doi: 10.22564/rbgf.v9i1.1099

RADON MEASUREMENTS DURING GTE/ABLE-3A AIRCRAFT MISSION IN ARCTIC REGIONS (JULY-AUGUST 1988)

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Radon measurements were performed during the 33 transit and mission flights of the GTE/ABLE-3A campaign aboard NASA Electra aircraft 429 from Virginia to Thule (Greenland), Barrow, Bethel and Cold Bay (Alaska) and over adjacent areas. Radon was measured by a real-time radon-meter based on electrostatic precipitation of Rn-daughter products and alpha-ray spectrometry. Large scale variations of tropospheric radon versus latitude were observed from the mean results of radon activity for all the flights. It appears that there is generally a good agreement between the radon activity means, considered by altitude band, and the assessed origin of the airmasses, on the basis of a low radon emission by permafrost and tundra covered continental areas in Arctic regions. From the significant lowest values of radon activities measured during the GTE/ABLE-3A, an average radon activity for Arctic air-mass was determined and found to be (56 ± 7) mBq/m^3. Radon free air-mass were not encountered, which indicates, in most cases, at least some continental influence, from the point of view of radon presence. The study of possible correlations between radon variations and events recorded for other species has not been pursued because of the high uncertainties associated to the very low radon activities recorded by the instrument in Arctic regions.

MEDIDAS DE RADÔNIO NAS REGIÕES ÁRTICAS DURANTE A CAMPANHA AÉREA GTE/ABLE-3A (JULHO-AGOSTO DE 1988) – Medidas de radônio foram realizadas durante os 33 vôos da Missão GTE/ABLE-3A a bordo da aeronave Electra 429 da NASA, da Virginia (USA) até Thule (Groenlândia), Barrow, Bethel e Cold Bay (Alaska, USA) e nas regiões adjacentes. O radônio foi medido por um medidor funcionando em tempo real e baseado na precipitação eletrostática dos produtos de decaimento do radônio e na espectrometria alfa. Variações de grande escala do radônio troposférico em função da latitude foram observadas através da análise das médias para todos os vôos. Observou-se geralmente uma boa concordância entre as médias das atividades de radônio por faixa de altitude, e a possível origem das massas de ar, considerando a baixa emissão de radônio nas regiões cobertas pelo permafrost e pela tundra nas regiões Árticas. A partir dos valores mais baixos das atividades de radônio registradas durante esta campanha, um valor de atividade típica da atividade de radônio nas massas de ar no Ártico foi determinada: (56 ± 7) mBq/m^3. Massas de ar desprovidas de radônio não foram encontradas, o que parece indicar na maior parte dos casos uma certa contribuição continental, do ponto de vista da presença de radônio. A análise das possíveis correlações entre as variações dos teores de radônio e eventos registrados para outras espécies medidas simultaneamente durante a missão não foi desenvolvida devido às incertezas elevadas, associadas às atividades de radônio muito baixas registradas pelo instrumento nas regiões Árticas.

1. INTRODUCTION

Radon measured in polar and sub-solar regions is very interesting to study air-mass movements and trace element transportations, because of its unique role as a natural, non chemically reactive, gaseous radioactive tracer of very low to practically null ground emission in these regions. Various series of radon measurements were performed during the last decades, in both hemispheres, for instance, at fixed stations (Polian et al., 1986; Pereira, 1990), at aircraft altitudes (Wilkniss et al., 1975; Wilkniss & Larson, 1984) or aboard ships during oceanic cruises (Wilkniss et al., 1974; Bonsang & Lambert, 1985).

In this work, we describe radon measurements that we have made during the 33 transit and mission

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Revista Brasileira de Geofísica; 1991, Vol. 9 (1), 69-76

flights of the GTE/ABLE-3A campaign aboard NASA Electra aircraft 429 from Virginia to Thule (Greenland), Barrow, Bethel and Cold Bay (Alaska) and over adjacent areas (Fig. 1 and Table 1). Radon was measured by a real-time radon-meter based on electrostatic precipitation of Rn-daughter products and alpha-ray spectrometry.

From a general to a more detailed analysis, radon data obtained during the mission may be interpreted in terms of: 1) large scale variations of tropospheric radon versus latitude; 2) vertical profiles as a function of the flight location and airmass characteristics; 3) detailed analysis based on event identification such as plumes and layers observed during the flights.

Large scale variations of tropospheric radon versus latitude are observed from the mean results of the mission and are compared with data from other works performed at lower latitudes. This kind of interpretation is interesting because it represents an extensive radon survey covering a large geographic area at aircraft altitudes.

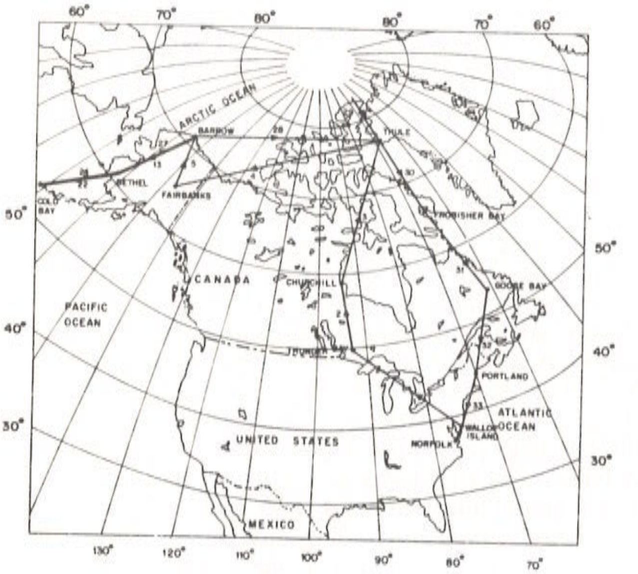

Figure 1. Map of North America with the part of the NASA Electra 429 flights during GTE/ABLE-3A mission. Radon was measured during all the flights of this campaign.

Figura 1. Mapa da América do Norte mostrando o percurso da aeronave Electra 429 da NASA durante a missão GTE/ABLE-3A. Medidas de radônio foram realizadas durante todos os vôos desta missão.

The main difference between radon emanation from soils at low, medium and high latitudes is expected to be due to the difference of solar energy flux providing much greater emanation of radon at low and medium latitudes than at high latitudes (Pereira et al., 1990). The effects of possibly different rainfall patterns during summer and the existence of permafrost implying a lower radon emanation at high latitudes also have to be taken into account. From these considerations, even without any concern about on the uranium and radium geochemistry of the ground, much lower radon concentrations are expected at higher latitudes, or under colder climatic conditions, as it was already observed by several authors (Lambert et al., 1982; Martens & Chanton, 1989).

A more detailed study of the distribution of radon along the path of the flights was tentatively investigated in relation with the results of some important other species and in correlation with meteorological data, but because of the very low counting rates recorded during these missions, results for short intervals of time are affected by very high uncertainties, and are therefore questionable on regard to positive or negative correlation with events recorded for other species. Furthermore, because of the very low count rates recorded, integration times long enough are needed to achieve statistical significance, which is incompatible with detection of short duration events. For this reason, this publication is restricted to wide are interpretations, based on results obtained by the integration of counting rate during long enough durations.

2. MEASUREMENTS AND DATA LOGGING

The physical part of the instrument is basically a radon-gas meter and is the same which was used during the GTE/ABLE-2B in 1987 in the Brazilian Amazon Basin (Pereira et al., 1990). It has been widely described elsewhere (Pereira et al., 1984; Pereira & Silva, 1989). This apparatus was greatly improved for the GTE/ABLE-3A mission by the addition of a new data logging system using a portable microcomputer. With this system, 5-minute interval counting rates within the ^{218}Po and ^{214}Po channels of the alpha-ray spectrum were transferred from the pulse height analyzer and recorded on floppy disks during the mission. Because of its availability on the pulse height analyzer, an RS232C communication protocol was used for the transfer of the data between the pulse height analyzer and the portable microcomputer.

The reduction of the counting rates to radon activities is made by using an efficiency factor, function of the instrument, cabin and outside pressures and temperatures and specific humidity (Pereira & Silva, 1989). Most of these factors are obtained from the on-board computer records; the cabin pressure and the instrument temperatures were hand written every 15 minutes by the operator of the radon meter and keyed into the computer after completion of the mission.

Typically a steady counting rate of 1 pulse per 5 minutes should represent about 300 mBq/m^3. Due to the low counting rates observed (0 or 1 or 2 a few units per 5-minute interval, 0 being the most frequent), the radon activity determination is complicated by two interacting factors: the uncertainties associated with the statistics of low counting rates and the fact that a certain counting rate corresponds to the integrated

Table 1. Itinerary of Electra aircraft during GTE/ABLE-3A mission (1988).

Tabela 1. Rota da aeronave Electra durante a campanha GTE/ABLE-3A (1988).

FL	FROM	TO	
1	Wallops Island, VA	Thunderbay, ONT	July, 7
2	Thunderbay, ONT	Churchill, MAN	July, 7
3	Churchill, MAN	Thule, Greenland	July, 8
4	Thule, Greenland	Fairbanks, AK	July, 9
5	Fairbanks, AK	Barrow, AK	July, 10
6	Barrow, AK	Barrow, AK	July, 12-13
7	Barrow, AK	Barrow, AK	July, 13-14
8	Barrow, AK	Barrow, AK	July, 15-16
9	Barrow, AK	Barrow, AK	July, 17
10	Barrow, AK	Barrow, AK	July, 18-19
11	Barrow, AK	Barrow, AK	July, 19-20
12	Barrow, AK	Barrow, AK	July, 21-22
13	Barrow, AK	Bethel, AK	July, 24
14	Bethel, AK	Bethel, AK	July, 26-27
15	Bethel, AK	Bethel, AK	July, 27-28
16	Bethel, AK	Bethel, AK	July, 28-29
17	Bethel, AK	Bethel, AK	July, 29-30
18	Bethel, AK	Bethel, AK	July, 31
19	Bethel, AK	Bethel, AK	Aug., 2-3
20	Bethel, AK	Bethel, AK	Aug., 3
21	Bethel, AK	Bethel, AK	Aug., 4
22	Bethel, AK	Cold Bay, AK	Aug., 7
23	Cold Bay, AK	Cold Bay, AK	Aug., 7-8
24	Cold Bay, AK	Bethel, AK	Aug., 8
25	Bethel, AK	Bethel, AK	Aug., 9
26	Bethel, AK	Bethel, AK	Aug., 9-10
27	Bethel, AK	Barrow, AK	Aug., 11-12
28	Barrow, AK	Thule, Greenland	Aug., 12
29	Thule, Greenland	Thule, Greenland	Aug., 13
30	Thule, Greenland	Frobisher Bay, NWT	Aug., 15
31	Frobisher Bay, NWT	Goose Bay, NFLD	Aug., 15
32	Goose Bay, NFLD	Portland, ME	Aug., 16
33	Portland, ME	Langley AFB, Va	Aug., 17

detection of the circulation in the instrument of a volume of air with a specific activity (unknown) during the interval of time the aircraft is crossing the layer which does not coincide with the counting intervals. This last factor is complicated by the time response curve of the instrument to a radon spike or step, due to the flow through the instrument and to the radioactive series between radon and its detected daughter products. An attempt to interpret the raw data by a deconvolution method is being done but in this work, only a direct correspondence activity/counting rate was used.

In this direct correspondence, another factor has to be taken into account. To explain it, a little comeback has to be made: during GTE/ABLE-2B missions, the data logging system used mainly a portable pulse-height analyzer, collected the counting rate only during the intervals chosen by the operator, on board and during the mission itself, on a real time basis; that is to say that the operator, following the flight plan and the intercom information, has to switch on the accumulation of the counting rate at the beginning of a horizontal leg and to switch it off at the end of the leg. The new data logging system used during GTE/ABLE-3A made the transfer of the radon corresponding counting rates every 5 minutes, from the same pulse height analyzer to a portable computer by serial RS232C transmission line. Although this system allows a more precise time definition of the results than the former one, it must be reminded that one 5-minute interval does not give by itself enough precision because of the scarcity of the pulses. This is in part overridden by the association of several intervals, according to the flight trajectory, and the decision for this operation is taken afterwards, during the interpretation of the data, and no more during the flights.

But, in all the cases, it must be mentioned that, because of the statistical nature of nuclear emission and detection and because of the scarcity of information carriers namely the ^{218}Po detection pulses, a result is always characterized by the value calculated and by its uncertainty calculated according to the rules. Because the errors associated to the calibration of the instrument are much lower than the statistical uncertainty (Pereira & Silva, 1989), only the later one is presented for each result.

Among the results presented in this work, several vertical profiles show a local increase of radon with altitude. They represent radon inverted profiles, which have been observed in many regions of the world, for various atmospheric conditions (Lambert et al., 1982; Pereira et al., 1990). However, it has been questioned whether such profiles may not be due to the effect on the detector itself of an increase of cosmic-ray primary or secondary components with increasing altitude, besides the detection of radon activities in the instrument chamber. The first argument against such a suggestion is that any semiconductor alpha-ray detector is not a convenient detector for protons, muons, neutrons or gamma-ray of cosmic-ray origin, because of the thickness of the layer sensible to ionizing particles. The second argument is based on an observational fact from these missions in Arctic regions. The most convenient regions to observe effect of cosmic radiation on the radon-meter should be polar regions, at high latitudes, where, as it is well known, cosmic radiation has a wider energy spectrum and is therefore globally more intense on Earth. During flights 4 and 28, from Thule to Alaska and return (Table 1), the aircraft crossed exactly the North Magnetic Pole region, at altitudes above 4500 m, but during these flights, radon activities recorded (58 ± 13) mBq/m^3 and (66 ± 13) mBq/m^3 respectively, were

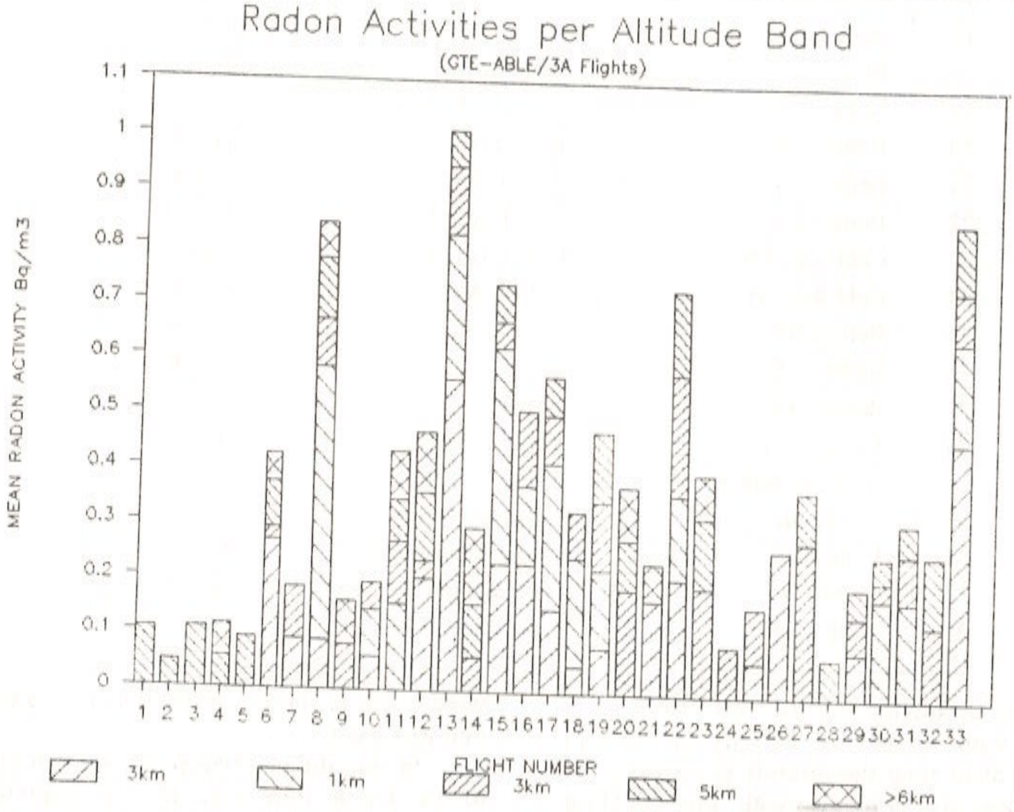

Figure 2. Radon activities (in Bq/m^3) per altitude band (.3 km for < 0.5 km; 1 km for 0.5 km to 1.5 km; 3 km for 1.5 km to 4.5 km; 5 km for 4.5 km to 6 km and > 6 km for > 6 km) for all the flights of GTE/ABLE-3A mission.

Figura 2. Atividades de radônio (em Bq/m^3) por faixa de altitude (.3 km para < 0,5 km; 1 para 0,5 km até 1,5 km; 3 km para 1,5 km até 4,5 km; 5 km para 4,5 km até 6 km e > 6 km para > 6 km) para todos os vôos da campanha GTE/ABLE-3A.

among the lowest observed during the whole GTE/ABLE-3A mission. These results, and the very low background obtained at ground level (without any extra protection against natural radiation from soil and building material) confirm that there is no direct effect of external ionizing radiations on the detector and that the observed profiles are not due to such effect. A certain sensitivity to electromagnetic pollution at short distance was observed, but convenient protection prevented measurements from being spoiled by such effect and may not be involved in the results presented.

3. RESULTS – GEOGRAPHICAL TRENDS

Figure 2 and Table 2 show the mean activities per interval of altitude for all the flights, expressed in mBq/m^3 (millibequerel per cubic meter) and calculated taking into account cabin pressure and temperature,

Table 2. Mean radon activities for all flights and by interval of altitude. These activities are expressed in millibecquerel per cubic meter of air (mBq/m^3) at the considered altitude and were corrected for instrument temperature, cabin pressure and humidity effects on the overall detection efficiency.

Tabela 2. Atividades médias do radônio por intervalo de altitude, para todos os vôos. Estas são expressas em milibecquerel por metro cúbico de ar (mBq/m^3) na altitude de vôo e foram corrigidas pela temperatura do instrumento, pela pressão da cabina e dos efeitos da umidade no rendimento global de detecção.

FL	0-500 m	500-1500 m	1500-4500 m	4500-6000 m	> 6000 m	All Heights
1	-	-	-	106 ± 27	-	106 ± 27
2	-	-	0 ± 138	47 ± 33	-	39 ± 28
3	-	-	0 ± 276	109 ± 22	-	107 ± 22
4	-	-	-	56 ± 21	59 ± 16	58 ± 13
5	227 ± 227	106 ± 106	140 ± 140	92 ± 22	-	102 ± 24
6	269 ± 156	0 ± 92	23 ± 17	82 ± 47	49 ± 28	67 ± 23
7	89 ± 40	0 ± 138	95 ± 25	-	-	89 ± 22
8	88 ± 62	493 ± 220	87 ± 28	109 ± 64	65 ± 65	126 ± 30
9	34 ± 34	191 ± 191	81 ± 26	42 ± 42	78 ± 29	71 ± 17
10	60 ± 30	84 ± 49	50 ± 29	-	-	64 ± 21
11	67 ± 67	156 ± 78	113 ± 34	75 ± 31	87 ± 43	105 ± 22
12	202 ± 83	0 ± 39	32 ± 23	123 ± 50	109 ± 44	90 ± 22
13	563 ± 329	262 ± 186	122 ± 30	63 ± 23	141 ± 141	124 ± 23
14	-	69 ± 69	61 ± 25	96 ± 29	137 ± 97	77 ± 18
15	231 ± 94	390 ± 225	47 ± 19	68 ± 26	-	106 ± 25
16	230 ± 73	143 ± 51	136 ± 52	-	-	169 ± 34
17	150 ± 61	264 ± 108	85 ± 28	71 ± 51	-	131 ± 28
18	49 ± 28	196 ± 113	83 ± 31	-	-	79 ± 23
19	83 ± 41	140 ± 99	122 ± 34	128 ± 57	133 ± 133	110 ± 24
20	0 ± 46	0 ± 55	187 ± 58	91 ± 42	96 ± 39	104 ± 23
21	168 ± 119	0 ± 55	23 ± 23	0 ± 28	68 ± 39	38 ± 18
22	208 ± 147	153 ± 89	217 ± 77	151 ± 57	-	184 ± 44
23	0 ± 35	61 ± 61	196 ± 55	125 ± 42	79 ± 39	120 ± 24
24	-	0 ± 276	90 ± 52	39 ± 39	-	64 ± 32
25	61 ± 35	0 ± 55	98 ± 29	55 ± 55	-	74 ± 19
26	263 ± 45	-	-	-	-	263 ± 45
27	319 ± 319	-	278 ± 197	92 ± 25	-	114 ± 28
28	0 ± 276	-	0 ± 138	70 ± 14	-	66 ± 13
29	82 ± 58	85 ± 85	63 ± 22	52 ± 23	-	64 ± 17
30	191 ± 191	178 ± 126	33 ± 24	43 ± 13	-	57 ± 16
31	183 ± 183	174 ± 124	84 ± 35	55 ± 21	-	84 ± 22
32	431 ± 431	95 ± 95	132 ± 43	124 ± 31	-	131 ± 26
33	462 ± 327	183 ± 130	91 ± 46	122 ± 33	-	139 ± 33
Tot.	140 ± 14	132 ± 19	93 ± 7	83 ± 6	74 ± 10	102 ± 4

and humidity corrected efficiency. In some cases, because of the short time spent within a layer of altitude, there is no value indicated or the value presents a rather high uncertainty. The mean specific activities for all altitudes and for all the flights althogether are also given. The general mean value for all the flights, (102 ± 4) mBq/m^3, is very low as compared with results obtained for other regions of the world (Lambert et al., 1982). Because of its higher statistical signification, it will be considered as a reference value for the comparison with individual values obtained during this GTE/ABLE-3A mission.

From the means by altitude bands for all the flights it was observed that radon shows generally low activities (< 600 mBq/m^3) to very low activities (< 300 mBq/m^3 for altitudes > 500 m) with a mean value of 102 ± 4 mBq/m^3 (all flights), lower than values found in the literature for the same region and much lower than values for temperate and tropical regions (at the same altitude). No distinct pattern was observed for above 2000 m masses of air of assumed continental or maritime arctic origin. Above 2000 m, radon was quite always present even with minute yields.

Furthermore, it appears, independently of the knowledge we may have on the area flown or on the nature or origin of the masses of air encountered, that there are two kinds of profiles: some (for example flights 5, 16, 29, 30, 31) show a steady decrease of radon activities versus altitude and other ones (for example flights 17, 27, 33) show an increase from under 500 m, to 500 m to 2000 m and then a decrease. Independently of this tendency, some profiles show slightly higher values at the higher altitudes (for example flights 4, 9, 11, 14, 20, 21, 28, 32). The profiles of the first kind, showing a steady decrease, are profiles for which the airmass at lower altitudes shows higher radon concentrations, associated with local emanation, generally above continental areas, or from not completely frozen continental areas. The profile of the second kind, showing lower radon concentrations near the ground, are typically characteristic of flights above frozen continental areas or oceanic areas, with little radon emanation, or with the presence of oceanic airmass at low altitude.

GENERAL TRENDS IN ARCTIC REGIONS

Profiles 4 to 14 are under influence of continental polar air, from Siberian or Alaskan origin. All these profiles show rather low mean radon value, and low values above 500 m, except for Flights 8 and 9, between 500 m and 1500 m, which indicate that radon emanation from polar continental remote areas is rather weak. They show also very low values under 500 m, except for Flight 15 and Flight 16, which indicate also a weak local production of radon, by tundra, which has been measured by Martens (1991). Forest fires were mentioned for Flight 14, but radon activity was rather low, except for a higher value, not very significant, above 6000 m, which does not give a convincing clue for a foreseen correlation between radon and forest fire.

Flights 15 to 19 are dominated by maritime polar air from the Gulf of Alaska (all but Flight 18) and from the Bering sea (Flight 18) according to Meteorological Data (1988). The radon activities measured are rather high, near the reference value or slightly higher, indicating either previous continental origin, or local origin from tundra emanation of previous days, once, in most of these flights, radon activity, under 500 m, is lower than at higher altitudes.

Flights 20, 21, 24, 25, 27 and 28 are under influence of polar continental air, mostly from Eastern Siberia. They gave rather low value indicating, a rather low emanation, as expected, and/or an "old" continental air, "old" being taken in the sense of the radioactive decay of radon (half-life 2.82 days). Flights 22 and 23 were indicated as being dominated by continental polar air above maritime polar air. Radon activities, integrated for the totality of the flights, seem to confirm this, showing higher values for altitudes between 1500 m and 4500 m than under, as expected.

Low altitude Flight 26 gave a significant rather high value of (263 ± 45) mBq/m^3, under 500 m. This is a clear indication of continental polar air, or more precisely of "young" continental air. This value corresponds to the highest mean value among all flights of the GTE-3A mission.

LATITUDINAL TRENDS BETWEEN 37ºN TO 83ºN LATITUDE

Flights 1, 2 and 3 are transit flights from Wallops Island (Virginia) to Thule (Greenland), crossing the Great Lakes region and Central and North-eastern Canada. Flight 2 was too short for a significant result as measurements were discontinued because of an excess of humidity inside the instrument. Values between 4500 m and 6000 m, for Flights 1 and 3, present a relatively small uncertainty and are both very close to the mean reference value for all the flights. These values, not being very low, indicate the presence of, at least in part, some continental air. Flight 4, from Thule to Fairbanks (Alaska), shows between 4500 m and 6000 m and above 6000 m, very low values, about half the reference value. These values may be considered as an indication, or more exactly, as a confirmation of the presence of radon depleted airmass from stratospheric and/or arctic origin.

On the way back, the three flights in arctic regions, Flights 28 (Barrow to Thule), 29 (North Pole Flight, from Thule to Thule, up to 83º19'N) and 30 (Thule to Frobisher Bay, Canada), show low radon activities: (66 ± 13) mBq/m^3, (64 ± 17) mBq/m^3 and (57 ± 16) mBq/m^3 respectively, values characteristic of arctic air, with arctic continental influence, in the sense of radon activities. Next flights, Flights 31 (Frobisher Bay to Goose Bay, Canada), 32 (Goose Bay to Portland, Maine) and 33 (Portland to Hampton, Virginia), show a steady increase of radon activities, with values of (84 ± 22) mBq/m^3, (131 ± 26) mBq/m^3 and (139 ± 33) mBq/m^3. This may be easily explained by the higher radon emanation by dryer and warmer soils of lower latitudes compared with wetter, colder and even frozen soils of higher latitudes at that time of the year (mid August which corresponds to northern hemisphere summer).

As it was seen before, it seems that it does not exist "pure oceanic arctic air" (air supposed to have travelled a time long enough over the ocean or over the ice cap, which practically does not emit radon, to become free of radon by radioactive decay): the lowest values obtained with the highest level of confidence (measurements long enough with a very low instrumental background count rate) over low radon high latitude region, may be considered as being representative of the atmospheric radon background far from its sources, at these latitudes and at that time of year. To obtain this value, the mean activity for the six flights (Flight 4, 21, 24, 28, 29, 30) which gave the lowest values at high latitude, was calculated and found to be (56 ± 7) mBq/m^3.

This result may be compared with a value of radon activity obtained in the central Pacific Ocean, near Hawaii, far from continental sources. Samples taken more than 20 km upwind of the island from 0.5 to 3.6 km altitude yielded 1100 dpm/100 m^3 (Wilkening, 1971; Moore et al., 1974) that is 183 mBq/m^3. This is characteristic of an airmass which is not radon free, same result as in the case of the arctic oceanic air. Furthermore, central Pacific oceanic air presents a radon activity which is about 3.3 times the value obtained in this work, for the arctic oceanic air. Although airmasses are not strictly confined in latitude bands, this ratio may be associated to the ratio of radon emitting continental areas between northern hemisphere low (Hawaii is located at 20°N) and high (this mission: between 60° and 83°N) latitudes.

4. CONCLUSIONS

On the whole, the results obtained confirm the general trend of those obtained by other authors and it appears that there is generally a good agreement between the radon activity means, considered by altitude band, and the assessed origin of the airmasses, on the basis of a low radon emission by permafrost and tundra covered continental areas in Arctic regions.

From the significant lowest values of radon activities measured during the GTE/ABLE-3A, an average radon activity for Arctic air-mass was determined and found, for this campaign, to be (56 ± 7) mBq/m^3. Radon free air-mass were not encountered, which indicates, in most cases, at least some continental influence, from the point of view of radon presence.

The study of the possible correlations between radon variations and events recorded for other species, has not been pursued because of the high uncertainties associated to the very low radon activities recorded by the instrument in Arctic regions.

ACKNOWLEDGEMENTS

We wish to acknowledge the support of NASA and GTE/ABLE-3A Program for the Brazilian participation in this mission. We also wish the recognize the help of NASA Electra crew and technicians. The participation in this mission was supported in part by Brazilian CNPq (Auxílio nº 400105/88-8) and INPE. We also wish to thank Enio Bueno Pereira for incentive and support and Sylvio Luiz Mantelli Neto for his active participation and technical support.

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Versão recebida em: 13/07/90
Versão revista e aceita em: 09/01/91
Editor Associado: M.A.F. Silva Dias

ERRATA

No artigo de P. Hubral "Seismic Reflection Tomography", vol. 7(2), 149-153, as Figuras 1 e 2 foram trocadas entre si.

In the article by P. Hubral "Seismic Reflection Tomography", vol. 7(2), 149-153, Figures 1 and 2 were interchanged.