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Evaluation of a Possibility to Identify Port Pollutants Trace in Klaipeda City Air Pollution Monitoring Stations

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Attempts are made to determine whether it is possible to identify fractions of air pollutants emitted in Klaipeda port in the data recorded in the city air monitoring station. Two components, SO_2 and NO_x , controlled aboard ship since 2006 were chosen for evaluation. To determine the port influence, a due account was taken of the location of monitoring stations. For this purpose the sectors where port pollutants could enter the samplers of air monitoring stations were identified. For the assessment of a potential impact the ratio between the number of hours, when the stations fixed some concentrations of NO_x and SO_2, and the number of hours when the port pollutants were able to reach monitoring stations was taken. Analysis was carried out in three periods of the year 2007 (the whole year, in February and in July) and in the intervals of 24 hours; at 02-04 night time, at 07-09 morning peak and at 16-18 evening peak. Analysis of SO_2 concentration data has shown that in 2007, and especially in July, the port influence on the stations area is possible, in February it is vaguely probable. NOx concentration analysis has shown that the level of this component in all cases, except only in February, is formed by other sources (motor transport).

Key words: Klaipeda port, air pollution, NO_x and SO_2 monitoring in city.

1. Introduction

With the growth of cargo transportation by sea, air pollution emissions from ships are constantly increasing. The latter, in relation to the land-based emissions sources, have not been strictly controlled for many years.

However, the MARPOL 73/78 Annex VI limiting NO_x and SO_2 emissions from ships, adopted in the IMO Conference in 1997 and coming into force in 2005-2006 (MARPOL, 2006), has changed the situation significantly. The most important measures implemented under this Annex have been the following: 4.5% and 1.5% of sulphur allowable content in marine fuels in the areas of general regime and in SECA areas, respectively, and restriction of nitrogen oxide emissions from ship engines which depend on the level of the nominal engine rated speed. IMO and EC have also adopted these two standards in their exchange program, whereby the sulphur content in marine fuels will not exceed 0.1% in the European seas (SECA districts) in 2015and - 0.5%-in the areas of general regime in 2020. NO_x emission rate will be tightened as well - from 9.8 to 17.0 g/kWh nowadays, - to 1.96-3.4 g/kWh in 2016. Despite the fact of the predicted development of the global shipping, it is expected that the global NO_x and SO_x emissions from ships will stabilize (NO_x) or reduce it approximately 4 times (SO_x) during the period of 2010-2020, but after 2020 both of these parameters will start to grow (Eyring 2005).

The latest IMO study showed that in 2007, SO_x and NO_x emissions from international shipping were evaluated as 15 and 25 Mt per year with a possible error of ± 20% (IMO, 2009). Many of these pollutants are discharged in a relatively small area but in particularly intensive maritime zones (English Channel in Europe, the Strait of Malacca in Asia, the North, Baltic and others seas) and ports. Thus, for example, in a Belgian maritime sector and ports the annual SO_2 and NO_x emissions in 2003-2004 accounted for 31 and 39 kt, or 30% and 22% , respectively, of the total emissions of Belgian balance (Meyer, 2008). In 1998 the NO_x emissions in the Bosporus and Canakkale channel zone from over 7000 ton ships accounted for 10% of those of the region's major port city Istanbul road transport (Kesgin 2001). At the port of Greek Piraeus (Athens area) the shipping's contribution to air pollution in the city in 2008-2009 was as follows: NO_x – 6.3%, SO_2 –

56.9% (Tzannatos, 2009). South Korean Bussan port ships were assessed for the contribution of NO_x and SO_x emissions to the overall pollution by 26.2 and 13.4 t/day, respectively, which represents 12.6% and 34.2% of the total amount of these components emitted by the port (3.6 mln. population) air basin from all sources (Song, 2009). The ENTEC research report indicates that in 2000 NO_x and SO_2 emissions from European ports were 158 and 161 kt, respectively, or 4.5 and 6.2% of the total shipping emissions in the European Region (ENTEC, 2002).

The Baltic Sea air basin is one of the most polluted in the world. In 2008, NO_x emissions from ships in the Baltic Sea amounted to 393 kt, SO_x – 135 kt (Jalkanen, 2009).

An increased load of air pollution from maritime transport contaminates the individual marine coastal areas and larger ports. Ports are usually located close to the city, the ship emissions are converging with city pollution sources resulting in an aggregate obtained by the environmental impact. In many ports, shipping intensity is increasing while the emissions from the other sources such as industry and the transport are decreasing (Georgieva, 2007).

Klaipeda port is not an exception where the ambient air quality is strongly influenced by the nearness of the sea (meteoparameters) and other different sources (marine and overland). The ambient air of the city is polluted by harmful substances emissions not only from traditional sources of industrial town–motor transport, industry and energy companies, but also the ship power plant particularly distinguished by its NO_x, SO_2, and particulate matter (PM). Klaipeda is a narrow, not wider than 2.5 – 3 km city extending from 11 to 12 km from north to south along the port from whose berths in many places some urban residential districts are not farther than 250 to 300 m. When prevailing western winds are blowing, practically the whole city is in the port pollutants dispersion loop area which strongly affects the formation of the air hygienic level in the town.

According to our studies in 2007, SO_2 and NO_x emissions from the ships operating in Klaipeda port were 0.93 and 1kt. Depending on the wind direction and speed, the emission of pollutants to the city air basin is mixed with emissions from the other local sources or from the sea and the Western Europe and Scandinavia, forming general background pollution in the city. In case of the other wind direction, the port pollutants participate in formation of the deposition in the Curonian Lagoon and the Baltic Sea area.

The ambient air conditions in Klaipeda port and city are currently inadequately controlled. The town has only two stationary stations monitoring the ambient air quality located 1-2 km from the port berths. The information provided by them being quite valuable is only of a limited, localized significance, no network can be developed on the basis of which it would be possible to form pollution maps of the city air basin. Air quality tests in the other city points, including the port area, are conducted episodically, mostly by the orders of interested companies (Klaipeda oil terminal, for example), they do not make a systematic picture.

Different programs (PHARE 2001 and PHARE 2003) have permitted researchers of Klaipeda University Maritime Institute to study port emissions (Smailys, 2007, Gedgaudas, 2005).

However, these studies have also been episodic and insufficient to reflect reasonably the port impact on the city air quality. It is therefore relevant to look for the ways of measuring this influence by means of the information provided by the city monitoring stations. This is of great importance because the vessels movement in the port of Klaipeda is growing and it is planned that in the next decade the number of ships visiting the port will increase from this year's 7-8 thousand to 15 thousand.

This article attempts to assess whether it is possible to distinguish the port pollutants fraction in the data of NO_x and SO_2 concentrations recorded in the ambient air monitoring stations of Klaipeda.

2. Research method

City ambient air pollution at any point is dependent on a number of sources whose emissions composition may be qualitatively very similar or even identical. Thus, for example, the emissions of all types of vehicles with internal combustion engines and thermal power plants must contain the following key components: CO_2, CO, CH, NO_x, SO_x, PM. The difference between these types of sources is usually only quantified and expressed in the value of individual components concentrations or in their relations (proportion). To identify the pollution effect of any single source on the general pollution level in a concrete place or area is simply to measure the concentrations of pollutants in the research area both when the source is operating and when its operation is stopped with all other conditions being unchanged.

In this case that method can not be used for two reasons; because there are no practical possibilities to stop activities in the research area (port) and because of the fact that all other sources are working stochastically, are uncontrolled and unregulated, with the constantly changing emissions.

Another method is based on the use of a superposition principle. This method can be applied if the synchronized data are available on both the values of concentrations of test components in the test area (or on its concrete points) and the emissions of the research source. The source projection on the research points and the area is calculated using one or the other authorized pollution dispersion model. This method was has been used by researchers in (Kesgin, 2001, Lucialli, 2007). In other cases, the changes of concentrations of the components-indicators in the research area or points have been recorded when the pollution source changed its location or the emission amount (Song, 2009, Smailys, 2007).

Klaipeda city has only two fixed monitoring stations (Air monitoring, 2007) and SO_2

concentrations are recorded only in one of them, thus their data can not be a basis for air pollution maps of the city. In addition, there are no authoritative data on main polluters, namely, the city and road transport emission levels change all the time. In this case, the authoritative values of pollutants concentrations can be recognized only at the points of monitoring stations. The data on air pollution emissions from port sources (ship) can be considered completely authoritative only in cases the ship's emissions are evaluated not by a general coefficients method (Trozzi, 1998), but directly measured during the operation of the ship's power plant (Smailys, 2007).

In this article, the method used is based on the analysis of the data taken from the stationary city air monitoring stations recorded during a number of years at the daily time intervals.

Depending on location of the monitoring stations and port pollution sources (Fig. 1.) wind direction sectors in which the port emissions could get to the sampling facilities of the city air monitoring stations have been evaluated. The first sector (symbol C), accounted for 138 degrees (azimuth range 169 - 307), the second (symbol S) - 116 degrees (azimuth range 193 - 309).

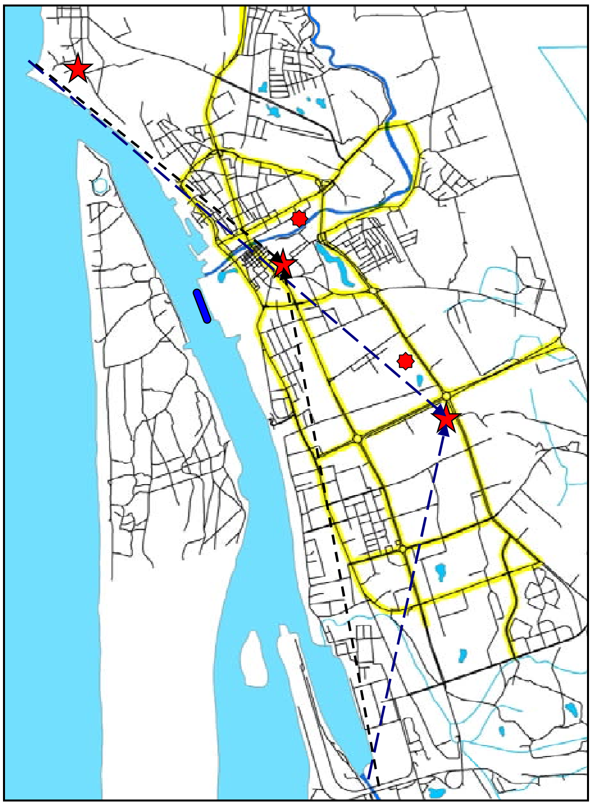

Fig. 1. Location of monitoring stations and pollution sources,
- power station,
- monitoring stations,
- ship location,
- monitoring station data on the sector's impact

Two emissions components - sulphur oxide (SO_2) and nitrogen oxides (NO_x) are selected as indicators. Their emissions from ships are controlled under the MARPOL 73/78 Annex VI. The sum (total amount) of nitrogen oxides is chosen because on the way from the port pollution source to the monitoring station the ratio of NO_2/NO due to NO conversion into NO_2 is increasing steadily, and if the components taken separately can distort the results.

The values of SO_2 and NOx concentrations recorded in the monitoring stations are relatively distributed into two groups - the lower and higher:

SO_2: lower - < 1 μg/m^3; higher:≥ 1 μg/m^3;
NO_x: lower - < 40 μg/m^3; higher: 40 μg/m^3;

Within the selected intervals (year, month, day, and part of the day) the sum of frequency is calculated in accordance with the following attributes**:**

1) STT - all numbers of concentrations in the selected period of time (number of measurements taken by the monitoring station);
2) STL - the number of all measurements, when the lower concentration value is fixed
3) STH - the number of measurements, when the higher concentration value is fixed;
4) SPT - all numbers of concentrations in the selected period of time, when the wind direction within the port has affected the sector;
5) SPL-the number of measurements, when in the port sector the lower concentration is fixed,
6) SPH - the number of measurements, when in the port sector the higher concentration is fixed

On the basis of these sums 3 relative coefficients have been calculated:

$$k_{PT} = \frac{SPT}{STT};\ k_{PL} = \frac{SPL}{STL};\ k_{PH} = \frac{SPH}{STH}$$

It can be said that the influence of the port may be noticed by the monitoring stations devices when the coefficients rates are set out in the following order:

$k_{PL}<k_{PT}<k_{PH}$

In this case the following condition is more important:

$k_{PT}<k_{PH}$

If the coefficients rates are inversed

$k_{PL}>k_{PT}>k_{BH}$

then, it will be reasonable to say that there is no possibility to notice the influence of the port in the records of a monitoring station.

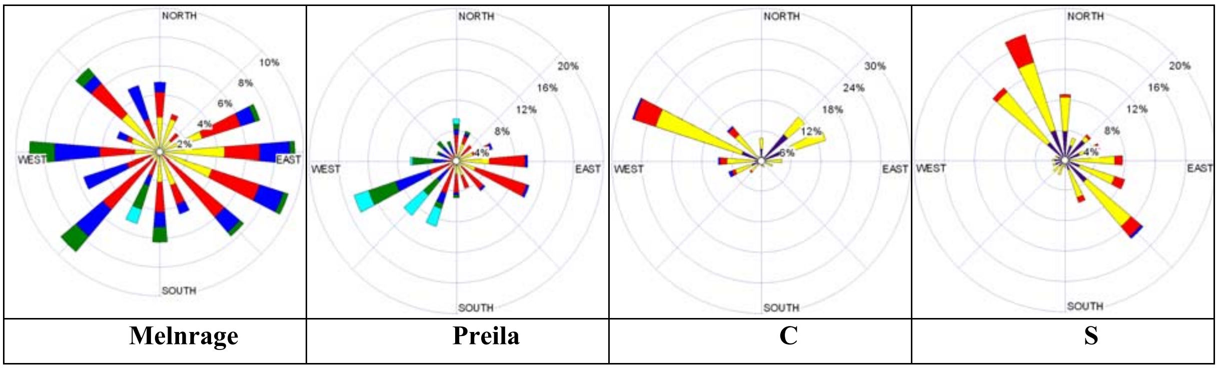

Fig 2. Windroses simultaneously recorded in the area of 4 monitoring stations during 6 weeks period.

When addressing the methodology, weather data ambiguities have to be dealt with. As can be seen in Figure 2, the windroses, simultaneously recorded at different but not at long distances located points, may be different beyond recognition. It is clear that wind directions recorded in stations C and S are purely local, and they have practically nothing to do with the main direction of the movement of air masses. The observed wind speeds also appeared to be different: at separately located Melnrage and Preila stations, they were up to 10 m/s and more, at stations C and S located inside the city blocks its maximum was up to 4-5 m/s.

On the basis of the windroses of Melnrage station the calculations have been performed (Fig.3). The winds recorded in this station, especially in the port sector, are least affected by relief factors, therefore they may be accepted as the most authoritative.

3. Research results and discussion

The data (hourly registrations) obtained from Klaipeda air monitoring stations (total volume of each station - 8147-registrations) obtained in 2007 were used in the study. The calculations were carried out and affecting coefficients were determined in three intervals: the whole year of 2007, in February and in July of 2007. In each time period all data per hour and the data ranges at 02-04 o'clock (night time), at 07-09 o'clock (morning time) and 16-18 o'clock (evening time – cities motor transport peak) were calculated. Intervals were selected to evaluate the possible differences in the monitoring data when practically there were no emissions from motor transport - night time, and when emissions were the highest -morning and evening peak hours.

Three data arrays were selected from the pollution parameters; NO_x was recorded in stations C and S, and SO_2 was recorded in station C (SO_2 was not measured in station S). The total measurements database - 36 blocks, analogous in structure and scope to the example, are presented in Table 1.

Final results are obtained according to the example in Table 1 and are presented in Table 2. These results are presented graphically in Figs 4, 5, 6, where the symbol L stands for a coefficient of lower concentrations k_{PL}, M - coefficient of the wind frequency in the port sector, H - coefficient of higher concentrations k_{PH}.

Table 1. A sample of calculation of port impact coefficients. Monitoring Station C. Component - SO_2. Period of time –the whole year. Time of day – 24 hours.

Wind direction	Number of hours when the wind is of a rhumb type	Number of hours when the amount of SO_2 concentration is	
		<1 μg/m³	≥1 μg/m³
N	287	208	79
NNE	273	180	93
NE	349	226	123
ENE	386	253	133
E	528	295	233
ESE	652	305	347
SE	715	272	443
SSE	422	119	303
S	360	95	265
SSW	484	179	305
SW	713	261	452
WSW	706	354	352
W	679	335	344
WNW	565	247	318
NW	625	287	338
NNW	403	258	145
Total	**8147**	**3874**	**4273**
Total in port sector (SPT)	**4041**	**1717**	**2324**
Port impact factor k_p	**k_{PT}=0,50**	**k_{PT}=0,44**	**k_{PT}=0,55**

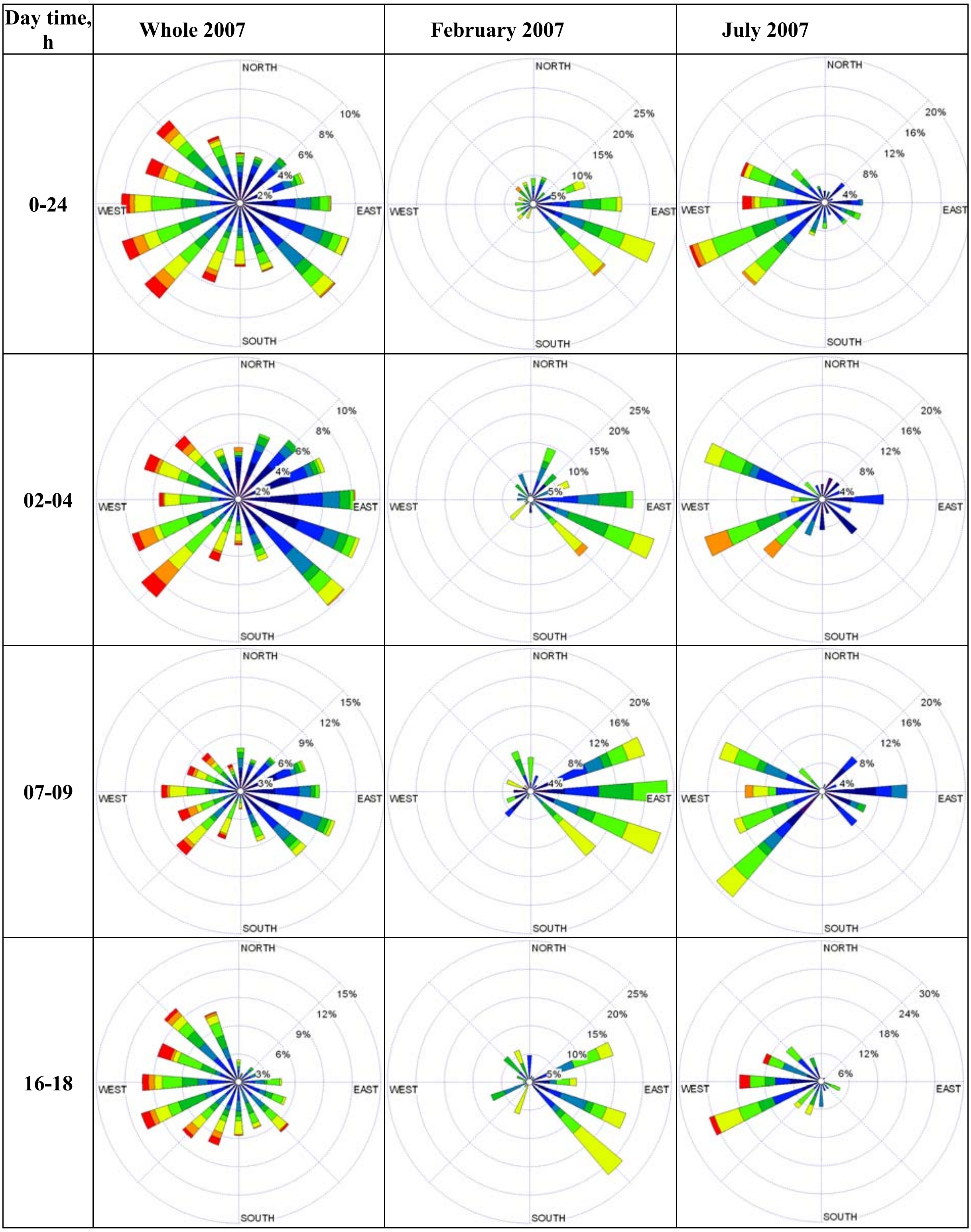

Fig. 3 Windroses during whole 2007, February 2007 and July2007.

Table 2. Results of calculation of port impact coefficients. Year 2007

Period	Day time, h	Station C (φ_{port}=0.38)						Station S (φ_{port}=0.32)		
		SO_2			NO_x			NO_x		
		k_{PT}	k_{PL}	k_{PH}	k_{PT}	k_{PL}	k_{PH}	k_{PT}	k_{PL}	k_{PH}
Whole 2007	0-24	0.50	0.44	0.54	0.50	0.54	0.37	0.44	0.56	0.21
	02-04	0.44	0.39	0.48	0.43	0.43	0.30	0.39	0.41	0.19
	07-09	0.43	0.39	0.45	0.42	0.58	0.23	0.40	0.63	0.19
	16-18	061	0.54	0.63	0.60	0.67	0.49	0.53	0.70	0.31
February	Day time, h	Station C (φ_{port}=0.38)						Station S (φ_{port}=0.32)		
		SO_2			NO_x			NO_x		
		k_{PT}	k_{PL}	k_{PH}	k_{PT}	k_{PL}	k_{PH}	k_{PT}	k_{PL}	k_{PH}
	0-24	0.19	0.20	0.19	0.19	0.20	0.19	0.18	0.27	0.10
	02-04	0.15	0.18	0.14	0.16	0.16	0.00	0.13	0.13	0.25
	07-09	0.15	0.24	0.10	0.17	0.12	0.25	0.17	0.28	0.11
	16-18	0.24	0.23	0.24	0.23	0.30	0.15	0.22	0.64	0.13
July	Day time, h	Station C (φ_{port}=0.38)						Station S (φ_{port}=0.32)		
		SO_2			NO_x			NO_x		
		k_{PT}	k_{PL}	k_{PH}	k_{PT}	k_{PL}	k_{PH}	k_{PT}	k_{PL}	k_{PH}
	0-24	0.73	0.65	0.76	0.72	0.74	0.61	0.67	0.76	0.37
	02-04	0.64	0.61	0.65	0.63	0.63	1.00	0.58	0.56	1.00
	07-09	0.66	0.55	0.71	0.64	0.78	0.31	0.63	0.82	0.31
	16-18	0.85	0.77	0.87	0.85	0.87	0.76	0.77	0.85	0.50

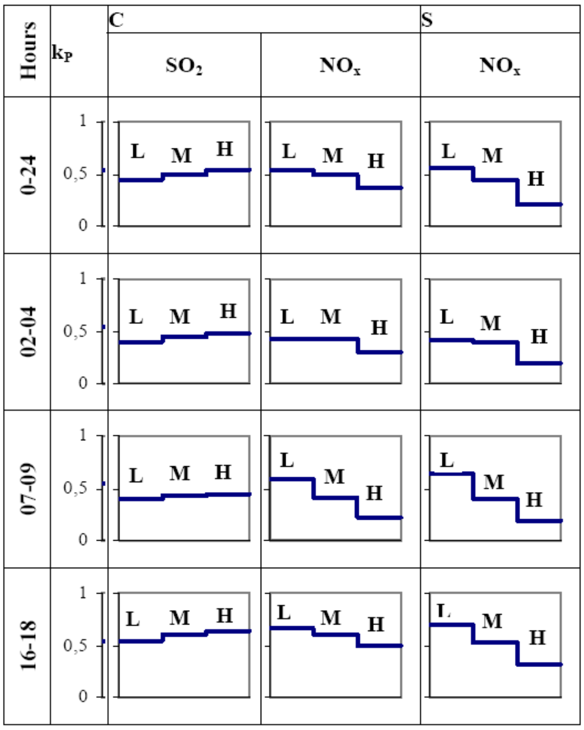

Fig. 4. Results of calculation of port impact coefficients during 2007

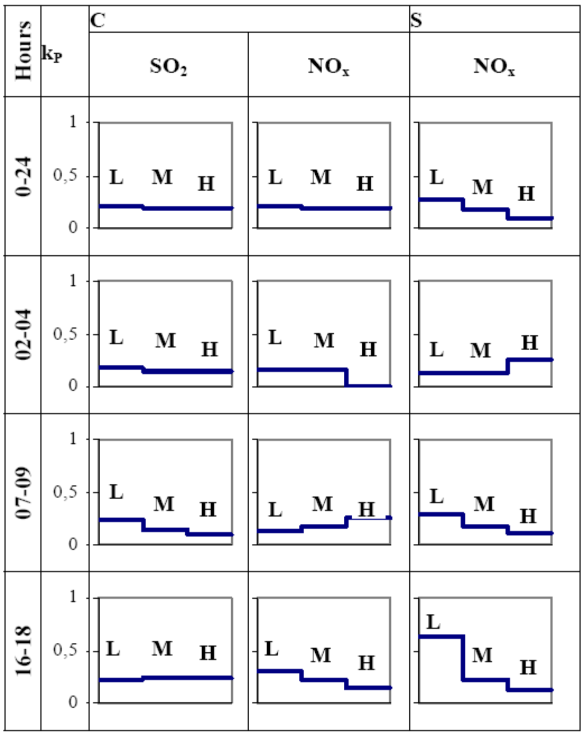

Fig. 5. Results of calculation of port impact coefficients. February, 2007

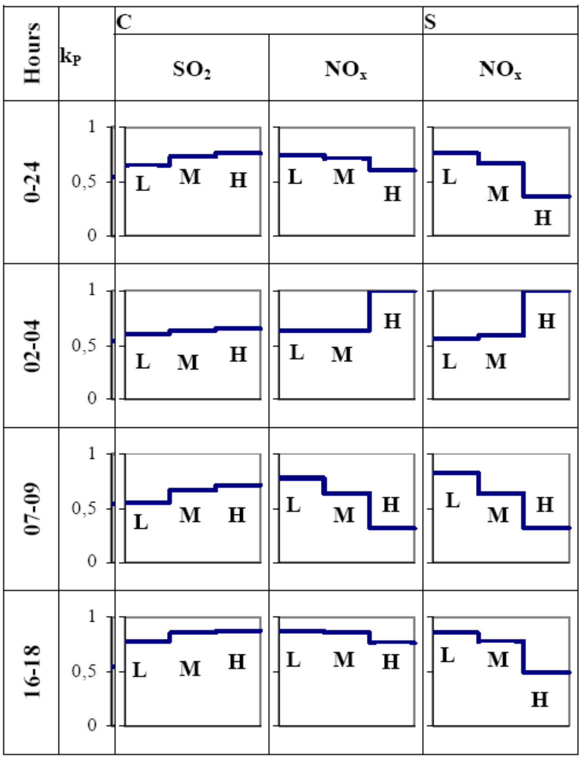

Fig. 6. Results of calculation of port impact coefficients. July, 2007

In a methodological part of this article we have adopted a provision that the impact of the port on the recorded data by the city ambient air stationary monitoring stations can be identified in the cases when coefficient (k_{PH}) of higher concentrations of frequencies of components (SO_2 or NO_x) is higher than average coefficient (k_{PT}) and (k_{PL}) of the lower concentrations is lower than average k_{PT}. It can be seen in Tables and Graphs that only two cases meet these conditions full well, namely, SO_2 registration data at station C during the year of 2007, and July of 2007.

However, during the summer time, the sources of the city SO_2 emission, the largest among them being Klaipeda thermal power stations, practically do not use fuel reserves – boiler oil and reduce emissions of SO_2 to minimum. It is also important to note that in the sector under the port impact there are no other regular sources of SO_2 emissions which could be reflected in the station data.

The conclusion that the port can influence the SO_2 registration data in station C theoretically could be used to deny or reduce the suspicion that it is affected by SO_2 background pollution brought from the Baltic Sea, Western European and Scandinavian countries by a long-pollutant transfer mechanism. Norwegian Meteorological Institute studies [17] have found that over 90% of the deposition of oxidized sulphur in Lithuanian coastal zone, including the port and town of Klaipeda, is forming the trans-boundary source.

However, the most authoritative data are presented by EMEP which supervises the work of all European air pollution monitoring stations. In publicly accessible web site (EMEP) the data are presented from the air monitoring station LT15R at Preila (Neringa) located in the Baltic Sea coastal area, from 1981 to 2007.

Table 3. Averages of SO_2 and NO_2 concentrations ($\mu g/m^3$) recorded in Preila air monitoring station (LT15R) during the year of 2007, and February and July of 2007

Period of time	Component	
	NO_2	SO_2
Whole 2007	1.1727	0.2726
February 2007	1.2239	0.4996
July 2007	0.7855	0.1261
Annual maximum	7.35	3.19

It is seen that all average background concentrations of NO_2 and SO_2 in 2007, compared to the data recorded in city air monitoring stations, are not significant and, according to our classification, are included into the range of lower size concentrations.

Summary of the data of Preila Station in the period of 1981 - 2000 shows that the background concentration of sulphur oxides in 2000 descended to the level of 0.5-2$\mu g/m^3$, while the maximum values were recorded at the S - SW winds directions, i.e. when the wind direction reached the sector of city monitoring stations of Klaipeda port (Sopauskiene, 2003). However, these data do not approve that SO_2 concentrations recorded in station C have originated from trans-boundary sources. In the above-mentioned work (Sopauskiene, 2003) the minimum of annual SO_2 average recorded in July, the maximum recorded in February fully justify the seasonality of fuel consumption for heating. It can be expected that this seasonality will be reflected in the data of station C, but it is not. The July data show that the relationship between the recorded levels of concentration influence and port influence is possible. At the same time the February results show that SO_2 concentration levels in the location area of station C are not formed by port, but by the other sources, Klaipeda thermal power station located near this station, in particular.

The fact that the port sources may affect the monitoring station data confirms the calculations of SO_2 emission dissemination from the point source emissions, hotteling at the port quay performed using the CALPUFF model (Calpuff). Emission source parameters are consistent with technical data of a large cruise ship "Constellation", regularly visiting Klaipeda. The ship location area is the cruise ship terminal, being the nearest to station C, wind direction - according to the station azimuth. Calculations of SO_2 pollution dispersion due to a wide range of wind speeds are shown in Figure 7. We see that even a strong dispersion, when wind speeds are greater than 10 m/s, associated with a port source of SO_2 concentrations at station C, is not less than 10 $\mu g/m^3$ that exceeds the background concentrations of this component significantly.

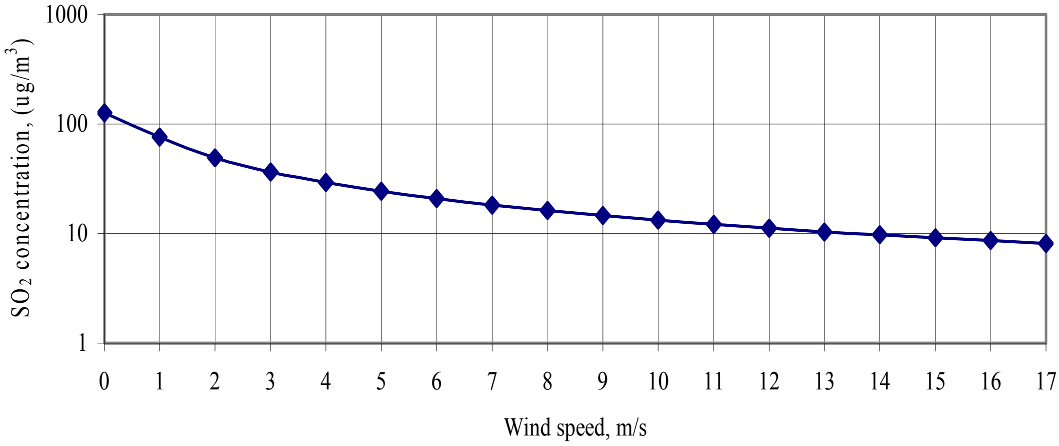

Fig. 7. *SO_2 concentration in a monitoring station in accordance with CALPUFF, when one-way but different speed winds (µg/m) are blowing*

All nitric oxide concentrations measured at stations C and S show that this component can not be used as an indicator of the port impact. Annual averages in both stations (see Figure 4) show that NO_x records are due not to the port, but to the other sources which are automobile emissions. At the same time in February and July, averages are quite controversial and do not allow to predict or deny the impact of the port. On the one hand, in July at night, when the vehicles in fact do not work, the NO_x concentration maximums were recorded in the port sector, which could suggest the feasibility of the port impact. In February at the night time in the port sector, higher NOx values were not recorded at the station C at all, and it could deny the impact of the port. However, the February data are not quite reliable because the windrose of this month (see Figure.3) shows that in 2007 there were no February winds from the port sector and SO_2 which was generated at the port did not reach station C samplers and was not reflected in the monitoring data.

4. Conclusions

1. Analysis of NO_x concentrations recorded in Klaipeda stationary air monitoring stations, 2007, has shown that according to these data it is not possible to identify and quantify the port impact on pollution of the city basin.
2. Records of SO_2 concentrations in station C provide some possibilities to exclude the impact of the port. In most cases the level of SO_2 concentrations exceeds (often - considerably) the background concentrations which are distinctive in the air mass of prevailing winds, and it can be accepted as reliable. The ratio of higher and lower concentration levels in the port sector, according to the annual and July data, is significantly higher per unit, and offers a possibility to think that the data of SO_2 concentrations, recorded in station C can be used as indicators of a port impact. This can also be confirmed when simulated strong SO_2 emission source distribution projection to station C provided the values of SO_2 (more than 10µg/m3) which actually exceeded the fixed values of SO_2 concentrations in the station.
3. Comparison of windroses created by stations C and S and Melnrage meteorological station recorded data of wind parameters. It appears that these three windroses have nothing in common. Windroses of city air monitoring stations fundamentally differ from each other and totally differ from the Melnrage station windrose.

It is clear that the city monitoring stations registered unreal air mass movement parameters because they were local air flows over the station dislocation area, moving by fixed street corridors.

The data from the stationary seaside Melnrage station can be considered authoritative. These data are not misrepresenting the relief factors and urban structure effects.

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Galimybės atsekti uosto teršalų pėdsakus Klaipėdos miesto oro taršos stebėsenos stotyse įvertinimas

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Straipsnyje bandoma nustatyti, ar yra galimybė išskirti Klaipėdos uoste išmestų oro teršalų frakcijų miesto aplinkos oro kokybės stebėsenos stočių užregistruotuose duomenyse. Vertinimui buvo pasirinkti du komponentai (SO_2 ir NO_x), kurie nuo 2006 metų kontroliuojami laivuose. Uosto įtakai nustatyti, remiantis uosto stočių tarpusavio išsidėstymu, buvo išskirti sektoriai, kuriuose uosto teršalai galėjo patekti į stočių oro mėginių priimtuvus. Galimai įtakai įvertinti buvo laikomas valandų skaičiaus, kai stotys fiksuodavo tam tikras NO_x ir SO_2 koncentracijas, ir valandų skaičiaus, kai uosto teršalai galėjo pasiekti stotis, santykis. Atlikta trijų 2007 metų laiko tarpų (visų metų; vasario; liepos) analizė, iš kurių kiekviename išskirti 4 paros laiko tarpai (visa para, nakties valandos 02–04; ryto pikas 07–09 ir vakaro pikas 16–18). Analizė parodė, kad pagal visų 2007 metų ir ypač liepos mėn. SO_2 koncentracijos duomenis uosto įtaka stočių rajone yra galima, o vasario mėnesį – mažai tikėtina. NOx koncentracijų analizė parodė, kad pagal šio komponento lygius visais atvejais, išskyrus tik vasario mėn., formuoja kiti šaltiniai (autotransportas).