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INFLUENCE OF EXPLOSIVE VOLCANIC PHENOMENA UPON DIRECT SOLAR RADIATION IN ROMANIA

Cristian Oprea[1]

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Abstract. On its way through the terrestrial atmosphere, direct solar radiation is subject to a diminishing (extinction) phenomenon caused by the constituent gases and aerosol. Extreme geophysical phenomena, such as explosive volcanic eruptions, can severely increase the quantity of aerosol in the atmosphere, intensifying the extinction phenomenon and causing a dramatic decrease in direct solar radiation. Analyzing the deviations of annual means from the multi-annual mean for six stations, this paper shows the influence of El Chichon's and Pinatubo's explosive eruptions upon direct solar radiation in Romania.

Introduction

Direct solar radiation is the part of solar radiation reaching terrestrial surface as a flux of parallel rays coming directly from the solar disc.

Among the other components of solar radiation, it is particularly sensitive to the perturbing action of astronomic phenomena regarding the Earth-Sun geometry and of geophysical ones, such as volcanic eruptions.

At the upper limit of the atmosphere, direct incident solar radiation measured at normal incidence reaches a mean of 1370 Wm^{-2}, denominated **solar constant.**

The Earth-Sun geometry causes a variation in solar constant from 1416 Wm^{-2} in the first decade of January to 1326 Wm^{-2} in the last decade of June, when the Earth is at perihelion and aphelion, respectively (Joel J, 1983).

As it enters the atmosphere, the flux of direct solar radiation grows extinct through absorption and diffusion due to the constituent gases and the atmospheric aerosol, function of solar radiation wavelength, nature of atmospheric constituents and length of radiation's optical trajectory through the atmosphere, which is connected to the Sun's height above the horizon h_o (Herovanu, 1938,1957).

[1] National Meteorological Administration, Bucureşti, România, cristian.oprea @yahoo.com

About 4% of it is absorbed by clouds and 19% by constituent gases and aerosol, 6% is reflected by molecular diffusion and 16% by diffusion of cloud particles. Only 25% of the incident flux reaches terrestrial surface as direct solar radiation (Kondratiev 1972,).

1.The atmospheric aerosol

The atmospheric aerosol includes micrometric and sub-micrometric air suspension particles. These are liquid or solid particles; by convention, this definition excludes cloud-generating water drops and ice crystals (Boucher O,1997)..

The atmospheric aerosol can come from primary sources (dust from terrestrial surface disintegration, volcanic ashes, industrial dust) and secondary sources, by gas-to-particle transformations (sulphates, organic compounds) (Boucher O, 1997).

The atmospheric aerosol plays an important part in the climatic system and mainly in the system's primary source of energy – incident solar radiation, by direct action through absorption and diffusion and by indirect action through its influence upon the cloud formation processes.

One of the most important parameters that characterize an aerosol population is their dimensional distribution.

According to Junge (Mészaros E 1981), aerosol particles fall into the following classes:

- Aitken particles: $r < 0.1\ \mu m$;
- large particles: $0.1 \leq r < 1.0\ \mu m$;
- gigantic particles: $r \geq 1.0\ \mu m$;

Boucher O. (1997) distinguishes three types of dimensional distribution of aerosol particles, similar to those of Junge:

- **fine mode,** hundredth micron size particles
- **accumulation mode,** a few tenths of micron size particles
- **thick mode,** diameter above a micron.

Generally, the thick particles, larger than a micron, result from mechanic soil erosion and sea wave action (wave-top breaking). Fine and accumulation particles result from gas-to-particles transformation processes.

The accumulation mode aerosol is most important as regards its action upon solar radiation. First, the diffuse efficacy on direct solar radiation depends upon the dimensional specter, refraction index and considered wavelength. This efficacy reaches at a high for the aerosol whose dimensions are equal to the wavelength. The maximum diffuse efficacy of accumulation mode particles is mostly situated in the visible range (Boucher O.1997).

2. Explosive volcanic eruptions

The quantity of atmospheric aerosol can sometimes be changed by exceptional geophysical phenomena, such as explosive volcanic eruptions. They throw up into the upper atmosphere (stratosphere) eruption products that can change, sometimes dramatically, its optical properties. Relying on documents and traditions, it was estimated that when New Zealand's Tampo erupted in 130 A.D., 30 billion tons of eruption products were thrown into the atmosphere, quantity which certainly spread widely around the planet (Lauscher, 1991).

On June 15, 1991, a Pinatubo-like volcano injected in the upper atmosphere between 15 and 30 million tons of sulphurous anhydride. Given the very fast atmospheric circulation in the stratosphere, these eruption products were widely spread, a punctual process (volcanic eruption) causing thus planet-wide perturbations. 30 days after the 1991 Pinatubo eruption, the resulted H_2SO_4 cloud encircled the terrestrial atmosphere.

The NOAA-provided satellite data regarding the 18 May 1980 eruption of St. Helens in Washington – USA, showed a medium intensity eruption, the cloud reaching 15 km in height ten minutes after eruption. Half an hour after eruption, the cloud was 27 km high and spread laterally tens of kilometers. It became stable at altitudes of 14-19 km and was spread into the stratosphere by dominant winds. Ten hours after eruption the cloud covered around 1000 km expanding at about 100 km/h. In Ritzville, 300 km away from the eruptive phenomenon, the layer of ashes reached 4 cm. The volume of eruption-related ashes was 1.1 km^3 (Lauscher, 1991).

The last century's major explosive volcanic eruptions are presented in Table 1, followed by a brief description of the volcanoes and their eruptive sequences (source: the Internet, see Bibliography).

Tab. 1 - Major volcanic eruptions in the 20th century and their characteristics

Date of eruption	Volcano	Coordinates	Mass of aerosol, km^3	DVI	VEI
4.04.1982	El Chichon	17,3°N, 93,2°V	12	800	5
15.06.1991	Pinatubo	15,1°N, 120,4°E	25-35	1000	6

EL CHICHON, the Yukatan Peninsula - Mexico**,** considered extinguished for good. February 1982, first signs of resumed activity.

March 28, 23:32 hrs, a powerful explosion ejects an eruptive cloud (gases, ashes) up to 17 km in height. Until April 4, three more explosions threw into the atmosphere volcanic products up to 35 km.

20 million tons of sulphurous anhydride was injected in the atmosphere within a month.

PINATUBO: 100 km north-west of Manila, capital of the Philippines, in the Luzon Island. In April 1991, after 600 years of calm, the volcano showed visible signs of activity.

Chronology of eruptive events:

7 June 1991- clouds of ashes affect a perimeter of about 20 km around the volcano.

12 June – three explosions of high intensity throw volcanic ashes in the atmosphere up to 25 km.

15 June – eruptive activity reaches climax. In a few hours' time 0.5 km^3 of ashes are pushed up to 40 km high and also 15-30 million tons of sulphurous anhydride.

The eruption activity went on until the end of August 1991.

7 July 1991, 22 days since the main eruption, the clouds of volcanic products made a complete tour of the planet.

The intensity of a volcanic eruption is characterized by two indexes:

DVI (Dust Veil Index, Lamb, 1970) – function of the extinction of solar radiation by the horizontal layer of aerosol and its duration;

DVI = 0,97 Rmax Emax T, (http:// www.barry.warmkessel.com/barry/7910.html)

where:

Rmax = maximum attenuation of direct solar radiation (%) at mid-latitudes in the hemisphere where eruption occurred;

Emax = maximum surface affected by the cloud. Emax = 1 whwn the eruption is produced between 20^o North and South latitude, 0,7 for 20^o-35^o North and South latitude, 0,5 for 35^o-42^o North and South latitude and 0,3 for greatest latitudes.

T = duration (months) of the attenuation of solar radiation.

VEI (Volcanic Explosivity Index, Newhall and Self, 1982): based on the geological characteristics of the power of explosion, maximum height of the eruptive cloud and volume of ejected volcanic material.

As shown in Table 1, the two eruptions were of exceptional intensity, both VEI and DV reaching maximum levels. These eruptions are similar to the August 1883 Krakatau's (Indonesia) eruption or that of Santorini (Greece) in 1500 B.C., which are considered the most powerful eruptions ever (DVI=1000 and VEI=8) (http:// www.barry.warmkessel.com/barry/7910.html).

3. Types of volcanic aerosol

Two kinds of aerosol are emitted after an explosive volcanic eruption:

- The first type includes **volcanic ashes** resulted from pulverizing magmatic rocks (lava) of a few microns in diameter. Volcanic ashes, consisting mostly of silicates, are relatively fast evacuated on tropospheric and stratospheric levels through the circuit of water in the atmosphere. The ashes have a maximum concentration in the initial phase of eruption, decreasing to a half within around

100 days and growing negligible after 400 days (Kondratiev, in .Jean - François M., Laurent Borrel 1995).

- The second aerosol type is composed of **sulphate gases**. It regards sulphurous anhydride and sulphur dioxide which are turned by oxidation in contact with atmospheric water vapors into drops of sulphuric acid ($H_2 SO_4$). These drops consist of around 75% $H_2 SO_4$ and 25% $H_2 O$ and are sized in the 0.1 - 1 □m range and, being light elements, last in the upper atmosphere (stratosphere) for years. Unlike the ashes, sulphuric acid drops resulted from chemical reactions in the atmosphere reach highest concentration by 200 days from eruption; it decreases to a half after 800 days and diminishes significantly only after 1600 days (Kondratiev, quoted by Jean - François M., Laurent Borrel 1995).

Within this interval, these genuine clouds of sulphuric acid are taken over by the much faster atmospheric circulation and are spread planet wide.

Here is an account on such a cloud, taken from the Romanian papers (Romania Libera Newspaper – 10 March 1982): *An U-2 reconnaissance jet belonging to the US forces went three times through the mysterious cloud circling our planet at a height of 16-20 km. The flight lasted six hours and penetrated the cloud at several altitudes - 16,600 km, 18,300 km and 20 km – taking samples. The 3 km - long enigmatic cloud of variable height is now above the Mexico Gulf region and consists of around one million tons of substances. Specialists assume that it resulted from a meteorite explosion or a volcanic eruption. Analyzing the first samples showed that an unobserved volcanic eruption having occurred in Africa or Asia six weeks ago caused the cloud.*

The same paper from 11 March 1982 reads: *New specifications are available after the U-2 flight through the mysterious cloud drifting around the Earth at 16000 m altitude, subject approached by our yesterday issue. It consists mainly of sulphuric acid drops, which points out most assuredly to its volcanic origin.*

4. Effects of explosive volcanic activity upon direct solar radiation set off by measurements

Measurements on direct solar radiation carried out in several locations of the globe and on a number of related parameters defining the optical condition of the atmosphere (opacity factor Linke T, transmission coefficient AST) showed significant deviations from the multi-annual means over 1982-1983 and 1991-1992.

AST has been continuously monitored since 1958 by the Mauna Loa Observatory and its values show sudden deviations from normal over the above mentioned periods (Trends 93), in accordance mainly with the two explosive volcanic sequences El Chichon and Pinatubo. While the estimated content of atmospheric aerosol was in 1979 of 0.57 km^3, only El Chichon throws in the atmosphere 12 km^3, a quantity about 2000 times greater. This eruption increased the mass of planetary atmospheric aerosol by 24%. The 1989 estimated volcanic aerosol mass is 0.75 km^3 and Pinatubo injects in the atmosphere a quantity of volcanic products 4000 greater than the general mass (source: the Internet, see Bibliography).

Atmospheric transmittance decreases abruptly from annual means around 0.93 – 0.94 to 0.80, about 16% lower (Trends, 93).

It takes around three years, according to Kondratiev's distributions, to revert to normal values. The aerosol cloud related to an explosive volcanic eruption migrates to the higher latitudes over a year.

For instance, the volcanic aerosol generated by the April 1982 El Chicon eruption reached the 30^o N latitude in January 1983 and the 45^o - 50^o N latitudes in April-May (Yamauchi T., 1995).

In Europe, at the Almeria Station (36,83^o N; 2,41^o V) – Spain, monthly means of direct solar radiation measured over 1990 - 1993 point out the whole eruptive sequence of Pinatubo. Thus, monthly means of direct radiation ranging between 950 and 1000 Wm^{-2} in 1991 decrease by the end of 1992 to 750 - 850 Wm^{-2}, about 15%, (Olmo F. J, Almos Arboledas L, 1995).

5. Effects of explosive volcanic activity upon direct solar radiation in Romania

In Romania, direct solar radiation at normal incidence is measured by a 9-radiometric station network (at low altitude: H<500m) and two high altitude stations (H> 1000m) on a daily basis at 9, 12 and 15 hrs in real solar time. Measurements are carried out when the solar disc is clear of clouds.

The equipment consists of AT-50 thermoelectric actinometer coupled with GSA galvanometer for low-altitude stations and Linke Feussner thermoelectric actinometer coupled with millivoltameter.

Direct solar-radiation flux is given by the formula:

$$S = (N - N_o \pm \Delta N)\, a_n \qquad (1)$$

where:

S = direct solar radiation at normal incidence;
N = number of ranges read on galvanometer or millivoltameter;
N_o = point of zero of the galvanometer or millivoltameter;
ΔN = indicating scale correction of the galvanometer or millivoltameter;

a_n = transformation factor in absolute units function of temperature read on GSA galvanometer’s thermometer or on Linke Feussner actinometer’s thermometer. .

For this study, a number of locations were considered, including 6 radiometric stations as shown in Table 2.

Tab. 2 -Measurement locations taken into consideration

Station	□	□	**H** $_{(m)}$	Article I. Period
Iasi	47° 10’ N	27° 36’ E	90	1961 - 2000
Cluj Napoca	46° 47’ N	23° 34’ E	410	1961 - 2000
Stana de Vale	46° 41’	22° 37’	1102	1986 – 1998
Fundata	45° 28’	25° 18’	1383	1986 – 1998
Bucuresti	44° 30’ N	26° 13’ E	91	1961 - 2000
Constanta	44° 13’ N	28° 38’ E	12	1961 - 2000

Only two of the above locations, the high-altitude ones, are within areas that host no major air pollution source. The rest are nearby large cities which, depending on wind direction, can change the optical characteristics of the atmosphere (Herovanu 1938).

Temporal series of the annual mean deviations of direct solar radiation from multi-annual mean were made up for each station – Fig. 1-5.

At Bucharest, Constanta, Iasi and Cluj Napoca, annual means of direct solar radiation were calculated from observations at 9, 12, 15 hrs real solar time over 1961 - 2000. Annual means at Fundata and Stina de Vale were calculated from observations made at 12 hrs real solar time, only for the winter months, when the sky is clear more often than in the warm season, over the reference interval 1986 – 1998.

For the Bucharest, Constanta, Iasi and Cluj Napoca Stations, there were also calculated the annual mean deviations of layer precipitable water (w) from multi-annual mean. By layer precipitable water (w) we mean the height of water layer that would appear at the base of the vertical column of air extending to the upper limit of the atmosphere by condensation of the column vapors (Herovanu 1957).

Figure 2 shows that the multi-annual deviations at Bucharest and Constanta run alike, indicating that they are subject to the same perturbing meteorological influences of the zonal atmospheric circulation type. Still, there are differences as the amplitude of both positive and negative deviations for Bucharest is higher than that for Constanta probably due strictly to certain local causes.

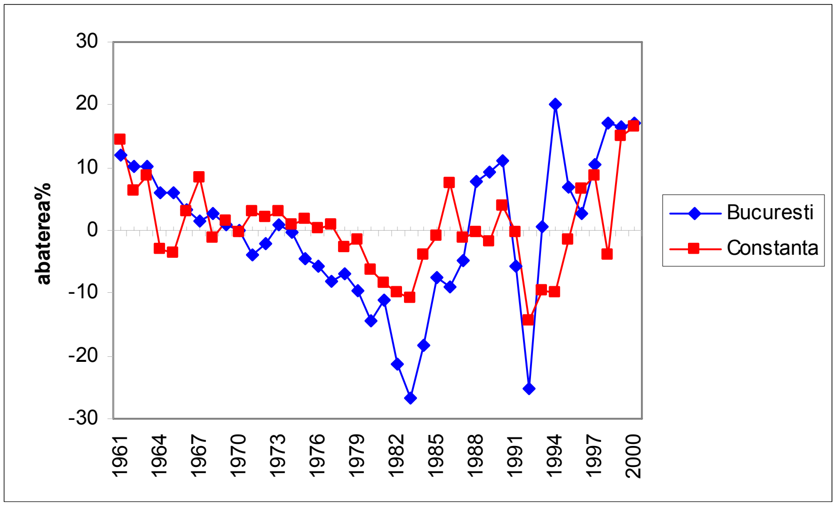

Fig. 1 - Comparative chart of the multiannual deviation of the annual average as to the multiannual average values for the direct solar radiation, in Bucharest and Constanta.

Against this background of variability, we can notice a sudden negative increase in the 1983 and 1992 deviations particularly at Bucharest, where they reach and go beyond 25%, Fig. 2. This indicates a significant decrease in direct solar radiation for these years.

It should be noticed that the above mentioned years follow closely the two explosive eruption sequences, El Chichon and Pinatubo – mentioned in Table 1.

These veritable radiative lows, corresponding to certain significant negative deviations, can only in part be found again at Iasi and Cluj Napoca, Fig.2. The 1983 Iasi deviation is 26.1% and the 1993 Cluj Napoca one is 18%.

At Fundata and Stana de Vale, negative deviations increased abruptly between 11 and 18% since December 1992. These high negative deviations lasted until 1994, when the veritable radiative decline blurred, Fig.3-5.

As regards these radiative lows set off by the six measurement points, the problem is to know if they are caused by the two above mentioned eruptions.

Analyzing the multi-annual variability of annual layer precipitable water (w) deviations, regarded as a main factor of the extinction of direct solar radiation (Herovanu

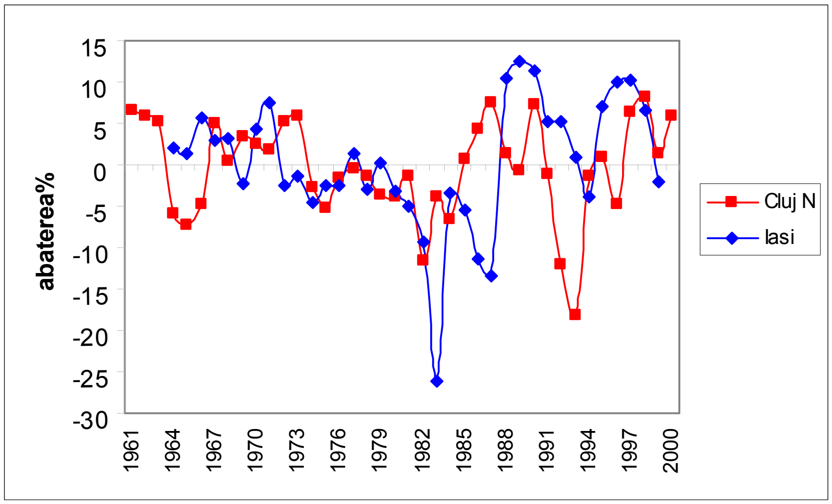

Fig. 2 - Comparative chart of the multiannual deviation of the annual average as to the multiannual average values for the direct solar radiation, in Cluj Napoca.

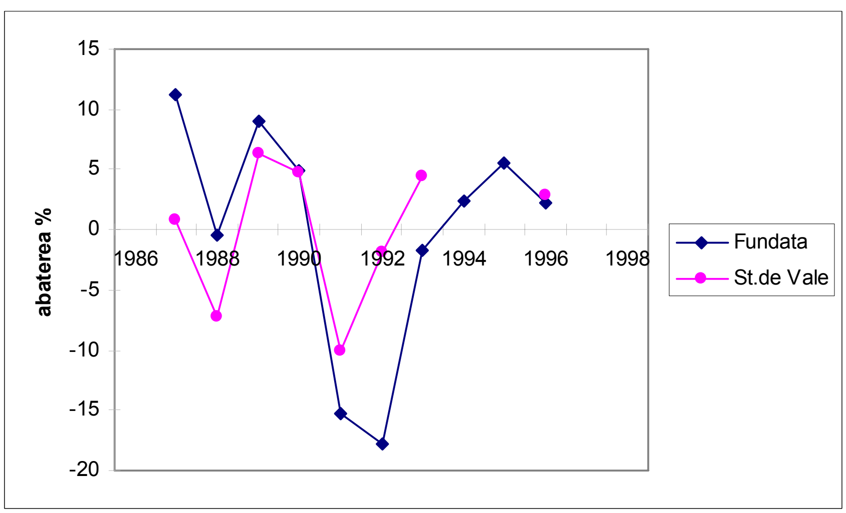

Fig. 3 - Comparative chart of the multiannual deviation of the annual average as to the multiannual average values for the direct solar radiation, in Fundata and Stina de Vale, in december.

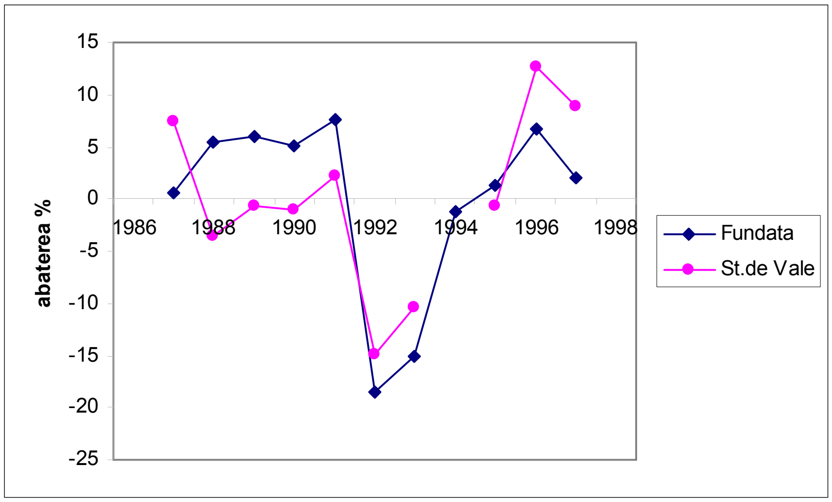

Fig. 4 Comparative chart of the multiannual deviation of the annual average as to the multiannual average values for the direct solar radiation, in Fundata and Stina de Vale, in ianuary.

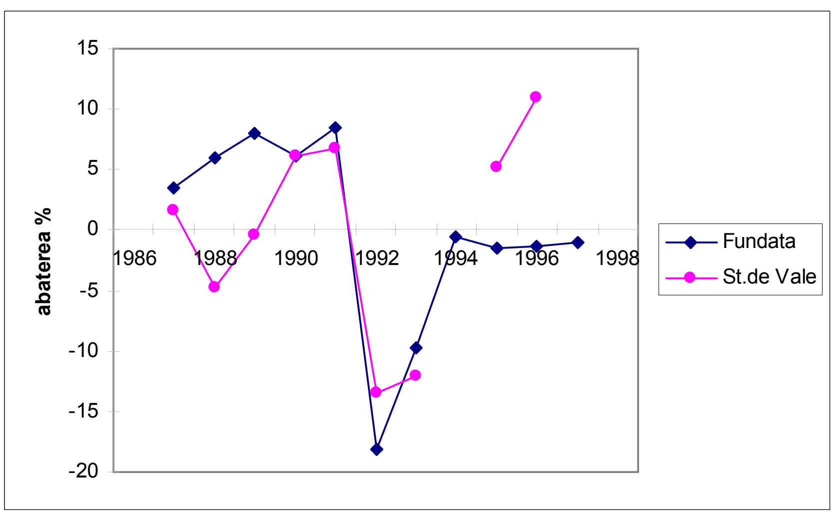

Fig. 5 - Comparative chart of the multiannual deviation of the annual average as to the multiannual average values for the direct solar radiation, in Fundata and Stâna de Vale, in february.

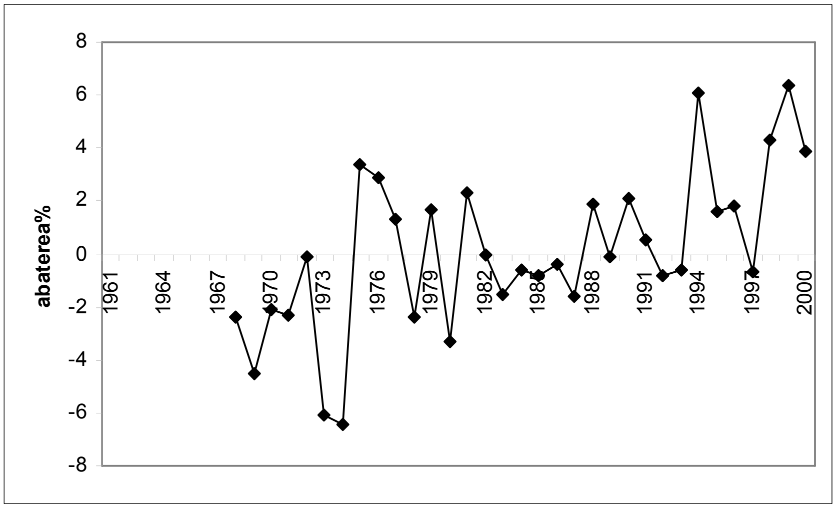

Fig. 6 - Multiannual evolution of the annual average deviation of the precipitable water, as to the multiannual average values, for the low altitude stations – Bucharest, Constanta, ClujNapoca, Iaşi.

1938, 1957), it can be noticed that it has no major deviations from the multi-annual mean, at least for 1983 and 1992 - Fig. 6, deviations reaching 2% at most. In these conditions, we must admit the influence of other source that intensifies the extinction of direct solar radiation, namely the two explosive volcanic eruptions.

Conclusions

Compared to the data on the two major eruptions of El Chichon and Pinatubo - Table1, the lows noticed in the multi-annual dynamics of annual direct solar radiation's deviation in Romania coincide. This phenomenon is clearly set off at locations within southern Romania both at low and high altitudes.

Direct solar radiation decreases abruptly and its increase back to normal values is slow and takes a few years, as the high altitude stations show it more conspicuously. The radiative low occurs about one year from eruption date, according to Kondratiev's dynamics of eruption products (1995).

These moments are undoubtedly due to an aerosol surplus generated in the upper layers of the atmosphere by the two volcanoes, which added to the optical action of the tropospheric natural or anthropic aerosol.

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