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Approaches to rainfall estimation and forecasting for urban wastewater disposal

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Abstract. The main disadvantages of the existing method of dealing with atmospheric precipitation in Saint Petersburg are examined. A new approach for automated measuring, monitoring, and forecasting atmospheric precipitation in a large industrial city (a case study of Saint Petersburg) was developed. A flowchart for an automated information system for atmospheric precipitation monitoring and forecasting is presented. To forecast precipitation amounts, an adapted mesoscale meteorological model Weather Research and Forecasting (WRF) was used. Daily sums of precipitation at the pilot training area (5 November–15 December 2015) were used as the initial raw information. Actual and forecast daily sums of precipitation were compared. Using statistical analysis, it was determined that the differences between them were insignificant. The examined computer information system for monitoring and forecasting atmospheric precipitation allows accurate gauging and predicting their daily sums. It might be used in operational practice for supporting the operation of the local municipal service, responsible for the functioning of the city's infrastructure.

Key words: rain gauge system, Saint Petersburg, automatic precipitation gauge, daily precipitation sums, forecasting model, regression technique.

INTRODUCTION

Saint Petersburg and its suburbs are located in the Atlantic continental area of the temperate zone. The city's climate has both oceanic and continental features, with quite mild winters and relatively hot summers. By its geographical location the city is in the humid zone where rainfall is largely determined by the intensity of cyclone activity [3, pp. 6, 99; 5, pp. 43–49; 11, pp. 420–423].

Environmental sanitation in big cities depends to a large extent on sustainable and effective operation of their wastewater disposal systems (canalization), ensuring disposal and treatment of all types of wastewater, as well as processing and use of sediments formed during the treatment [2, p. 1]. Lack of attention towards well-timed disposal of stormwater often leads to flooding at some areas, breaks in operation of various enterprises and transportation, damage to equipment and materials stored at warehouses and ground floors, and other emergencies. Damage caused by heavy rainfall might sometimes be compared to the damage caused by large-scale fires [6, p. 3; 12, pp. 137–141].

Saint Petersburg – the northern largest metropolis in Russia – occupies an area exceeding 1400 km^2. The distribution of daily sums of atmospheric precipitation over such a vast territory is not homogeneous. The existing method of gauging atmospheric precipitation in the city has several disadvantages: significant inaccuracies in measurements, absence of an automated system for measuring precipitation amounts, absence of an operational data transmission system that would deliver theme assured data to municipal services supporting the

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city's infrastructure operation. Real-time monitoring, statistical analysis, and forecasting of daily rainfall sums are among the most important tasks for the Roshydromet as rainfall sums affect urban rainwater disposal systems. However, to carry out their responsibilities in supporting the population's comfort, the housing services and utilities, the Ministry for Civil Defence, Emergencies and Elimination of Consequences of Natural Disasters and subdivisions of the State Unitary Enterprise 'Vodokanal of St. Petersburg' require a more effective system of monitoring and forecasting daily precipitation sums. Suggesting such a system is the primary goal of this paper.

MATERIALS AND METHODS

In accordance with the requirements of Roshydromet and the World Meteorological Organization (WMO) [7, p. 7; 8, p. 164], atmospheric precipitation measurements are made with an automatic precipitation gauge. Application of the gauge allows achieving the required measurement range and accuracy. A precipitation gauge OTT Pluvio2 (Fig. 1) is one of such automatic gauges that has the Rosstandart type approval Certificate of measuring instruments (see Appendix 1) and has proven itself in contemporary international practice. The OTT Pluvio2 gauge is made by the well-known German company OTT Hydromet GmbH; the Russian company KNTP is its authorized dealer as well as an industrial partner of the Russian State Hydrometeorological University (RSHU).

Fig. 1. General layout of the automatic OTT Pluvio2 gauge.

The OTT Pluvio2 gauge measures atmospheric precipitation using the weighing principle. It measures both the amount and intensity of liquid, solid, and mixed types of precipitation. Unlike other producers' gauges the OTT Pluvio2 measures the weight of precipitation in a container. Most existing gauges made by other companies operate on a different principle: they collect water and snow and when their amount reaches a particular weight the cup overturns, thus, they count the number of dumpings. According to the Pluvio2 developers it measures the weight of the container regardless of the amount of the water inside, and that is its main advantage over competing tools. Besides, it also allows considering such factors as temperature and wind speed, which might impact measurement results.

The margins of random error while measuring precipitation with the OTT Pluvio2 automatic gauge are shown in Table 1. Measurement errors meet the requirements set for newly implemented measuring tools [7, p. 7].

The gauge was placed at the pilot testing area on Beliy Island. The gauge installation and the set-up of the OTT netDL 1000 data logger, necessary for the collection and transmission of precipitation data to a server, were carried out by the KNTP LLC.

Daily sums of atmospheric precipitation at the testing area (5 November–15 December 2015) were used as initial primary information.

The forecasting of hydrometeorological variables is based on various data, coming from different sources, which implies the possibility of using such data for developing an integrated input database for a forecasting model. In this research an adapted mesoscale meteorological Weather Research and Forecasting (WRF) model was used (Fig. 2). The WRF model is a numerical weather prediction system, which can be used both for forecasting hydrometeorological variables and for scientific research in the field of hydrometeorology. It was developed by a scientific community in the USA, including the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR). In Russia this model is widely used as a supplementary weather forecasting tool (in the Hydrometeorological Center of Russia, Far Eastern Regional Hydrometeorological Research Institute (FERHI), and RSHU) for atmospheric research [10, p. 5–15] and as a tool for dealing with radar data [1, pp. 5–19].

Table 1. The margin of error comparison

Measured parameter	Unit of measurement	Measurement range	Resolution	Absolute error	Ratio error, %
Amount of precipitation in integration interval	mm	0.20–500.00	0.01	+0.1	+5
Precipitation tank fill-up	mm	0.20–1700.00	0.01	+0.1	+5

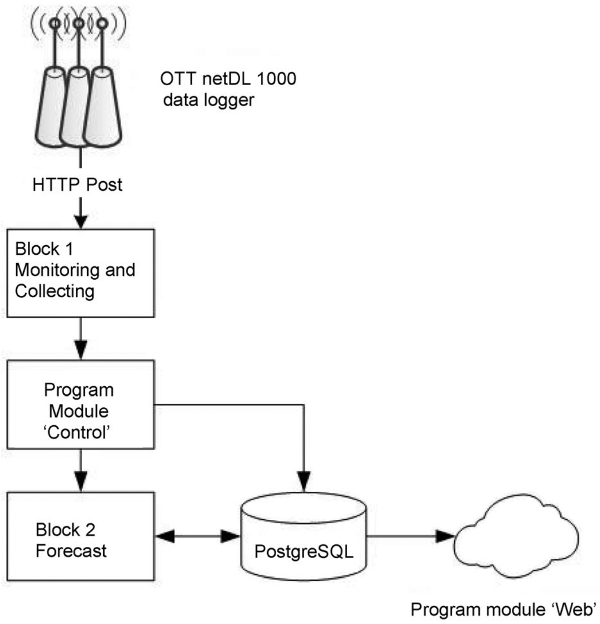

Fig. 2. Flowchart for the model of the automated information system for monitoring and forecasting stormwater runoff balance for a city's wastewater disposal systems.

The numerical mesoscale WRF model is a system that consists of program modules: module for initial and boundary data preparation (WRF Preprocessing System), hydrometeorological data assimilation module (WRF Data Assimilation), dynamical solver (Advanced Research WRF), post-processing module (WRF Post-processing System).

The initial data for forecasting include:

- data from the external global meteorological model GFS (Global Forecast System) or NCEP; GRIB2 format;
- hydrometeorological data from Roshydromet network stations, directly located in the area of modelling; GRIB format; and
- data on radial speed and radar reflectivity, provided by the Doppler weather radar; LITTLE_R format.

The result of the forecasting model processing is a forecast of hydrometeorological characteristics for the next day. For the underlying surface the following parameters are forecast: surface pressure, wind speed, wind direction, temperature, relative humidity, and intensity and amount of atmospheric precipitation. While forecasting the amount of atmospheric precipitation their accumulated sums for the period of calculation were determined. Grid spacing was 10 km, the values of the hydrometeorological parameters were recorded at 1 hour interval.

Upon the forecasting block completion, the forecast results are reformatted and saved in the database.

Table 2. Numerical characteristics of the data

Parameter	Roshydromet	Forecast	Pluvio2
Mean	4.3849	1.99	2.63
Standard deviation	9.99	5.99	6.58
Variance coefficient	2.27	3.00	2.49
Minimum	0	0	0
Maximum	49.00	40.76	42.76

Table 3. Correlation between different data

Correlated data	Correlation coefficient
Forecast – Pluvio2	0.86
Pluvio2 – Roshydromet (observed)	0.67
Forecast – Roshydromet (observed)	0.74

RESULTS AND DISCUSSION

For assessing the quality of daily sums of atmospheric precipitation forecasting in Saint Petersburg the relationship between forecast ($Q_{forecast}$) data, actual (Q_{actual}) data provided by the Roshydromet, and data measured with Pluvio2 (Q_{pluv}) at the pilot testing area was analysed. The numerical characteristics of the data are presented in Tables 2 and 3.

According to the Chaddock scale, the calculated correlation coefficient for Forecast–Pluvio2 $r = 0.86$ proves a very close relationship between forecast and actual daily sums of atmospheric precipitation [4, p. 252].

Another way to assess the forecast quality was based on testing the hypothesis about the equality of two distribution centres [9, pp. 239–240]. For this, the means of actual and forecast amounts of atmospheric precipitation and their dispersions (σ^2) were calculated. As a result the following values were determined: the mean of $Q_{pluv} = 2.63$; $\sigma^2 = 6.58$; the mean of $Q_{forecast} = 1.99$; $\sigma^2 = 5.99$. This shows that the difference between the means should be considered insignificant. Therefore, the difference between actual and forecast daily sums of atmospheric precipitation is not significant either.

CONCLUSIONS

The examined computer data system for monitoring and forecasting atmospheric precipitation allows making reliable one-day-ahead atmospheric precipitation amount forecasts. Statistical analysis of the three data types (Roshydromet observations, measured with Pluvio2, and forecast data) allowed us to draw the following conclusions:

- the most reliable correlation exists between the forecast data and the data measured with Pluvio2 ($r = 0.86$);
- the Roshydromet observation data correlates to the data measured with Pluvio2, but is twice as big as the measured data.

The results of this investigation quite well correspond to the results of the statistical analysis of precipitation distribution over the Saint Petersburg territory (2012–2013), which stated spatial variability of precipitation sums and pointed out that additional rain gauges should be installed for more accurate atmospheric precipitation accounting.

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APPENDIX 1

Certificate of measuring instruments


ФЕДЕРАЛЬНОЕ АГЕНТСТВО
ПО ТЕХНИЧЕСКОМУ РЕГУЛИРОВАНИЮ И МЕТРОЛОГИИ

СВИДЕТЕЛЬСТВО

об утверждении типа средств измерений

DE.C.27.010.A № 34342/1

Срок действия до 27 декабря 2018 г.

НАИМЕНОВАНИЕ ТИПА СРЕДСТВ ИЗМЕРЕНИЙ
Датчики атмосферных осадков OTT Pluvio^2 200, OTT Pluvio^2 200 RH, OTT Pluvio^2 400

ИЗГОТОВИТЕЛЬ
Фирма "OTT Hydromet GmbH", Германия

РЕГИСТРАЦИОННЫЙ № 39842-08

ДОКУМЕНТ НА ПОВЕРКУ
Приложение К к Руководству по эксплуатации

ИНТЕРВАЛ МЕЖДУ ПОВЕРКАМИ 2 года

Свидетельство об утверждении типа продлено приказом Федерального агентства по техническому регулированию и метрологии от 27 декабря 2013 г. № 1532

Описание типа средств измерений является обязательным приложением к настоящему свидетельству.

Заместитель Руководителя
Федерального агентства Ф.В.Булыгин

"30" 12 2013 г.

Серия СИ № 013434

REFERENCES

1. Veltishchev, N. F. and Zhuponov, V. D. Experiments on radar reflectivity data assimilation in the WRF-ARW model. *Meteorologiya i gidrologiya*, 2012, No. 3, 5–19 (in Russian).
2. Karmazinov, F. V. *Povyshenie ekspluatatsionnoj nadezhnosti, upravlyaemosti i effektivnosti sistemy vodootvedeniya krupnogo goroda* [Increasing maintenance reliability, controllability and efficiency of a large city water disposal system]. Doctoral Dissertation. Saint Petersburg, 2000 (in Russian).
3. Meleshko, V. P. (ed.). *Klimat Sankt Peterburga i ego izmeneniya* [Climate of Saint Petersburg and its changes]. The Voeikov Main Geophysical Observatory Publ., Saint Petersburg, 2010 (in Russian).
4. Makarova, N. V. and Trophimets, V. Ya. *Statistika v Excel* [Statistics in Excel]. Finansy i statistika Publ., Moscow, 2002 (in Russian).
5. Malinin, V. N. and Guryanov, D. A. Atmospheric circulation impact on winter temperature variability in Saint Petersburg. *Izvestiya Rossiiskogo Pedagogicheskogo Universiteta A. I. Herzen,* 2014, No. 168, 43–49 (in Russian).
6. Alekseev, M. I. and Kurganov, A. M. *Organizatsiya otvedeniya poverkhnostnogo (dozhdevogo i talogo) stoka s urbanizirovannykh territorii* [Organization of surface runoff (rainfall and snowmelt) diversion from urbanized territories]. ACB SPbGASU Publ., 2000 (in Russian).
7. RD 52.18.761–2012 Sredstva izmerenij gidrometeorologicheskogo naznacheniya setevye. Obshchie tekhnicheskie trebovaniya [Hydrometeorological network measurement tools. General specifications] (in Russian). https://www.normacs.ru/Doclist/doc/11HUA.html (accessed 2016-12-15).
8. Guide to Meteorological Instruments and Methods of Observation. WMO-No. 8, 2008.
9. Smirnov, N. V. and Dunin-Barkovsky, I. V. *Kratkij kurs matematicheskoj statistiki dlya tekhnicheskikh prilozhenii* [Short course of mathematical statistics for technical applications]. Fizmatgiz Publ., Moscow, 1959 (in Russian).
10. Smirnova, M. M., Rubinstein, K. G., and Yushkov, V. P. Evaluation of atmospheric boundary layer's characteristics presenting with the regional model. *Meteorologiya i gidrologiya*, 2011, No. 12, 5–16 (in Russian).
11. Frumin, G. T. and Davydenko, E. V. Interannual dynamics of atmospheric precipitation in Saint Petersburg. In *Materialy 9 mezhdunarodnoj nauchno-prakticheskoj konferentsii* '*Analiz, prognoz i upravlenie prirodnymi riskami v sovremennom mire (GEORISK – 2015)*' (Osipov, V. I., ed.). Vol. 1. RUDN Publ., Moscow, 2015, 420–423 (in Russian).
12. Frumin, G. T., Dikinis, A. V., and Krashanovskaya, Y. V. Concentration of metals in soils of St. Petersburg. *Ecologicheskaya khimiya*, 2015, **24**(3), 137–141 (in Russian).

Sademete hulga ja linnades ärajuhtimist vajava heitvee koguse prognoosimisest

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On uuritud Sankt-Peterburgis kasutusel oleva sademevee mõõtmise süsteemi puudusi. On välja arendatud suurele tööstuslinnale sobiv meetod automaatseks sademevee mõõtmiseks, seireks ja prognoosiks ning välja pakutud selle info graafilise esitamise viis. Prognoosimiseks kasutati selleks kohandatud WRF- (Weather Research and Forecasting) mudelit. Algandmetena kasutati katsepiirkonnas 5. novembrist 15. detsembrini 2015 mõõdetud sademete päevaseid summasid ja võrreldi tegelikke sademeid prognoositud kogustega. Statistiline analüüs näitab, et erinevused mõõtmise ja prognoosimise tulemuste vahel on tähtsusetud. Uuritud arvutiprogamm sademete seireks ja prognoosiks võimaldab täpset mõõtmist ning päevaste summade leidmist. Meetodit saab kasutada linna taristu talituse eest vastutava teenistuse igapäevatöös.