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MONITORING OF CLOUD AND PRECIPITATION DURING AIR POLLUTION TRANSPORT IN WARFARE EPISODE IN SERBIA

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Abstract. During warfare episode from 18 to 20 April 1999, when oil refineries at Novi Sad and Pančevo, chemical industries at Belgrade and Pančevo, coal mine at Priština, wood processing works at Kuršumlija and tobacco production plant at Niš were targeted, the crucial measurements of the concentrations of some persistent organic pollutants (POPs) in fine aerosol phase at Xanthi (Greece) have been performed. This study addresses an analysis of air pollution transport during the above mentioned warfare episode in Serbia and its properties as reflected on precipitation measured at the territory of Serbia. The washout of POPs in Central and Southern Serbia is considered in the pollution episode of 18-20 April as the predominant process of removing POPs from the atmosphere.

Keywords: cloud, precipitation, dioxin, furans, POP washout.

AIMS AND BACKGROUND

During NATO campaign in Serbia in the period from 18 to 20 April 1999 several reports in 1999 provided independent assessments of the environmental impact after air strikes to chemical industries and oil facilities in the Belgrade area (Barič and Pančevo) and oil refinery in Novi Sad[1-6]. Preliminary findings from these reports on environmental consequences of bombardment during 18-20 April 1999 can be summarized as follows:

– air pollutants at high concentrations including toxic substances (soot, CO_2, SO_2 and NO_x) and even carcinogenic compounds (PAHs, VCM and POPs) were released in the atmosphere from destroyed chemical industries and oil refineries;

– the water pollution from oil spills and a variety of chemicals (VCM, EDC, HCl, heavy metals and others) will last for many years;

– the pollution of the soil near the destroyed chemical plants and in Central and Southern Serbia after washout of POPs from the atmosphere are significant.

The present work has focused on analysis of cloud and precipitation measured during episode of 18-20 April 1999 on the territory of Serbia as the predominant process of removing POPs from the atmosphere.

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DATA ANALYSIS

Emission in the episode of 18-20 April 1999. Practically simultaneous release of smoke plumes from the oil refineries at Novi Sad and Pančevo occurred with total burning rate of 2000 t h^{-1} during the first 12 h after bombing at midnight between 17 and 18 April 1999. Average emission of carbon particles[7,8] in overlapping plumes is estimated approximately as 65 t h^{-1}.

An ammonia plant and a factory for nitrogen fertilizers, installation of vinyl chloride (VCM) and polyvinyl chloride (PVC) production at the Pančevo industrial zone were hitted at 01:10 a.m. on 18 April. A reservoir with 1200 t of VCM and 6 train cisterns of 30 t VCM each were destroyed. The VCM concentration was 530 000 ng/m^3 at 3000 m distance from source between 06:00 and 08:00 a.m. Approximately 8 t of mercury are missing in an electrolysis system of the Pančevo petrochemical complex. Only 200 kg were poured out in the wastewater canal and 50-80 kg were found on the concrete floor of a factory two-three months after bombing[3]. The most part of mercury was likely evaporated. 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[9].

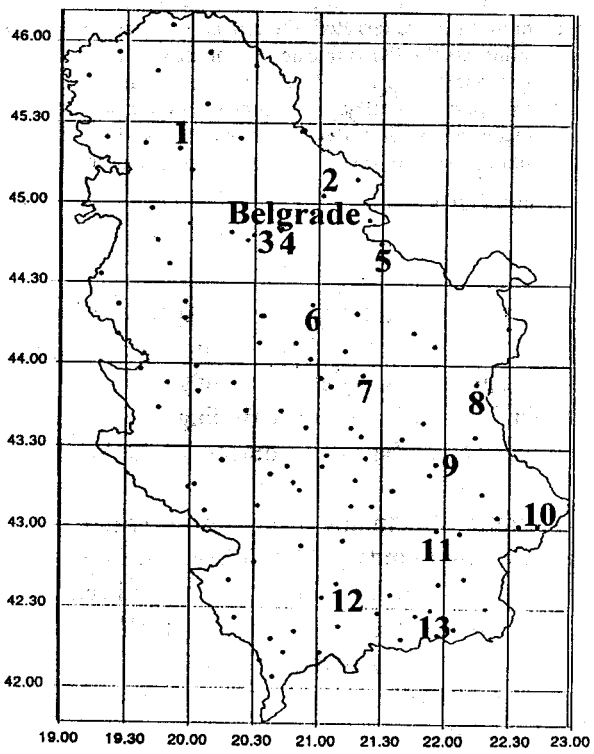

Fig. 1. Map of Serbia with the meteorological stations used together with the targeted sites (*) during warfare episode from 18 to 20 April 1999
1 – Novi Sad (*), 2 – Banatski Karlovac, 3 – Belgrade, 4 – Pančevo (*), 5 – Veliko Gradište, 6 – Smederevska Palanka, 7 – Ćuprija, 8 – Niš (*), 9 – Kuršumlija (*), 10 – Dimitrovgrad, 11 – Leskovac, 12 – Priština (*), 13 – Vranje

Late on 18 April coal mine at Priština (Kosovo) also was hitted. Oil refinery at Novi Sad was hitted at 01:50 a.m. on 19 April. Also, during the same day, wood processing works at Kuršumlija (Southern Serbia) and tobacco production plant at Niš (Southern Serbia) were targeted. Targeted sites during warfare episode from 18 to 20 April 1999 are represented in Fig. 1.

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Meteorological conditions and cloud and precipitation analysis. The synoptic case during 18-20 April 1999 was characterised by an upper trough located in the northern part of Serbia. There was a small pressure gradient field in the lower levels. That synoptic case produced a light variable wind near the surface, and much intensive westerly wind in the upper levels.

Under such conditions, heterogeneous transformation processes of primary pollutants are intensive. However, polycyclic aromatic hydrocarbons (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 (Xanthi, Greece) as a fine aerosol[10,11] and washed out from the atmosphere.

The transport of any pollutant over long distances in the atmosphere is strongly influenced by the time-dependent depth of the layer over which it is dispersed. In the unstable situation (the case of 18 April) the boundary layer extends up to height characteristically between 400 and 2000 m (Ref. 12).

According to visual observations of the smoke plumes from oil-refinery fires at Novi Sad and Pančevo under war conditions[11] the top heights were estimated as 3000 m with typical convective clouds forming on the windward edge of the plume.

Base height and type of clouds, which gave precipitation, measured at the meteorological stations during 18 April 1999 are represented in Fig. 2.

On 18 April 1999 forenoon and early afternoon predominant clouds were Cu, Sc, Scop and Scstr with bases in the interval between 1000 and 1200 m height. During afternoon, the front followed by heavy rain, thunderstorm and intense wind from the west direction was observed in the northern and central parts of Serbia, except at the meteorological station Ćuprija (the front passed between 09:00 and 10:00 h). The cold front was characterized by appearance of cloud Cbcap with base of 800 m height above the ground.

Cu, Sc, Scop and Ns clouds were observed with bases from 300 m height in Belgrade to 1000 m height at Banatski Karlovac, Veliko Gradište and Ćuprija stations, after passing the front in the Northern and Central Serbia.

The front was not observed in the south-easterly part of Serbia, but precipitations from Cu, Sc, Scop, Stfra, Ns and Asop clouds were measured (Dimitrovgrad, Leskovac and Vranje). The meteorological stations in that part of Serbia are located at greater height than the stations in the northern and central parts of Serbia. According to that feature, cloud bases were observed at greater heights, i.e., in the interval between 600 and 3000 m height above the ground.

The above mentioned features indicated that, during warfare episode on 18 April 1999, the boundary layer in which washout was occurred, changed between 300 m (Belgrade) and 3000 m (Dimitrovgrad) with the most frequency between 600 and 1200 m height above the ground.

The maximum precipitation sums during 18 April 1999 were observed at the wider Belgrade area and at the south-easterly part of Serbia (Fig. 3*a*).

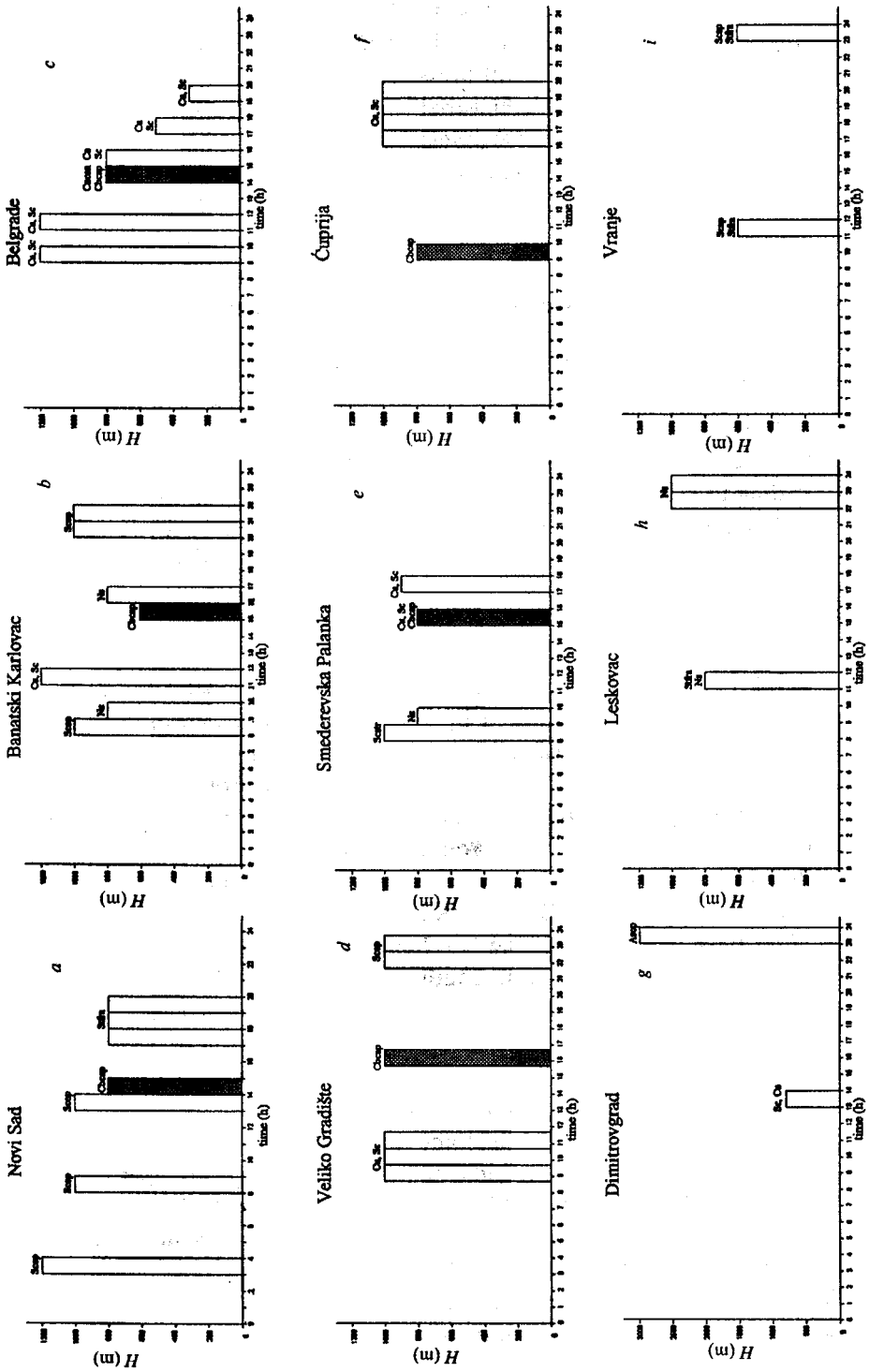

Fig. 2. Base height and type of clouds which gave precipitation at the above meteorological stations during 18 April 1999 (# labelled the front passing)

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On 19 April, after passing the front, clouds Scop, Stfra, Stop, Cufra and Ns were observed with bases between 600 and 1200 m height above the ground. The maximum precipitation sums during 19 April 1999 were measured south-easterly from Belgrade and at the southerly part of Serbia (Fig. 3*b*).

A new front was registered on 20 April 1999 (day without bombing at the territory of Serbia) from the west direction, which caused heavy rain with amount greater than 15 mm at the western part of Serbia (Fig. 3*c*). Also, precipitation sums at the central part of Serbia were between 4.0 and 14 mm.

The lower level trajectories from Pančevo[11] indicate that polycyclic aromatic hydrocarbons (PAHs) and dioxins and furans (as burning products of polyvinyl chloride-PVC and vinyl chloride monomer-VCM) are transported towards the wider Belgrade area in the first 12 h after bombing. Wet deposition removes about 70% of dioxins and furans from the atmosphere with washing ratio in the range of 10 000 to 18 000 (Ref. 13). The washing ratios of PAHs bound with aerosol are in the range of 10^3 to 2×10^5 and reach the maximum value in summertime[13] .

Being directly proportional to precipitation sums, maximum of wet fluxes of PAHs and dioxins/furans might be expected in the zone of geographical latitude between 43°30′ and 45° and along the trajectories to the Bulgarian border (Fig. 3). It is well-known defoliant effect of dioxins/furans and in the vegetation period of 1999 many vegetables (especially tomato and pepper) and trees (especially apple, cherry and quince) were practically naked. During September many cherry trees in the central part of Serbia are foliaged and flourished again.

Vegetation plays very important role in degradation processes of PCBs[13]. Photodegradation in the atmosphere is the most influencing process on the half-lives of POPs. For example, PAH half-lives in air are in the range of 55 to 170 h, while in the natural water these values are 10 times and in soil 100 times higher[13]. Depending on the season and species, dioxins/furans have the half-lives in the atmosphere in the wider range of 40 to 3000 h. Half-lives of these species in water

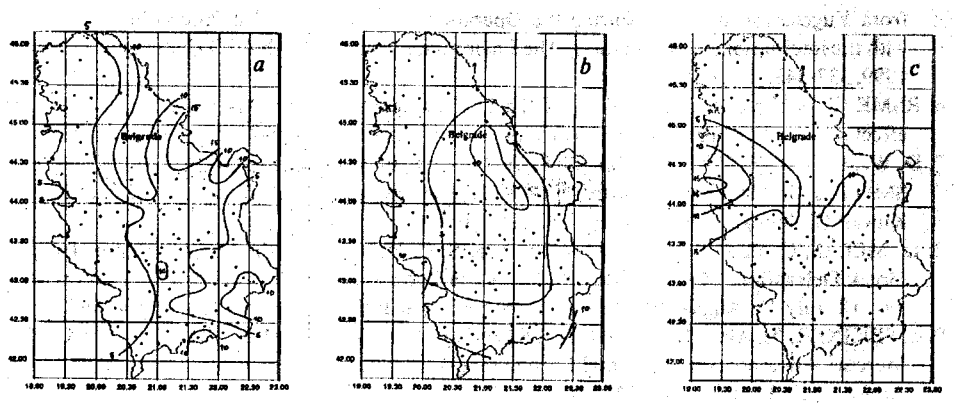

Fig. 3. Daily precipitation sums (mm) at Serbia during: *a* – 18; *b* – 19; *c* – 20 April 1999.

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are in the range of 550 to 1700 h, in soil – 2 years and in the bottom sediments – 6 years.

CONCLUSIONS

In our analysis of the cloud and precipitation during bombing of chemical industry, oil refinery and fuel storage at Novi Sad and Pančevo during episode of 18-20 April 1999 we concluded the following:

– transport of persistent organic pollutants (dioxins and furans, PCBs and PAHs) across Serbian territory which is confirmed by crucial measurements at Xanthi (Greece);

– POPs washout in the atmosphere in the layer between 300 and 3000 m height above the ground;

– the maximum of POPs washout in the vicinity of targeted sources in the Central Serbia in the zone between 43°30′ and 45° geographical latitude and along the air trajectory at 850 hPa to the south-eastern border with Bulgaria.

According to the half-lives of some POPs in soil and bottom sediments and a possibility of remission, measures to protect water resources and food production are urgently needed.

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