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Dew chemistry near a motorway in SW Poland

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Abstract

The main goal of this paper is to show the influence of a large linear source of air pollution on dew formation and chemistry. Dew sampling was performed during the growing season of 2009 at three sites near Wroclaw in SW Poland in the vicinity of A4 motorway. Two of the sampling sites were set in a distance of 30 meters from the motorway edge on the opposite sides (S and N) of the road to monitor dew efficiency and chemistry depending on wind direction. The third one was set 1.25 km to the NNW of the former pair to represent background rural conditions beyond the road influence. All three sites and the motorway are surrounded by vast arable grounds with intense agriculture activity. Three insulated plane radiative condensers, each 1 m^2 in area, inclined around 15º, were installed at measurement sites. Two series of measurements were performed: the first in April lasted twenty days including several days without sampling, the second in September was continuous and lasted eleven days. Altogether there were nineteen dew or hoarfrost sampling days, nine in April and ten in September. Basic meteorological data were gathered three times daily. Water yield of three condensers was compared to meteorological data and between each other. The research findings show that the most favorable weather conditions corresponding to high amounts of dew or hoarfrost were characterized by synoptic scale warm air advection, high relative humidity, moderate wind speed i.e. 2,5-3,5 m/s and radiative weather. The samples from condenser located in calm air site usually had less volume than the other in windy place. The motorway heat source imposed a strong impact on efficiency of dew. The condenser on the leeward site of the road was characterized by much smaller yield of condensed water in comparison to its windward counterpart. Both dew and hoarfrost chemistry show strong influence of the motorway. The two samplers in close vicinity of road are much more loaded by compounds commonly linked to traffic emissions. The total ionic concentration is significantly less at the site located over one kilometer from the motorway. The anions connected with car fumes i.e. NO_3^- were about two times less common than in other two. The amounts of these compounds varied as well between condensers on the opposite sides of the road. The leeward sampler was quite more loaded by these ions. In general the most abundant ions in samples were: NO_3^- (30%), SO_4^{2-} (11%), Cl^- (7%), Ca^{2+} (24%), Mg^{2+} (4%), NH_4^+ (7%), Na^+ (5%), K^+ (5%), H^+ (7%).

1. Introduction

Atmospheric pollutants are transported onto the ground in two ways: by dry deposition caused generally by gravitational sedimentation and by wet deposition where the main medium consists of precipitation particles and atmospheric deposits. One of wet deposition pathways is dew and hoarfrost. They both are mainly formed during nighttime on any surface cooled by the negative radiation balance. Dew formation [1] is the most efficient in: radiative weather conditions [3], characterized by a low level of cloudiness; large nocturnal decline of air temperature; relatively low atmospheric turbulence [4]; high absolute and relative air humidity. The process of dew formation takes place in the lowest parts of the atmospheric boundary layer, usually polluted most. This causes high pollutant concentrations in dew samples when compared with other forms of deposition [2].

The most important source of emission affecting chemical composition of dew/hoarfrost is primarily burning of fossil fuel in domestic and industrial furnaces, but also emissions associated with road transport, industrial production, agriculture, etc. An important source of some constituents is a natural, mineral dust from soil erosion.

The main goal of this study is to examine the influence of intense road traffic on dew chemistry and on pollutant deposition via dew.

2. Measurements

2.1. Study area

The field program was conducted in the vicinity of A4 motorway near Wrocław in SW Poland. This road is a part of the international route E40, which connects southern part of Poland with Germany and other EU countries. The road crosses in this section a rural landscape from ENE to WSW direction. The traffic is notoriously heavy, even at night, and lorries constitute about one third of vehicles. The density of traffic is estimated as more than 30 000 vehicles per day. Two measurement sites were located in a distance of 30 m from the motorway edge on the opposite sides (southern – AS and northern – AN condensers) (Fig.1.). The third condenser (AR) was located in a distance of 1.25 km to the NNW direction from AN and AS sites.

Figure 1: Location of three measurements sites.

The analyzed area was located in the lowland (130-150 m asl.) with a slightly wavy land relief. The area of research has an agricultural character with small isolated wood complexes. The nearest village-type loosely built-up area is situated about 1 km from the research sites. In a distance of approximately 20 km towards ENE the centre of Wrocław city is located with total population of 630 000 dwellers.

The collection sites AN and AS were set on a gentle slope within an arable ground area. Towards E and ENE, in a distance of approximately 150 m from them, there is a viaduct above the A4 accompanied by earth ridges perpendicular to the motorway axis. The AR condenser was also located in an arable ground area with a small forest to the west.

2.1. Method

Measurements were conducted in two campaigns in the year 2009 during growing season. The first one took place between 01.04.2009-20.04.2009 including some days without sampling due to logistic reasons. Nine sets of daily samples of dew/hoarfrost were obtained during this series. The second series of measurement was continuous and lasted eleven days from 18.09.2009 to 28.09.2009. During the September series 10 sets of daily samples of dew were obtained from each site.

Three insulated radiative condensers, each 1 m^2 in area, oriented towards WSW with inclination of 15° angle, were installed at measurement sites (Fig.2.). The surface was covered with polyethylene and 5 cm thick insulating layer made of styrofoam.

Figure 2: The AS dew condenser with the motorway in the background.

The condensers were cleaned up with deionized water, about sunset just before the potential start of a dew formation episode. The deposited dew/hoarfrost was collected with a use of a polyethylene scraper in polyethylene containers not later than 0.5 hours after sunrise. After that samples were stored before analysis in the dark, at about 4°C for no longer than 1 month.

During the measurements the basic meteorological data like cloud coverage, wind direction and speed, were gathered three times per a collection night. Additionally, at the sampling time, air temperature and relative humidity were measured on three near-ground levels. Another important source of continuous meteorological data was *Wrocław Strachowice* - the airport synoptic station located in a

distance of about 10 km from research sites in NE direction.

3. Results

3.1. Dew efficiency

Average daily efficiency of dew/hoarfrost formation was about 180 ml/m^2. Maximal value was reported 25.09.2009 and reached 389 ml/m^2 (Fig.3.). There has been a substantial increase in the efficiency of deposits formation between both series. In April the average volume was about 140 ml/m^2 and in September series it was approximately 210 ml/m^2. The highest average efficiency of dew/hoarfrost was found at AS (199 ml/m^2) while at AN and AR sites it was 170 ml/m^2 and 173 ml/m^2 respectively. The AR condenser was characterized by the smallest variability of samples volume. The efficiency of the deposits formation in the close vicinity of the motorway showed dependence on the direction of advection of air.

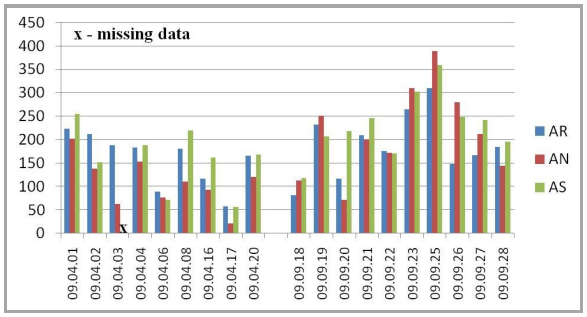

Figure 3: The volume [ml/m^2] of dew/hoarfrost daily samples at motorway (AN and AS) and background (AR) sites.

3.2. Dew chemistry

The average volume-weighted contamination of dew/hoarfrost samples defined by the TIC index (total ionic content of: SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Ca^{2+}, Mg^{2+}, Na^+, K^+, H^+) was 0.55 meq/dm^3 with strong variations depending on the series. During the April series the average value of TIC was 0.72 meq/dm^3, while in September series it was 0.45 meq/dm^3. Differences of TIC index between the measuring sites were also substantial. At the AN and AS condensers the average value reached 0.62 meq/dm^3, and for AR 0.38 meq/dm^3. The average value of conductivity was 64.4 µS/cm. The relations between series and sites were similar to these in TIC. In the structure of ions the largest share had NO_3^- and Ca^{2+} ions (Fig.4.). The other analysed constituents shared 5-11% each one. Only ions of Na^+ and H^+ showed substantial differentiation between series or sampling sites. Concentration of NO_3^- ranged between 0,003 meq/dm^3 and 0,71 meq/dm^3, while in case of Ca^{2+} between 0,02 meq/dm^3 and 0,85 meq/dm^3. Amounts of NH_4^+ changed from day to day independently of wind direction.

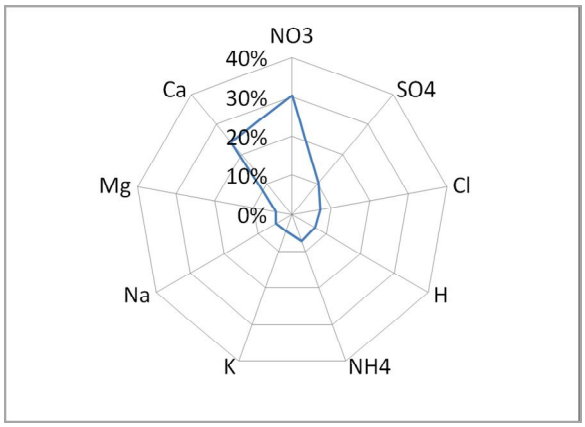

Figure 4: Relative contribution of selected ions in averaged dew samples (molar concentrations weighted by volume). Samples from all 3 sites during both April and September series were taken into account.

The overall pH (derived from H^+ concentrations weighted by volume) of the samples was strongly acidic and reached 4.4. In the April series the pH was 4.1 and in the September series it was 4.8. Parameters showing the impact of maritime aerosols on dew chemistry (Cl^-/Na^+, SO_4^{2-}/Na^+, K^+/Na^+, Ca^{2+}/Na^+, Mg^{2+}/Na^+) reached values highly exceeding those characteristic for sea water.

4. Discussion

The increased average volume of samples collected during the September series of measurement is mainly caused by higher water vapour supply due to high average temperature and relative humidity during dew formation. It was noted that the radiative weather conditions, moderate intensity of wind speed (2,5-3,5 m/s) and descending trend in minimum air temperature from day to day had a positive impact on dew formation. The least dew efficiency at AN condenser is determined by frequent impact of

motorway. In days with E-sector circulation, the AN condenser was on leeward side of the road. The air heated above the motorway was characterized by significantly increased water vapour deficit what determined lower dew yield than on the opposite side of the road. Difference between AN and AS condenser in sample volume in the same dew episode reached 3 to 1 ratio.

Contamination of the collected samples defined by TIC was relatively low if compared with earlier data gathered in Poland [5]. Higher concentrations of pollutants in April series was mainly due to larger quantities of NO_3^- and Ca^{2+} ions. AN site shows the highest difference between both series.

The results of April as well as September series confirmed the role of wind direction on dew pollution. In spring series the dominant wind direction was from the eastern sector, so inflowing air above measuring sites was earlier transformed above a long section of the motorway. Condenser AN was located in this condition on the leeward side of the road. The largest average load of pollution on AN site was in situation when wind direction was parallel to the motorway. The increased quantities of NO_3^- ions were resulted mainly from fuel combustion in vehicle engines, and Ca^{2+} ions and the other were linked with the secondary emission of pollutants from motorway surface by gusts made by fast moving vehicles. The increase was additionally strengthen by attrition of concrete surface and vehicles tires. Variable air advection in the September series caused the dew pollution on both side of motorway to be generally similar. Dependence on wind direction is clearly visible for each day of measurement. Different directions of air flow indicate no clear impact of the A4 motorway on the site AR. High Ca^{2+} share in ionic structure was additionally caused by background pollution determined by dust from industrial and urban area which could be long-transported in terms of lack of atmosphere washing-out by rain. Higher concentration of NH_4^+ ions were linked with agricultural activity.

5. Conclusions

The dew efficiency reached an average value of 180 ml/m^2 per night. The main factors determining its formation include: warm and humid air advection in synoptic scale, low cloud coverage, high relative humidity and substantial nocturnal drop of temperature. The efficiency of dew formation depends on wind direction in relation to the motorway. On the leeward side of the motorway the volume of collected samples is even 3 times smaller than on its windward counterpart.

Dew/hoarfrost chemistry in the close vicinity of the motorway remains under its strong influence. The overall level of contamination of atmospheric deposits is relatively low, however the site located on the leeward side of the road shows a significant increase in pollution. The research revealed that pollution concentrations depended on the direction of air advection, the time-lag from the last atmosphere washing-out episode and distance from the motorway. A large share in ionic structure of NO_3^- ions was caused by the combustion of fuel in car engines, while Ca^{2+} and other ions from the secondary emission of pollutants from the road surface by traffic. Ions of NH_4^+ had probably agricultural origin.

Acknowledgements

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