REGIONAL AIR POLLUTION CAUSED BY A SIMULTANEOUS DESTRUCTION OF MAJOR INDUSTRIAL SOURCES DURING THE 1999 AIR CAMPAIGN IN YUGOSLAVIA

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ABSTRACT

During NATO's 78 day Kosovo war, 24 March – 10 June 1999, almost daily attacks on major industrial sources have caused numerous industrial accidents in Serbia. These accidents resulted in releases of many hazardous chemical substances including the persistent organic pollutants (POPs). Important detection of some POPs in fine aerosol form took place at Xanthi in Greece and reported to the scientific world. The paper focuses on two pollution episodes: (a) 6-8 April; and (b) 18–20 April. Using the Eta model trajectory analysis, the regional pollutant transport from industrial sites in northern Serbia (Novi Sad) and in the Belgrade vicinity (Pančevo), respectively, almost simultaneously bombed at midnight between 17 and 18 April, corroborated measurements at Xanthi. At the same time the pollutant puff was picked up at about 3000 m and transported to Bulgaria, Romania, Ukraine, Moldavia and the Black Sea. The low-level trajectories from Pančevo below 1000 m show pollutant transport towards Belgrade area in the first 12 hours. The POP washout in central and southern Serbia in the second episode was deemed to have constituted the principal removal mechanism. In this episode maximum POP wet deposition was found in central Serbia and along the 850 hPa trajectory towards south-eastern Serbia and the Bulgarian border. The most intensive bombing of major industrial sources was in April 1999 in which maximum number of days with precipitation (20-26 a month) was registered in central and south-western Serbia in comparison with the period of 1960-1990. Maximum monthly precipitation sums, higher than 100 mm, appeared in central and north-eastern Serbia, while a deficit, less than 50 mm, was registered in north-western and southern Serbia.

Key words: Accidental gas release; War impact assessment; Particulate matter; Pollutant transport modelling; POP deposition

INTRODUCTION

During NATO campaign in Yugoslavia, from 24 March to 10 June 1999, almost daily attacks on the chemical, petrochemical, plastic plants, refineries, fuel storage tanks, automobile plants, machine industry, food processing plants, heating plants, water treatment plants, and the electric power grid including transformers have caused numerous industrial accidents throughout Serbia.

Some persistent organic pollutants (POPs) in fine aerosol phase (<2.5 μm) were detected at Xanthi in Greece [1]. Two regional air pollution episodes are described: the first in the period of 6-8 April and the second in the period of 18-20 April[1,2]. Table I provides a summary of major industrial facilities, together with timing and exact location, bombed during April 1999. The backward trajectories constructed by the HYSPLIT_4 (Hybrid Single Particle Langrangian Integrated Trajectory) model indicated that the Priština fuel storage depots and the chemical industry at Lučani near Čačak are potential sources of POPs detected at Xanthi in the first episode, but the coal mining near Priština and a wood processing plant at Kuršumlija in the second episode excluding origin from Pančevo [2].

This study has focused on the second episode since the referenced sources are not capable of producing pollution in the regional scale, which did take place. The other potential sources are major industrial sources at Novi Sad and Pančevo simultaneously targeted at midnight between 17 and 18 April (Table I). Regional air pollution was simulated as reflected on typical trajectories. Trajectory calculations were implemented in the Eta model. In addition, the factual observed data for rainfall distributions in central and south-eastern Serbia were analysed in order to estimate the POP deposition and environmental impact in this episode. Besides that, the effects of uncontrolled particulate matter release on precipitation in Serbia in April 1999 were discussed indicating potential impact zones of wet deposition.

Table I. Major industrial sources targeted in Serbia and Kosovo in April 1999

DATE	TIME LSST (UTC+2.0)	LOCATION	TARGET (Description)
4	2:00	Bogutovac (C. Serbia)	Oil product storage
4	3:20	Čačak (Central Serbia)	Household appliances factory
4	4:25	Smederevo (C. Serbia)	3 industrial objects with big fuel storage
4	4:30	Belgrade	Beopetrol storage depots
4	4:30	Pančevo near Belgrade	Power plant in NIS Oil Refinery
5	2:10	Priština (Kosovo)	Facility lubricant and greases storage
5	2:45	Lučani (Central Serbia)	Chemical plant
5	3:35	Niš (Southern Serbia)	Tobacco factory, electric warehouse
5	22:15	Sombor (N. Serbia)	Industrial zone with fuel storage facilities
5	22:30	Novi Sad (N. Serbia)	Bitumen storage (lubricants production complex) & termo-power and heat stations
6	0:30	Priština (Kosovo)	Fuel depot (at airport)
6	1:30	Prizren (Kosovo)	Cement plant & 2 gas and crude oil depots

6	11:25	Priština (Kosovo)	Fuel storage
6	23:00	Priština(Kosovo)	Fuel storage
6	20:35&23:00	Lučani (Central Serbia)	Chemical industry
6	23:00	Čačak (Central Serbia)	Household appliances factory
6	Late at night	Sombor (N. Serbia)	Gas and crude oil installations
7	2:40	Novi Sad (N. Serbia)	Central storage depot: crude oil & lubricant
7	2:40	Priština (Kosovo)	Fuel storage
7	3:00	Sombor (N. Serbia)	Fuel depot (oil & kerosene)
7	4:40	Niš (Southern Serbia)	Industrial zone
8	0:30	Bogutovac (C. Serbia)	Power house & oil fuel storage
8	4:20	Lučani (Central Serbia)	Chemical industry & power supply plant
8	14:40	Sombor (N. Serbia)	Underground fuel storage tanks
8	Late at night	Prizren (Kosovo)	Agricultural and industrial complex
9	0:48	Smederevo (C. Serbia)	Kerosene and petrol tanks
9	1:20	Kragujevac (C. Serbia)	Car factory
10	Late at night	Gnjilane (Kosovo)	Battery factory
12	2:30	Pančevo near Belgrade	Oil refinery
12	2:40	Kragujevac (C. Serbia)	Car factory
12	3:00	Kruševac(C. Serbia)	Factory & municipal heating plant
12	23:20	Sombor (N. Serbia)	Fuel depot (kerosene, diesel and crude oil)
12	22:35	Pančevo near Belgrade	Oil refinery
12	22:50	Novi Sad (N. Serbia)	Oil refinery
12	Late at night	Priština (Kosovo)	Oil -fuel storage
13	0:20	Čačak (Central Serbia)	Household appliances factory
13	1:00	Sombor (N. Serbia)	Fuel storage
13	1:45	Priština (Kosovo)	Fuel depot & Plastics factory
13	5:30	Smederevo (C. Serbia)	Oil-fuel storage
13	5:50	Pančevo near Belgrade	Oil refinery
13	15:00	Priština (Kosovo)	PVC factory & oil fuel storage
13	Late at night	Sombor (N. Serbia)	Serbian oil company
14	0:00	Nova Varoš (S. Serbia)	Hydroelectric power station
14	5:30	Valjevo (Central Serbia)	Krušik industrial complex
14	Late at night	Pančevo near Belgrade	Petrochemical industry, nitrogen fertiliser plant
14	Late at night	Pančevo near Belgrade	Petrochemical complex (VCM plant)
15	1:20	Kragujevac (C. Serbia)	Car factory

15	4:45	Niš (Southern Serbia)	Airport warehouse
15	5:00	Kruševac (C. Serbia)	Mining equipment and machinery factory
15	22:15	Bački Petrovac (N. Serb.)	Oil refinery
15	22:40	Pančevo near Belgrade	Petrochemical complex (VCM plant)
15	23:20	Pančevo near Belgrade	Nitrogen fertiliser plant
16	2:00	Valjevo (Central Serbia)	Fuel reservoir and industrial complex
17	22:15	Novi Sad (N. Serbia)	Oil refinery
17	22:30	Barič near Belgrade	Toluene diisocyanate factory
18	1:00	Novi Sad (N. Serbia)	Oil refinery
18	1:00-1:10	Pančevo near Belgrade	Petrochemical complex, nitrogen fertiliser factory & oil refinery
18	22.30	Priština (Kosovo)	Belaćevac coal mine
19	1.50	Novi Sad (N. Serbia)	Oil refinery
19	3.15	Kuršumlija (S. Serbia)	Wood processing works
19	23.07	Niš (Southern Serbia)	Tobacco production plant
19	Late at night	Barič near Belgrade	Chemical plant
20	3:17	Valjevo (Central Serbia)	Krusik industrial complex
20	3:40	Kuršumlija (S. Serbia)	Electric distribution and chemical industry
21	0:25	Valjevo (Central Serbia)	Krušik industrial complex
21	Late at night	Bački Petrovac (N.Serb.)	Agricultural & industrial complex
22	0:40	Valjevo (Central Serbia)	Krušik industrial complex
23	2.20	Niš (Southern Serbia)	Industrial zone
24	1.10	Niš (Southern Serbia)	Metal processing & electric supply industry
24	2.40	Kraljevo (Central Serbia)	Fuel storage
24	3.15	Novi Sad (N.Serbia)	Masut & oil storage depots
25	2.40	Novi Sad (N. Serbia)	Oil refinery
25	2:40	Valjevo (Central Serbia)	Krušik industrial complex
25	Late at night	Niš (Southern Serbia)	Agricultural & industrial complex
26	1.40	Pričević (Central Serbia)	Fuel storage facilities
28	1.30	Novi Sad (N. Serbia)	Oil refinery & agricultural complex
28	2.30	Požega (Central Serbia)	Fuel storage
29	1.10	Požega (Central Serbia)	Fuel storage
29	1:15	Novi Sad (N. Serbia)	Oil refinery
29	3.25	Smederevo (C. Serbia)	Fuel storage
29	23.25	Novi Sad (N. Serbia)	Oil refinery
30	2:40	Valjevo (Central Serbia)	Krušik industrial complex
30	Late at night	Užice (Central Serbia)	Fuel storage

Table II. Number of days with daily precipitation sum ≥ 0.1 mm for April in Serbia

N	Meteorological station	*h* (m)	1999	Mean in the period from 1961 to 1990	Maximum in the period from 1961 to 1990
1	Palić	102	13	11.6	20
2	Sombor	88	16	12.2	18
3	Bečej	75	15	11.7	19
4	Novi Sad	84	14	12.3	18
5	Zrenjanin	80	15	12.0	18
6	Kikinda	81	13	11.8	19
7	Vršac	84	16	12.5	17
8	Loznica	121	20	14.0	23
9	Sremska Mitrovica	81	16	13.6	20
10	Valjevo	176	20	13.1	18
11	Belgrade	132	20	12.7	17
12	Kragujevac	185	19	12.2	18
13	Smederevska Palanka	122	18	12.4	17
14	Veliko Gradište	82	18	13.0	20
15	Crni Vrh	1037	24	15.6	25
16	Negotin	42	15	11.5	19
17	Zlatibor	1028	23	15.6	22
18	Sjenica	1038	23	13.7	22
19	Požega	310	21	12.9	20
20	Kraljevo	215	25	13.4	19
21	Kopaonik	1710	26	16.5	22
22	Kruševac	166	23	12.0	19
23	Ćuprija	123	22	12.7	17
24	Niš	201	19	12.8	19
25	Leskovac	230	24	11.9	18
26	Zaječar	144	17	11.9	19
27	Dimitrovgrad	450	18	13.1	21
28	Vranje	432	18	13.0	23
29	Priština	573	18	12.1	18
30	Prizren	402	19	12.8	19

BACKGROUND

In the first episode the concentrations up to 260 ng m^{-3} of total polycyclic aromatic hydrocarbons (PAHs), which are generally products of incomplete combustion of fossil fuels, were increased 20 times compared to the background levels at this site. The total polychlorinated biphenyls (PCBs) concentrations peaking at 2.5 ng m^{-3}, conceivably released from damaged electric transformers, were increased 10 times in comparison with usual concentrations transported from sources in northern and north-western directions[1]. The concentrations equalling 25 pg m^{-3} of dioxins/furans, which are products of

uncontrolled combustion in petrochemical industrial plants, energy distribution system using pyralene and regular combustion of missile and aircraft fuels, were also increased 10 times compared to background levels at this site. The concentrations of dioxin/furans equalling 13 pg m^{-3}, and PAHs at 60 ng m^{-3}, were both increased 5 times in the second episode.

Modelling of long-range transport of dioxins/furans employs concentrations in I-Teq (Index-Toxicity equivalent coefficient) ranging from 0.05-1. Unity is the maximum toxicity for 2,3,7,8–TCDD (tetrachlorodibenzo-p-dioxin), which was found in both episodes with increased concentrations at Xanthi. According to Melas[2] the periods of north-westerly flow favouring transport of air masses from former Yugoslavia to the south were limited. On 7 April a ridge of high pressure resulted in drier weather in the Balkans with winds blowing from northerly direction. These conditions lasted for no more than 1.5 days. Short-lived spell with northerly flow occurred on 18-19 April as well.

The part of description concerning aerosol sampling is completely reproduced from the published papers of Rapsomanikis et al.[1] and Melas et al.[2]

As mentioned before, aerosol samples were collected at Xanthi, Greece (41.15 ^{o}N, 25 ^{o}E), on a moving glass fibre filter band GF10 6 cm width with 1 μm nominal porosity of a high volume sampler. They were also collected by a PM2.5 μm High Volume Dichotomous Virtual Impactor (HVDVI)[3] on glass fibre 90 mm diameter GF/F filters with nominal porosity of 1 μm. Parts of the filter band and parts of the HVDVI filters, constituting of 24 h samples, were analysed using high resolution gas chromatography coupled with high resolution mass spectrometry by Scientific Analysis Laboratories Ltd (SAL), U.K. The background concentrations for the compounds of interest in the area was estimated from samples of filter band for days that air masses originating from Yugoslavia before the NATO campaign were identified.

METHODOLOGY

Eta model is a regional weather prediction primitive equation model for synoptic and meso-scale processes. The model uses several sophisticated numerical methods and parameterisation[4,5]. Using the viscous sublayer scheme for surface mixing[6] the Eta model has clear advantages in performing the surface pollutant flux calculations. This is also the case with the calculation of air trajectories at lower levels in complex topographic conditions as on the Balkan Peninsula.

Trajectory Calculation

Construction of three-dimensional atmospheric trajectories provides a valuable diagnostic tool for illustrating and studying three-dimensional flow fields and associated transports. Trajectories are calculated from simulated wind fields, with both horizontal and vertical wind components derived from the Eta model. Trajectories can be calculated forwards and backwards in time. Air back trajectories are calculated by specifying final parcel locations and time, and then tracing the parcels with decreasing time to ascertain their origins. Time steps for forward and backward trajectories were 1.5 min and 60 min, respectively.

The horizontal wind components (*u, v*) from the Eta model are defined on a latitude-longitude (λ, φ) grid, and the vertical component of motion $\dot{\eta} = d\eta/dt$ is defined at interfaces at points staggered with respect to the horizontal velocity points. For a given position and time, the new location for integration of one time interval was accomplished

by a two-step approach. To derive needed wind components at a given position, bilinear horizontal and linear vertical interpolations are performed. First, bilinear interpolation is performed horizontally on the two η model levels that encompass the trajectory position in the vertical. Then, linear vertical interpolation is done on the two horizontally interpolated values to obtain the wind component at the parcel's position. This interpolation is done for all three-wind components. Using these interpolated wind components u_1, v_1, $\dot{\eta}_1$, a first estimate of the new position ($\lambda_1, \varphi_1, \eta_1$) for the parcel was obtained. A new set of wind components (u_2, v_2, $\dot{\eta}_2$) was then calculated in the same manner for this new location. The final displacement was calculated using the average of the two sets of wind components:

$$\lambda^{\tau+1} = \lambda^{\tau} + \frac{(u_1 + u_2)}{2} \Delta t \frac{180/\pi}{R\cos\left[(\varphi_1{}^{\tau+1} + \varphi^{\tau})/2\right]},$$

$$\varphi^{\tau+1} = \varphi^{\tau} + \frac{(v_1 + v_2)}{2} \Delta t \frac{180/\pi}{R},$$

$$\eta^{\tau+1} = \eta^{\tau} + \frac{(\dot{\eta}_1 + \dot{\eta}_2)}{2} \Delta t,$$

where τ is time level, R is the mean radius of the earth, the factor 180/π is needed to convert (λ, φ) from radians to degrees, η is a dimensionless, normalised value from 1 to 0. This procedure is repeated until the desired final time is reached. Lazić and Tošić[7] have recently described the more detailed calculation of trajectories, including the analysis of mountain height effect just in the area of interest to this research.

RESULTS AND DISCUSSION

The work performed has focused on the Eta trajectory analyses and important Xanthi measurements since the monitoring system in Yugoslavia has not provided samples representative of the POP detection. It is essential to emphasise that the current models for air pollution dispersion have been designed for continually emitting sources with a constant strength and not for decreasing buoyancy applications such as fires resulting from explosions. Hence, all cases are examined individually. Pollutant emissions from fires have a limited lasting interval due to its own range and intensity. Initially, impact zones are distributed to larger distances since the smoke plume top reaches significant height. Consequently, with decreasing fire intensity, impact zones approach to the closer vicinity of the targeted object. The observation of the Kuwait oil smoke plume in springtime showed that the plume top reached a maximum height of 5,000 m[8]. According to visual observations of the smoke plumes from oil-refinery fires in Novi Sad and Pančevo under war conditions in Yugoslavia 1999[9], the top heights were estimated as 3,000 m with typical convective clouds forming on the windward edge of the plume. Under such conditions, heterogeneous transformation processes of primary pollutants are intensive. However, PCBs, PAHs, dioxins and furans in gaseous phase have low solubility in cloud water and oppositely high retention to carbon particles (soot) that might be transported to the long distances as fine aerosols[10].

Simultaneous bombing of industrial targets in Novi Sad and Pančevo on 18 April resulted in adverse pollution effects in Central and Eastern Europe. As an example, the Timis

county Environmental Protection Agency from Romania reported that the maximum allowable concentrations for sulphur dioxide, nitrogen oxides and ammonia were exceeded by 5-10 times in the period between 18 and 26 April 1999. The Republic of Serbia Ministry of the Environment report estimated that destruction of the Pančevo and Novi Sad oil refineries caused approximately 30,000 tonnes of crude oil and oil products to be burned resulting in intense releases of CO_2, soot, SO_2, NO_X and PAHs. At the same time the nitrogen fertiliser plant was bombed in Pančevo (Table I) producing very intensive emissions of ammonia, nitric acid and hydrocarbons. The installations of VCM (vinyl chloride monomer) and PVC (polyvinyl chloride) production were bombed at 01:10 a.m. (Table I) resulting in destruction of 1200 t reservoir with 440 t of VCM and 6 train cisterns containing 30 t of VCM each. Burning of VCM lasted until 8 a.m. and 3: 30 p.m. respectively. The VCM concentration was 530,000 ng m^{-3} 6:00 and 8:00 a.m. Approximately 8 t of mercury are missing in an electrolysis system of the Pančevo petrochemical complex. Only 200 kg was poured out in the wastewater canal and 50-100 kg was found on the concrete floor of a factory two-three months after bombing[11]. A part of mercury was likely evaporated due to fire. Under oxidising conditions in plume in the presence of chlorine, a significant fraction of Hg(II) from Pančevo might be adsorbed to elemental carbon particles[12]. Almost simultaneous releases of smoke plumes from the Novi Sad and Pančevo refineries (Table I) occurred with total burning rate of 2,000 t h^{-1} during the first 12 h after bombing at midnight between 17 and 18 April 1999. Using the methodology applied in the case of the Kuwait oil smoke plume[7], an average emission of carbon particles in overlapping plumes[13] is estimated approximately as 65 t h^{-1}.

Trajectory calculations are implemented in the Eta model. A realistic simulation of real data is achieved using the model with a 56 km horizontal resolution and 32 layers in the vertical. Numerical simulation for forward trajectories is initialised at 0000 UTC 18 April and 2100 UTC 19 April for backward trajectory using ECMWF (European Centre for Medium-Range Weather Forecasts) analysis as the initial conditions. Initial fields of geopotential height, wind components and specific humidity, at ten standard pressure levels, were obtained by bilinear interpolation from the ECMWF operational initialised analyses. Time-dependent lateral boundary values were taken from the ECMWF analyses, linearly interpolated between analysed fields available at 6 h intervals. They are used at the outermost boundary points only. The row next to the outer boundary is a blend (four-point space interpolation) of the outer row and the third row inside, which is the outermost integration row of the model.

The synoptic case during 18-21 April 1999 was characterised by an upper trough located in the northern part of the area of interest. There was a small pressure gradient field at lower levels. That synoptic case produces a light variable wind near surface, and much intensive westerly wind at upper levels. Fronts were observed during 18 and 20 April followed by heavy rain, thunderstorm and intense wind (17 m/s) from western direction.

The maximums of the daily-accumulated precipitation (10-15 mm) during 18 April were observed at the larger Belgrade area and in the south-easterly part of Serbia. Also, the maximums of the precipitation (10 mm) were registered south - easterly from Belgrade on 19 April after passing the front, and in the southern part of Serbia. A new front was registered on 20 April from western direction, which caused heavy rain with amount of 15 mm in the western part of Serbia [4, 14]. The similar distribution of the accumulated precipitation over 24 h for the same days is obtained by the Eta model simulation [4].

According to the forward trajectories [4,9], the pollutant puff was picked up over the area of oil-refinery fires and moved eastward over Romania, Bulgaria, Moldavia, Ukraine and the

Black Sea. The regional transport of PAHs and of dioxins and furans as burning products of PVC and VCM from Pančevo (λ=20°40', φ=44°53') occurred at 850 hPa (about 1500 m) over Xanthi, Thrace (λ=25°φ=41°9') on 18/19 April. Transport of PAHs from Novi Sad (λ=19°50', φ=45°20') has been observed above 2000 m at Xanthi until noon of 19 April. The backward trajectories originated from Xanthi at 45 h of integration (Fig. 1) explicitly show air pollution transport from Pančevo and Novi Sad. It is important to underline that the backward trajectory at 850 hPa (about 1500 m) calculated by the HYSPLIT_4 model[2] was designed for territory without industrial sources that have been targeted during NATO campaign in Yugoslavia[11]. Approaching to Xanthi, wind speed in air parcel was significantly reduced up to 6000 m height (Fig. 1c) indicating thus unfavourable conditions for pollutant dispersion.

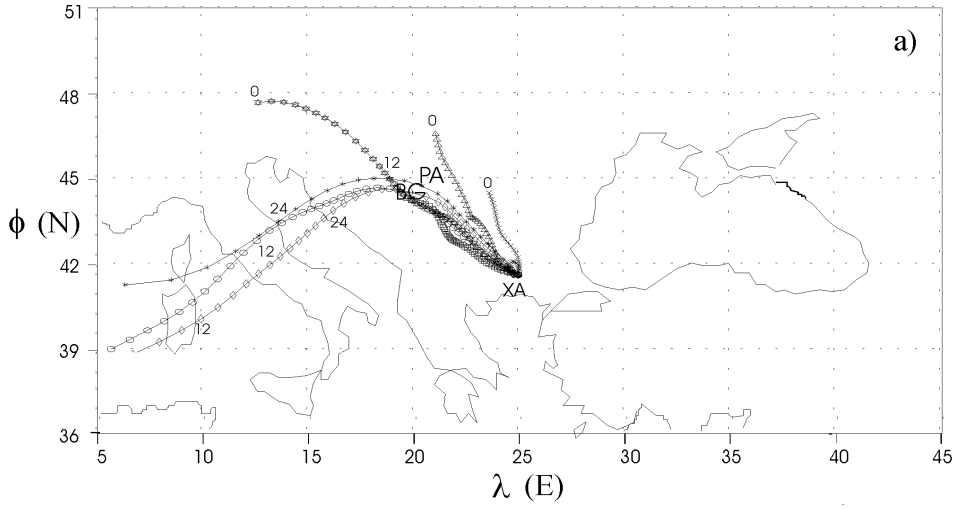
The lower level trajectories from Pančevo indicate pollutant transport in short-regional and local scales towards the Belgrade area (λ=20°28'.φ= 44°48') in the first 12 h after bombing [4,9]. The proximity of large cities (Belgrade, Novi Sad), where surface and elevated inversions occurred, together with complex topography and heat island effects, contributed to an enhanced deposition of primary and secondary pollutants within the territory of Serbia. Namely, complex topography increases surface roughness[15] and surface inversions produce unfavourable conditions for pollutant dispersion. Wet deposition is most important for dioxins and furans[16]. This process removes about 70 % of these compounds from the atmosphere with washing ratio in the range of 10,000-18,000. The washing ratios of PAHs bound with aerosol are in the range of 10^3-2x10^5 depending on the seasons and reach the maximum value in summertime[10].

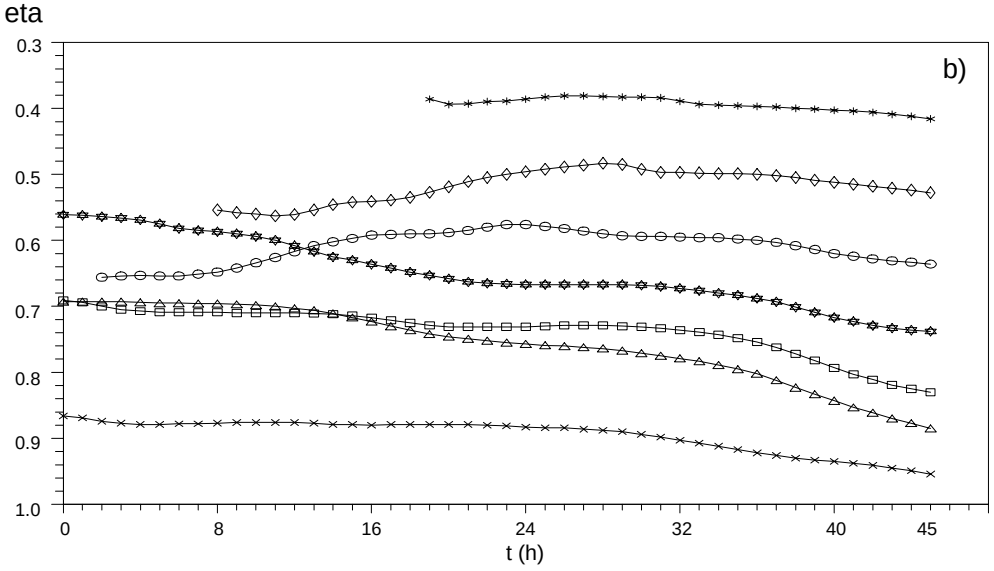
Given direct proportionality to the accumulated precipitation, maximum of wet deposition fluxes of PAHs and dioxins/furans had likely been appeared over the Belgrade area and along trajectories towards the Bulgarian border. Well known defoliant effect in the vegetation period (April through September) was observed on many trees in this part of Serbia and in particular on apple trees, which were practically naked. Vegetation plays very important role in degradation processes of PCBs[10]. Photodegradation in the atmosphere is the most influencing process on the half-lives of POPs. For example, PAHs half-lives in air are in the range of 55-170 h, while in natural water these values are 10 times and in soil 100 times higher[10]. Depending on the season and species, dioxins/furans have the half-lives in the atmosphere in the wider range of 40-3,000 h. Half-lives of these species in water are in the range of 550-1700 h, in soil 2 years and in bottom sediments 6 years. The results of investigation of soil pollution caused by accident in the Sevezo region of Italy indicated the half-life of 2,3,7,8-TCDD to be not less than 10 years[10].

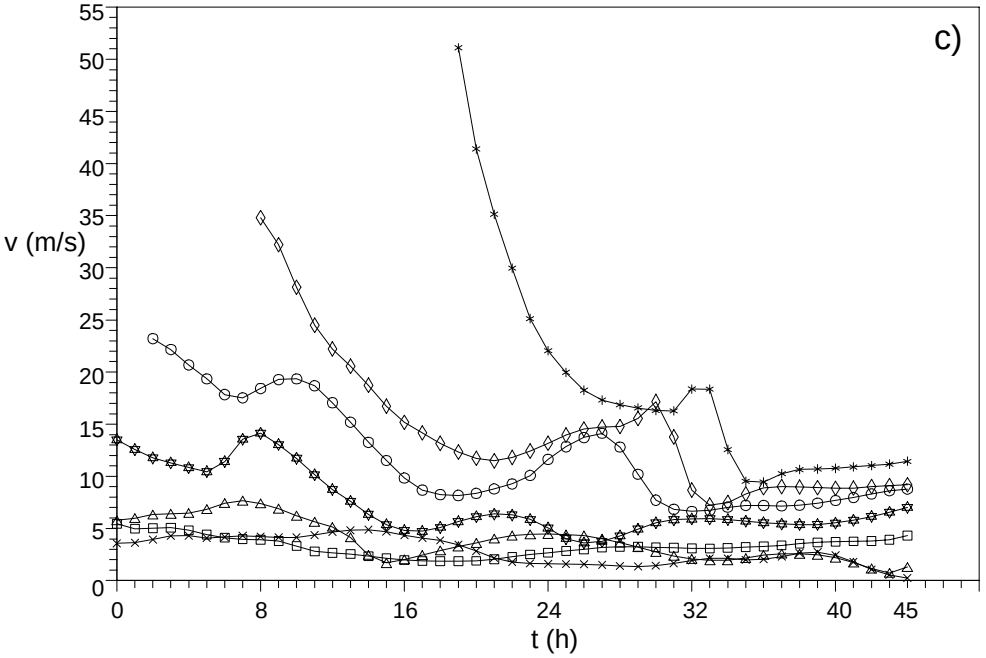
As mentioned the washout of PAHs and dioxins/furans on the territory of Serbia is their predominant deposition process in the episode of 18-20 April 1999. Long-term consequences for the environment are unpredictable at the present time. More research needs to be directed to study this problem. Generally speaking, on the basis of the spatial distribution of total precipitation sums for April 1999 (Fig. 2) potential impact zones of wet deposition might be identified. Maximum monthly precipitation sums, higher than 100 mm, appeared in central and north-eastern Serbia, while a deficit, less than 50 mm, was registered in north-western and southern Serbia. In the first approximation this deficit means twice lower POP deposition in soil.

Uncontrolled release of particulate matter as cloud condensation nuclei (CCN) caused greater number of days with precipitation sum $P \geq 0.1$ mm in comparison with the mean values in the period from 1961 to 1990 (Table II). Increased number of days with $P \geq 0.1$ mm, in comparison with the maximum in the period from 1961 to 1990, was observed in

the central part of Serbia, as well as at the mountain area of south - western Serbia. Especially great number of days with $P \geq 0.1$ mm in April 1999 was registered at the area bounded by meteorological stations Ćuprija, Kraljevo, Kruševac, Kopaonik and Leskovac. Transport of particulate matter in local and short-regional scales from Lučani and Priština during 5-7 April was towards the south-western part of Serbia[17]. In that part of Serbia there is the highest mountain of Serbia, Kopaonik, with peak altitude of 2017 m. According to this feature and trajectory calculations[17] one may be concluded that upwards effects could be responsible for the maximum number of days with $P \geq 0.1$ mm in April 1999.







* LT=1 (z=6142m) ◊ LT=2 (z=4664m) O LT=3 (z=3416m) ✡ LT=4 (z=2370m) □ LT=5 (z=1505m) Δ LT=6 (z=1023m) × LT=7 (z=434m)

Fig. 1. Backward trajectories from Xanthi (λ=25°, ϕ=41°9') starting at 2100 UTC 19 April 1999: a) horizontal positions (numbers along trajectories indicate the time of integration in hours); b) vertical positions; c) wind speed along trajectories.

CONCLUSION

The regional POP transport from refineries in Pančevo and Novi Sad, as well as a petrochemical plant in Pančevo, hit at midnight between 17 and 18 April, was confirmed over the territory of central and south-eastern Serbia towards Thrace (Greece) using the Eta trajectory analyses. The concentrations of polycyclic aromatic hydrocarbons and of dioxins and furans, that have been found in the 24 h air samples at Xanthi on 18/19 April 1999 at the distance of 500-600 km from potential sources, are higher than expected ones in polluted areas in Europe in this part of the year[10]. The maximum of POP washout was in the vicinity of targeted sources in central Serbia and along the air trajectory at 850 hPa (cca 1500 m) to the south-eastern border with Bulgaria in the pollution episode of 18-20 April 1999. Unfortunately, in this part of Europe the regional monitoring network for POPs is not still put in place. Taking into consideration the half-lives of some POPs in soil and bottom sediments (up to 10 years for 2,3,7,8-TCDD), and also a possibility of re-emission, the urgent measures to protect water resources and food production have to be undertaken.

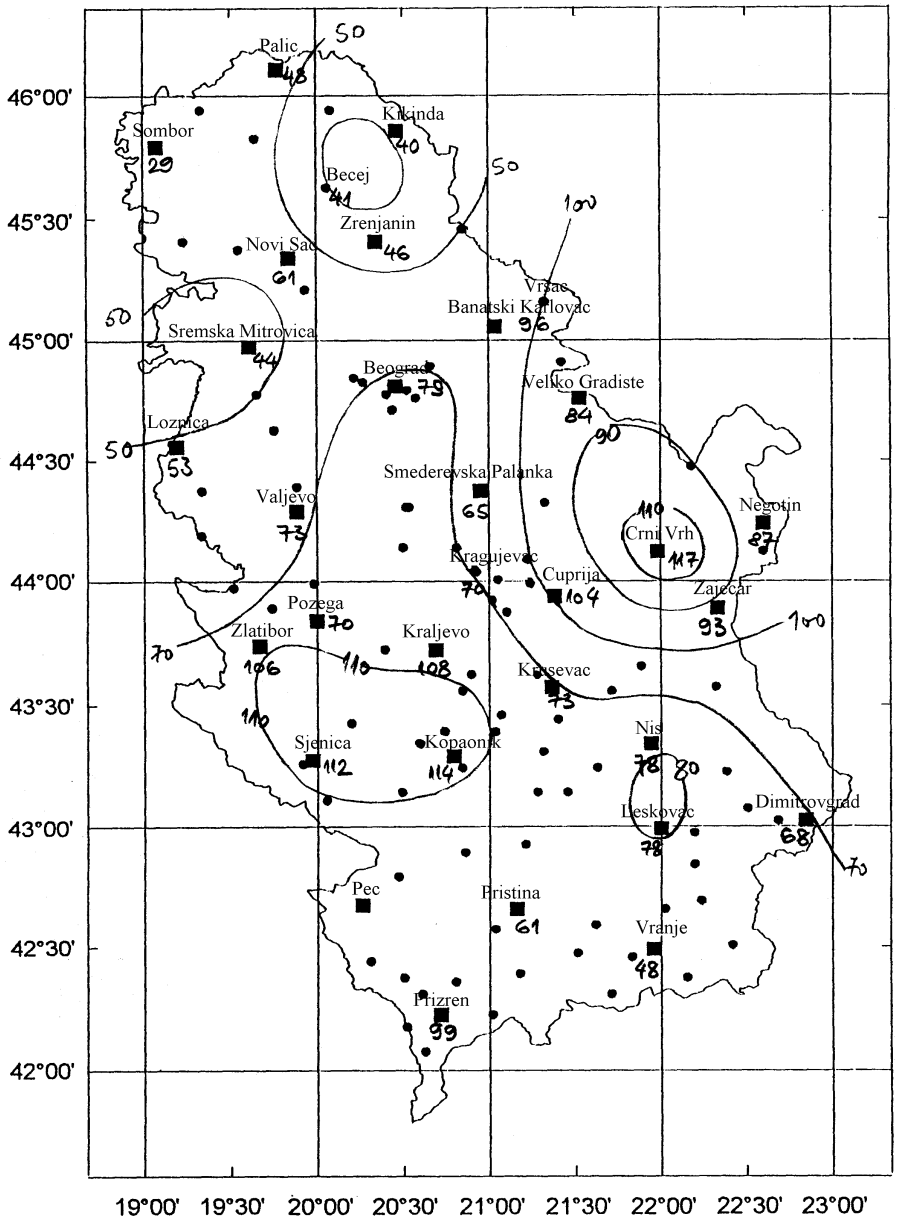


Fig. 2 Spatial distribution of total precipitation sum (mm) for April 1999 in Serbia

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