GLOBAL DISTRIBUTION OF ^{137}Cs INPUTS FOR SOIL EROSION AND SEDIMENTATION STUDIES

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Abstract

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A global distribution of ^{137}Cs deposition from the atmospheric nuclear tests, with estimates for 1996, excluding Chernobyl contribution, is presented, based on the global deposition data for ^{90}Sr. The data can be used to identify areas and countries, especially in the southern hemisphere, where the ^{137}Cs inventories are appropriate for soil erosion and sedimentation studies.

1. INTRODUCTION

Soil erosion is increasing all over the world, as a consequence of deforestation and inadequate agricultural practices. The negative impacts of soil erosion are twofold: loss of fertile top soil, which dramatically reduces food production yields, and environmental problems due to the transference of sediments to surface water bodies, which produces serious siltation problems in lakes and reservoirs.

The use of environmental ^{137}Cs for measuring soil erosion and deposition is well accepted. The average erosion or deposition rate over the last 3-4 decades can be estimated measuring the ^{137}Cs inventories in soil cores. Average siltation rate in lakes and reservoirs can also be estimated if the 1962 ^{137}Cs peak is noticeable in the vertical distribution of this radionuclide in bottom sediment core samples.

Unfortunately this technique can only be used in areas where the total ^{137}Cs deposition in the soil is great enough to allow its precise quantification, as the results are based on differences of concentration among samples. Very long counting times would increase the detection limit, but for practical reasons, counting times longer than 24 hours per sample are not convenient. The use of high efficiency detectors with Compton anticoincidence systems allows also the measurement of very low levels of ^{137}Cs, but their cost is too high for many developing countries.

To identify regions and countries of the world where the ^{137}Cs technique can yield good results for the evaluation of soil erosion and sedimentation processes, it is important to know the global deposition pattern of ^{137}Cs.

2. ACTIVITY OF ^{137}Cs INTRODUCED INTO THE ATMOSPHERE

^{137}Cs has been introduced into the atmosphere by the detonatión of fission nuclear weapons. The activity produced is proportional to the weapon fission yield. It is assumed that the specific production rate for ^{137}Cs is 6.4×10^{15} Becquerel per megaton [1]. From the first atmospheric atomic explosion in Hiroshima in 1945 to the last in October 1980 in China, some 217.2 megatons of fission devices have been detonated in the atmosphere. The total activity of ^{137}Cs introduced into the atmosphere in that period can be estimated at 1400 PBq.

The deposition of this debris onto the surface of the planet is called fallout and it can be grouped into three categories: local, tropospheric and stratospheric. Local fallout, defined as the deposition within 100 miles of the test area, depends on the altitude and power of the detonation. If the fireball reaches the surface of the soil, higher amounts of local fallout are produced due to soil volatilisation. The local fallout consists of particles usually bigger than 50 μm. [2, 3]. Due to the

remoteness of the test sites and to the relatively large particle size of the debris, this fraction is not suited for erosion studies. If local fallout is not considered, the total amount of ^{137}Cs globally dispersed from all the atmospheric nuclear tests is 912 PBq [4].

The distribution of the radioactive debris between troposphere and stratosphere depends on the power of the bomb. For nuclear bombs smaller than about 100 Kt, detonated in temperate latitudes, the radioactivity tends to remain in the troposphere. For detonations greater than 500 Kt, the debris is injected almost completely into the stratosphere [5].

In the stratosphere, at altitudes lower than 20 km, where most of the nuclear detonations have been carried out, the half-life for the transfer of aerosols between the hemispheres through the equator is about 60 months, while the half-life for transfer to the troposphere is only about 10 months, depending on the latitude [1]. Consequently, the bulk of the fallout from one test occurs over the hemisphere of injection.

The distribution of radioactive debris in the troposphere, either that introduced directly there or that transferred from the stratosphere, is governed by atmospheric circulation patterns. In each hemisphere there are two main air circulation cells, between the equatorial high pressure, sub-equatorial high pressure and sub-polar low pressure belts. At low latitudes, between the first two, the air near the surface circulates towards the equator, where it is heated and rises to an altitude of about 10 km. At this altitude, it starts to move horizontally towards the poles, coming down at latitudes of about 30 degrees, closing the first cell. At latitudes higher than 40 degrees, in the second cell, air near the surface moves northward, rising at about 60 degrees. At high altitudes, the air then moves in the direction of the equator, coming down to surface at a latitude of approximately 30 degrees. This circulation pattern explains why fallout is higher at medium latitudes, usually from 40 to 50 degrees and very low near the equator. The mean residence time of the dust introduced into the troposphere is on the average about 30 days [6].

3. ATMOSPHERIC REMOVAL PROCESSES

Fallout can be classified as dry fallout, which is removed from the atmosphere in dry weather, and wet fallout which is removed by precipitating weather conditions (rain or snow). Dry deposition is at least ten times lower than the wet fallout [7].

Rainfall removes aerosols from the troposphere mainly by droplet formation around the particle (rainout) and by scavenging (washout). This last process is not very effective, because the radioactivity concentration in rain remains almost constant along the rain episode [2]. For very small particles ($< 0.01 \mu m$), Brownian motion may play an important role for the transfer of aerosols to water particles, especially in clouds where small water droplets have a long residence time [2, 5]. The amount of radioactivity removed by the rain depends on the radioactivity concentration in the cloud. [2].

According to these considerations, the total amount of radioactivity deposited on the earth's surface depends on the atmospheric concentration of radioactivity and the amount of rainfall.

4. GLOBAL DEPOSITION OF ^{137}Cs

Radioactive fallout has been monitored all over the world since the early fifties. Studies performed in the late 40s identified ^{90}Sr as the most dangerous radionuclide in fallout, due to its biological fixation in bones and the consequent risk of developing bone cancer. Due to the significance of this radionuclide, its deposition has been monitored worldwide through two networks, one operated by the USA and another one by the UK. These data were used to elaborate a map with cumulative ^{90}Sr deposits in 1967 [8]. Unfortunately, ^{137}Cs deposition is not so widely documented.

It is possible, however to reconstruct the deposition pattern of ^{137}Cs using the ^{90}Sr data. The rate of production of these two nuclides (fission yields) is very well known. It has been proven that there is no fractionation between these radionuclides during the atmospheric transport [5]. The production rate for ^{137}Cs in fission weapon tests is 1.6 higher than for ^{90}Sr [4].

TABLE I. GLOBAL DEPOSITION OF Cs-137 (in Petabecquerels)

	Northern Hemisphere				Southern Hemisphere			Global
	Cs-137 deposition				Cs-137 deposition			
year	annual	cumulative (decay corrected)	yearly fraction %	year	annual	cumulative (decay corrected)	yearly fraction %	cumulative
1954	4.7	5	0.59	1954	2.3	2	0.98	7
1955	20	25	2.53	1955	11	13	4.68	38
1956	31	55	3.92	1956	9	22	3.83	77
1957	30	84	3.80	1957	10	31	4.26	115
1958	40	122	5.06	1958	11	42	4.68	164
1959	80	199	10.13	1959	9	50	3.83	249
1960	18	213	2.28	1960	7	56	2.98	268
1961	21	229	2.66	1961	13	67	5.54	296
1962	92	315	11.65	1962	19	85	8.09	400
1963	150	458	18.99	1963	20	103	8.52	561
1964	100	548	12.66	1964	22	123	9.37	670
1965	34	569	4.30	1965	23	143	9.80	712
1966	19	575	2.41	1966	10	149	4.26	725
1967	9	571	1.14	1967	7	153	2.98	724
1968	12	570	1.52	1968	5	155	2.13	725
1969	7	564	0.89	1969	10	161	4.26	725
1970	7	558	0.89	1970	6	163	2.56	722
1971	9	554	1.14	1971	7	167	2.98	721
1972	4	546	0.51	1972	5	168	2.13	714
1973	3	536	0.38	1973	4	168	1.70	704
1974	5	529	0.63	1974	6	170	2.56	699
1975	4	521	0.51	1975	4	170	1.70	691
1976	2	511	0.25	1976	3	169	1.28	680
1977	4	503	0.51	1977	2	168	0.85	671
1978	4	496	0.51	1978	2	166	0.85	662
1979	2	487	0.25	1979	1.5	163	0.64	650
1980	1	476	0.13	1980	1	161	0.43	637
1981	3	469	0.38	1981	0.5	158	0.21	626
1982	1	459	0.13	1982	0.5	154	0.21	613
1983	1	449	0.13	1983	1	152	0.43	601
1984	0.5	440	0.06	1984	0.5	149	0.21	589
1985	0.5	430	0.06	1985	0.5	146	0.21	576
1986	70	490	8.86	1986	0.5	143	0.21	633
1987	0.5	480	0.06	1987	0.5	140	0.21	620
1988	0.5	469	0.06	1988	0.5	138	0.21	607
1989	0.5	459	0.06	1989	0.5	135	0.21	594

Adapted from Playford et al., 1990

The ^{90}Sr data obtained from the worldwide monitoring network of the UK have been transformed into deposition of ^{137}Cs for both hemispheres in Table 1. The yearly global deposition of ^{137}Cs and data for the decay-corrected cumulative deposition are included in this Table. The 70 PBq introduced in the northern hemisphere in 1986 from Chernobyl have also been included. Based on these data, it can be calculated that the amount of ^{137}Cs which was deposited on the earth surface *until 1967 is 82% of the total amount in the northern hemisphere and 74% in the southern.*

From the original map on the global deposition pattern of ^{90}Sr in mCi/km^2, an equivalent one has been elaborated for ^{137}Cs, in mBq/cm^2 (Figure 1). The isolines correspond to the situation observed in 1967 but the values have been corrected taking into account the additional average deposition expected after that date, and the radioactive decay to 1996.

Some changes in the general patterns of the isolines could also be expected, due to the nuclear explosions by China and France, carried out after 1967 in the northern and southern hemispheres.

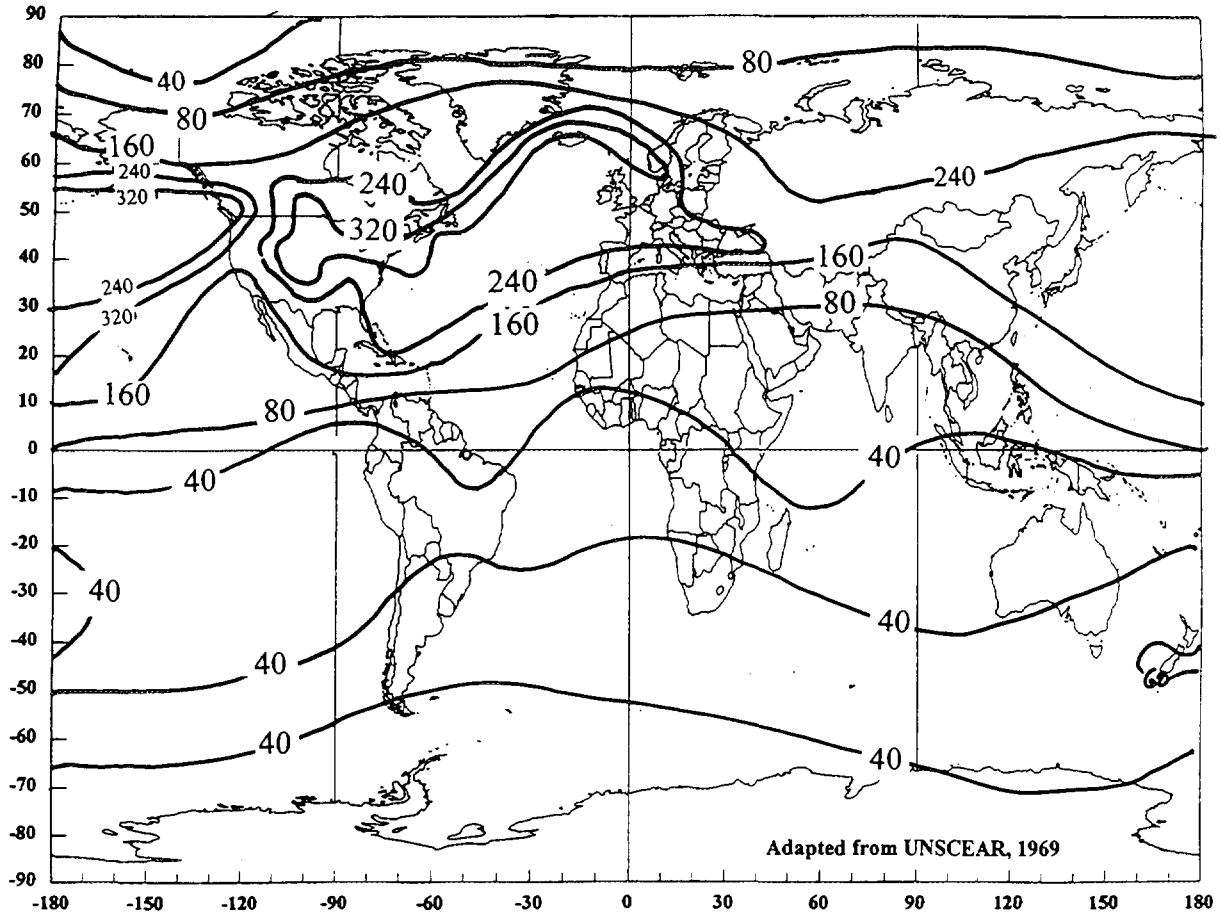

FIG. 1. Global inventory of ^{137}Cs from nuclear tests (in mBq/cm^2, estimated for 1996). Adapted from UNSCEAR, 1969 [8].

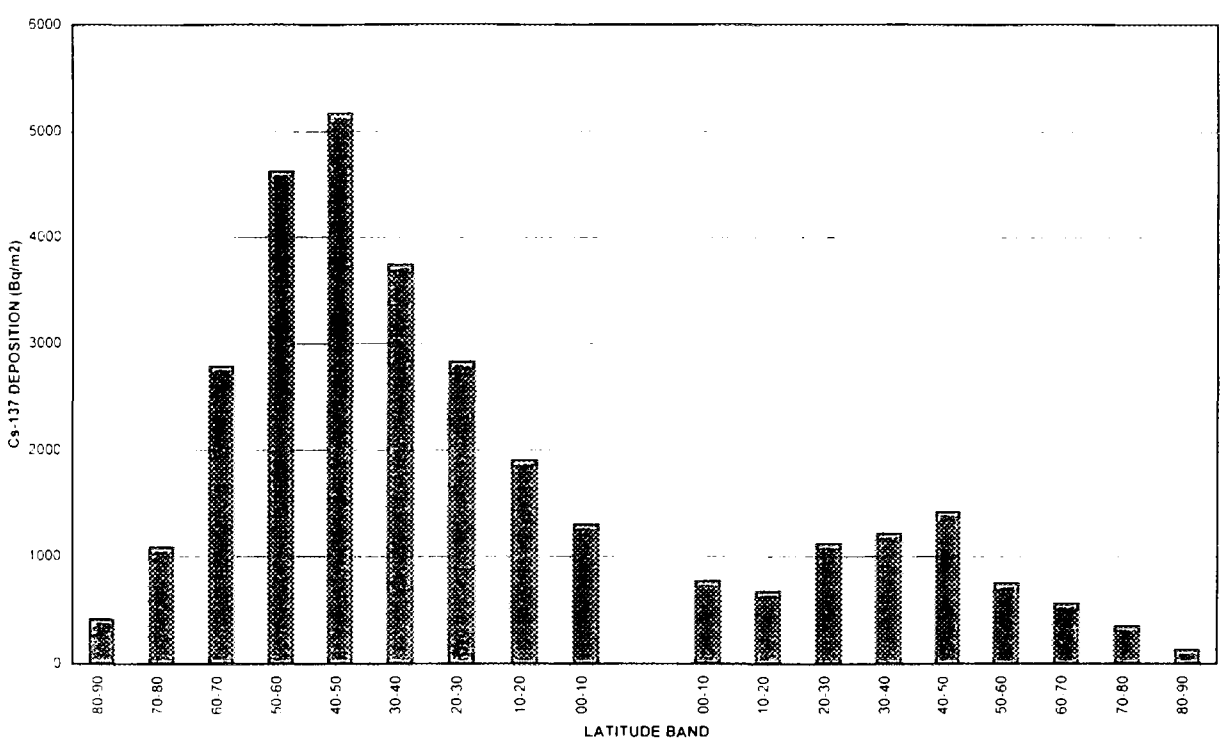

FIG. 2. Distribution of ^{137}Cs deposition by latitude bands.

However, as these two countries contributed with less than 10% to the total ^{137}Cs introduced into the atmosphere, these changes should not be very significant. On another hand, the Chernobyl accident produced important changes of the ^{137}Cs distribution pattern in some European countries. This fact is not reflected in Figure 1.

The distribution of ^{137}Cs deposition in the globe, by latitude bands, is presented in Figure 2. It has been elaborated with ^{90}Sr data presented in [4]. No further deposition has occurred since publication of the data. It can be seen that between the peaks in each hemisphere, the minimum deposition data are not in the equator but between 10° and 20° in the southern hemisphere.

5. CONCLUSIONS

The global ^{137}Cs deposition data were used to identify regions or countries, especially in the southern hemisphere, where the ^{137}Cs input would be appropriate for soil erosion studies. As such, regions in the southernmost parts of Africa (South Africa, Namibia and Botswana) and South America (south of Brazil, Uruguay, Argentina, Paraguay and Chile) seem to be adequate.

The potential of the ^{137}Cs technique for areas located near the equator has also been a matter of study. The northern part of South America, Central and West Africa, and Southeast Asia, should have enough ^{137}Cs in the soil for soil erosion studies. Countries in Africa and America located between latitudes 0 and 30°S should be excluded, as the ^{137}Cs inputs may be very low.

It is expected that additonal data on ^{137}Cs inventories in soils will soon be provided and more reliable information on the global distribution of ^{137}Cs and its potential for the study of soil erosion and deposition in the southern hemisphere will be available.

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