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THE EFFECT OF TEMEPRATURE INVERSIONS ON THE PARTICULATE MATTER PM 10 AND SULFUR DIOXIDE CONCENTRATIONS IN SELECTED BASINS IN THE POLISH CARPATHIANS

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Abstract: Temperature inversions are considered a phenomenon contributing to an increase in the concentration of air pollutants. The goal of the study is to determine the impact of the temperature inversions on particulate matter PM 10 and sulfur dioxide concentrations in small towns located in the basins of the Polish Carpathians, i.e. Jaslo, Zakopane, and Zywiec. The measuring series of stations located in cities with a far greater degree of urbanization, i.e. Krakow, Nowy Sacz and Przemysl, were used comparatively. The study covers an analysis of two heavy air pollution episodes that occurred in January 2016. According to the obtained results, the persistence of the strong episodes of high concentrations of particulate matter PM 10 and SO_2 was associated with the influence of extensive high pressure systems favourable to the slow sinking of air particles. Their long-term persistence led to the development of subsidence inversion in the lower and middle troposphere and also, at night, radiation inversions enhanced by katabatic winds of cool air. The increase in the concentration of the particulate matter PM 10 and sulphur dioxide was also supported by the location in the vicinity of the single-family houses heated mainly by combustion of low quality coal (e.g. Nowy Sacz, Zakopane, Zywiec). Despite a much larger population and a greater degree of urbanization, the values of the discussed air pollutants recorded in Krakow and Przemysl were comparable to, or even lower than in much smaller towns located in the Carpathian basins.

Key words: temperature inversion; air pollution; particulate matter; sulphur dioxide; the Polish Carpathians

1. INTRODUCTION

Temperature inversions, which are a situation of the increase in air temperature along with height, are usually regarded as a negative phenomenon that contributes to the occurrence of sudden ground frost, fogs and mists, and the increase in the concentration of air pollution (Jacobson, 2002). Areas particularly predisposed to the formation of surface-based inversion and, therefore, high concentrations of air pollutants are concave landforms, especially mid-mountainous valleys and basins.

So far, the issue of seasonal variability in the concentrations of air pollutants and their meteorological conditions in areas with concave landforms has been raised primarily in relation to highly urbanized areas of North America (Whiteman et al., 2014; Green et al., 2015), Asia (Aryla et al., 2008; Zhuang et al., 2014) and Europe (Anttila et al., 2016; Langeron & Staquet, 2016). The conducted studies demonstrated that, regardless of the location, the distribution of concentrations of air pollutants, including particulate matter, was above all characterized by distinct seasonal variations, peaking in the cool season. This was most commonly associated with the long-term persistence of inhibition layers which were supported by the occurrence of extensive systems of high pressure (Langeron & Staquet, 2016). The occurrence of high pressure systems restricting air movement was an important factor leading to the deterioration of the aerosanitary state also in areas of lesser hypsometric diversity (Unal et al., 2011; Russo et al., 2014; Trivedi et al., 2014; Wang et al., 2014). Local emissions of pollutants related to residential heating, road transport and industry also played a significant role there.

Similar results were obtained in studies conducted in southern Poland - Upper Silesia (Leśniok et al., 2010; Radomski & Widawski 2011; Blažek et al., 2013) and Krakow (Bokwa, 2011 Bielec-Bąkowska et al., 2011). Concentrations of particulate matter PM 10, sulphur dioxide and nitrogen dioxide reached the highest values in winter, which was associated with a reduced solar radiation inflow, low temperatures, and increased emissions of air pollutants from home furnaces. In addition, the studies of Leśniok et al., (2010) and Bielec-Bąkowska et al., (2011) showed that instances of exceeding maximum standards were recorded frequently in the presence of vast areas of increased pressure - a high centre and an anticyclonic wedge, as well as the advection of air from the southern sector.

Detailed analysis of selected smog episodes, whose aim was to determine the relationship between air quality and circulation conditions as well as selected meteorological and topographical conditions, were conducted, among others, by Malek et al., (2006) - Logan (USA), Olofson et al., (2009) - Gotteborg (Sweden), Silcox et al., (2012) - Salt Lake City (USA) and Rahman et al., (2015) - Kuala Lumpur (Malaysia). They showed that high concentrations of air pollutants were most commonly associated with local boundary stability. A special case among these publications is the study of meteorological and environmental aspects of one of the worst national air pollution episodes in the United States. Extremely high concentrations of particulate matter PM 2.5 observed in January 2004 in Logan, a town with a population of about 100,000, were associated with both the location of the town in a highly concave landform and the meteorological conditions hindering the dispersion of air pollution - the occurrence of temperature inversion reinforced by a strong high pressure system and the persistence of snow cover (Malek et al., 2006).

This paper refers to the study of the occurrence of extreme air pollution episodes in cities located in concave landforms, and to the idealized numerical simulations performed by Rendón et al., (2014), which suggest that the increase in the degree of urbanization is not the only factor determining air quality. The aim of the study is to investigate the impact of the occurrence of temperature inversions on the concentrations of selected air pollutants in small towns located in the basins of the Polish Carpathians - Jaslo (37,000 inhabitants), Zakopane (27,000 inhabitants), Zywiec (32,000 inhabitants). The obtained results were compared with the measurements performed in cities of a far greater degree of urbanization located nearby, i.e. Krakow (760,000 inhabitants), Nowy Sacz (85,000 inhabitants), and Przemysl (67,000 inhabitants).

2. THE STUDY AREA

The spatial extent of the study comprises the area of four mesoregions located in the Polish Carpathians, i.e. Jaslo-Krosno Basin (Jaslo), Nowy Sacz Basin (Nowy Sacz), Zywiec Basin (Zywiec) and Podtatrzanski Trench (Zakopane) (Kondracki 2002). Krakow and Przemysl, however, are situated on the border of several physico-geographical units in the valleys of two large rivers, i.e. the Vistula and the San. Jaslo-Krosno Basin, Nowy Sacz Basin, Zywiec Basin and Podtatrzanski Trench constitute concave landforms surrounded by hills and mountains (Fig. 1). Their bottoms are located at a height of 240-270 meters above sea level in the case of Jaslo-Krosno Basin, 280-300 m above sea level in Nowy Sacz Basin, 340-500 m above sea level in Zywiec Basin, and up to from 750 to 1,000 meters above sea level in Podtatrzanski Trench, whereas the terrain height differences range between 500 to 1,600 m (Fig. 2). The topography of the areas in question is a factor highly conducive to the stagnation of cool air in the depressions and the formation of cold-air pools, as well as the occurrence of inversion layers inhibiting the mixing of air. Moreover, in Zywiec Basin, a large reservoir with an area of 10 km^2 located on the river Sola, exerts substantial influence on weather conditions, including the occurrence of fogs and mists.

The air quality monitoring stations selected for the analysis are characterised by a strong diversity of the surrounding buildings. The measuring points in Nowy Sacz, Zakopane and Zywiec are surrounded by single-family houses heated mainly by combustion of low quality coal. On the contrary, the stations in Przemysl and Krakow II are located in the vicinity of multi-family buildings connected to the district heating network. The highest concentrations of air pollutants are expected to be measured at the station Krakow I, which is characterised by intense vehicle emissions. The important role is also played by the presence of tenements where the density of coal heated apartments is still substantial. In turn, measuring point in Jaslo is located on the outskirts of the city. Taking into account that there is no industry in the vicinity of the town, the concentration of air pollutants is thought to be relatively low and caused mainly by the residential coal combustion.

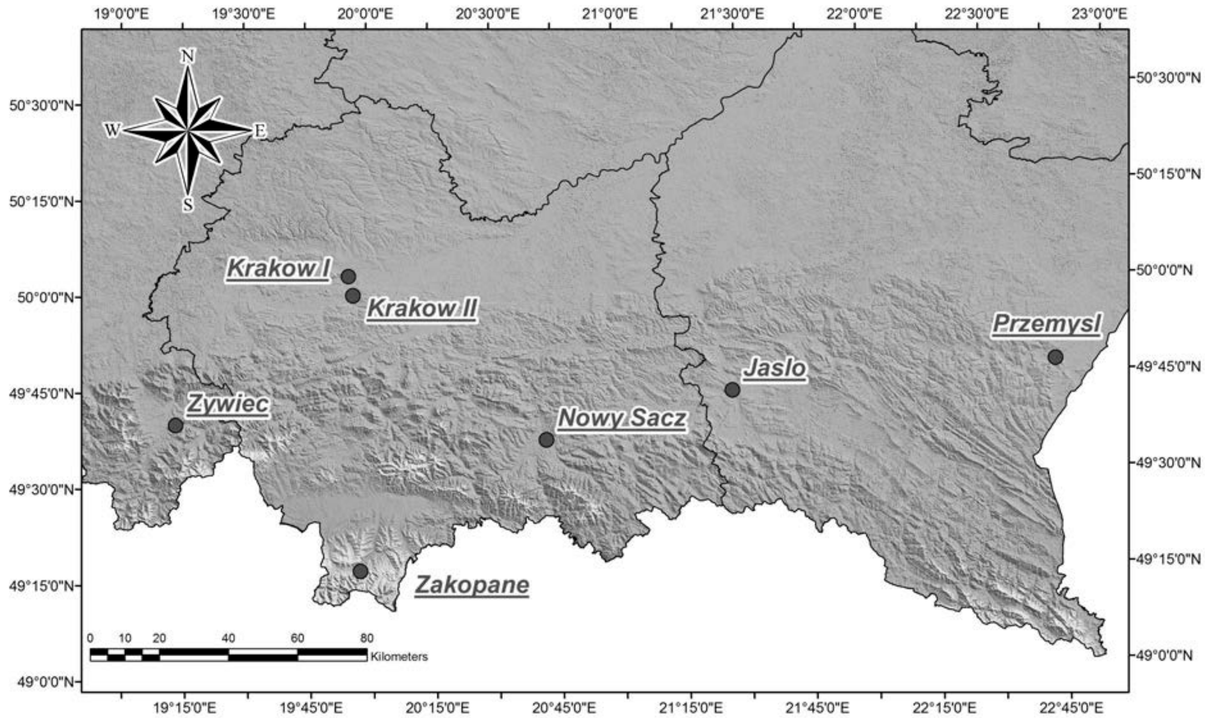

Figure 1. Location of the study area (Krakow I - Krasinskiego Avenue, Krakow II – Kurdwanow).

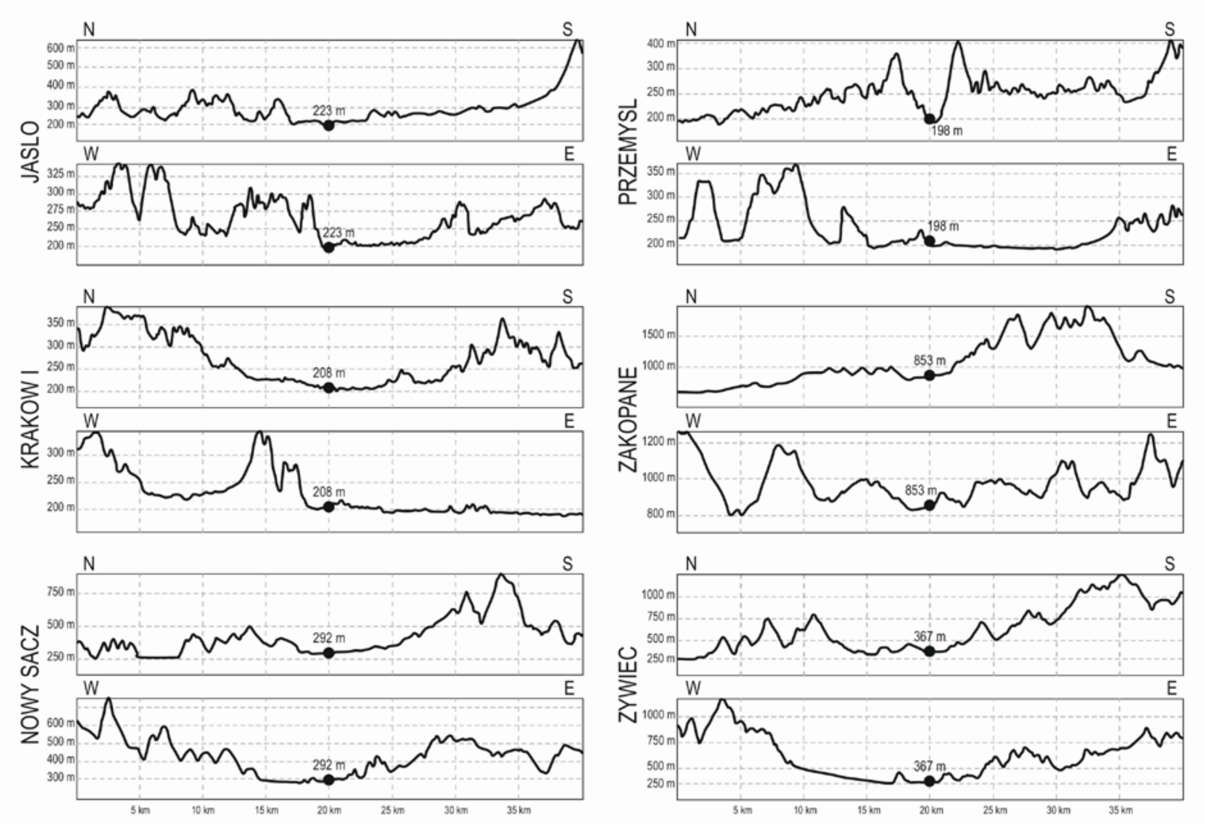

Figure 2. Terrain profiles of the analysed basins based on Google Earth.

3. DATA AND METHODS

The study covers the analysis of two episodes of high concentrations of air pollutants that occurred in southern Poland from 30 December 2015 to 11 January 2016, and from 18 January to 27 January 2016. It was conducted on the basis of the average daily and hourly concentrations of PM 10 and sulphur dioxide SO_2 obtained from the information portals of provincial environmental inspectorates.

Measurement data from the following stations were used: Jaslo, Krakow (Krasinskiego Avenue for PM 10, and Kurdwanow district for SO_2, respectively), Nowy Sacz, Przemysl, Zakopane and Zywiec. The synoptic conditions were characterized using the data obtained from the HOBO data loggers located in selected Carpathian basins (Krakow, Zakopane, Zywiec), SYNOP reports from Bielsko-Biala, Krakow, Krosno, Kasprowy Wierch, Nowy Sacz, Przemysl and Zakopane stations, MSL pressure and upper air maps, upper air sounding plots for Lviv, Poprad-Gánovce and Prostejov stations and ERA-Interim reanalysis (Dee et al., 2011). In addition, backward trajectories of the Hybrid Single-Particle Lagrangian Integrated Trajectory model were used in order to determine the direction of the inflow of air masses (Stein et al., 2015). The HYSPLIT model has so far been successfully used in analysis of the inflow and conditions of both anthropogenic dispersions, i.e. particulate matter, sulphur oxides, nitrogen oxides (Segura et al., 2013; Ji et al., 2012; Lee et al., 2013), radionuclides (Kinoshita et al., 2011; Bowyer, 2013; Draxler et al., 2015), as well as natural air pollution, i.e. volcanic dust (Kvietkus et al., 2013; Mortier et al., 2013) and forest fires (Rolph, 2009; Li et al., 2010).

4. RESULTS

4.1. Episode I: 30 December 2015 - 11 January 2016

4.1.1. The concentration of particulate matter PM 10 and sulphur dioxide

The average daily concentration of PM 10 exceeded EU air quality standards for the majority of the measuring stations in almost the entire period from 30 December 2015 to 11 January 2016. However, the daily maximum of its concentration did not occur at the same time at all of the measuring points. Accordingly, it was recorded on 1 January in Jaslo (134 μg/m^3), Nowy Sacz (161 μg/m^3), and Krakow (191 μg/m^3), on 3 January in Zakopane (201 μg/m^3), on 6 January in Przemysl (135 μg/m^3), and on 10 January in Zywiec (374 μg/m^3). A distinct decrease in the concentration of suspended particulate matter was found on 8 January 2016, when the standards were not exceeded in Przemysl, Zakopane and Zywiec. In the following days of the pollution episode in question, there was no re-growth of this concentration only in the case of Jaslo. It is worth noting that in Krakow, Nowy Sacz and Przemysl, despite a much larger population and a greater degree of urbanization, the recorded values of the discussed characteristics were comparable to, or even lower than in the much smaller towns located in the Carpathian basins. The concentration of particulate matter PM 10 was characterized by considerable daily variability with its maximum after sunset, i.e. between 4.00 pm and 01.00 am UTC. The communication station Krakow Krasinskiego Avenue is an exception, where due to the increased traffic maximum concentrations occurred in the afternoon hours, i.e. between 12.00 pm and 5.00 pm UTC. The greatest variability in the concentrations of PM 10 in the studied period was characteristic of Zywiec and Zakopane (Fig. 3). The coefficient of variation amounted to 99% for Zywiec, and 89% for Zakopane. By far, the smallest variability was observed at the station in Krakow, with the coefficient of variation equal to 56%. The lack of a clear daily cycle of the concentration of PM 10 in Krakow should be explained by the presence of dust emissions from home furnaces at night, and the increased intensity of traffic during the day. The analysed episode was characterized by the presence of several distinct increases in the concentration of air pollutants, the number and longevity of which was dependent on the location of the station. The maximum average hourly concentrations of PM 10 were, respectively, 304 μg/m^3 in Krakow, 318 μg/m^3 in Przemysl, 330 μg/m^3 in Jaslo, 338 μg/m^3 in Nowy Sacz, 469 μg/m^3 in Zakopane, and 595 μg/m^3 in Zywiec.

The average daily concentrations of sulphur dioxide were characterized by considerable variability in time, and large differences between the individual measuring stations. The daily maximum of its value occurred, respectively, on 6 January in Krakow (22.2 μg/m^3), Przemysl (31.3 μg/m^3), Nowy Sacz (35.0 μg/m^3), Jaslo (35.2 μg/m^3), and Zakopane (74.4 μg/m^3), and on 9 January in Zywiec (85.4 μg/m^3). The EU air quality standards of daily and hourly concentrations of sulphur dioxide were not exceeded at any of the analysed stations (Fig. 4). Large differences in the concentrations of this pollutant showed no links with the number of population or the degree of urbanization. However, they resulted from the diverse share of home furnaces which used fossil fuel with increased sulphur content. The lowest concentrations of SO_2 were listed at the station Krakow Kurdwanów, which is surrounded mainly by multi-family residential development that uses the district heating network. The analysed stations are characterized by distinct differences in the daily course of the concentration of SO_2. In the case of Zakopane and Zywiec, there are two peaks of its concentration, i.e. in the morning and evening hours, with its minimum around noon. A different distribution is characteristic of the other stations, i.e. one peak in the hours between 7.00 pm and 10.00 pm UTC in Jaslo, one peak between 3.00 pm and 5.00 pm UTC in Przemysl, and two peaks between 10.00 am and 12.00 pm, and between 5.00 pm and 9.00 pm UTC in Nowy Sacz. The station Krakow Kurdwanów is an exception, where the daily course of the discussed characteristics showed no clear daily minimum or maximum. The hourly concentrations of SO_2 at all of the measurement stations were characterized by moderate variability. The highest value of the coefficient of variation was determined for Jaslo (81%), and lowest for Krakow (55%). The maximum hourly average concentrations of SO_2 amounted to, respectively, 42.8 μ/m^3 in Krakow, 54.1 $\mu g/m^3$ in Przemysl, 69.1 $\mu g/m^3$ in Jaslo, 72.2 $\mu g/m^3$ in Nowy Sacz, 117.6 $\mu g/m^3$ in Zakopane and 211.3 $\mu g/m^3$ in Zywiec.

4.1.2. Synoptic conditions

The analysed pollution episode developed in a situation of the dominance of high pressure systems over Central Europe. In the period from 31 December to 2 January, southern Poland remained under the influence of an anticyclonic wedge associated with an extensive high pressure system, in the centre of which, located over the White Sea, the pressure reached the value of over 1045 hPa. The mixing processes were then inhibited by the presence of an extensive subsidence inversion formed as a result of the descending motion of air in the high-pressure centre reaching the middle of the troposphere.

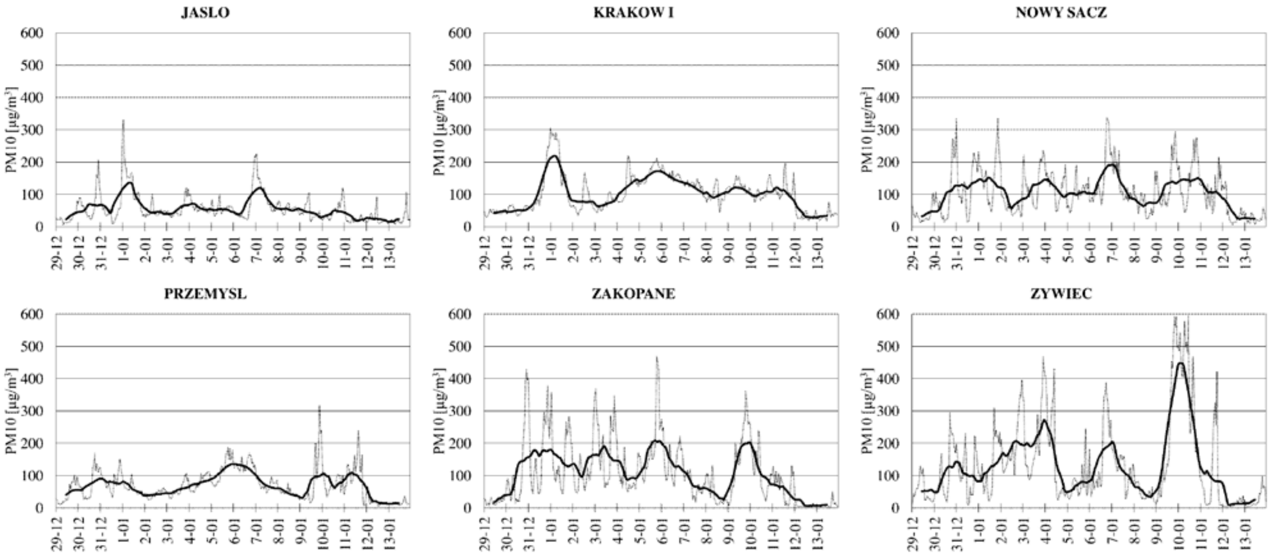

Figure 3. The hourly average (grey line) and 24-hour moving average (black line) concentration of particulate matter PM 10 at selected air quality measurement stations from 29 December 2015 to 13 January 2016.

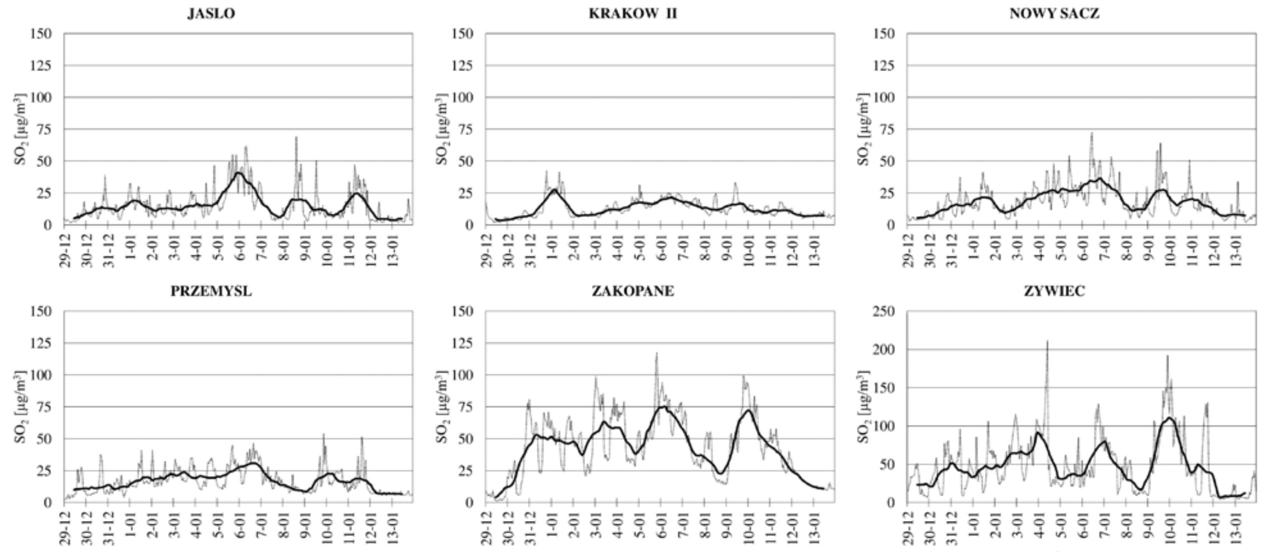

Figure 4. The hourly average (grey line) and 24-hour moving average (black line) concentration of sulphur dioxide at selected air quality measurement stations from 29 December 2015 to 13 January 2016.

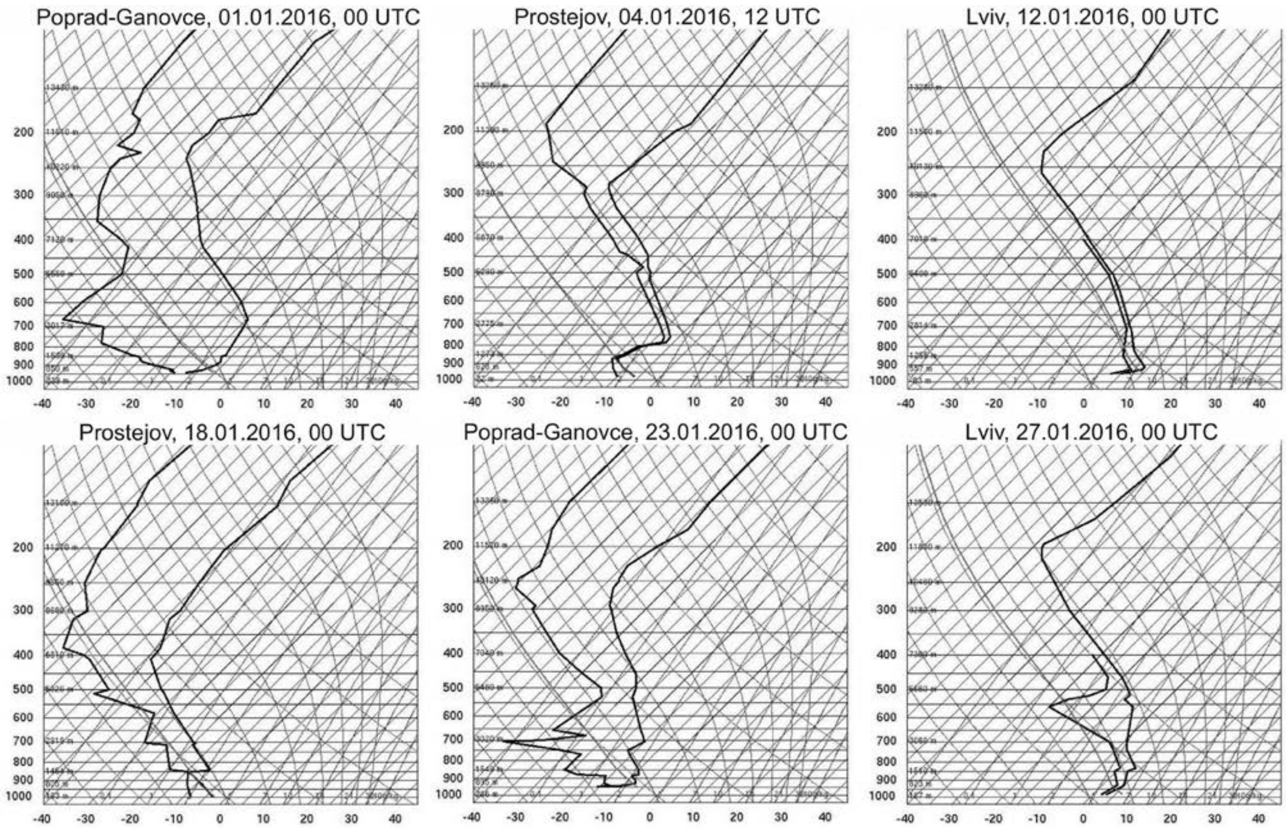

Figure 5. Upper air sounding plots for selected dates: Episode I - left column, and Episode II - right column (http://weather.uwyo.edu/upperair/sounding.html).

This was conducive to the persistence of the radiation inversions emerging at night hours. Their presence resulted in significant decreases in the temperature of air in the concave landforms which, according to the data recorded by the HOBO sensors on 1 January around 6.00 am UTC, amounted to -13.3°C in Krakow, -14.6°C in Zakopane, and -12.5°C in Zywiec. The analysis of the backward trajectory suggests that the subsidence of air occurred most intensely in southern Poland. In the case of Jaslo, a long stagnation of air in the boundary layer was observed (Figs. 5, 6, 7).

On 3 January, a shallow low pressure centre moving from the east caused the rebuilding of the pressure field, as a result of which until 5 January southern Poland remained in the zone of influence of the high-pressure ridge, and then, until 7 January in the low-gradient areas of increased pressure - the barometric col. On 4 January, a significant increase in the concentrations of air pollutants in the western part of the study area was recorded. According to data from the aerological station in Prostejov and the vertical profiles of temperature and humidity developed on the basis of the data from ERA-Interim reanalysis, it was a result of occurrence of an inversion associated with the upcoming occluded fronts, and the advection of warmer air above the boundary layer (Fig. 5, Fig. 6).

Significant decreases in the concentrations of particulate matter PM 10 and sulphur dioxide on 8 January were due to the occurrence over the study area of an occluded front associated with a low-pressure system centred over the Jutland Peninsula. The movement of the front was accompanied by a distinct increase in wind velocity conducive to the dissipation of inhibition layers and air mixing (Fig. 6).

The last increase in the concentrations of air pollutants in the days from 9 to 11 January was conditioned by the location of the area in the zone of the fuzzy field of atmospheric pressure. The strong increment in the PM 10 concentration recorded in Zywiec on 10 January should be equated with the advection of relatively warm and dry air in the free troposphere (at the isobaric levels of 850 and 700 hPa), which was associated with the movement of low pressure systems in the direction of Central Europe. From 10 to 12 January, there was also a marked increase in the concentrations of air pollutants in Przemysl (PM 10 and SO_2) and Jaslo (SO_2). Its reasons are explained by the plots made in Lviv, where strong radiation inversions occurred during the night hours. Taking into account backward trajectories, the subsidence of air particles in the southern part of Poland is clearly marked (Fig. 5, Fig. 6, Fig. 7).

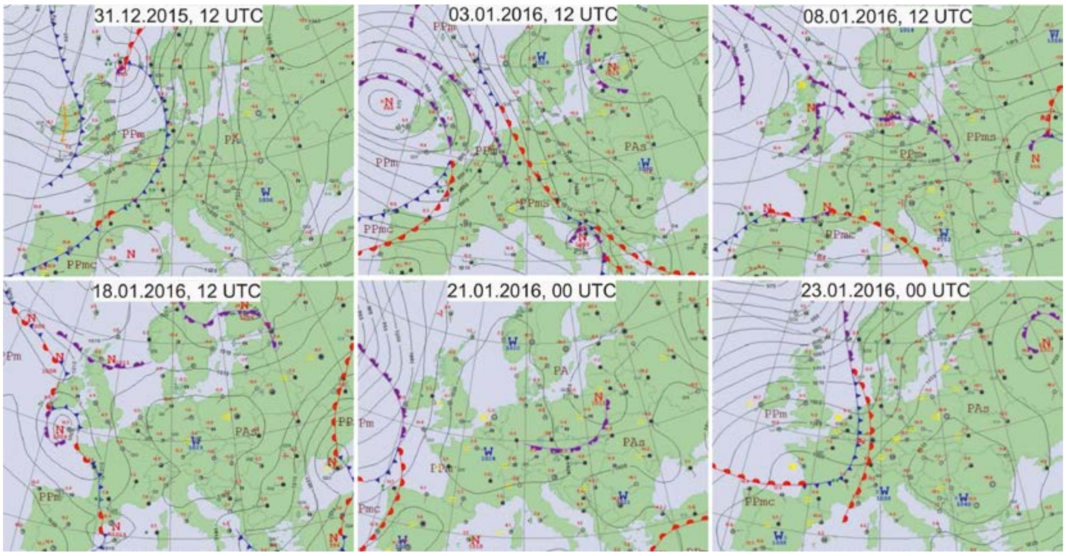

Figure 6. MSL pressure map for selected dates: Episode I - left column, and Episode II - right column (http://www.pogodynka.pl/).

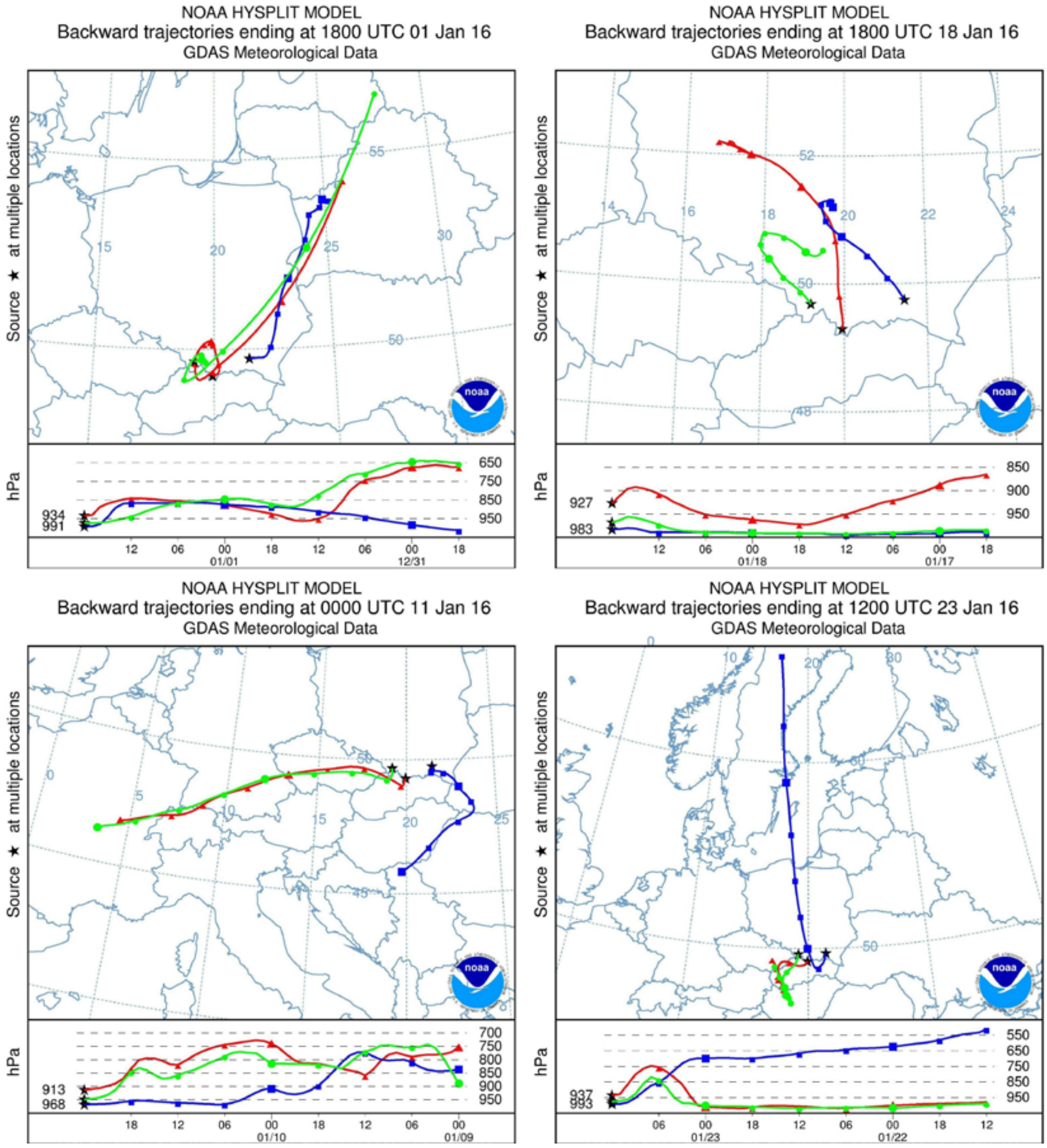

Figure 7. Backward trajectories (48 hours) for selected dates for Zywiec (green), Zakopane (red), Jaslo (blue): Episode I - left column, and Episode II - right column (http://ready.arl.noaa.gov/HYSPLIT.php).

4.2. Episode II: 18 January 2016 - 27 January 2016

4.2.1. The concentration of particulate matter PM 10 and sulphur dioxide

The average daily concentration of particulate matter PM 10 exceeded admissible standards during almost the entire period from 18 January to 27 January 2016 at the stations in Krakow, Jaslo, Nowy Sacz, and Zywiec. Its daily maximum concentration was greatly varied depending on the measuring point. Accordingly, it was recorded on 17 January in Przemysl (94 μg/m^3), on 18 January in Zywiec (167 μg/m^3), on 23 January in Jaslo (126 μg/m^3), in Zakopane (155 μg/m^3), and in Krakow (329 μg/m^3), and on 26 January in Nowy Sacz (206 μg/m^3). The decrease in the concentration of PM 10 was observed on 21 January 2016. In the second phase of the episode, clearly higher values of the discussed characteristics were recorded in Nowy Sacz, i.e. from 24 to 26 January the concentration of particulate matter there was significantly higher than at other measurement stations. The PM 10 concentration showed a clear daily cycle with the primary maximum between 5.00 pm and 2.00 am UTC, and the secondary maximum between 8.00 am and 11.00 am UTC. In the case of Jaslo, the highest concentrations of particulate matter were observed from the evening till morning hours. Similarly, to the first episode, the exception was the communication station Krakow Krasinskiego Avenue. As a result of the intensified traffic, peak concentrations occurred there between 11.00 am and 11.00 pm UTC. The greatest variability in the concentrations of PM 10 in the studied period was characteristic of the stations in Zakopane and Zywiec (Fig. 8), where the coefficient of variation amounted to 117% and 102%, respectively. The maximum hourly average concentrations of PM 10 amounted to, respectively, 188 μg/m^3 in Przemysl, 243 μg/m^3 in Jaslo, 355 μg/m^3 in Nowy Sacz, 412 μg/m^3 in Zakopane, 444 μg/m^3 in Krakow, and 511 μg/m^3 in Zywiec.

Similarly, to the first episode, the daily average concentrations of sulphur dioxide showed considerable variability in time, and big differences between individual measuring stations. The daily maxima of their values occurred, respectively, on 18 January in Zywiec (74.9 μg/m^3), on 23 January in Przemysl (17.6 μg/m^3), Krakow (47.4 μg/m^3), and Zakopane (63.3 μg/m^3), on 24 January in Nowy Sacz (37.6 μg/m^3), and on 27 January in Jaslo (56.9 μg/m^3). The EU air quality standards of daily and hourly concentrations of sulphur dioxide were not exceeded at any of the analysed stations. These stations were characterized by a marked daily variability in the studied period. In Krakow, Nowy Sacz, Zakopane, and Przemysl, there were two distinct daily maxima of concentrations of sulphur dioxide. The first of these appeared in the morning hours, and the second began at sunset and lasted until about midnight. However, the high concentrations of SO_2 in the hours between 5.00 pm and 10.00 pm UTC were observed at the stations in Jaslo and Zywiec. The hourly concentrations of SO_2 at all of the measurement stations were characterized by moderate variability from hour to hour (Fig. 9). The maximum hourly average concentrations of SO_2 amounted to, respectively, 47.5 μg/m^3 in Przemysl, 81.4 μg/m^3 in Jaslo, 90.6 μg/m^3 in Nowy Sacz, 92.3 μg/m^3 in Krakow, 144.4 μg/m^3 in Zakopane, and 160.6 μg/m^3 in Zywiec.

4.2.2. Synoptic conditions

The factor that initiated the growth of air pollution during the second of the analysed episodes was a vast high pressure centre whose central part was moving from the territory of Germany on 18 January, over the Czech Republic on 19 January, and as far as to Romania on 20 January (Fig. 6). The descending motion of air particles occurring within the high-pressure centre resulted in the formation of subsidence inversion, which was periodically accompanied by radiation inversions. On 18 January, the subsidence inversion was clearly marked at the isobaric level of 850 hPa (Fig. 5). The advection of Arctic air masses in the lower troposphere and the long-term stagnation in the surface layer was then visible primarily in the southern part of Poland (Fig. 7).

The short-term decline in the concentrations of air pollution at all of the measuring stations on 21 January was caused by the movement over southern Poland of an occluded front, which was associated with a shallow low pressure centre with its central part over the Baltic Sea. Behind the atmospheric front, another high-pressure system formed again, in the central part of which the pressure reached the value of up to 1040 hPa on 23 and 24 January (Fig. 6). This resulted in another increase in the concentrations of particulate matter and sulphur dioxide. The intensive subsidence of air particules, accompanied by a slump in the dew point temperature at the level of 850 hPa, was evident at the time mainly in southern Poland (Fig. 6, Fig. 7). In addition, the strong radiation inversions associated with the stagnation of cool air, lingering in the valleys and basins, were enhanced by the katabatic winds from the mountain ranges surrounding them in the south (Fig. 7). The air temperature recorded around 6.00 am UTC by the HOBO data loggers amounted then to, respectively, -17.5°C in Krakow, -19.1°C in Zakopane, and -17.6°C in Zywiec, while at high elevated mountain observatory at Kasprowy Wierch (1,991 m above sea level) it was only -13.0°C.

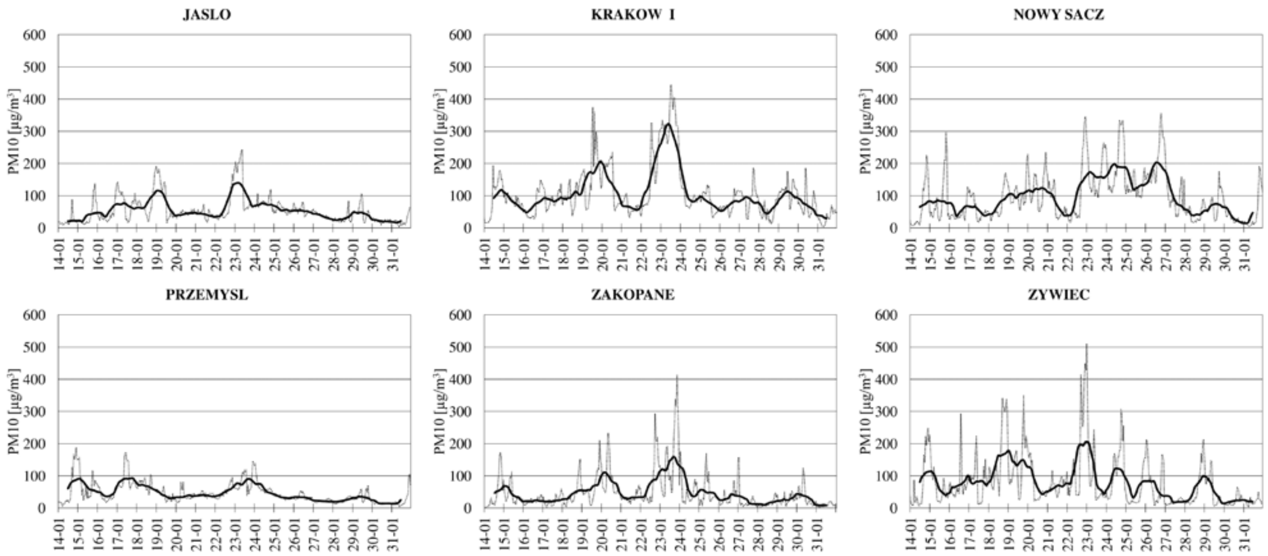

Figure 8. The hourly average (grey line) and 24-hour moving average (black line) concentration of particulate matter PM 10 at selected air quality measurement stations from 14 to 31 January 2016.

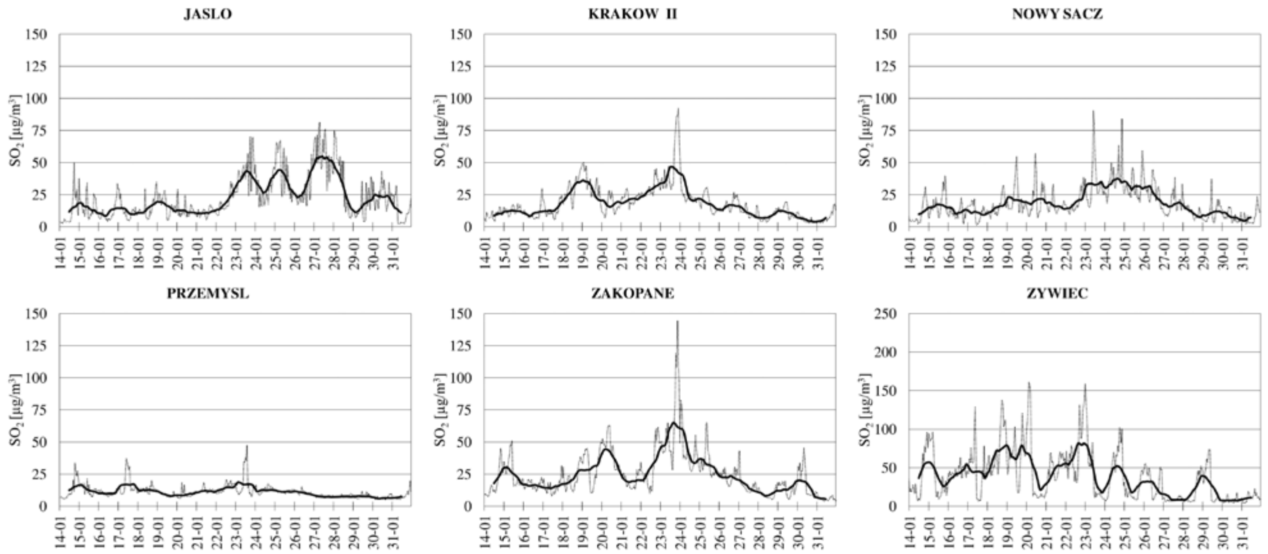

Fig. 9. The hourly average (grey line) and 24-hour moving average (black line) concentration of sulphur dioxide at selected air quality measurement stations from 14 to 31 January 2016.

The rebuilding of the barometric field over Europe, and the dominance of cyclonic circulation from 26 January resulted in a marked improvement of the aerosanitary state. Numerous low pressure centres with systems of atmospheric fronts which moved over the northern part of the continent, caused an increase in wind velocity conducive to the dissipation of inhibition layers and vertical air mixing. Isolated instances of an increase in air pollution were then recorded only in the eastern part of the study area, i.e. on 26 January in Nowy Sacz (PM 10), and on 27 January in Jaslo (SO_2). They were caused by the occurrence of nocturnal inversions (Fig. 5).

5. DISCUSSION AND CONCLUSIONS

In analogy to the studies of Leśniok et al., (2010) and Bielec-Bąkowska et al., (2011) mentioned at the beginning, as well as to the paper of Fu et al., (2008) on a strong smog episode in the delta of the Yangtze River, the persistence of strong episodes of high concentrations of air pollutants was associated with the impact of extensive high pressure systems. They were conducive to the subsidence of air particles and an increase in the atmospheric stability, which in turn led to the subsidence inversion in the lower and middle troposphere. Moreover, similarly to the article of Malek et al., (2006), the occurrence of radiation inversions resulting from the intense radiative cooling of the ground during the night hours, reinforced by katabatic winds, was identified. The topography of the discussed areas was, therefore, a factor highly conducive to the stagnation of cool air in depressions and to the formation of the cold-air pools.

The conducted analysis has shown that in addition to the repeatedly described in the literature anticyclonic situations, an increase in the concentration of air pollutants may be supported by the location within the barometric col, or a high-pressure ridge in the zone of the fuzzy field of atmospheric pressure. This applies particularly to cases where in the upper and middle troposphere an advection of warm and dry air occurs, which was also pointed to by Langeron & Staquet, (2016). The cause of the occurrence of high concentrations of pollutants in the analysed episodes was also the formation of frontal inversions which accompanied the slow movement of atmospheric fronts, slowed down by high pressure areas restricting their movement.

The comparison of air pollution concentrations in small towns located in Carpathian basins, including Krakow, Nowy Sacz and Przemysl, proved that the aerosanitary state is not only conditioned by the degree of urbanization, which is consistent with the simulations made by Rendón et al., (2014). The lower concentration of these pollutants in cities with a larger population and degree of urbanization could be conditioned by the development of the urban heat island effect, and the higher vertical mixing associated with it, which is a result of the higher heating of the urban surface. The increased thermal turbulence was conducive to more efficient ventilation in more urbanized areas. In addition, the existence of large differences in the concentration of sulphur dioxide between the analysed stations was identified. It probably resulted from the varied share of home furnaces using low quality fossil fuel with an increased sulphur content, which was also pointed to by Blažek et al., (2013).

Given the impact of air pollution on the human health, leading to an increase in the incidence of respiratory infections as well as cardiovascular and oncological diseases (Pascal et al., 2013; Kim et al., 2015), it is essential to take action in order to reduce the emission of the harmful air pollutants. The remedial actions must be undertaken not only by governments, but also by local authorities and individual households. The efforts should be directed, inter alia, at encouraging the change old high-emission stoves onto cleaner combustion solid fuel stoves, improvement of public transport policy and promotion of access to renewable energy sources. In conclusion, it must be stated that occasionally addressing the air quality problem in relatively small cities and towns located in the concave formations of land in the scientific literature indicates that the seriousness of the problem is underestimated. According to the authors, this issue requires increased attention so as to broaden the operation of the air quality monitoring network, as well as scientific studies that discuss the situations conducive to the presence of air pollution episodes.

Acknowledgments

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