Investigation of the radioactive aerosol distribution over oceans and some problems of the latitudinal exchange in the tropical zone

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ABSTRACT

On the basis of data from Soviet research ships six cases of the radioactive fission product distribution in the lower layer of the air in different meridional zones of the globe are considered. An attempt is made to reveal some circulation conditions of air propagation from the middle latitudes into the tropics and the other hemisphere (in the surface layer).

A problem on the influence of polar intrusions on the evolution of intertropical convergence zone is touched upon.

The problems of the distribution of the radioactive products from nuclear explosions into the lower latitudes and their transfer into the other hemisphere are closely connected with the atmospheric circulation investigation in the tropical zone and the problem of the air exchange between the hemispheres. Air exchange mechanism in the tropical zone is a comparatively poorly studied question of the general atmospheric circulation, though there are many articles on the particular questions of the circulation in the tropics and a number of good summaries (Riehl, 1954; Khromov, 1956; Pedelaborde, 1958). One of the main difficulties is the impossibility of tracking for separate "air masses" and air volumes in the lower latitudes due to the rapid transformation of the temperature and moisture fields. In many cases tracking in the tropical latitudes becomes possible when various characteristics of the air radioactivity are used as a tracer of "air masses".

In this paper an attempt is made to reveal the circulation conditions of air propagation from the middle latitudes into the tropics and the other hemisphere (in the surface layer) on the basis of investigation of the radioactive fission product distribution in different meridional zones and the synoptical analysis of reasons causing these or those radioactivity variations. The influence of the Polar intrusion on the evolution of intertropical convergence zone is also touched upon.

To find the reasons of various radioactivity distribution in the surface air level complex of atmospheric processes were taken into account —firstly the transfer of radioactive products from the stratosphere into the surface air level and secondly their transfer in this surface air level. This method was used by one of the authors of the report in the previous article (Dmitrieva, 1965). According to that article it was believed that stratospheric radioactive air is transferred rapidly into the surface air level by separate portions under certain aerosynoptical conditions. According to Dmitrieva & Kasatkina (1965) these conditions are: (1) the presence in the upper troposphere of well formed "sharp" trough with very high wind speeds at each side from its axis and the horizontal wind shear along the axis and (2) the region of the intensified pressure behind the cold front in the cyclone rear or a wave near the earth surface (more often in the forming ridge). As was shown above, rapid descending ("sliding") transfer of the stratospheric air downwards in the middle latitudes takes place along the inclined isentropical surface from the stratosphere into the troposphere.

This point of view on the mechanism of

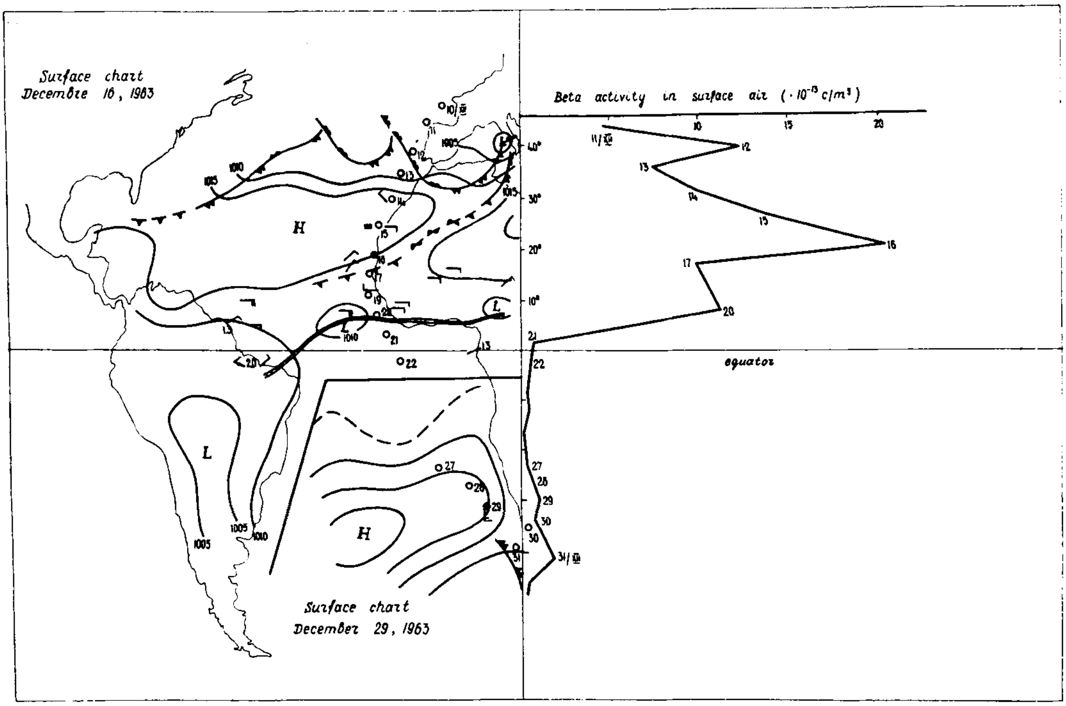

FIG. 1. *Route I.* The ship positions and their data (circles and figures to the right in the left hand corner of the figure). General β-activity variation in the lower layer of the air corresponding to the route (the right hand corner of the figure). Weather charts of the ship positions marked in the figure with black circles.

radioactivity transfer from the stratosphere into the troposphere is similar to that of STALEY (1960, 1962). As it is known from theoretical investigations Staley thinks the barocline troposphere zones considering then the south parts of high-altitude intensive troughs as the transfer mechanism of radioactive debris from the stratosphere into the troposphere in the extratropical latitudes. Staley examines this experimentally from beta-activity measurements near the dry inversions by means of aircraft sampling. Beta-activity maximum was detected in the inversions or near them.

For brevity we shall call the rapid transfer of the stratospheric air portions into the surface air level under the described above conditions "the stratospheric break".

Material and its analysis

Data from the Soviet Research Ships making journeys in the Atlantic, Indian and Pacific oceans served as an initial material to obtain the radioactive product distribution in the surface air in the middle and tropical latitudes. Six meridional radioactivity distributions are considered in the present paper. The ship routes that gave the radioactivity distributions were the following.

I. In the east of the Atlantic along the western European coasts and Africa from the north to the south in December of 1963.

II. In the same region but from the south to the north in April of 1964.

III. From the Mediterranean into the Indian Ocean via the Red Sea in July of 1960.

IV. From the Indian Ocean via the Javanian Sea to the west of the Pacific Ocean of the northern hemisphere in August of 1960.

V. From the west of the Pacific Ocean in the northern hemisphere into the eastern part of the Indian Ocean of the southern hemisphere in September–October 1961.

VI. Along 180° meridian from the southern hemisphere (from 40° S) into the northern one up to 10° N, and then to the north-west in December of 1961 and January of 1962.

Let us consider each route separately.

Route I and its dates are shown in the left hand corner of fig. 1 (circles and figures are to the right from them). In the right hand corner of the figure the average total beta-activity of the air for 24 hours is presented.

One can see at the right hand corner of Fig. 1 that the maximum concentration was observed at 20° N and about 40° S. The deep minimum between them was in the 10° S region. In the middle latitudes of the northern hemisphere air radioactivity varied strongly along the ship run.

The analysis of the daily synoptic charts for the discussed period showed that the atmospheric processes over the Atlantic in the northern hemisphere are characterized by intensive cyclonic activity. High altitude frontal zone was at 30–40° N. Cyclonic disturbances transferred one after another from the west to the European western coasts and to the Mediterranean. All significant air radioactivity variations in the middle latitudes of the northern hemisphere are associated with the fronts, that were crossed by the ship. Reduced concentration values were observed before the warm front and in the warm sector. Radioactivity increased sharply behind the cold front in the cold air. Radioactivity increasing behind the cold front or in the high region in the middle latitudes was noted in a number of other works (for example, MURAJAMA, 1959, 1962; KOPCEWICZ, 1962; GAT *et al.*, 1963; BEKER, 1963; LAVRENCHIK, 1965; VILENSKII *et al.*, 1965). This is in agreement with the ideas on the mechanism of radioactivity transfer into the surface air level given in the introduction on the basis of papers (DMITRIEVA, 1965; DMITRIEVA & KASATKINA, 1965; STALEY, 1960, 1962).

The most interesting peculiarity of the meridional radioactivity distribution in the given route is the presence of sharp maximum observed at the latitude about 20° (a black circle in the left hand corner of Fig. 1 and the corresponding peak in the right one). Then synoptic situation near the earth surface was characterized by appearence over the African western coast (20–30° N) of the ridge behind the slightly frontal section (in Fig. 1, Weather chart, December 16, 1963). A deep trough with very high wind speeds in the periphery was detected at altitudes over this region. One should pay attention to the fact that the observed situation was just the same when the stratospheric breaks into the surface layer at the middle latitudes occur (DMITRIEVA & KASATKINA, 1965). One may assume that in this case the radioactivity maximum was associated with recent intensive stratospheric break into the surface layer in the subtropical zone. From the weather chart on December 16, 1963 it may be seen that radioactive air in the surface layer had an opportunity to move from the African western coasts to the west and south-west to the north part of South America. Further ship's movement to the south was accompained by sharp decrease of radioactivity near the African coasts. Slight radioactivity increase was observed on December 20 before the intertropical convergence line at the 5° N latitude. The crossing of this line was accompained by sharp radioactivity decrease up to the minimum values. Thus the intertropical convergence line over the Atlantic eastern part in the period under discussion was a considerable obstacle for propagating in the surface air level of the northern hemisphere to the equator. Over the north of South America the convergence zone lowered to the south from the equator and therefore there were conditions for movement of the northern hemisphere air to the equatorial region of the southern hemisphere. The role of the intertropical convergence zone as a barrier in the interlatitudinal exchange of the tropical surface air was also noted by VILENSKII *et al.* (1965) and LABEYRIC & LAMBERT (1963).

Route II. Meridional radioactivity distribution in the lowest layer of the Atlantic eastern part during the back ship run differs considerably from the first route. The radioactivity variation in April–May of 1964 is shown in the right hand corner of Fig. 2. The ship movement is indicated by circles in the left hand corner of the figure (black circles—ship position for the corresponding weather charts). The dotted line in the right hand corner gives the radioactivity variation at run I.

The appreciable peculiarity of the radioactivity distribution at run II is the presence of the great maximum in the northern hemi-

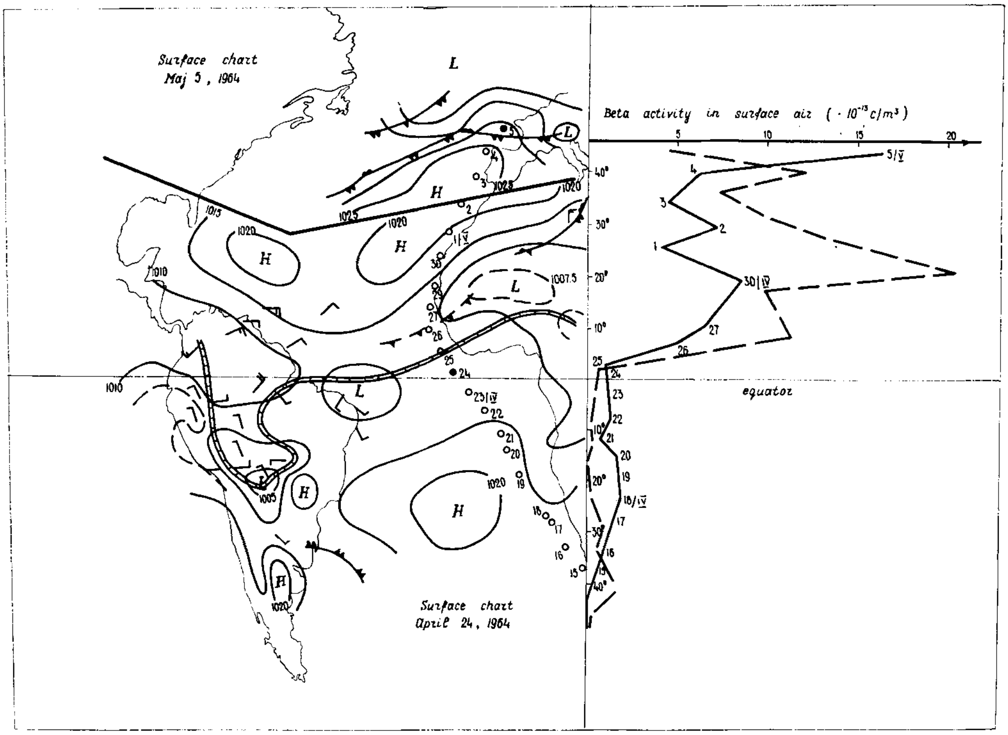

FIG. 2. *Route II.* The same legend as for Fig. 1.

sphere not at 20° N but about 40° N. There is the peak in the radioactivity variation in the subtropical latitudes but its intensity is considerably less than in December. The analysis of the synoptical processes in April of 1964 and their comparison with the synoptical processes in December of 1963 permitted to establish that the high-altitude frontal zone which was near the African north-western coasts in December shifted to the northern regions (45–55° N). In this frontal zone wind speeds in the upper troposphere were 100–200 and more km/h. The meridional processes were not observed clearly, but horizontal cyclonic wind shear in very strong currents in the rear of surface air level cyclonic disturbances were noted. These disturbances moved very rapid over the Atlantic from south-west and further over the Europe to the east and south-east. The maximum value of the radioactivity concentration in run II was observed on May 5 in the rear of one of such disturbances over the Bay of Biscay in the surface ridge (in Fig. 2, weather chart, May 5).

The second peculiarity of atmosphere processes of the given period is a development of an upper-air deep trough over northern and north-east African regions in the second part of April. Thus in route I the intrusion of the stratospheric air into the surface level occurred at western African coasts near the intertropical convergence zone but in route II the transport of air from the upper atmosphere into the surface level could occur in regions located further from the place of ship crossing the convergence zone (south-east Mediterranean Sea, Northern Africa). Along the route of movement in the surface level to western African coasts radioactive aerosol concentrations decreased in it. Therefore evidently radioactivity at 20° N over the western part of the Atlantic Ocean (solid line Fig. 2) was considerably lower in the second route than in the first one (dashed line Fig. 2).

One should pay attention to more smoothed variation of radioactivity in the region of 5–10° N to the North of the convergence line (Fig. 2). The analysis of synoptical charts and

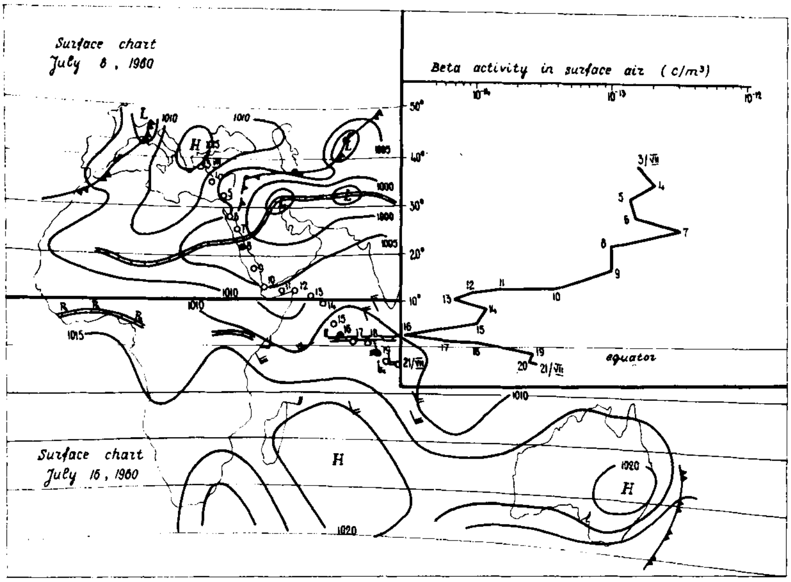

FIG. 3. *Route III.* The same legend as for Fig. 1.

the convergence line permitted to arrive at the conclusion that the convergence line evolution over the Atlantic is closely connected with the intrusion of air from middle latitudes. Sometimes cold front of western African coasts moving to lower latitudes, as if combines with the convergence line and leads to its "sharpening". In other cases it stops to the North of it, enters the system of depressions over Africa and at north-east coasts of the South America and it plays the role of the convergence line while the old part of the convergence line over the eastern Atlantic weakens and vanishes. Some time later in its turn this new convergence line may change for a new one. Thus some portions of air of middle latitudes of the northern hemisphere probably enter the equatorial regions of western Africa to the south of the convergence line. Instability of the convergence line near the equator over the eastern Atlantic during the period in question may explain a comparatively slower increase of the radioactivity concentration while ship crossing the frontier from south to north in route II.

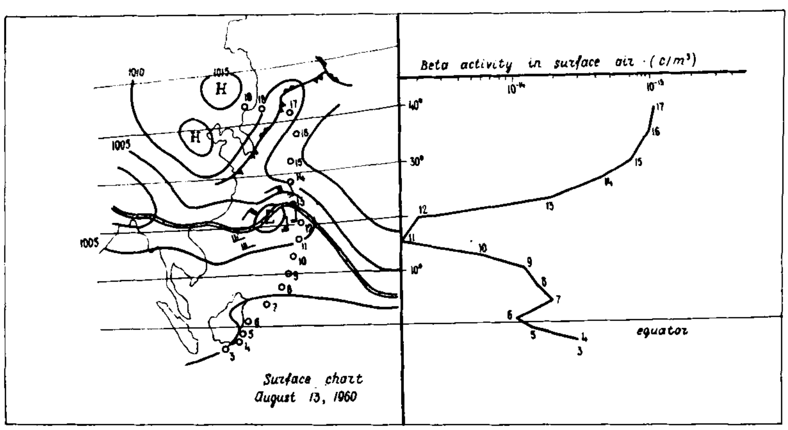

FIG. 4. *Route IV.* The same legend as for Fig. 1.

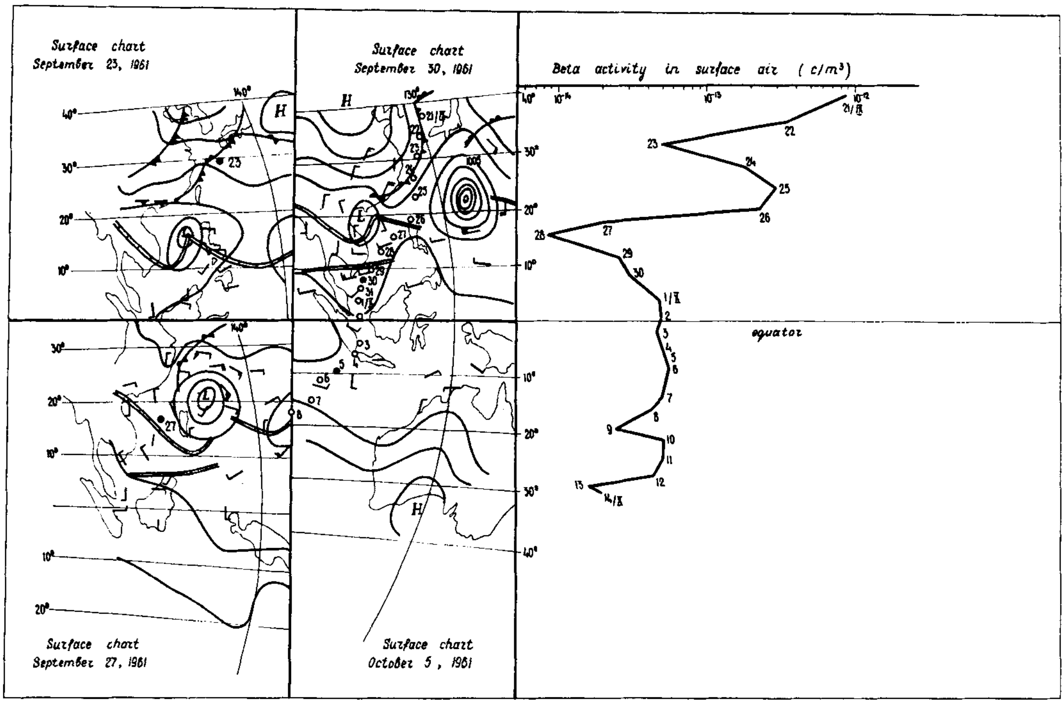

FIG. 5. *Route V*. The same legend as for Fig. 1.

The left part of the weather chart of April 24, 1964 (Fig. 2) can serve as an example of a possible air extent near the surface layer from the northern hemisphere into the southern one up to 20° S. Air movement to south-west near the equator over the South America may be interpreted as inertial.

Routes III and IV. An analysis of the data of routes III and IV (Figs. 3 and 4) will be short as the result of observations of these routes have been discussed in detail in paper by VILENSKII, DMITRIEVA & KRASNOPEVTSEV (1965). The peculiarity of synoptical conditions of routes III and IV was summer depression over northern Africa and southern Asia. The convergence zone was associated with it and when the ship was crossing it large variations of the concentration of fission products in air were observed. To the north of the convergence line the concentration was appreciably higher than to the south. For all of that it should be mentioned that the convergence line both over the Red Sea and the western Pacific Ocean was weakly expressed by meteorological data.

Favourable conditions for the stratospheric air extent into the surface layer were in middle latitudes in route IV and III. And over the Red Sea (route III) the surface air then came directly to the convergence zone and here at 20° N the maximum of radioactivity occured. In route IV over the western Pacific the maximum concentration was observed considerably to the north, about 40° N, behind the cold front in the region of stratospheric break.

An interesting peculiarity of route III was the revelation of the second convergence line in the region of equator in the Indian Ocean. To the north of it the air was poor in radioactive products of artificial origin, but to the south their concentration increased appreciably. It was explained by the fact that in the Indian Ocean over subtropical and middle latitudes of the southern hemisphere in the discussed period there were conditions for stratospheric air extent to the surface level and for its further movement to the equator.

Route V was over the western part of the Pacific Ocean. Synoptical conditions in September 1961 were very complex there (Fig. 5). In the region of Japan there were continuous

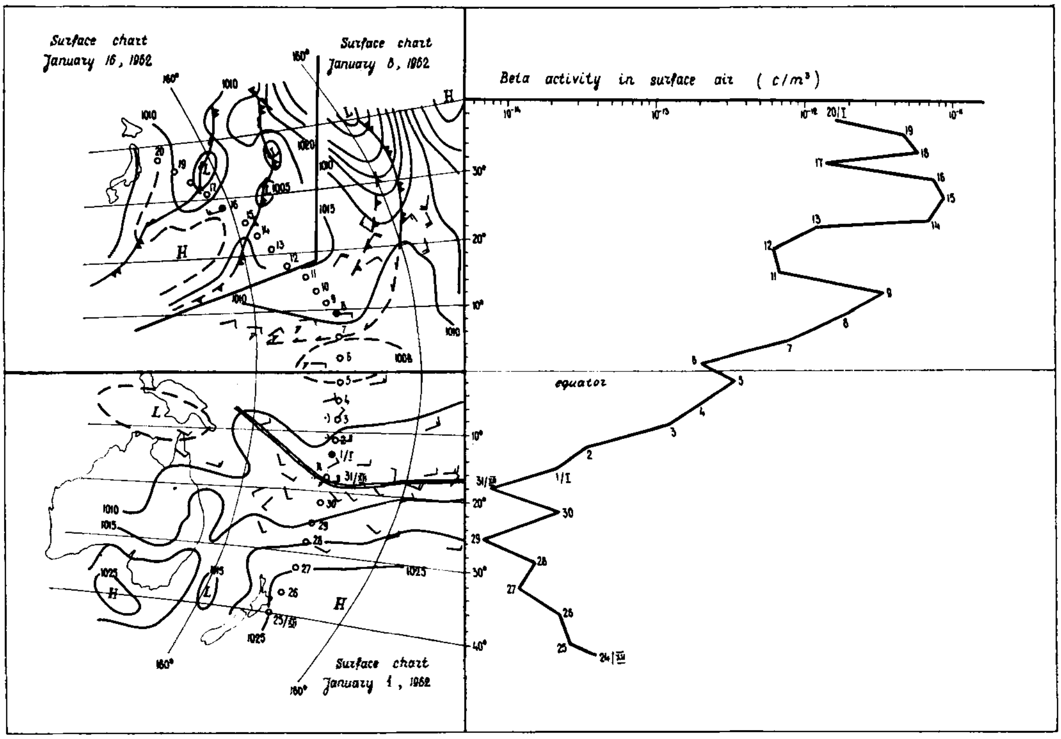

FIG. 6. *Route VI.* The same legend as for Fig. 1.

air intrusions from west and north-west. Tropical cyclones transferred to south-west of the northern part of the Pacific Ocean. Radioactivity variations of the surface level air as well as in previous routes were in a good agreement with synoptical conditions (Fig. 5). The maximum of radioactive concentration occured at the latitude of 40° N in cold air masses. The ship was crossing the convergence line (chart of September 27, 1961, Fig. 5) at 15° N. In this case after crossing the convergence line a sharp decrease of radioactivity was observed. Minimum radioactivity in the given route was observed in the region of 15–10° N. Rapid increase of radioactivity beginning with 10° N while further movement of the ship to the south-west was connected with crossing of the second convergence line to the south of which there was probably air of the southern hemisphere.

This conclusion was based firstly on the fact that the same level of radioactivity is observed both to the south from the frontier in the northern hemisphere and in the southern hemisphere up to 30° S; secondly predomination of winds with a southern component in the equatorial zone of this region.

In connection with synoptical analysis of the given route let us mention the following:

1. While cyclone moving from the South-East to the South-West of the Pacific Ocean, the second (southern) convergence line move somewhat to the North (weather charts of September 27 and 30, Fig. 5).

2. In slightly developed tropical cyclone the convergence zone was still well expressed and it was an obstacle for interlatitudinal air exchange. In well developed tropical cyclone such an exchange evidently occurs (September 30, Fig. 5).

Route VI is characterised by sharp almost continuous increase of radioactivity commenced about 15° S while the ship moved along 180° meridian from the southern hemisphere to the northern one in January 1962 (the curve in the right part of Fig. 6). This increase was associated with the ship crossing the convergence line located over this region in the southern hemisphere at southern periphery of the equatorial depression (January 1, 1962, Fig. 6). The indicated convergence line evidently was the southern boundary of intertropical convergence zone in the central part of the Pacific Ocean. Its location is in a good agreement with a mean climatic position for January obtained by LUKYANOV & ROMANOV (1963). It should be mentioned here that the northern boundary of the zone did not occur during the period in question. To the north of the convergence line as it was indicated by KRASNOPEVTSEV (1964) there were fresh radioactive products from nuclear tests carried out in autumn of 1961 in the northern hemisphere.

One may believe that fresh radioactive products revealed in January 1962 in the southern hemisphere were transferred from the northern hemisphere in the surface level air. Their movement across the equator probably was fulfilled in more eastern regions under the influence of well developed meridional processes over the eastern part of the Pacific Ocean. The increase of radioactivity concentration was interrupted when the ship crossed the equator and then continued its movement to about 12° N (curve in Fig. 6). In our opinion an increase of radioactivity in lower latitudes of the northern hemisphere was connected with the movement near the surface level of the stratospheric air to this region. This air entered the surface level in more northern regions behind the cold front of the cyclone with the center at 40° N.

The weather chart for January 8, 1962 (Fig. 6) gives the southern boundary of the air which is as if continuation of the cold front approximately is shown by one-end arrows.

And then under complex atmospheric processes (for example weather chart for January 16, 1962) it is possible to see a relation between radioactivity variations and synoptical conditions.

Conclusions

1. There is a clear connection of all the sharp increases of radioactivity in the ground level air with radioactivity movement from the stratosphere under synoptic conditions indicated in papers by DMITRIEVA (1965), DMITRIEVA & KASATKINA (1965), STALEY (1960, 1962). Stratosphere breaks were observed mainly in middle latitudes and probably they occured at more southern latitudes (20–30° N). In connection with it a question arises about the role of "stratospheric breaks" in the evolution of anticyclone at subtropical latitudes. This problem requires special detail investigations.

2. "Depth" of stratospheric radioactive air movement in the surface level air to the south is defined by a configuration and intensity of anticyclones at subtropical latitudes of the northern hemisphere and by a character of pressure field at subtropical latitudes of the southern hemisphere. In certain situations in the both hemispheres a transfer is possible in the surface level air from circulation system of one hemisphere to the circulation system of the other one. Probably that while air crossing the equator (sometimes across isobars) inertion of the movement is of the most importance.

3. The southern boundary of the penetration in the surface layer radioactivity air of the northern hemisphere to the southern one as a rule is defined by position, structure and intensity of the intertropical convergence zone. But the evolution of the intertropical convergence zone is determined in some cases by the air intrusion from middle latitudes to the tropics.

REFERENCES

BEKER, F., 1963, Chastota poyavleniya chastic v 1957–1958 gg. i ee zavisimost ot tipa vozdushnykh mass. V sb. "Radioaktivnye Chasticy v atmosfere", Gosatomizdat, Moskwa.

DMITRIEVA, G. V., 1965, Sinoptiko-klimaticheskaya skhema globalnykh stratosfernykh radioaktivnykh vypadenii. V. sb. "Radioaktivnye isotopy v atmosfere i ikh ispolzovanie v meteorologii", Atomizdat, Moskwa, str. 283–292.

DMITRIEVA, G. V., and KASATKINA, V. I., 1965, Aerosinopticheskie usloviya poyavleniya u poverkhnosti zemli oblastei povyshennoi koncentracii stratosfernykh radioaktivnykh produktov. Tam je, str. 293–306.

GAT, J. R., TEIGE, I., PAZY, N., and ROSINTAL, N., 1963, Early radioactive fallout in Israel following the 1961 nuclear weapon tests. *Tellus* **15**, pp. 89–95.

KHROMOV, S. P., 1956, Mussony v obshchei cirkulyacii atmosfery v sb. "A. I. Voeikov i sovremennaya klimatologiya", Gidrometeoizdat, Leningrad.

KOPCEWICZ, T., 1962, An attempt to explain temporary variations in ground air-layer pollution in Central Europe by radioactive substances deriving from nuclear explosions. *Acta geophys. polon*, **10**, N 4.

KRASNOPEVTSEV, YU. V., 1964, O perenose radioaktivnykh aerosolei v troposfere iz severnogo polushariya v yujnoe. Meteorologiya i gidrologiya, N 4, Moskwa.

LABEYRIC, Y., LAMBERT, G., 1963, Sur l'existence d'une barrière de diffusion entre les troposphères de hemisphères Nord et Sud. *C. R. Acad. Sci.*, 12, 256, pp. 2664–2667.

LAVRENCHIK, V. N., 1965, Globalnoe vypadenie produktov yadernykh vzryvov. Atomizdat, Moskwa.

LUKJANOV, V. V., and ROMANOV, YU. A., 1963, Polojenie klimaticheskikh frontov nad severnoi chastyu Tikhogo okeana. Rezultaty issledovanii po programme Mejdunarodnogo Geofizicheskogo Goda, okeanologicheskie issledovaniya. X razdel programmy MGG, N 9.

MURAYAMA, N., 1959, On the relationship between the variations of airborne radioactive concentrations and the sea level pressure patterns in Japan. *Journal of Meteorological Research*, **2**, No. 7, Tokyo.

MURAYAMA, N., 1962, On the relation between radioactive rainfall and meteorological conditions. *Geophys. Magazine*, **31**, pp. 147–156.

PEDELABORDE, P., 1958, *Les Moussons.* Paris.

REIHL, H., 1954, *Tropical Meteorology.* New York.

STALEY, D. O., 1960, Evaluation of potential-vorticity changes near the tropopause and the related vertical motions, vertical advection of vorticity and transfer of radioactive debris from stratosphere to troposphere. *J. Meteorology*, **17**, pp. 591–620.

STALEY, D. O., 1962, On the mechanism of mass and radioactivity transport from stratosphere to troposphere. *J. of Atmospheric Sciences*, **19**, No. 6.

VILENSKII, V. D., DMITRIEVA, G. V., and KRASNOPEVTSEV, YU. V., 1965, Estestvennaya i iskusstvennaya radioaktivnost atmosfery nad okeanami i ee svyaz s meteorologicheskimi faktorami. V sb. "Radioaktivnye izotopy v atmosfere i ikh ispolzovanie v meteorologii", Atomizdat, Moskwa, str. 307–322.

ИССЛЕДОВАНИЕ РАСПРЕДЕЛЕНИЙ РАДИОАКТИВНЫХ АЭРОЗОЛЕЙ НАД ОКЕАНАМИ И НЕКОТОРЫЕ ВОПРОСЫ МЕЖШИРОТНОГО ОБМЕНА В ТРОПИЧЕСКОЙ ЗОНЕ

На основании данных советских научно-исследовательских судов рассмотрено шесть случаев распределения радиоактивных продуктов деления в приводном слое воздуха в разных меридиональных зонах земного шара. Сделана попытка выявить некоторые циркуляционные условия распространения воздуха умеренных широт в тропики и в другое полушарие (в приземном слое). Затрагивается вопрос о влиянии полярных вторжений на эволюцию междутропической зоны конвергенции.