



Water and chemical input via hydrometeors in central European mountains with Szrenica Mt. as an example

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Abstract

Atmospheric pollutants are transferred to the ground by the contribution of various types of hydrometeors. Due to the different techniques of measurement, comparative analyses between them are often neglected. Hence, the main goal is to compare chemistry of different types of hydrometeors and their role in both: water balance and pollutants deposition.

The results of water input and atmospheric deposits chemistry at the Szrenica Mt. during the period between XII 2008 – II 2010 are presented. The volume-weighted TIC (Total Ionic Content) of dew, hoarfrost and fogwater (both solid and liquid) was 345, 134, 425 $\mu\text{eq}\cdot\text{l}^{-1}$ respectively, while typical TIC value for precipitation was 233 $\mu\text{eq}\cdot\text{l}^{-1}$. The chemical composition of dew, hoarfrost and fog water differ significantly from each other and from precipitation, depending on background emission and atmospheric processes. Taking into account both concentration and volume of deposited water, comparison between pollutant load of hydrometeors was possible.

1. Introduction

The Szrenica Mt. [1330 m a.s.l.; $\varphi=50^{\circ}48'$, $\lambda=15^{\circ}31'$] is situated in the western part of the main ridge of the Giant Mts. located along the Polish/Czech border and falls steeply northward on the Polish side (1000 m of relative height). Giant Mts., as a part of Western Sudety Mts., are located in one of the most polluted region in Europe [3]. During typical SW-W-NW wind conditions they are exposed to highly polluted air from heavy industry densely situated at the distance of tens to hundreds kilometers on the windward side of the mountains. Atmospheric pollutants are transferred to the ground via various types of hydrometeors: atmospheric precipitation and non-precipitation atmospheric deposits i.e. dew and hoarfrost as well as rime and liquid fog.

The local climate at Szrenica Mt. is well established on the basis of 40 years of measurements made at the meteorological observatory of the University of Wrocław [9]. Precipitation is the main source of water flux at the Szrenica Mt. reaching 1430 mm annually. In general, precipitation is nonseasonal with the highest sums in June, July and August (>150 mm monthly), and the lowest in February and March (less than 90 mm). The seeder-feeder mechanism typically causes an increase in precipitation at the Szrenica Mt. of about 50% relative to the lowlands [3], [6], [13]. This effect is that orographic cloud droplets are scavenged by upper level precipitation leading to a significant increase of both precipitation and pollutant deposition.

At the Szrenica Mt. a significant part of water flux from the atmosphere is formed by direct deposition from fog. It is the most frequently observed atmospheric phenomenon, being present on average 45% of the time [2], [4]. Fog is most often of orographic origin connected with the forced ascent of humid air on a windward slope. Thus orographic fog is a kind of advective and adiabatic types of fog combined. Such kind of fog is more typical for the cold season (XI-IV) because of predominance of humid air masses and small diurnal temperature range [2], [4].

While precipitation and fog deposition is described quite well, there exist only very limited information concerning the composition of dew and hoarfrost in Poland. Dew and hoarfrost are formed especially during the anticyclonic type of weather with no wind and clear night skies, rare at summit position [1]. The annual number of days with dew in lowland part of Poland varies around 100-160 and decreases to 10-30 days per year in case of conspicuous mountain summits and ridges. Hoarfrost frequency show similar spatial distribution from less than 30 days at well exposed mountain summits to more than 80 days annually in concave landforms and central regions of Poland [5], [11].

2. Experimental

The following hydrometeors: precipitation, dew, hoarfrost, liquid fog and rime samples were collected daily during the period between December 2008 and February 2010. Cloud water samples were taken daily with the use of simple passive collector set 2 m above the ground. Liquid fog droplets ($T > 0^{\circ}\text{C}$) were deposited on 160 strings vertically oriented and shaped by plastic hood, which reduced rain contamination. In case of rime ($T < 0^{\circ}\text{C}$) passive collector consists of duralumin rod. It was used to measure rime efficiency expressed by the weight of ice deposit and the length of vanes of rime. A polyethylene covered cable was used to collect rime samples destined for chemical analysis. Dew and hoarfrost samples were collected using a sampler based on the design described by Muselli et al. [8]. Surface of this sampler (100 cm x 100 cm) was made of rigid polyethylene foil mounted on a wooden frame, thermally isolated from the ground with 5 cm thick polystyrene foam and mounted 50 cm above the ground with the surface at 15-degree angle. Pollutant deposition transferred via precipitation was calculated on the basis of water volume measured by standard Hellmann gauge and chemistry from the rain collector – plastic container placed on the ground or snow cover.

All samples were collected in the morning after each deposition event. To reduce the disturbing effect of ongoing dry deposition, the collecting samplers surface were cleaned before exposure, rinsed with deionized water and wiped. Selected anions and cations were quantified against synthetic rain standard using ion suppressed chromatography (ICS 3000, Dionex Corporation, USA). This synthetic standard is Reference Material No. 409 (BCR-409, Institute for Reference Materials and Measurements, Belgium) and Analytical Reference Material Rain (National Water Research Institute, Environment Canada) [10].

Information regarding chemical composition of analyzed hydrometeors was interpreted with the context of meteorological data-type of air mass, character as well as direction of atmospheric circulation. Barometric system causing synoptic airflow, 16 directions of atmospheric circulation and three pressure system types were distinguished (cyclonic, anticyclonic and transition).

3. Results

The highest values of TIC (Total Inorganic Ionic Content) were observed in case of fog ($425 \mu\text{eq}\cdot\text{l}^{-1}$), but the much lower was characteristic for hoarfrost ($134 \mu\text{eq}\cdot\text{l}^{-1}$) and precipitation ($233 \mu\text{eq}\cdot\text{l}^{-1}$, Fig. 1, Tab. 1). Because of substantial differences, dew and hoarfrost are presented separately, opposite to liquid and solid deposit of fog, similar to each other.

Differences between precipitation and fog chemistry are connected with thickness of air layer where each of them originates. Atmospheric precipitation is formed due to the processes occurring within the deep air layer, often reaching the middle or even upper part of the troposphere, where the concentration of pollutants emitted from the ground is much lower. The concentration of pollutants dissolved in fog water was 2 times higher than in precipitation, which resulted from the more polluted nature of the boundary layer than the free atmosphere. TIC for dew was significantly higher in comparison with precipitation and surprisingly twice as big as for hoarfrost. This is due to the changing depth of the atmospheric boundary layer which is frequently protruded by the Szrenica Mt. especially in wintertime anticyclonic conditions. During warmer half of the year higher vertical mixing is observed. The relative purity of hoarfrost can be explained by the suppression of vertical mixing during winter conditions and the clean air subsidence predominantly reaching the top of Szrenica summit. Air pollutant transport is limited vertically and maritime aerosol is much more important in such conditions.

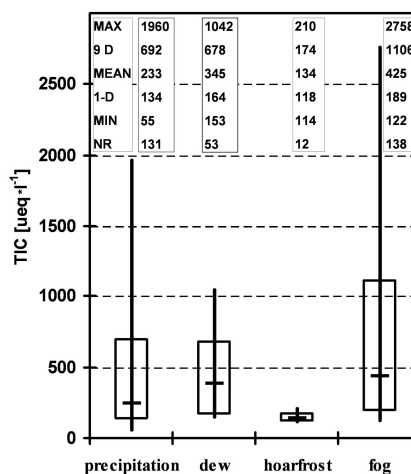


Figure 1: TIC statistical indices (max., 9th decile, mean, 1st decile, min. and the number of samples).

Table 1: Chemical composition of precipitation (P), dew, hoarfrost (H) and fog at the Szrenica Mt.

Analytes	P	Dew	H	Fog
N (samples)	131	53	12	138
Conductivity	18,0	18,2	9,9	52,8
pH	4.49	5.30	4.85	4.06
TIC	233	345	134	425
Na ⁺	19.5	25.0	17.0	31.4
NH ₄ ⁺	32.5	32.3	12.4	79.5
H ⁺	32.5	5.0	14.0	65.8
K ⁺	6.9	10.1	1.7	5.9
Mg ²⁺	4.9	30.9	12.2	12.3
Ca ²⁺	36.1	67.7	19.6	52.3
Cl ⁻	32.3	30.6	24.5	31.9
NO ₃ ⁻	28.8	84.3	21.7	75.2
SO ₄ ²⁻	39.9	30.6	11.3	70.5

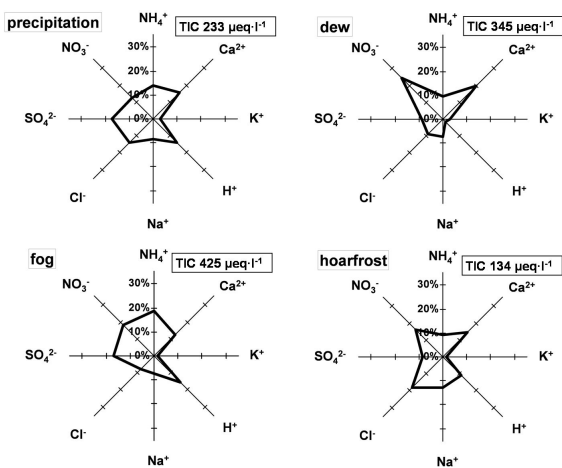


Figure 2: Ionic composition of atmospheric hydrometeors.

As the results hoarfrost chemical composition was quite different to other hydrometeors (Cl⁻, NO₃⁻, Ca²⁺ and Na⁺ with contribution 18, 16, 15 and 13%, respectively) (Tab. 1, Fig. 2). This indicates that despite the inland location of this site, maritime components are at least significant in overall deposition.

For fog water samples equilibrium between NH₄⁺, NO₃⁻ and SO₄²⁻ was characteristic (19, 18, 17%, respectively). Because of altitude, differences in boundary layer depth and much more vigorous circulation during cyclonic weather, fog water collected at the Szrenica Mt. may include solute contribution from emission sources located at much larger upwind distances [5], [7].

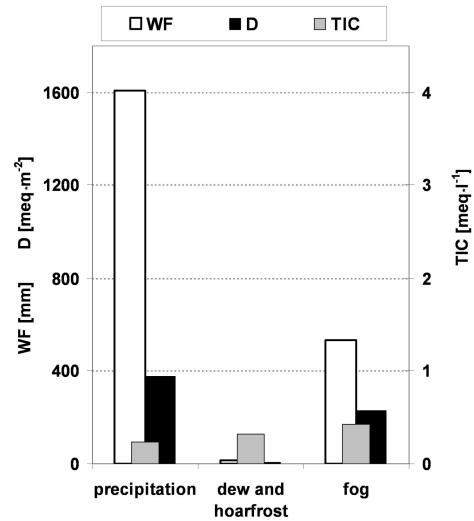


Figure 3: Water flux (WF), TIC, and pollutant deposition (D) via precipitation, fog, dew/hoarfrost sampled at the Szrenica Mt. between 1.12.2008 and 28.02.2010.

The following components: NO₃⁻, SO₄²⁻, Ca²⁺ and NH₄⁺ were the principal ions in chemical structure of dew and precipitation. A relatively high contribution of Ca²⁺ especially in dew and precipitation can be attributed to the use of CaCO₃ in the desulphurisation process in some electric power plants and an increased construction activity in the surrounding regions.

The estimation of pollutants load accumulated by a given hydrometeor is possible when the average TIC and the volume of water reaching a unit area are known (Fig. 3). Dew and hoarfrost provide water quantities much lower than fog or rain, but is a modest supplementary source of water [12]. According to TIC value equal to 314 µeq·l⁻¹ and 14,5 mm of water, pollutant load accumulated by dew/hoarfrost (between 01.12.2008 and 28.02.2010) was around 4,5 meq·m⁻². This was additional 1,2% of the pollutants load delivered via atmospheric precipitation. In case of fog, due to 274 foggy days per year accompanied by high wind speed, pollutants load is much more important but substantial differences exist depending on particular location. In this case, landuse expressed by roughness is a very important factor responsible for the huge differentiation in fog droplet deposition on a microscale. At the Szrenica summit, covered by dwarf pine, water flux from fog is estimated as thirty per cent while pollutant deposition via fog constitutes a half of that via precipitation. However, on well

exposed ridges covered by coniferous forest the direct fog water flux is comparable with precipitation while fog pollutant deposition may even dominate. The highest value was recorded at the edge of a forest stand close to the tree line [3].

6. Summary and Conclusions

In all types of atmospheric deposits different ions play an important role: SO_4^{2-} and Ca^{2+} in precipitation, NO_3^- and Ca^{2+} in dew, Cl^- and NO_3^- in hoarfrost as well as NH_4^+ , NO_3^- and SO_4^{2-} in fog. Chemical composition differ significantly as a result of e.g. different circulation pattern and activity, origin and the age of air masses, the range of vertical mixing. Pollutant concentrations in hoarfrost were surprisingly low, decreasing even below those observed in precipitation.

Taking into account both concentration and volume of deposited water, dew and hoarfrost form a neglectable path of pollutants flux to the ground being responsible for additional 1,2% of deposition through atmospheric precipitation. This does not apply for fog which becomes a significant component of wet deposition at mountain ridges when compared with precipitation alone, leading to the destructive environmental results.

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