METEOROLOGICAL PARAMETERS CALCULATED FROM NUMERICAL WEATHER PREDICTION MODEL

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Abstract

Currently, two way relationship between meteorology and GNSS (Global Navigation Satellite Systems) is starting to be exploited. The GNSS community uses meteorological observations and models to address the signal propagation issues. The meteorology community is also applying GNSS observations into Numerical Weather Prediction, nowcasting and climate studies.

This paper is a part of a bigger study, which main goal is to build integrated model of troposphere from three main data sources: GNSS data, meteorological ground-based observations and NWP model. In this paper main focus is to inter-compare two last data sources. Chosen NWP model is Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). Outputs from COAMPS were interpolated into a position of stations using different methods and then compared with measurements on meteorological stations.

Keywords

GNSS meteorology, data validation, data integration

1 INTRODUCTION

The inter-dependence between meteorology and GNSS (Global Navigation Satellite Systems) has been growing for last decades, providing both communities incentives, data, and research challenges. This two way relationship resulted in using NWP models and meteorological observations in the GNSS processing to reduce the troposphere impact on the signal propagation (e.g. [4]). Whereas the GNSS observations are constantly gaining significance as an important data source in weather forecasting [1], nowcasting [3] and climate studies [8].

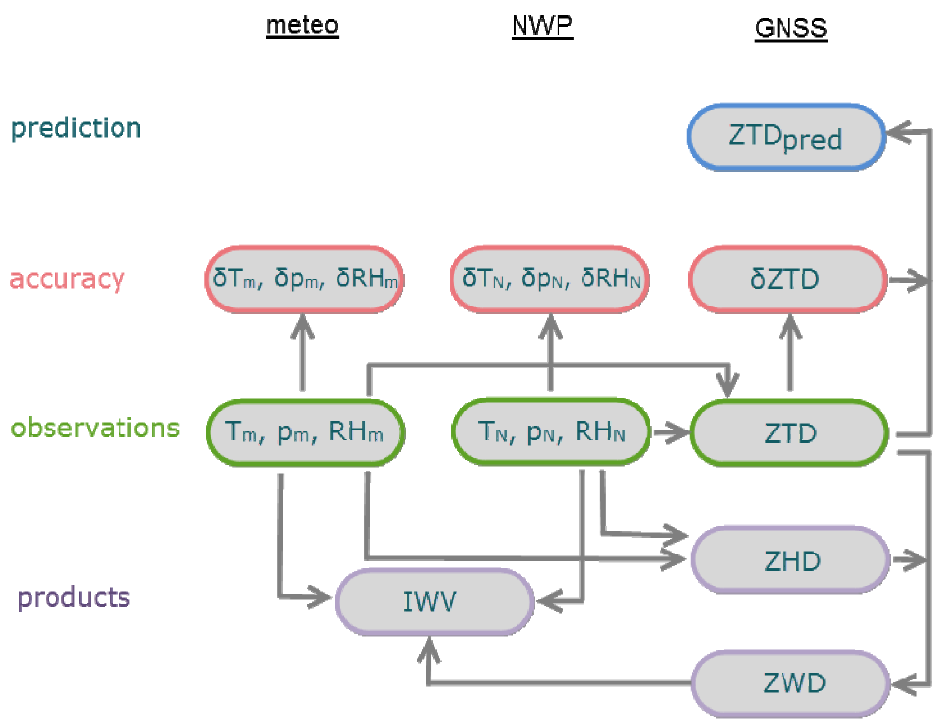

Fig. 1 Flow chart describing outputs from integrated model of troposphere

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This study is a part of a bigger project, which main goal is to build integrated model of troposphere. Figure 1 shows the overview of how the integrated model will look like. First step is to process the observations from three different sources (meteorological ground-based observations, meteorological parameters from Numerical Weather Prediction (NWP) models and Zenith Total Delay (ZTD) from GNSS stations) into one model with homogenous time and space resolution. Then the accuracy of parameters will be establish and some advanced products will be calculated, such as Zenith Wet Delay (ZWD), Zenith Hydrostatic Delay (ZHD) or Integrated Water Vapour (IWV). Final step is to obtain short-term predictions of ZTD.
In this study we describe one part of the first step, which is a comparison between meteorological parameters from ground-based meteorological stations and meteorological parameters from NWP model. The following section describes chosen NWP model, third section is about methods of interpolation, in section 4 we present some example comparisons and at the closure of this paper we present some conclusions.

2 NUMERICAL WEATHER PREDICION MODEL COAMPS

Numerical Weather Prediction (NWP) is one of the most common methods to forecast the weather. Several NWP models are exploited, but in this study we have chosen to use model COAMPS (Coupled Ocean/Atmosphere Mesoscale Prediction System). COAMPS was built in the Naval Research Laboratory in U.S. [5] and in Poland is provided by The Applied Geomatics Centre (CGS) of Military University of Technology in Warsaw (www.cgs.wat.edu.pl).
COAMPS outputs are in the form of 3-dimensional matrix, with dense horizontal grid (in this study 13x13 km grid was used) and 30 levels of σ-type vertical coordinate (that means, that height component follows Numerical Terrain Model). First σ-level is 10 meters above the terrain and last level is 31050 meters above the terrain (but levels are not uniformly distributed). The horizontal grid is shown in figure 2. COAMPS 24-hours predictions with 1-hour resolution are given twice a day (at 0:00 UTC and 12:00 UTC). In this study, three parameters from COAMPS were considered: air pressure, temperature and water vapour pressure (which is first converted into relative humidity to be interpolated into the stations locations and then converted back to water vapour pressure).

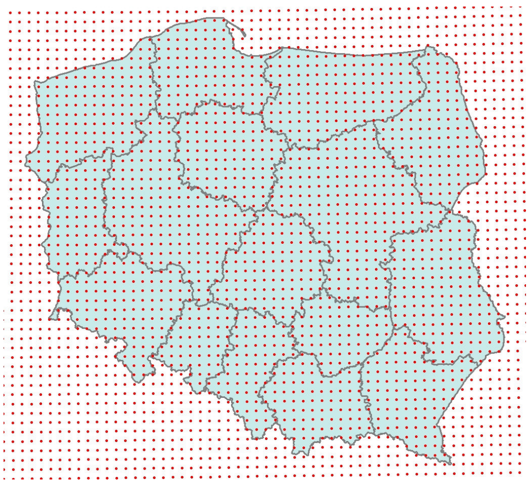

Fig. 1 *COAMPS horizontal node points over the area of Poland*

3 METHODS OF INTERPOLATION OF METEOROLOGICAL PARAMETERS

To compare meteorological parameters (temperature *T,* relative humidity *RH* and air pressure *p*) from COAMPS with meteorological parameters obtained from stations, we interpolate the parameters from COAMPS nodes to the location of station. First method (let's call it '4 points') was by using a weighted average from 4 nearest points [2]:

$$T = \frac{\sum_{i=1}^{n} T_i \cdot w_i}{\sum_{i=1}^{n} w_i}, \text{ where } w_i = \left(h - h_i\right)^{-4} \tag{1}$$

$$RH = \frac{\sum_{i=1}^{n} RH_i \cdot w_i}{\sum_{i=1}^{n} w_i}, \text{ where } w_i = \left(\left(x - x_i\right)^2 + \left(y - y_i\right)^2 + \left(h - h_i\right)^2\right)^{-2} \tag{2}$$

$$p = \frac{\sum_{i=1}^{n} \exp\left(\log P_i + \frac{h_i - h}{18400\left(1 + \frac{T + T_i}{540}\right)} \right) \cdot w_i}{\sum_{i=1}^{n} w_i}, \text{ where } w_i = \left((x - x_i)^2 + (y - y_i)^2 \right)^{-2} \quad (3)$$

where T_i, p_i, RH_i, h_i, x_i, y_i are tempereture, air pressure, relative humidity, height and horizontal coordinates of i-th COAMPS node respectively and *T, p, RH, h, x, y* are tempereture, air pressure, relative humidity, height and horizontal coordinates of interpolated station respectively.

For air pressure also another method of interpolation was adopted – modified formula given by Karabatić et al. [6]. In this method, only one closest COAMPS node is involved. That is why, in this study, we name this method 'The nearest neighbour' method:

$$P = P_C \left(\frac{T_C - \gamma(h - h_C)}{T_C} \right)^{\frac{g \cdot M}{R \cdot \gamma}} \quad (4)$$

where P_C, T_C and h_C are air pressure, temperature and height from the closest COAMPS node; $\gamma = 0.0065$ *[K/m]* is a temperature gradient; $M = 0.028944$ *[kg/mol]* is a molar mass of air; $R = 8.31432$ *[N·m/(mol·K)]* is a gas constant; Φ is a station latitude and g is a gravitational parameter given by Hitsh [7]:

$$g = 9.8063\left(1 - 10^{-7} \frac{h_C + h}{2} \left(1 - 0.0026373 \cdot \cos(2\phi) + 5.9 \cdot 10^{-6} \cdot \cos^2(2\phi) \right) \right) \quad (5)$$

4 COMPARISONS

When values of meteorological parameters from COAMPS nodes are interpolated into location of stations it is possible to compare them with values measured on stations. Three different types of stations were considered: the most accurate stations from EUREF Permanent Network (EPN) (but with only 8 constantly operating stations), 21 meteorological sensors at the airports ('METAR stations') and 96 meteorological stations that belongs to Institute of Meteorology and Water Management ('SYNOP' stations).

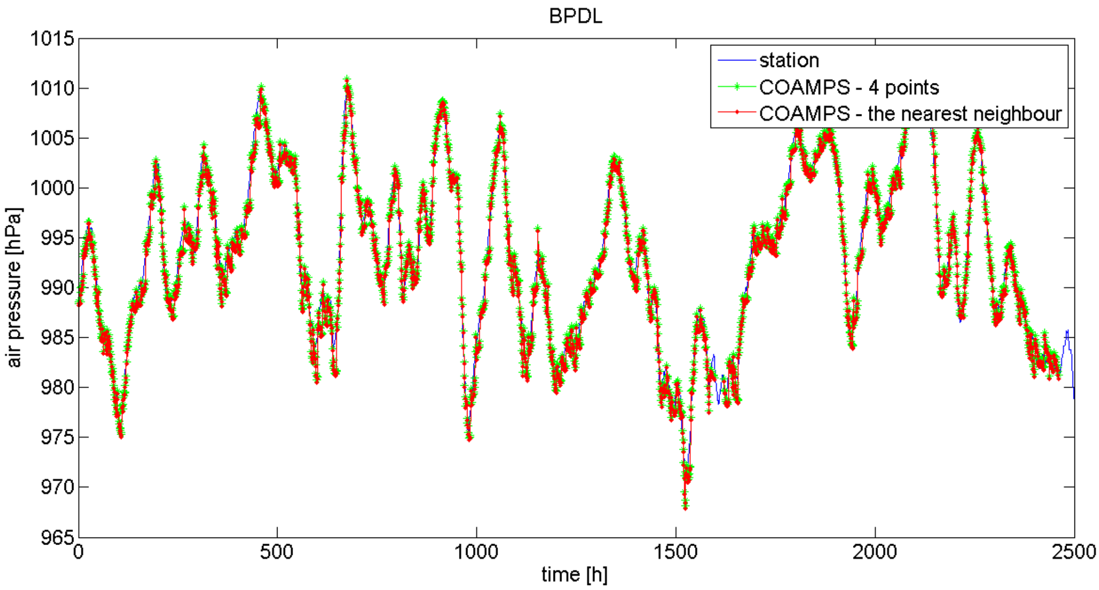

Fig. 3 *Air pressure comparisons between values at the station Biała Podlaska (BPDL) and COAMPS outputs (two methods of interpolation). Period: 1.12.2012-13.03.2013*

Figure 3 and 4 show comparison of air pressure, with two methods of interpolation for stations Biała Podlaska (BPDL) and Żywiec (ZYWI) respectively. These are EPN stations. For station BPDL, which is situated in lowland, methods interpolate values of air pressure very similarly and the interpolations are very close to measures values. But, for station

ZYWI, which is situated in mountainous area, '4 points' method interpolate values of pressure very badly – bias at the level of 30 hPa is observed. On the other hand, 'the nearest neighbour' method performs very well, same as in the lowlands. We observe this behaviour for all stations, that on lowlands both methods performed similarly, but in the mountains, 'the nearest neighbour' method was better. Therefore, only this method will be concerned in further analysis.

Figure 5 show comparison of temperature for station ZYWI. Only one method of interpolation was used. The biases from residuals (values of COAMPS minus measured values) are shown at the histogram on the right. Biases vary from -10 K to 10 K, but most frequently they equal to 3-5 K. In the case of relative humidity (fig. 6) comparisons performed much worse; we observe large biases – they are at the level -30 to -10%. If this is fault of inadequate method of interpolation or a NWP model, is a subject for further studies.

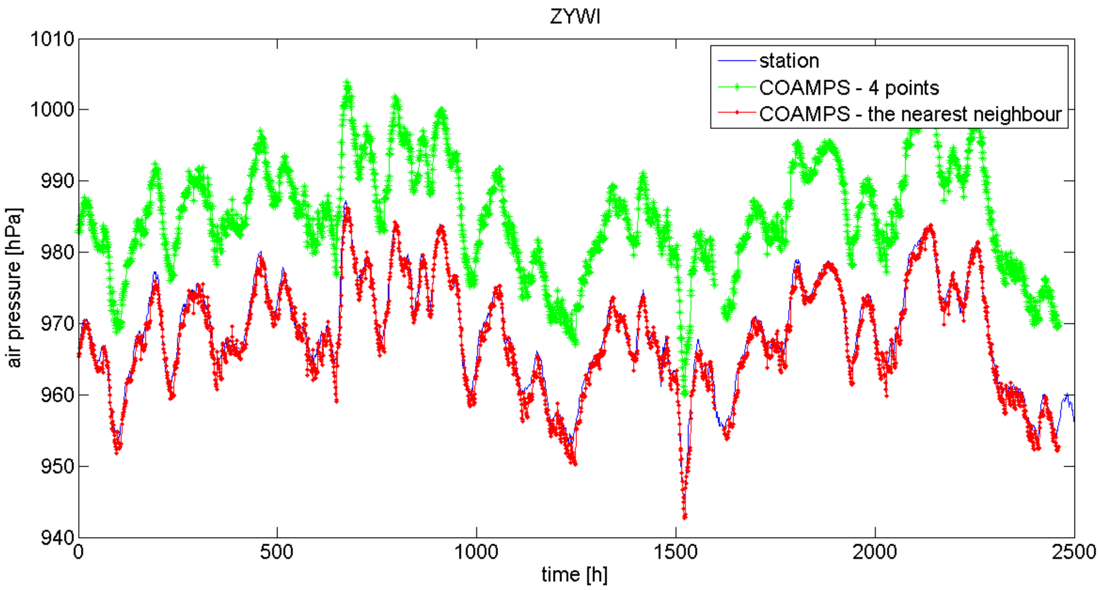

Fig. 4 *Air pressure comparisons between values at the station Żywiec (ZYWI) and COAMPS outputs (two methods of interpolation). Period:1.12.2012 - 13.03.2013*

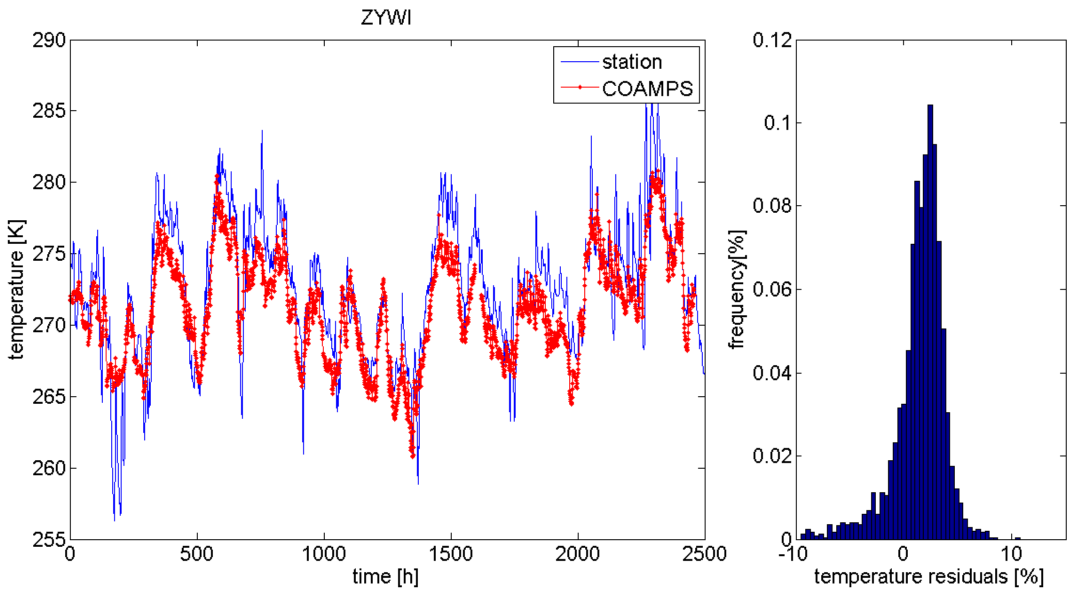

Fig. 5 *Temperature comparisons between values at the station Żywiec (ZYWI) and COAMPS outputs). Period: 1.12.2012-13.03.2013*

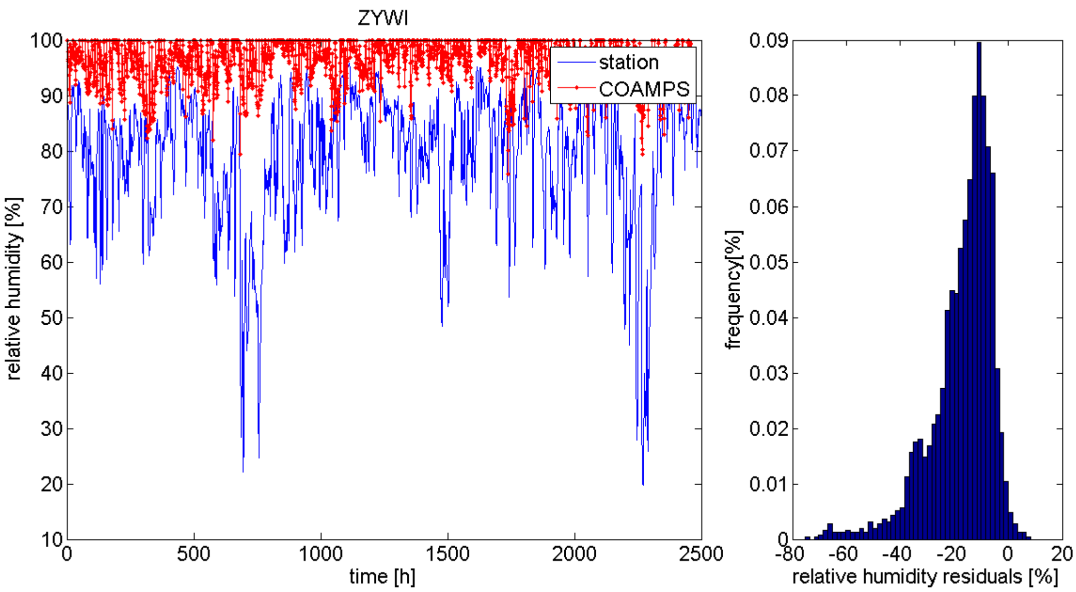

Fig.6 *Relative humidity comparisons between values at the station Żywiec (ZYWI) and COAMPS outputs). Period: 1.12.2012-13.03.2013*

We made such comparisons for every station with meteorological sensor. Figures 7, 8 and 9 show mean biases and standard deviations for all METAR and SYNOP stations for temperature, air pressure and relative humidity respectively. For temperature mean biases are at the level of -2 to 2 K, with few exceptions, that reach even -10 K. Standard deviations are evenly spread and equals to 2-6 K. For relative humidity the biases are much bigger and equals from -10 to -20 %, with standard deviations from 5 to 15 %. This is definitely to big dispersion and it requires further studies. In the air pressure case (with only 'the nearest neighbour' method of interpolation), Poland is divided to three subgroups – in the north biases are equal to 1-2 hPa; at the diagonal from north-west to south-east there are at the level of -5 hPa; and at south they are again positive and equal to 2-3 hPa. Standard deviations are at the level of 0-2 hPa, with the exception of earlier mentioned diagonal, where they are bigger and reach even the value of 8 hPa.

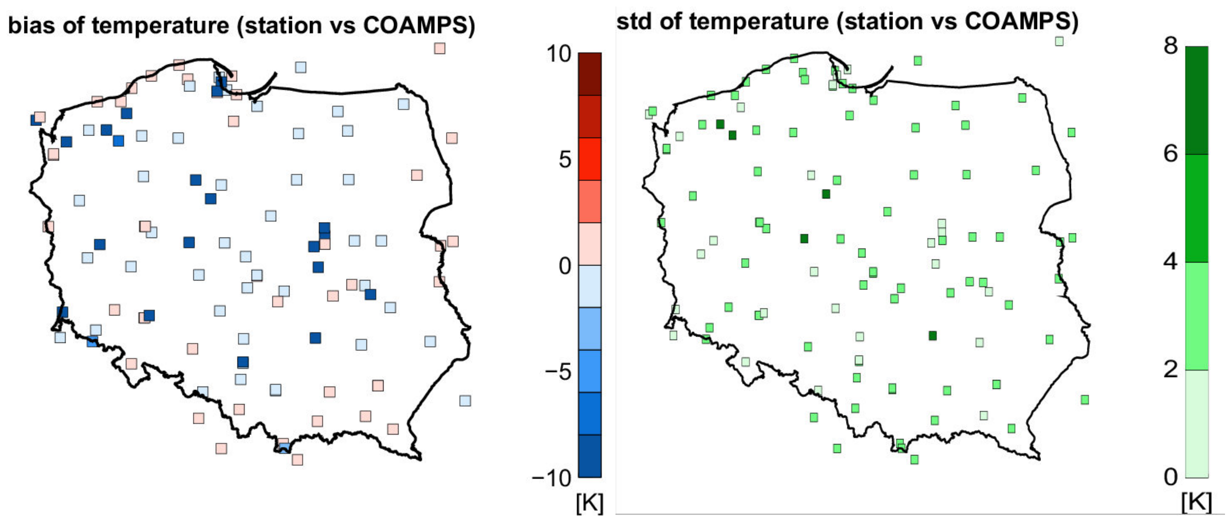

Fig.7 *Biases and standard deviations of temperature for all METAR and SYNOP stations.*

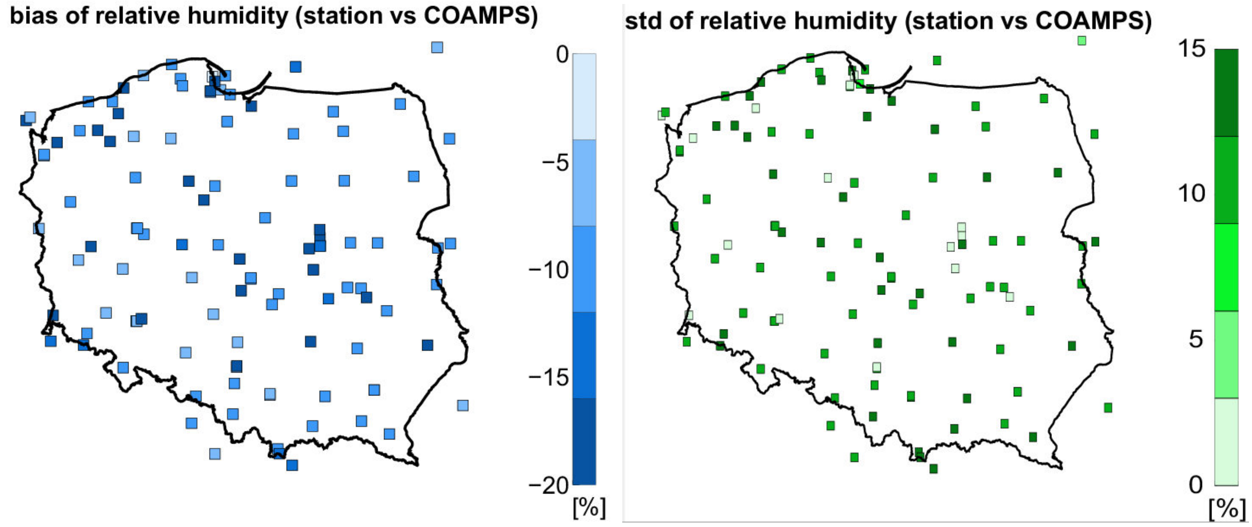

Fig.8 *Biases and standard deviations of relative humidity for all METAR and SYNOP stations.*

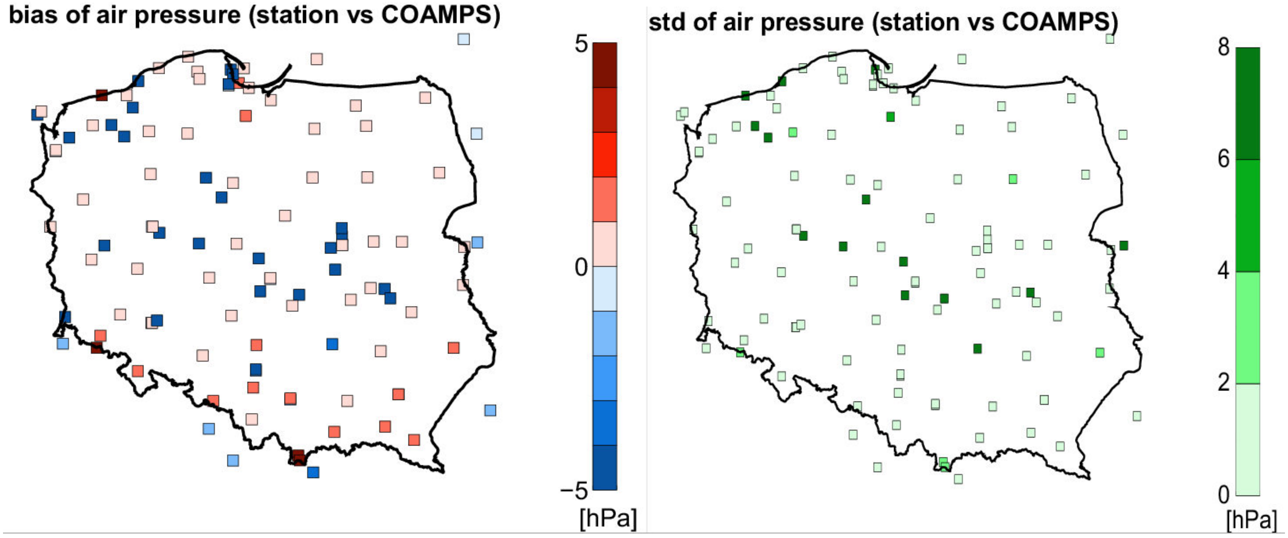

Fig.9 *Biases and standard deviations of air pressure for all METAR and SYNOP stations.*

5 CONCLUSIONS

We compare NWP model COAMPS outputs with meteorological parameters obtained from stations. The best results are in terms of temperature, where mean biases are in the level of -2 to 2 K with standard deviations 2-6 K. For air pressure we chose better method of interpolation, which is 'the nearest neighbour' method, and the biases are equals to 1-3 hPa for majority of Polish territory with standard deviations 0-2 hPa. We obtained the worst results for relative humidity with biases from -10 to -20 % and standard deviations from 5 to 15 %. We don't know if it this is caused by wrong interpolation method or bad measurements (on stations or in NWP model). Further studies on this problem will be performed. Next step is also to find a good accuracy assessment method, because we are not certain, if station sensors are not corrupted (we can be sure only in case of precise EPN sensors).

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