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Composition and origins of aerosol during a high PM_{10} episode in Finland

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We investigated the sources of a PM_{10} episode in September 2001 on the coasts of the Gulf of Finland. The episode lasted six days with the peak phase lasting over 14 hours. The highest hourly PM_{10} concentration was 190 μg m^{-3}. Exceptional meteorological conditions strongly influenced the course of the episode. Very warm air masses came from central Asia forming a stable inversion over the Gulf of Finland. Dust emissions from the Estonian and Russian oil-shale burning industrial areas near the southeastern coast of the Gulf of Finland were transported over the Gulf above the inversion layer. After reaching the northern coast the PM was mixed down by convection and partly by gravitation, and then transported westwards along the coastline. The chemical analyses by SEM/EDX and IC indicated that the particles had both the characteristics of the oil-shale burning emissions and soil dust. Windy conditions in the Kazakhstan Ryn Peski desert raised soil dust into the air. This dust was transported towards Scandinavia and mixed with the anthropogenic emissions. Such large quantities of coarse particles from foreign sources have not been observed earlier in Helsinki.

Introduction

The large particle emission sources in Estonia and Russia in the south-eastern part of the Gulf of Finland have caused widespread concern in Finland. The most important of these sources are the Narva Power Plants (Fig. 1), which use oil shale, a local energy source, the ash content of which is 46% (Häsänen *et al*. 1997). At full capacity of 3 GW, the annual consumption of oil shale has been 22 Mt (Jalkanen *et al*. 2000). The annual particulate emissions, 186 000 t in 1992 (VTT 1994), have decreased to 50 000 t in 2000 (Statistics 2001). Several other remarkable particle emission sources are situated around the southeastern coast of the Gulf of Finland, including the Slantsy cement plants and the St. Petersburg metropolitan area.

The model simulations of Sofiev *et al*. (2003) showed that the alkaline dust emissions from Estonian sources are large enough to create remarkable background deposition in the Baltic

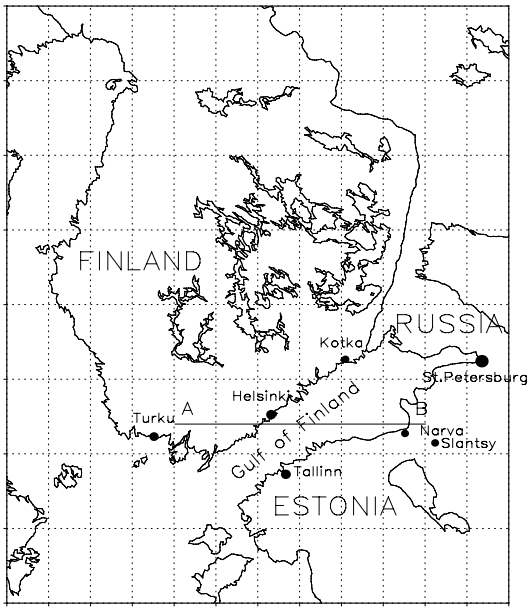

Fig. 1. The map showing air quality monitoring cities on the northern coast of the Gulf of Finland and the main pollutant sources in the southeastern part of the study area. The line A–B shows the *x*-axis of the vertical cross-section of concentration profile illustrated in Fig. 7.

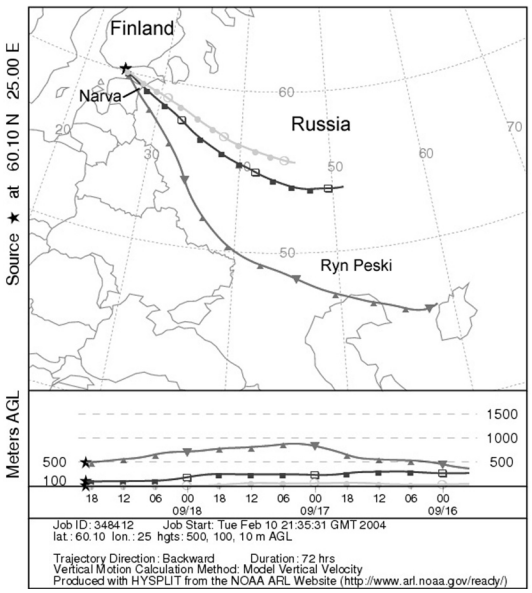

Fig. 2. The backward trajectories (72 h) of air masses arriving in Helsinki on 18 September at 19:00 (UTC) and going over Narva Power Plants in NE Estonia. This trajectory direction prevailed during the whole episode of warm air between 17–23 September 2001.

Sea region. The distribution of these large anthropogenic particulate emissions were studied by Jalkanen *et al*. (2000) who found out that episodes of massive particulate calcium emissions are clearly observed in aerosol, deposition and mosses in the eastern Gulf of Finland region. Particulate matter (PM) episodes were reported from many other countries, e.g. from England and Wales (Ryall *et al*. 2000), Lanzhou Valley China (Ta *et al*. 2004), Taiwan (Tsai & Cheng 2004), Brisbane Australia (Chang *et al*. 1999), eastern Spain (Rodriguez *et al*. 2002), and northern Italy (Marcazzan *et al*. 2002). Asian and Saharan dust may be transported globally and increased PM concentrations are observed far from sources (IPCC 2001, Seinfeld *et al*. 2004).

Between 17 and 23 September 2001, high concentrations of PM were observed at several air quality research stations along the coasts of the Gulf of Finland and in the central part of Sweden. From the prevailing weather conditions, backward simulations and NOAA Hysplit model trajectories (Fig. 2), we assumed that the air masses were transported from the above mentioned Russian and Estonian pollutant sources and could carry fine particle soil dust also from longer distances. It was possible to study the composition of this PM, since the monitoring network constructed for the recording of air quality in Finnish cities includes also continuous sampling of PM. Interesting samples can later be studied to assess the origin of air pollutant episodes (Tervahattu *et al*. 2002). This possibility is crucial to an understanding of the transport of particulate air pollutants over longer distances.

In the present article we describe the distribution and duration of the 17–23 September 2001 episode and the prevailing weather conditions in order to assess the sources of elevated concentrations of PM along the coast of Finland. The chemical composition of PM was studied using individual particle analysis by a scanning electron microscope coupled with an energy dispersive X-ray microanalyzer (SEM/EDX), and by bulk analysis with ion chromatography (IC). Eulerian model simulations were used to detect the route of the PM from the most evident sources and to investigate the meteorological conditions affecting the course of the episode.

Experimental methods

Aerosol measurements

The Environmental Office of the Helsinki Metropolitan Area Council (YTV) is continuously monitoring PM_{10} concentrations in six locations, including urban, urban background, suburban and regional background sites. $PM_{2.5}$ concentrations are monitored at one urban monitoring station and at one urban background station. The PM measurements and PM sampling used in this study were carried out at an urban site in Vallila (60°13´N, 24°58´E). The monitoring height was about 4 m. The particle masses were measured using two Eberline FH 62 I-R's (Eberline Instruments, GmbH, Germany) equipped with either a PM_{10} or a $PM_{2.5}$ inlet. It is a continuous particulate mass monitor that is based on real-time monitoring of β-attenuation of a sample collected on a glass fibre filter tape (GF 10). The Eberline instruments operate at an elevated temperature (about 25 °C). A 24-hour collection time was used for PM sampling.

Individual particle analysis by SEM/EDX

We studied PM samples collected during the main phase of the episode on 18–19 September. Spots of PM (diameter ~2 cm) from the Eberline filter tape were studied with SEM/EDX. Three samples of both PM_{10} and $PM_{2.5}$ from Helsinki Vallila (urban station) and two PM_{10} samples from the rural background area of Helsinki (Luukki) were investigated. Two additional PM_{10} samples collected by an Eberline instrument in Kotka, eastern coast of Finland (Fig. 1), were studied. The SEM/EDX samples were prepared by pressing a two-sided tape attached to an aluminium plate onto the filter spot covered with particles. The samples were covered with carbon (Agar SEM Carbon Coater) to make the sample surface conductive. 100–150 randomly selected particles (1–10 μm in diameter) were analysed with EDX from each filter focusing the beam in the middle of the particle. The elemental composition of individual particles was studied with a SEM (ZEISS DSM 962) coupled with an EDX (LINK ISIS with ZAF-4 measurement program). This instrumentation has been used in individual particle studies (e.g. Mamane *et al*. 1980, Ganor *et al*. 1998, Kasparian *et al*. 1998). The accelerating voltage was 20 kV. The total X-ray count rate was calibrated with cobalt. From each particle an X-ray spectrum was collected with a preset time of 15 s. The shape and size of the particles were recorded and the EDX spectrum measured. The elemental weight percentages of Al, Ca, Cl, Fe, K, Mg, Na, O, S, Si and Ti for each particle were calculated.

Several factors complicate the analysis of uneven particles with complex shapes. It has been evaluated that the atomic fractions in the particles, as assessed by the ZAF procedure, have relative errors between 10% and 20% (Goldstein *et al*. 1992, Paoletti *et al*. 1999). The accuracy of the selected sample size was studied with mineral particles in a separate study by our group (Kupiainen *et al*. 2003). 500 particles from one sample were analysed and then divided into five subsamples of 100 particles. The SD of the frequency of different particle types in the subsamples varied between 0.5 and 4.9. According to Mamane *et al*. (2001), several hundred particles are needed to provide adequate characterization by SEM/EDX for many purposes in the individual particle research of ambient aerosol samples. However, in the case of high concentrations of fairly uniform particles observed during the episode, sample size used in our work (*see* above) is supposed to give the shares of the main particle types with good confidence.

An analytical field emission SEM, JEOL JSM 6335-F coupled with a LINK ISIS EDX was used for a more detailed research of PM and to prepare the SEM-images of the particle samples. These samples were covered by chromium to make the sample surface conductive.

Bulk analyses of PM by IC

In addition to Eberline measurements, a virtual impactor (VI; Loo and Cork 1988) was used for collection of airborne particulate matter in downtown Helsinki (Vallila), Finland. The VI equipped with a PM_{10} inlet divided particles into the fine (cut-off diameter $D_p < 2.5$ μm) and coarse (2.5 μm < D_p < 10 μm) fractions. Its total sampling flow rate was 16.7 l min^{-1} and the

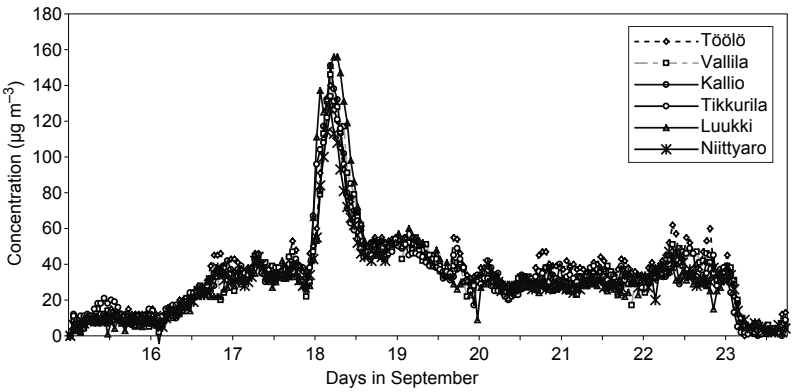

Fig. 3. The concentrations of PM_{10} at six monitoring stations in Helsinki area, including rural background station Luukki, during 15–23 September 2001 (data of the Helsinki Metropolitan Area Council, Environmental Office).

sampling durations were as follows: before the episode (13–17 September) 5715 min, during the main phase of the episode (17–20 September) 4280 min, and during the latter phase of the episode (20–24 September) 5450 min. The VI samplings were started at 14:30. Millipore polytetrafluoroethylene (PTFE) filters (pore size 3 μm, diameter 47 mm) used in the VI were weighed with a Mettler M3 microbalance before and after samplings.

The PTFE filters were wet with methanol (Riedel-de Haën, pro analysis) and extracted with deionised water (Millipore Alpha-Q) for a Dionex DX500 ion chromatography (IC). The elution order of analysed cations was as follows: Na^+, NH_4^+, K^+, Mg^{2+}, and Ca^{2+}. The ions were detected with a conductivity detector and identified according to their retention time in the IC column. The quantitation was based on the calibration done by running nine external standards which contained known amounts of each cations. The stock standard solution of Na^+ was prepared from Fluka standard solution (1000 mg l^{-1}) and those of NH_4^+, K^+, Mg^{2+}, and Ca^{2+} from Merck standard solutions (1000 mg l^{-1}). The sampling, storage of filters and IC analysis protocols are presented in detail by Kerminen *et al.* (2000) and Teinilä *et al.* (2000). The field blank concentrations were clearly smaller (two orders of magnitude for most of analytes) than the concentrations in the actual samples.

Modelling

Transport of dust from the Estonian and Russian sources to Finland was simulated with the dynamical grid model Hilatar, with a 0.2°, around 22-km grid distance, and a 56.25–225 s time step. The soil dust transport from semi-arid desert areas was simulated with a 0.4° resolution model (Hongisto and Sofiev 2004). Both dust models use as input the operational weather predictions of HIRLAM (HIgh Resolution Limited Area Model) of the FMI with six-hour time intervals. The model structure and verification are described by Hongisto (1998, 2003) and Sofiev *et al.* (2001). Backward trajectories were produced, using the vertical motion model in the HYSPLIT4 (HYbrid Single-Particle Lagrarian Integrated Trajectory) model (Draxler and Rolph 2003).

Results and discussion

Description of the PM episode

The beginning of the episode was observed almost simultaneously at more than 10 stations which measure continuously PM_{10} concentrations along the southern coast of Finland. The highest hourly PM_{10} concentrations (190 μg m^{-3}) were first detected in the afternoon of 18 September on the south-eastern coast of Finland in Kotka and some hours later in the Helsinki area and in Turku on the south-western coast (the locations of the sites are presented in Fig. 1). The concentrations were very high (Fig. 3) as compared with the annual mean (< 20 μg m^{-3} in Helsinki; Aarnio *et al.* 2001) or to those measured before and after the episode which were below 10 μg m^{-3}. The episode lasted from 17 to 23 September, during which warm air masses streamed from the southeast (Fig. 2) and PM_{10}

concentrations were at least twofold compared with the normal situation.

In Tallinn, Estonia, the highest concentrations (130–140 μg m^{-3}) were observed on 18 September (T. Truuts Estonian Environmental Research Center pers. comm.). Three stations in Stockholm and one in Uppsala, Sweden, monitored simultaneously high PM_{10} concentrations on the morning of 19 September as well as increased PM concentrations later in the week (C. Johansson, Slb-analys, Miljöförvaltningen pers. comm.). However, high PM_{10} levels were not registered at inland monitoring stations in Finland or in northern or southern Sweden. The particles were mainly coarse ($PM_{2.5}$–PM_{10}); however, in Helsinki the concentrations of the fine fraction (< $PM_{2.5}$) rose simultaneously to over 40 μg m^{-3}.

The main phase of the episode which lasted > 14 hours was very unusual in the Helsinki area. Similar high PM_{10} concentrations are measured only during springtime when local road dust pollutes urban air. During such episodes PM_{10} concentrations vary substantially between the monitoring stations in Helsinki area and remain low at the rural background station Luukki (*see* Fig. 3).

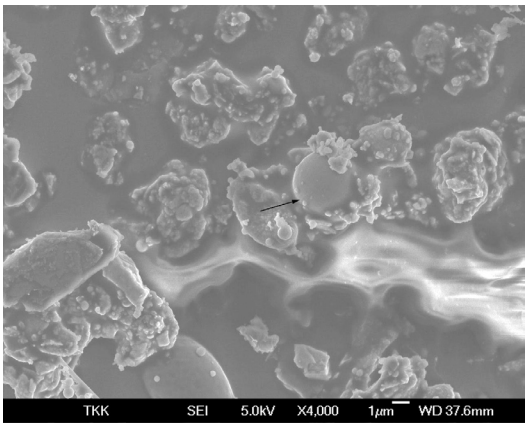

Fig. 4. A FESEM-photo of one typical particle sample during the episode. Many particles have a spherical shape (arrow) but they are covered with fine particles adhered on the surface. Scale bar 1 μm.

Identification of the particulate matter

Individual particle analysis

The particulate matter in all studied samples was quite similar, each sample being composed of relatively homogeneous material. Many particles were spherical with very small particles adhered on their surface (Fig. 4). The spherical shape suggests an origin from fuel combustion. Similar spherical shapes were found to be typical of Narva Power Plants in previous investigations (Jalkanen *et al*. 2000, Teinemaa *et al*. 2002) as well as our own SEM research in this work.

Supermicron particles are produced from the inorganic material that remains in the solid or liquid phase during combustion (*see* Lighty *et al*. 2000). A small portion of the mineral matter may be vaporized and condenses to form submicron particles (Amdur *et al*. 1986). In the combustion of oil shale, vaporized semi-volatile compounds may also condense on the fly-ash particles including several polyaromatic hydrocarbons (PAHs), some of which are mutagenic and/or carcinogenic (Teinemaa *et al*. 2002).

In Fig. 5, we compared the SEM/EDX measurements of individual particles collected during the episode with dust samples collected by us on the surface of pine needles near the Narva Power Plants in 1998, using these as a reference. The comparison shows that the elemental composition of the two samples was very similar. Both were characterized by a high Ca content, which is very exceptional for aerosol samples collected in Helsinki (Haapala 1999) but typical of the emissions from Narva (Häsänen *et al*. 1997, Jalkanen *et al*. 2000).

The emissions from Narva Power Plants are characterized by a high calcium content. According to Häsänen *et al*. (1997), Ca emissions were 36 000 t in 1992, which was 5% of all anthropogenic Ca emissions occurring throughout Europe and much more than the total Finnish Ca emissions of 10 000 t (Lee and Pacyna 1999, Jalkanen *et al*. 2000). Oil shale contains much $CaCO_3$, which is dissociated to CaO at high temperatures (Jalkanen *et al*. 2000). Most of the sulphur dioxide and other acidic compounds are neutralized by CaO in the furnace and gas ducts. Neutralization of SO_2 continues in the stack gases and in the atmospheric plume and the Ca/S ratio decreases sharply in the passage from combustion chamber to fly ash (Häsänen *et al*. 1997).

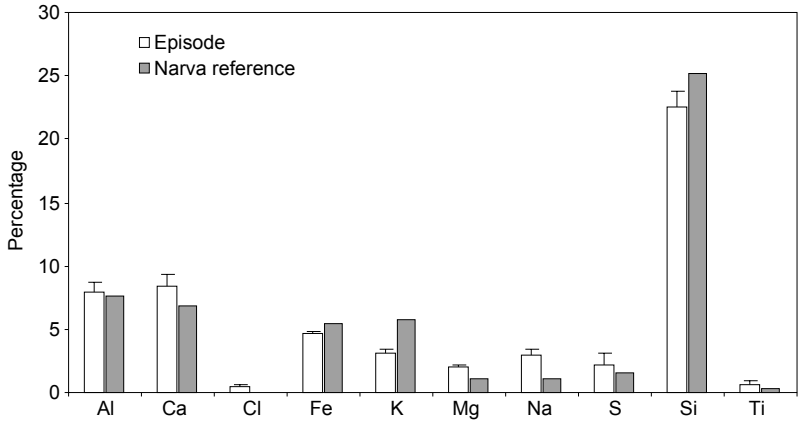

Fig. 5. SEM/EDX-analyses of the particle sample of the current episode (Helsinki, 18 March 2001, the peak of the episode, *see* Fig. 3; n = 5) and a reference sample collected near Narva in 1998.

As compared with our results, Häsänen *et al*. (1997) measured considerably higher Ca concentrations and lower Si concentrations in their aerosol samples collected in the immediate vicinity of the Narva Power Plants during 1992–1993 and thus representing almost totally the emissions of the power plants. Differences between the results of Häsänen *et al*. (1997) and ours indicate that our episode samples contained particles from sources other than Narva. Considerable amounts of coarse particles were identified as local road dust particles (Haapala 1999). The local background PM_{10} concentration was estimated to be not more than 15–20 μg m^{-3} based on the annual mean and September mean concentrations in Helsinki (Aarnio *et al*. 2001) and on the PM_{10} concentrations before and after the episode (Fig. 3). This is ~10% of the highest PM_{10} concentration and 25%–30% of the highest daily mean during the episode. This PM has a much lower Ca content and higher Si content than Narva emissions and clearly had an impact on the corresponding total element concentrations of the episode samples. Similarly, our own "Narva"-samples, collected on the surface of pine needles 10 km from the Power Plant, contained Ca-poor soil dust particles (including quartz) originating from the non-vegetated sandy soil of the forest and thus had lower Ca concentrations and higher Si concentrations than the samples of Häsänen *et al*. (1997).

Additionally, most of the spherical particles were covered by very small particles which give their own chemical content in the individual particle analysis by SEM/EDX. The modelling results (*see* below) suggest that fine soil dust was transported during the episode from the dry areas in central Asia. The Ca concentration of this dust must have been lower than that of the Narva emissions. The model simulations also showed that large emission sources in the St. Petersburg area and Slantsy may have contributed to the PM during the episode. PM from St. Petersburg originated from several sources, which do not produce Ca rich emissions (Pöyry 1990). In contrast, emissions from the Slantsy cement industry are very alkaline containing even more Ca than the Narva emissions.

Bulk analyses of PM

It was not possible to obtain detailed bulk analyses of the PM of the episode peak, because for that purpose we had only composite samples collected during 3–4-day periods. However, the composition of the PM during the main episode phase was clearly different from the preceding sample or the average composition of the PM in Helsinki during 1996–1997 (Pakkanen *et al*. 2001; as a reference in Fig. 6). The episode sample was characterized by a high Ca concentration (Fig. 6) particularly in the coarse fraction ($PM_{2.5–10}$). When considering that this sample was collected on 17–20 September, we concluded that the Ca concentration during the episode peak must have been much higher. The high Ca level once again indicates the impact of emissions from the Narva Power Plants. Jalkanen *et al*. (2000) also observed high Ca-concentrations

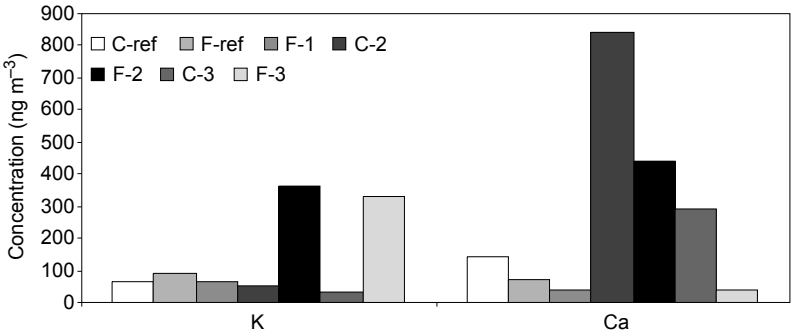

Fig. 6. The potassium and calcium concentrations of different particle size fractions as mean reference values during 1996–1997 (Pakkanen *et al.* 2001) and in our study. C-ref = coarse-reference; F-ref = fine-reference; F-1 = fine before the episode (13–17 Sep. 2001); C-2 = coarse during the main phase of the episode (17–20 Sep. 2001); F-2 = fine during the main phase of the episode; C-3 = coarse during the latter phase of the episode (20–24 Sep. 2001); F-3 = fine during the latter phase of the episode.

in aerosols collected at Virolahti, eastern Finnish coast of the Gulf of Finland as the impact of the Estonian emission sources, the highest daily Ca-concentration being almost 1500 ng m^{-3} in November 1991.

Potassium concentrations were high in the fine fraction of the episode samples (Fig. 6). This corresponds well with the results of Häsänen *et al*. (1997), who measured with SEM/EDX the highest K concentrations of the Narva emissions in the size range 0.94–3.9 μm. Our SEM/EDX investigations also confirmed the higher concentrations of K in the $PM_{2.5}$ particles (4.3%) than in the $PM_{2.5–10}$ fraction (2.5%). The difference was statistically significant ($p < 0.001$, Wilcoxon Rank Sum Test). K and S gave very significant correlation in the $PM_{2.5}$ fraction ($p < 0.01$, Spearman Rank Correlation), as is typical of the fine particles of the Narva emissions.

Weather conditions

Conditions for the episode began to develop on 14 September when the western parts of a Siberian high strengthened, remaining in almost the same position for more than one week. Along its southern flank exceptionally warm air (Ilmastokatsaus 9/2001) was transported from the semiarid central Asian areas north of the Aral Sea and the Caspian Sea towards Fennoscandia. The warm air mass was exceptionally deep: in Finland the temperature at the Jokioinen sounding station was around 9 °C warmer at altitudes of 0.75–1.4 km than the corresponding1961–1980 September average (Sounding Statistics 1984). On 12–17 September the wind conditions in the Kazakhstan Ryn Peski desert were strong enough to lift soil dust to the air.

The warm front crossed southern Finland during the night of 16 September. The temperature inversion as well as strong turning of the wind direction with height was detected at the Kivenlahti mast (Helsinki area), beginning in the morning of 17 September and lasting to the end of the episode. During the time of the peak concentrations, the temperatures were exceptionally high throughout Finland (Ilmastokatsaus 9/2001). In the morning of 18 September the air temperature was still about the same as the sea surface temperature, and the atmospheric boundary layer mixing height (h_{mix}) over the Gulf of Finland was 150–250 m. In the afternoon the hot airflow spread over the region and stable stratification developed over the sea area. Vertical mixing over the Gulf of Finland became very weak, the eddy diffusivity coefficient K_z at an altitude of 70 m being < 6 2 m^2 s^{-1} and locally even < 2 m^2 s^{-1}, which means that the layer was very stable. Over land and coastal areas, the morning h_{mix} was below 500 m but grew to over 1.2 km in the afternoon. Simultaneously K_z grew to over 50 m^2 s^{-1} at an altitude of 330 m, and mixing down to the surface was efficient.

No rain was measured either in Estonia or southern Finland during the episode. Accord-

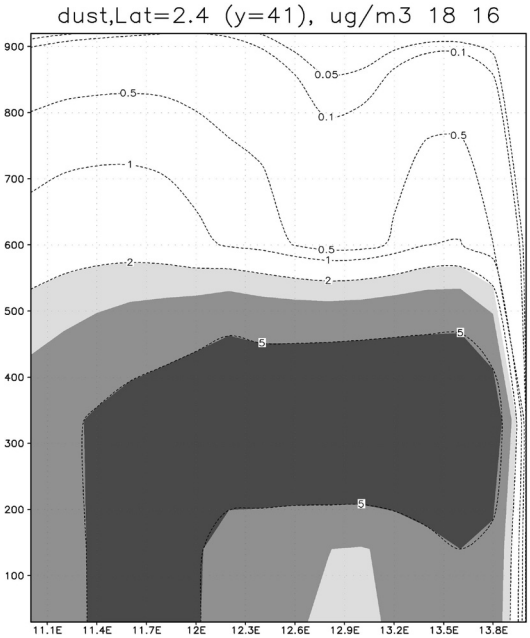

Fig. 7. Vertical cross-section of the daytime concentrations (arbitrary Units) of dust emitted from the Narva Power Plants (on the right side) on 18 September at 16:00 (UTC) over the Gulf of Finland, along the line A–B of Fig. 1. The pollutants are mixed down along the Finnish coast (on the left side).

ing to the meteorological analysis it was evident that the PM could have originated from the Estonian oil shale-burning power plants. In Finland the coastal wind velocity at 110–335 m height slightly exceeded 10 m s^{-1}, thus a particle released in Narva would be transported to Helsinki in about five hours.

Simulations

The origin of the measured concentrations was first estimated with backward simulations. The results confirmed that both the Helsinki and Turku concentrations were transported to the measurement places over the Narva region by surface winds, while the Narva dust plume would reach Kotka if the winds at a height of around 600 m were used. Turbulence conditions near Kotka were strong, so the upper level dust could have been mixed down (Tervahattu *et al*. 2002).

The forward simulations were made to each source area. The plume rise was estimated using the Briggs formulae, vertical dimensions of the plume was calculated at a distance of 5 km from the sources. During the entire episode, the effective height of emissions from the 180–250 m high stacks of Narva Power Plants was between levels 3 and 4 (335–600 m). Horizontally, the emissions were mixed evenly over the entire grid square. Since the plume rise equations are derived for buoyant hot gases, the nocturnal effective stack height may have been too high for coarse dust particles. During daytime the error is small, because the emissions are mixed even higher due to convection.

The principal transport height over the Gulf of Finland was at level z = 3 (335 m). At the emission site, the dust from the Estonian power plants was mixed to the surface only at noon and in the afternoon. This also occurred, however, in the morning on the Finnish side of the Gulf. Dilution over such a stable area as the Gulf with a constant wind direction should be very small. In the model, the advection algorithm produces the biggest artificial dispersion for diagonal winds within a rectangular grid; so the plume from Narva to Kotka was more dispersed than the plume from Narva to Helsinki.

The daytime dispersion conditions are illustrated as vertical cross-sections of concentration profiles in Fig. 7, along the line A–B in Fig. 1 extending from the southeast to the northwest over the Gulf of Finland, the emission areas being located in the right corner. Concentrations were mixed to the surface on the Estonian coast at the emission grid in the southern cross-section. The middle (in Fig. 7, *see* the location in Fig. 1) and northernmost cross-sections show how the pollutants were transported mainly at an altitude of 300 m over the sea and mixed down when reaching the Finnish coastline. At the end of the episode the pollutants are mixed down also over the sea when the air was cooled enough in comparison to the sea surface temperature.

When the Russian sources were taken into the simulations, the modelled surface concentrations were higher because the Slantsy stack heights are low. For St. Petersburg and Slantsy an emission of 500 g s^{-1} was assumed (N. Goltsova and M. Kaasik pers. comm.). The concentrations rose simultaneously both on the northern and southern coasts of the Gulf in the afternoon of 18 Septem-

ber (Fig. 8). The flow was channelled, so that the high-level Estonian plumes met the flow originating from St. Petersburg over the Finnish coastline, while the low-level emissions also remained for a short time above Estonia. This situation prevailed the entire afternoon. In the evening the St. Petersburg emissions were transported towards central Finland, and the peaks on the next morning show more clearly an Estonian origin.

The long-range transport of fine particles from desert soil was also studied because the warm air masses came from the semi-arid areas in central Asia, and the wind conditions there were strong enough to lift soil dust to the air. The NAAPS surface concentration maps also showed that a dust cloud from that direction towards Scandinavia was observed at the time of the episode (http://www.nrlmry.navy.mil/aerosol/index_frame.html; Naval Research Laboratory Marine Meteorology Division, Monterey, CA, USA). Hongisto and Sofiev (2004) showed that moderate dust events from the Caspian sand deserts appear quite frequently in Scandinavia. Simulations with Westphal *et al.* (1987, 1988) source formula to the Ryn Peski desert in Kazakhstan, with critical friction velocity of 0.35 m s^{-1} are presented in Hongisto and Sofiev (2004). This area had been suffering from drought for the whole summer of 2001. Especially on 16 September, when the forecasted surface wind velocity in Kazakhstan exceeded only 11 m s^{-1} over land, the weather conditions were favourable to lift soil dust from the ground. Simulations confirmed that there was evidently a long-range transport of soil particles on the model layers 3 and 4, which were mixed with the Estonian dust plumes and to the surface over convective areas. Since the relative humidity was high, it is also possible that fine soil dust could have been adhered on the surface of the Estonian particles (Fig. 4) while passing over this emission area.

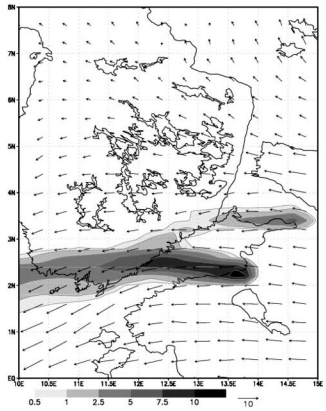

Fig. 8. Modelled (forward simulations) dust concentrations (arbitrary units) from Narva, Slantsy and St. Petersburg sources at model level 3, around 335 m, on 18 September 2001 at 15:00 (UTC).

Summary and conclusions

The episode lasted six days and its peak phase over 14 hours. The episode was due to a combination of exceptional meteorological conditions, the large particle emissions of the Narva Power Plants in Estonia and long-range transport of soil dust. Based on chemical analyses and model simulations, we estimated that most of the PM during the episode peak originated from the Narva Power Plants. The contribution from local sources was about 10% during the peak of the episode but on remarkably higher levels over the 24-hour sampling periods. Other Russian and Estonian industrial sources gave minor contributions to the PM but the model dimensions are too scarce to get an exact picture of the dispersion of these emissions in such a very stable situation. Long-range transport of desert soil dust from the Ryn Peski area also had an impact on PM_{10} concentrations but we cannot calculate accurately these concentrations since the desert dust term is rather uncertain and the Ryn Peski area is located near the simulation edge of HIRLAM.

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