Meteorological Physics, Australia.

Measurements of total ozone by means of the Dobson spectrophotometer have been obtained at the main laboratory at Aspendale, Victoria (38° S) since 1955, at Brisbane (27° S) since 1956, at Macquarie Island (54° S) since 1957 and at Port Moresby (8° S) since April 1965. Recently a programme of ozone soundings using the Mast-Brewer instrument has been instigated at Aspendale.

Artificial radio-activity occurring in rainfall at Aspendale as a result of nuclear tests has been measured since 1958. Similar data is also available for other Australian stations in papers published by the Australian Atomic Weapons Test Safety Committee.

[1] Paper presented at the CACR Symposium on Atmospheric Chemistry, Circulation and Aerosols, Visby, Sweden, August 18–24, 1965.

A continuous record of solar radiation data has been obtained at Aspendale since 1959 by a variety of meteorological instruments. Recently these data have been re-examined and have yielded considerable information regarding the movement of volcanic dust from the Bali eruption of March 17, 1963.

2. Ozone observations

Monthly mean values of total ozone observed at Aspendale are presented in Fig. 1. The familiar spring increase is seen with the maximum occurring in September of each year. Using the Aspendale ozone data up until 1961, Funk & Garnham (1962) drew attention to a two-year cycle. The more recent data of Fig. 1 for the years 1962–1965 reveals a modification of this feature, such as would occur if the oscillation were not exactly biennial. A more complete discussion of this is being prepared for publication elsewhere (Kulkarni).

Kulkarni (1962) has discussed the distribution of ozone with latitude in the Southern Hemisphere and finds that the greatest amount occurs in October at a latitude of 54° S. This is unlike the Northern Hemisphere where the Spring maximum occurs at much higher latitudes. The Southern Hemisphere "Spring" maximum is found to occur in September at 38° S, in October at 54° S and in December at 75° S.

In a recent analysis of Umkehr measurements Kulkarni (private communication) has constructed height-latitude distributions of ozone for the Southern Hemisphere. These show features similar to many other tracers with isopleths of maximum concentration sloping downwards from 30 km at the equator to 20 km at the pole in summer, and with the maximum concentration in spring occurring at 54° S at a height of 20 km.

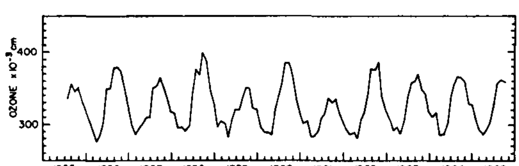

Fig. 1. Total ozone at Aspendale 38° S.

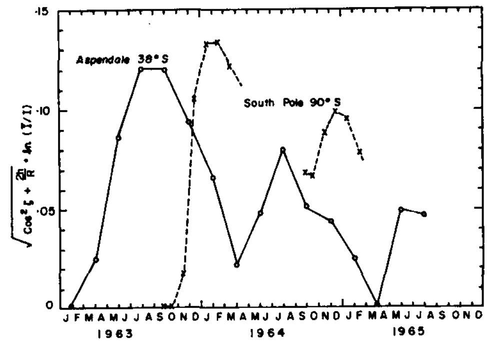

Fig. 2. Quantity of volcanic dust inferred from solar radiation measurements at Aspendale and the South Pole.

3. Volcanic dust

Following the Mt. Agung eruption on March 17, 1963, at Bali (8° S), the volcanic ash is known to have spread on a global basis at a height in middle latitudes of about 18–20 km (Hogg, 1964; Mossop, 1964; Meinel & Meinel, 1964). Solar radiation data at Aspendale and the South Pole have been used to illustrate the arrival of the dust layer (Flowers & Viebrock, 1965; Dyer & Hicks, 1965).

If $\bar{I}$ represents the normal value of the direct solar beam at the surface of the earth and I the value found in the presence of volcanic dust it can readily be shown that the quantity $\sqrt{\cos^2\zeta + 2h/R\ln(\bar{I}/I)}$ is an index in arbitrary units of the quantity of dust present. ζ is the zenith angle, h the height of the dust stratum and R the radius of the earth. Except when the sun is very close to the horizon and the reduction ΔI of the solar beam is large, the above expression reduces to $\cos\zeta \cdot \Delta I/\bar{I}$.

In Fig. 2 the solar radiation data is analysed in this way. Data for the years 1957–1962 were used to establish the normal values of the South Pole. The years 1958–1962 were used in a similar manner for the Aspendale data.

The major arrival of the dust occurred at 38° S after 4–5 months and after 11 months at the South Pole. A return of the dust at reduced intensity is evident at 37° S for the winters of 1964 and 1965. This is consistent with the occurrences of spectacular sunsets over Southern Australia during late 1963, the winter of 1964, and to a lesser extent the winter of 1965.

Applying simple diffusion theory in the familiar form $x^2/2\ Kt = 1$ for the arrival of the first maximum concentration we find K values of

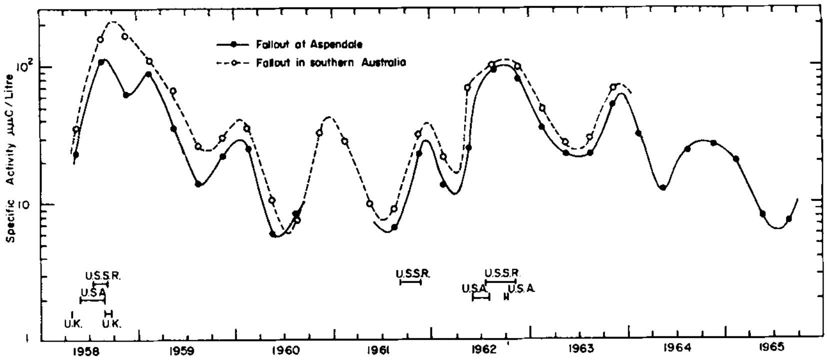

FIG. 3. Total β-activity in rain water at Aspendale and over Southern Australia.

4×10^9 cm^2 sec^{-1} for Aspendale data and 1.4×10^{10} cm^2 sec^{-1} for the South Pole data. Alternatively a meridional mean motion model would require poleward velocities of 25 cm sec^{-1} and 32 cm sec^{-1} respectively. These values are consistent with those suggested by other tracers. A discussion of seasonal effects on the basis of either diffusion theory or mean motion would require setting up an elaborate model, and would be beyond the scope of this paper.

4. Artificial radio-activity

Measurements of total β-activity in rainfall at Aspendale since 1958 are presented in Fig. 3 in the form of specific activity. Similar data published by the Australian Atomic Weapons Test Safety Committee averaged for Perth, Adelaide, Melbourne, Hobart and Sydney are included. These stations lie in a narrow latitude belt (32° S–43° S).

Seasonal effects are clearly evident for the years 1959, 1960, 1961, 1963 and 1964, with the maximum specific activity occurring in November–December. No atomic tests were conducted in the Southern Hemisphere during these years. The arrival of new debris approximately six months after the 1958 and 1962 tests is clearly responsible for the broader peaks of these years. Decay measurements verified the origin of these fission products (DYER & YEO, 1960; DYER & HICKS, 1965).

There is evidence of a long stratospheric residence time in that, except for the periods of fresh injections the general level of radioactivity shows little diminution over several years. A further evaluation of this aspect requires either correction for decay or the use of individual long-lived isotopes.

The arrival of new material in middle Southern latitudes from the 1962 equatorial tests is graphically illustrated in data from the balloon-borne soundings made at Mildura (34° S) (HASL, 1961–1965) (Project "HIBAL" carried out by Australian Department of Supply and Health and Safety Laboratory, U.S. Atomic Energy Commission). Fig. 4 shows a time-height analysis of measurements obtained of concentrations of Sr^{90}.

It is clear that the initial arrival of debris some six months after the 1962 tests occurred at a level of about 18 km. However, another centre of concentration arrived early in 1963 at the 32 km level and the greatest concentration in the middle of 1963 at the 25 km level. All of this material has isotopic ratios showing it to be of recent origin. This should not be construed as evidence that the stratosphere is well mixed, as is sometimes done, but merely as an indication that all the material comes

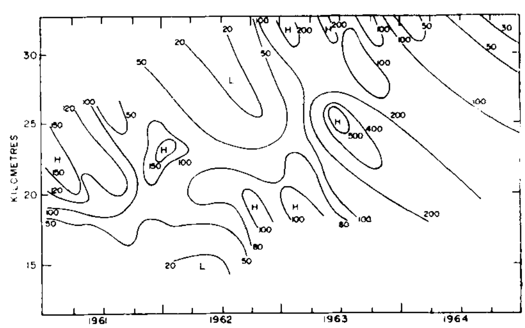

FIG. 4. Sr^{90} concentrations at Mildura (34° S) (d.p.m./1000 S.C.F.).

from the same test series. Indeed, the concentration diagram of Fig. 4 illustrates that the stratosphere is not well mixed.

Seasonal effects are illustrated by the arrival early in 1961 and 1962 of concentrations of Sr^{90} at the 23 km level. There is a strong suggestion in the slope of the isopleths of about 1 km/month that this material is responsible for the maximum fall-out observed in rain 8–9 months later.

5. Discussion

The evidence provided by the radio-active fall-out measurements and the volcanic dust data clearly indicates that the stratospheric transfer processes between equator and the South Pole involve times of the order of six months to middle latitudes and eleven months to the pole.

Seasonal effects are evident with different tracers showing maxima at slightly different times of the year, presumably due to their occurring at different heights.

A plausible suggestion would be that there is an equatorial reservoir of the various tracers considered at different heights being drawn on at different times of the year. There is considerable support for this suggestion from the 26-month wind oscillation recently discovered. This moves downward in the equatorial stratosphere at the rate of about 1 km/month. Such a wind oscillation requires an inflow and outflow of momentum, presumably by eddy transfer (TUCKER, 1964). Mixing of this sort would transfer particulate matter away from an equatorial source with a 13-month cycle. Different levels would be drawn on at different times in the same way as momentum. This process may be superimposed on a genuine (12-month) seasonal transfer.

The present results are encouraging and indicate that observations of the Southern Hemisphere circulation are broadly consistent with those being made in the Northern Hemisphere. Some differences have been observed, however, in the case of ozone.

Further work at this laboratory is being planned to investigate the interaction between stratosphere and troposphere. An ozone sounding programme is already under way and is expected to yield informative results. Measurements of various cosmic-ray produced isotopes have begun with a view to constructing profiles extending into the stratosphere. It is also intended to make observations of water vapour in the stratosphere such as has already been carried out in the Northern Hemisphere.

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ИСКУССТВЕННАЯ РАДИОАКТИВНОСТЬ ОЗОНА И ВУЛКАНИЧЕСКОЙ ПЫЛИ КАК ТРАССЕРА АТМОСФЕРЫ В ЮЖНОМ ПОЛУШАРИИ

Использование измерений искусственной радиоактивности для изучения процессов переноса в атмосфере особенно привлекательно для Южного полушария, вследствие отсутствия испытаний атомных бомб в других областях, кроме экваториальных.

Наблюдения вулканической пыли в Аспендейле (38° ю. ш.) после извержения на о. Бали в 1963 году показали, что основная масса пыли достигла этих широт спустя примерно шесть месяцев на высоте 20 км. Простая диффузионная теория подразумевала бы коэффициент горизонтального переноса, равный 4×10^9 см^{2}сек$^{-1}$. Подобная величина могла бы быть получена из первоначального появления искусственной радиоактивности в выпадениях осадков, последовавших за серией испытаний атомных бомб на экваторе в 1962 году.

Однако, пробы в стратосфере, проведенные в Милдура (35° ю. ш.) указывают, что направленный к полюсу перенос делящихся продуктов является довольно сложным. После шести месяцев первое появление делящихся продуктов хорошо обнаруживается на высоте 18 км, но другие, более сильные центры активности появляются на 33 км после 6–9 месяцев, и на 25 км — после 12 месяцев.

Сезонные эффекты наблюдаются во всех трассерах, но с различными максимумами, имеющимися в слабоотличающиеся времена года, что предположительно обусловленно различием высот, на которых происходит перенос из экваториального резервуара.