Urban wind analysis in Warsaw

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1 Introduction

The population of large urban areas is growing rapidly. By 2050 it is predicted that two-third of global population will be the city inhabitants. As the cities constantly grow the high-end technology is being utilized to manage urban development, which leads to the concept of Smart Cities - friendly and intelligent infrastructure for their citizens.

One of the key factors of Smart City concept is the promotion of green energy from renewable sources, another important problem for cities is the smog and air pollution. A high quality wind conditions form weather forecasting model may be necessary to calculate the ventilation index for the different city areas.

The aim of this work is to provide assessment of the use of numerical weather prediction (NWP) models for wind speed and wind direction forecasting in the urban space. Roughness length is an important concept in urban meteorology, accounting for the structure and type of buildings, roads, parks and rivers within the city area. These parameters are affecting meteorological conditions as winds which are the single most important source of free kinetic energy and a major factor determining the urban air quality.

For further practical use, the forecast data from numerical model COSMO at 2.8 resolution has to be verified with the data from urban meteorological stations. In this work we use the 2015 year data from two WMO network stations located in Warsaw at Okęcie and Bielany. The Okęcie station is located at the Okęcie airport in the south-western suburbs of the city, while the station Bielany is located in the northern part of the city in the valley of the Vistula River.

These locations were chosen to account for an impact of the city structure on the daily course of wind speed and wind direction. Detailed calculations and analyzes of observational and COSMO wind data were performed for the whole 2015 year, accounting for the annual, seasonal, monthly and hourly wind variability.

2 COSMO numerical weather prediction model in Poland

Model COSMO version 5.01 is run at IMGW-NRI operationally four times per day using two nested domains at horizontal resolutions of 7 km and 2.8 km.

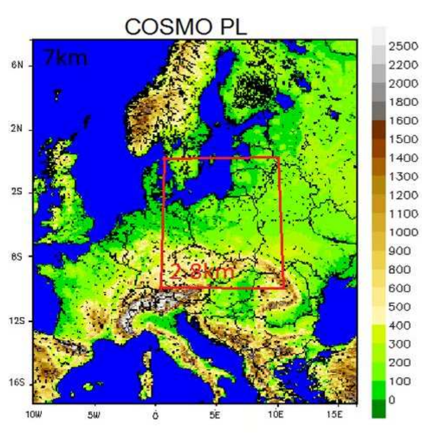

Figure 1: Cosmo model domain

Table 1: Operational setups of the COSMO-PL models.

Horizontal Grid Spacing [km]	7	2.8
Domain Size[grid points]	415 x 445	380 x 405
Forecast Range [h]	78	12
Inital Time of Model Runs[UTC]	00 06 12 18	1h frequency
Model Version Run	5.01	5.01
Model providing LBC date	ICON	COSMO PL7
LBC update interval [h]	3h	1h
Data Assimilation Scheme	Nudging	Nudging

COSMO model runs in a deterministic mode using initial (IC) and boundary (BC) conditions from ICON global model. Implemented in the COSMO observational data assimilation (DA) system is based on the nudging technique to improve forecast quality. DA allows for ingesting weather data measurements - as these carried out at SYNOP stations acquired from the WMO/GTS network.

The model is starting at 00, 06, 12, 18 UTC and produces 78 hour and 36 hour forecasts respectively at 7 and 2.8km resolutions.

3 Observational network

Our studies are based on the wind speed and wind direction data from the 2015 year, attained from two stations in Warsaw:

- Synoptic station **Okęcie(24h)** located on the south-west of Warsaw, within the Warszawa-Okecie airport.

- Climatological station **Bielany(6,12,18 h)** located in the northern part of Warsaw at the area of Institute of Meteorology and Water Management.

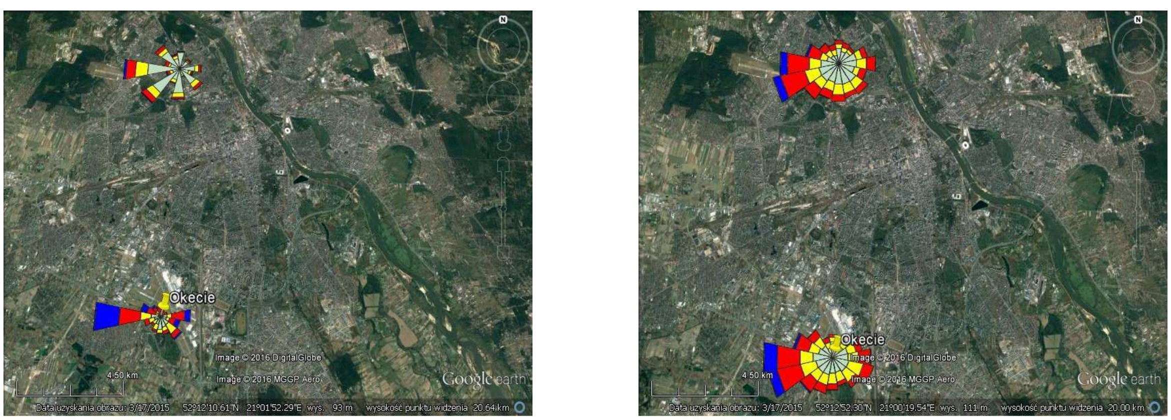

Figure 2: Wind roses in 2015 year at the Bielany and Okęcie stations (upper synop(left),lower model(right))

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For our research we have collected data from all 24 hours of the synoptic station Okęcie and from three terms (06,12,18 h) of the Bielany climatological station from the whole 2015 year. Both stations are the multiannual network WMO stations. The station Warszawa Okęcie is located in the south-western parts of the city at the airport, while the station Bielany is situated in the northern part of the city near the Vistula River in the Institute of Meteorology and Water Management.

4 Data analysis

A wind rose is a concise and illustrative product showing wind speed and wind direction at a certain location. It provides information about the frequency of winds blowing at certain speed ranges from the particular direction, as well as its time percentage. For the selected locations we compare wind roses generated from NWP model with data from observational stations. Results are used both for the current meteorological analysis and for studies of a longer period of time. For current analysis WRPLOT View program was used [1].

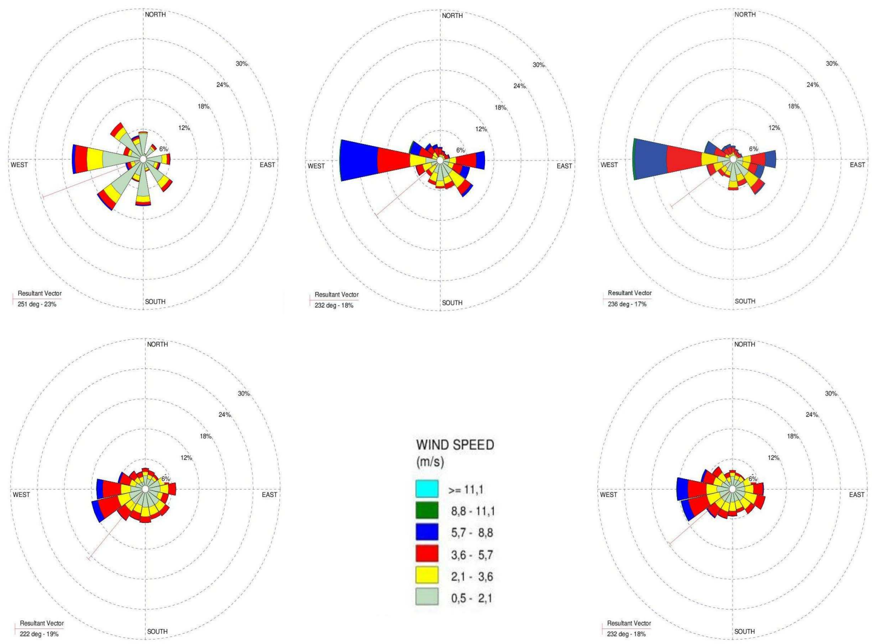

Figure 3: Wind roses: top - observation data: from left Bielany 3h, Okęcie 3h, Okęcie 24h; bottom - model: left Bielany, right Okęcie from 2015 year.

For direct comparison SYNOP observations from three terms (06,12,18 hours) at the Okęcie station have been selected. The predominant wind direction during the whole year for the station Okęcie is western. Surprisingly, we can observe very large convergence as for the wind direction and wind speed (Fig.3, Tab 2) calculated for the 3 hour and 24 hour averages, which shows how well is the data from 06,12,18 hours representative of a daily cycle.

A different distribution is observed at the station Bielany because it is located in different part of the city, between the residential area and forest, in a close proximity to the Vistula river, which significantly affects the distribution of winds in this area.

The winds have more scattered directions from north-west to south-east direction. COSMO model results show rather uniform wind speed and wind direction regardless of the location which indicates the need for implementing more detailed parametrization of urban effects.

Further analysis at the Bielany station (Tab 2) show smaller averaged annual wind speed (2.14 m/s) than at the Okęcie station (3.76 m/s) and over twice weaker winds speed dominating (Fig.4) in the class (0.5-2.1 m/s). By comparing model results with observational data we can see that at Okęcie station model wind speeds (2.94 m/s) are generally smaller than the observed one (3.57 m/s).

The class with the smallest wind speeds (0.5-2.1 m/s) increases by 30%, while the class with high wind speeds (5.7-8.8 m/s) significantly reduces by 10%. Whereas at the station Bielany situation is reversed, with higher wind speeds being observed in the model. The class of (3.6-5.7 m/s) increases of about 25%, while class of very weak winds (0.5-2.1 m/s) is reduced.

Table 2: Average wind speed and calm winds at Bielany and Okęcie for 2015 year

station	hours	calm wind	avg wind speed
Bielany obs.3h	1095	3.93	2.14
Okęcie obs.3h	1095	3.11	3.76
Okęcie obs.24h	8751	5.18	3.57
Bielany model	8724	0.11	2.79
Okęcie model	8724	0.16	2.94

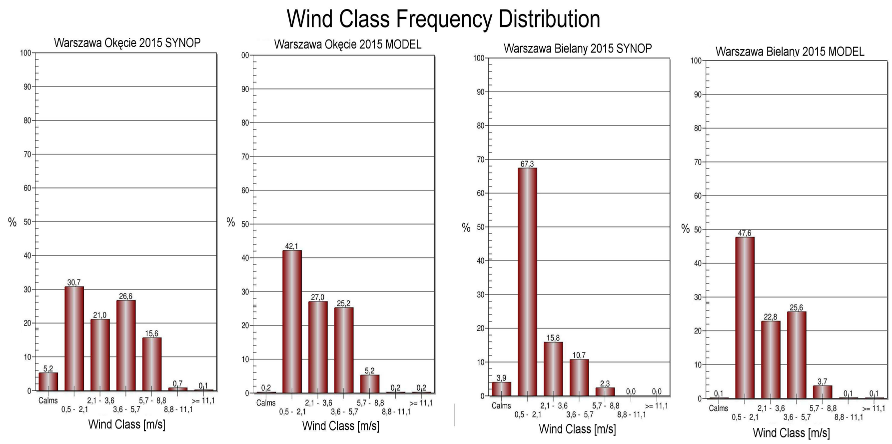

Figure 4: Wind class frequency distribution for 2015 year. From left: Okęcie synop/model, Bielany synop/-model.

A more detailed analysis was performed for the whole 2015 year (Fig. 5-8) and for individual months (Fig. 9-11) using hourly data (06,12,18 hours) from both meteorological stations and the COSMO model at 2.8km resolution . At both stations Bielany and Okęcie we can see for the observations a greater scatter in wind direction than in the data calculated by the model. (Fig 5-6).

Comparing the annually averaged wind speed (Fig. 5-10) we see that for Bielany, the wind speeds calculated from the model are higher than those observed at the station. At the Okęcie station situation is reversed, where wind speeds of observation are higher than those calculated by the model.

Comparing monthly averages for these hours we observe the highest wind speeds for 12 hours for both observations and model. The exception is the January at Okęcie with strong winds (over 4 m/s) throughout the day, where wind speeds of 18 hour is slightly higher than the wind speed at 12 hour.

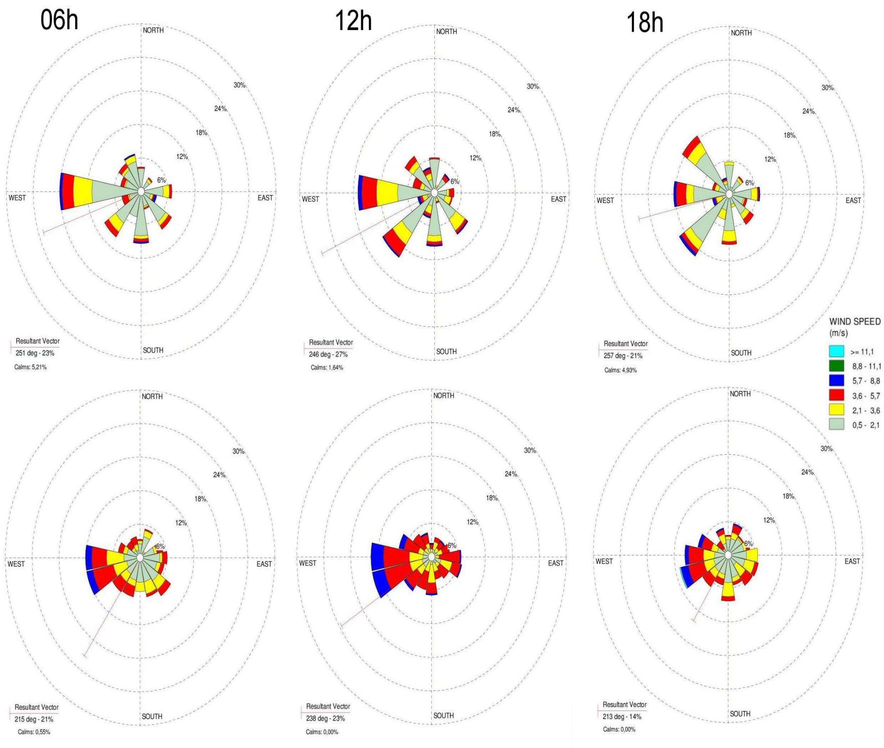

Figure 5: Hourly wind roses form 2015 year at Bielany station. From left: 06h 12h 18h, top - observation, bottom - model

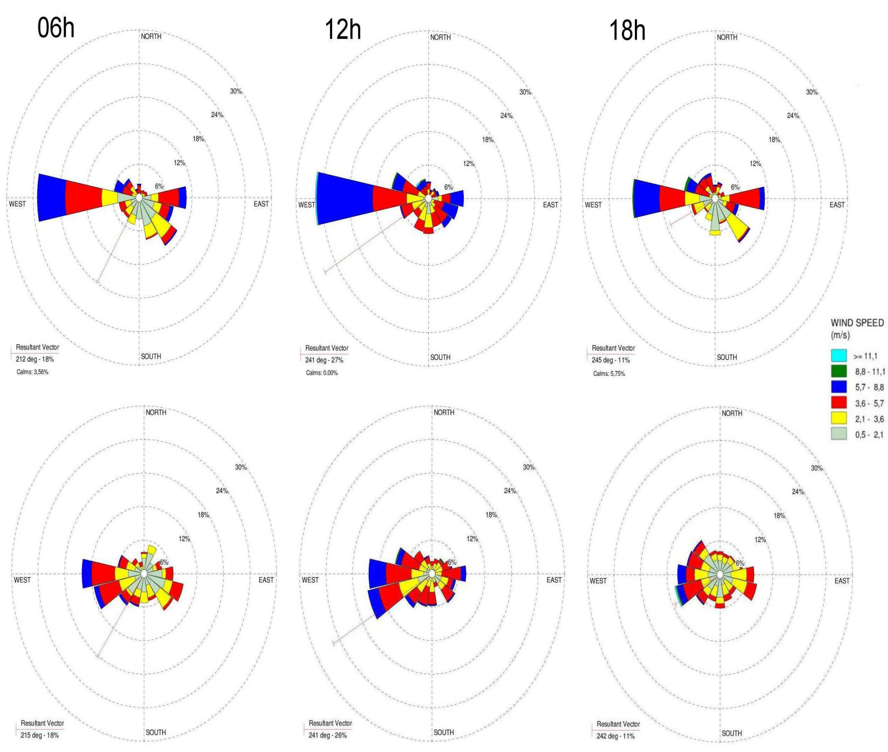

Figure 6: Hourly wind roses for 2015 year at Okęcie station. From left: 06h 12h 18h, top – synop, bottom - model

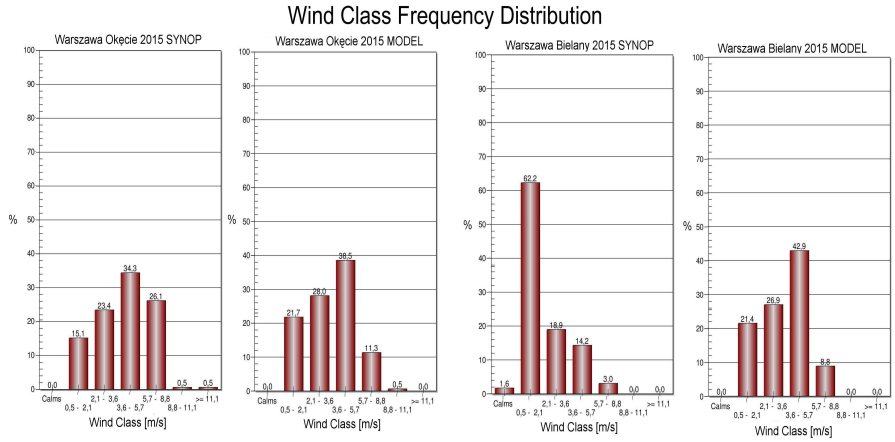

Figure 7: Wind class frequency distribution for 12 hour. From left: Okęcie synop/model, Bielany synop/-model

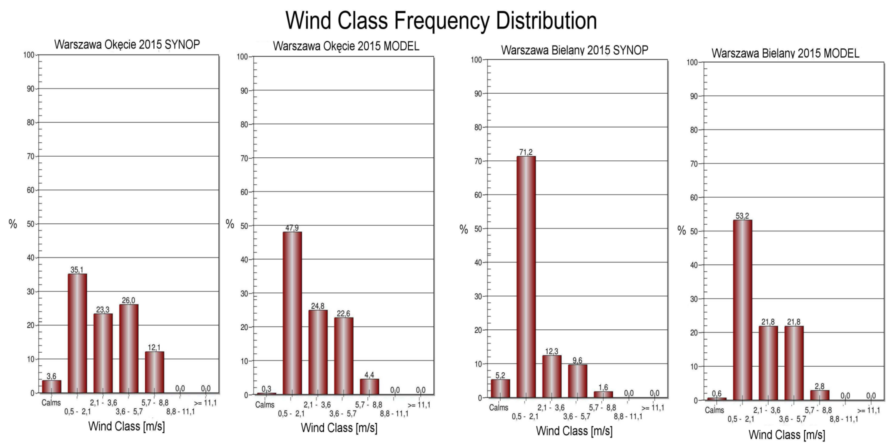

Figure 8: Wind class frequency distribution for 06 hour. From left: Okęcie synop/model, Bielany synop/-model

Monthly average wind speeds of 06 and 18 hour are similar in nature. In some months, we notice higher value of wind speeds for the 06 hours and the other for 18 hours. Therefore, to follow runs in individual wind speed classes only hours of 06 and 12 were selected (Fig 7,8). The general character of individual classes of wind frequency from the 12 hour is similar for Okęcie station and COSMO model.

The classes for higher wind speed (5.7-8.8 m/s) are significantly lower in the model (around 15%), whereas three lower wind speed classes from (0.5 to 5.7 m/s) are higher in the model (about 5% in each of these classes). At the station Bielany wind class frequency distribution from the 12 hour is completely different between model and the observations (Fig 7).

In model, the most numerous class is (3.6-5.7 m/s), which accounts for over 40% of cases, while at the station the most numerous class is (0.5-2,1 m/s) which accounts for over 60% of wind speed cases. The model for station Okęcie predicts for the classes (3.6-8.8 m/s) wind speeds lower than observed, while for the station Bielany the wind classes (2.1-8.8 m/s) have significantly higher speed than the observed one.

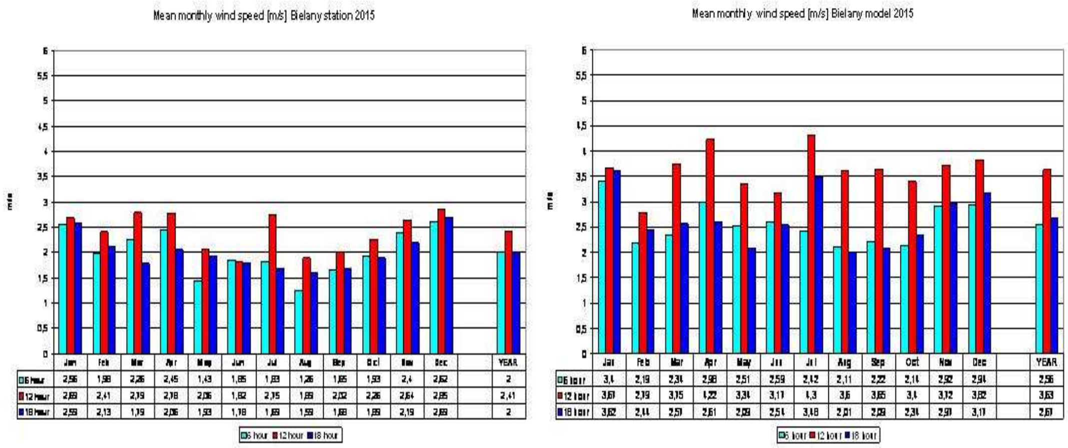

Figure 9: Mean monthly observation wind speed from 6,12,18 hours: Bielany,top/bottom station- model during the 2015 year

In the course of annual wind speeds from three terms (Fig. 9) at the station Warsaw-Bielany, the highest wind speeds we observe for the case of 12 hours, while the speed from hours 06 and 18 are smaller and have similar values to each other. The greatest differences in the course of the day between the hours of 12 and 06 and 18 are observed in July and the smallest in January, where the wind speeds during the day are very close to each other.

At the station Bielany we notice the lower wind speeds in the warm season from May to October (except for 12 hours in July), while higher wind speeds in the cold season from November to April. Comparing observational data with data from COSMO model we notice a higher wind speeds in model than observed at the station with a clearly dominant speeds from 12 hours.

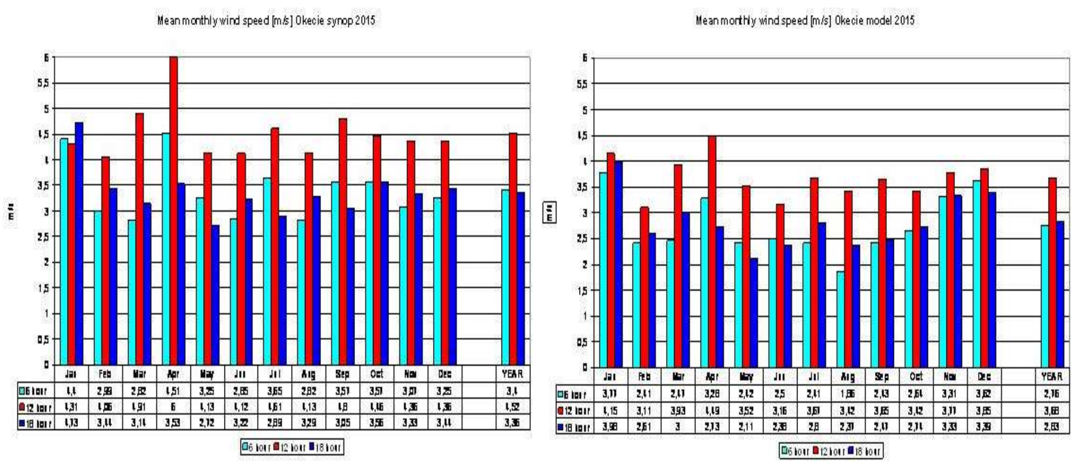

Figure 10: Mean monthly model wind speed from 6,12,18 hours: Okęcie, top/bottom synop-model during 2015 year

At the station Warsaw-Okęcie SYNOP data don't mark clearly the annual course (Fig.10) Wind speeds from 12 hour are dominant and their typical values for all months exceeds 4m/s. The exception is January where the difference in speeds between 06,12,18 hours are minimal and the highest wind speed is observed at 18 hour. The highest diurnal wind speed occurred in the month of April with a maximum 6 m/s for 12 hour case, and in January. The yearly velocity distribution in the 06,12,18 hours is different. The model forecasts in general underestimate the observations, which is well-preserved character of daily run.

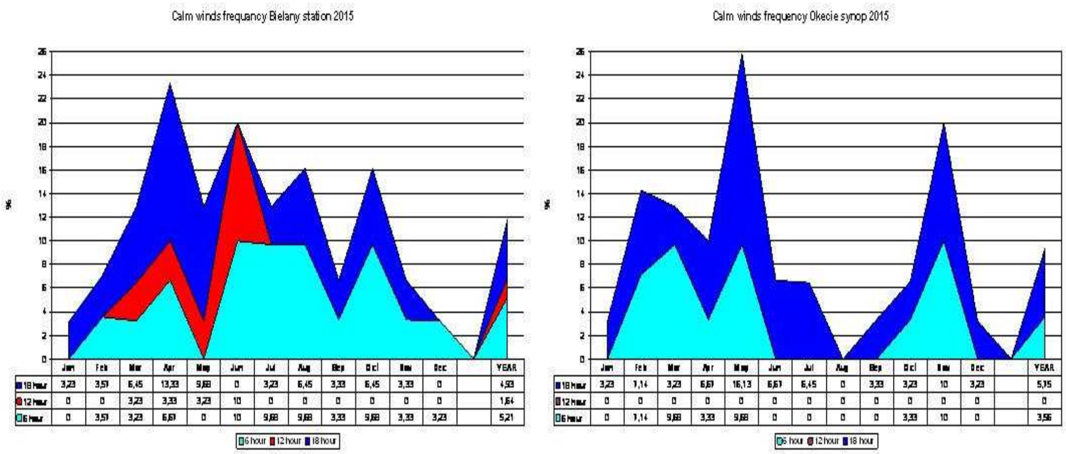

Figure 11: Calm wind frequency from 6,12,18 hours: top Bielany/bottom Okęcie in 2015 year

Figure 11 shows the calm wind frequency at the stations Bielany and Okęcie in selected hours of the day. At the station Okęcie of 12 hours there is no single case of calm wind in any month. For a few months in the summer and winter there was no calm wind at 06. In August there were no calm winds for any term during the day. Much more calm winds is observed at the station Bielany. In the months March and April calm wind is observed in all 06,12,18 hours. Minimum amount of calm winds we observe during the winter and maximum during the spring. In the COSMO model (tab.1,2) calm winds practically are not predicted very often (less than 1%) and are included in the lowest class of wind speed.

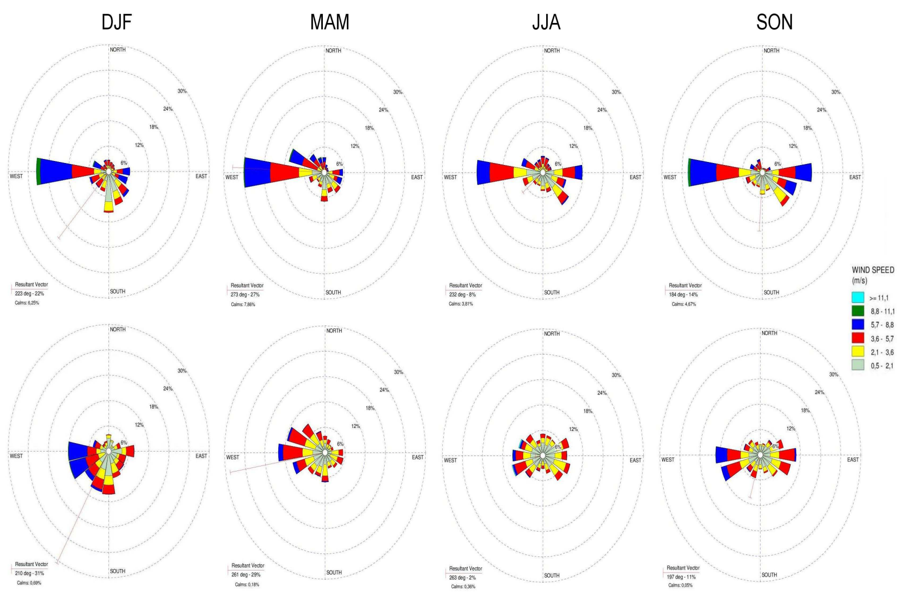

Figure 12: Seasonal wind roses: from December 2014 to November 2015 top, Okęcie synop , bottom Okęcie model

By analyzing the seasonal wind speed at the station Okęcie (Fig.12) we see the dominance of typical western circulation. However, in the individual seasons of 2015 there are observable differences in the flow direction. In the winter and spring (DJF, MAM) there are southern wind components, whereas at the end of summer (JJA) and autumn (SON) there are periods with a predominance of eastern and south-eastern winds. The model shows smaller wind speeds than the observed and a greater spread of wind directions.The best compatibility

Table 3: Seasonal average wind speed and calm wind,Okęcie 2015

Season	DJF	MAM	JJA	SON
avg. wind speed (m/s) synop	3.79	3.71	3.27	3.57
avg. wind speed (m/s) model	3.29	2.90	2.66	2.90
calm wind (%) synop	6.25	7.86	3.81	4.67
calm wind (%) model	0.69	0.18	0.36	0.05

of wind directions is during the autumn (SON).

In winter (DJF) directional dispersion in the model comes from the west to the south and for spring from the south-west to north-west. The highest amplitude of seasonal wind speeds is during winter (DJF) and the lowest in summer (JJA) (Tab.2). The model generated wind speed are for the whole season smaller than observed.

The lowest wind speed differences between observations and model are in winter (DJF) and the highest in spring (MAM). By analyzing calm winds, we see that in the model they are practically not existent. In the observation at the station Okęcie calm winds have higher values in winter (DJF) and spring (MAM) than in summer (JJA) and autumn (SON). In the spring, the amount of calm wind maximal and reaching almost 8%.

Summary

The aim of our work is to assess usability of model generated wind data for the idea of Smart Cities to exploit renewable energy of wind in urban areas, and possibly its effect on the boundary later dispersion and reduction of smog. Wind speed in Warsaw is sufficient for the installation of modern wind turbines for the production of renewable energy in the city. We compared two stations of which Okęcie can be treated as a suburban station while Bielany as a station in the city center. We observe a clear influence of the city on reducing wind speeds and changing wind directions related to the city infrastructure and the Vistula river. Three hours (06,12,18) were selected from the station Okęcie for comparison with the data at the station in Bielany. Data from 3 hour average were compared with 24 hour averages at the station Okęcie resulting in very small differences of wind speeds and directions.

Numerical model forecasts were also compared with observational data with the major difference being a lack of the calm winds in the model forecast. At the station Okęcie model wind directions are more scattered and have lower amplitude of wind speed, but distribution in each class shows a large similarity with observations. For the station Bielany model predicts much higher wind speed than the observed and numerical forecast did not reflect properly the wind direction. The further research will be continued with the direct implementation of urban effects within the TERRA-URB parametrization implemented the COSMO model.

References

[1] Lakes environmental software WRPLOT View *https://www.weblakes.com/products/wrplot/*

[2] Starosta K.,and Wyszogrodzki A.: Assessment of model generated wind energy potential In Poland. COSMO News Letter No.16