A comparison of the radiosonde and NCEP–NCAR Reanalysis data over Central Europe

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Abstract. The aim of this study is to determine the usefulness of the NCEP–NCAR (National Centers for Environmental Prediction & National Center for Atmospheric Research) Reanalysis data in investigating air temperature, the geopotential height of isobaric levels and wind parameters in the troposphere over Central Europe. The study compares the values of selected meteorological elements, designated on the basis of the NCEP–NCAR, with the values measured at four aerological stations: Łeba, Legionowo, Lindenberg and Poprad. The comparison was made by analysing the correlation coefficient, the mean error and the root mean square error. The analysis was conducted for six isobaric levels using daily data from the period 2001–2010. It was found that the reanalysis data show high concordance with the measurement data. Therefore, the NCEP–NCAR Reanalysis is a valuable source of data that can be used to study atmospheric processes. This applies to the whole troposphere, with the exception of its lower layers over mountain areas.

Key words

NCEP–NCAR Reanalysis, sounding, air temperature, geopotential height, wind parameters.

Introduction

Data from the free atmosphere constitute now one of the cornerstones of the weather forecasting. They are also more and more often used in climatology to analyse various meteorological elements. The main source of data from the free atmosphere is the direct measurements made during the aerological sounding, using the radiosondes. The results of such measurements are undoubtedly a valuable source of information for the daily weather service. However, they are rarely used by the climatologists. Long-term series of radiosonde data contain a number of deficiencies, sometimes even with respect to several years. In addition, aerological stations are unevenly distributed, making spatial analysis difficult, especially in areas where the density of these stations is small. Another source of data from the free atmosphere is meteorological reanalyses, resulting from the integration of a variety of measurement data (e.g. the radiosonde data), using mathematical models. The reanalysis data do not contain time gaps. Furthermore, owing to the use of interpolation methods, they are defined for equally distributed geographical grid nodes (the so-called grids). Currently, several independent gridded databases are available. Of these, the NCEP–NCAR Reanalysis (Kalnay et al. 1996) is used most often, among others, because of the long series of data, on-going updates and easy access.

Thus, a question arises whether a series of radiosonde data can be supplemented or even replaced with reanalysis data (Gaffen et al. 2000; Woyciechowska, Bąkowski 2006). Given the uncertainty associated with gridded data (resulting from the application of mathematical models and the integration of various input data), the answer to this question requires a prior evaluation of the quality of these data (Hodges et al. 2011), and their credibility in the study of weather and climate (Xinghua, Fuqing 2013). It seems that the easiest way to evaluate reanalysis data is to compare them with the measurement data. So far, a number of works making such comparisons mainly with the traditional data deriving from the measurements taken at the Earth's surface, have been developed. The results of reanalyses were also compared with the data from measurements in the free atmosphere (e.g. Marshall 2002; Woyciechowska, Bąkowski 2006; Xinghua, Fuqing 2013). However, studies of this kind, carried out for areas with different regional conditions, may yield different results. This is due to the presence of local atmospheric processes, the identification of which using the models of reanalyses is not appropriate everywhere (Schafer et al. 2003). The results of such studies are therefore not representative of the whole of the Earth, which is diverse in terms of the topography or the density of the measurement network. Thus, the continuation of studies comparing the results of reanalyses with the *in situ* data seems necessary.

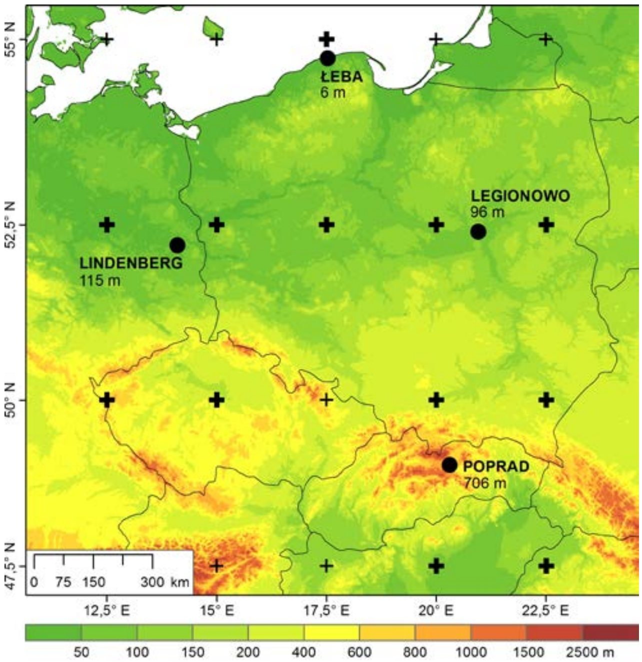

Figure 1. *The location of the aerological stations from which the data were taken (black circles) and NCEP–NCAR grid points used for interpolation (bolded black crosses). Terrain elevations according to USGS (2000). Stations elevations are expressed in meters a.s.l.*

Materials and methods

The purpose of this study is to determine the usefulness of the NCEP–NCAR Reanalysis data for studying the air temperature, geopotential height of isobaric levels as well as wind speed and direction in the troposphere over Central Europe. The study compares the values of selected meteorological elements obtained from the NCEP–NCAR data with the values measured at aerological stations in Łeba, Legionowo, Lindenberg and Poprad. The analysis was performed for six pressure levels: 850, 700, 500, 300, 250 and 200 hPa, using the daily values (00 and 12 UTC) from the period 2001–2010.

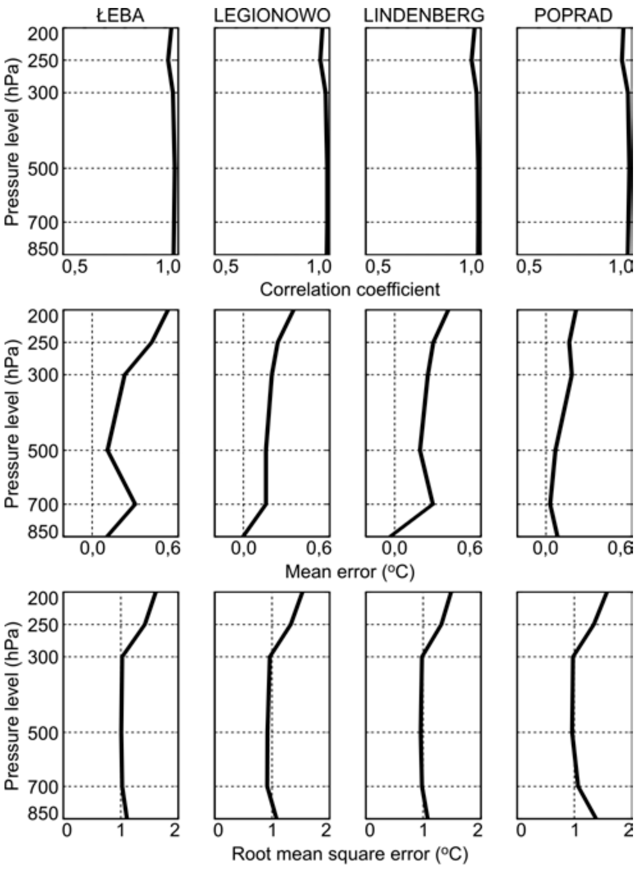

Figure 2. *Vertical profiles of the correlation coefficient, mean error and RMSE obtained by comparing the NCEP–NCAR and radiosonde data (air temperature) at four aerological stations in the period 2001-2010.*

The aerological data were obtained from the Department of Atmospheric Science, University of Wyoming. Unfortunately, these data contain time gaps, which is mainly due to the specificity of radiosonde measurements. The completeness of aerological data used in this study ranges from 87% in Łeba to 97% at the other stations. The NCEP–NCAR Reanalysis data are available for the geographical grid nodes distributed every 2.5° latitude and longitude. In order to allow direct comparison, the values obtained from the reanalysis were interpolated to the exact location of aerological stations using the bilinear interpolation method from the nearest four grid points (from two in the case of Łeba). The location of aerological stations considered in this study, along with the distribution of the grid points used for the interpolation, is shown in Fig. 1.

The comparison of the NCEP–NCAR data with the radiosonde data was performed using Pearson's correlation coefficient, the mean error and the root mean square error. In the case of wind direction, due to the vector nature of this variable, the calculation of standard correlation coefficients was not possible. Instead, an analysis of the differences between the frequencies of wind directions, calculated on the basis of the two data series was carried out. It should be noted that the values of the correlation coefficients presented in this paper are statistically significant at $p<0.05$. When calculating the mean error, the measurement data were subtracted from the NCEP–NCAR data. Thus, positive (negative) results of the mean error indicate overstated (understated) values of the reanalysis.

Results and disscussion

The comparative analysis of air temperature carried out indicates a high concordance of the NCEP–NCAR data with the measurement data, especially in the layer of the troposphere up to 300 hPa. This concordance is confirmed by the high values of the correlation coefficient (Fig. 2, top row), and the relatively small values of the mean error (Fig. 2, middle row) and RMSE (Fig. 2, bottom row).

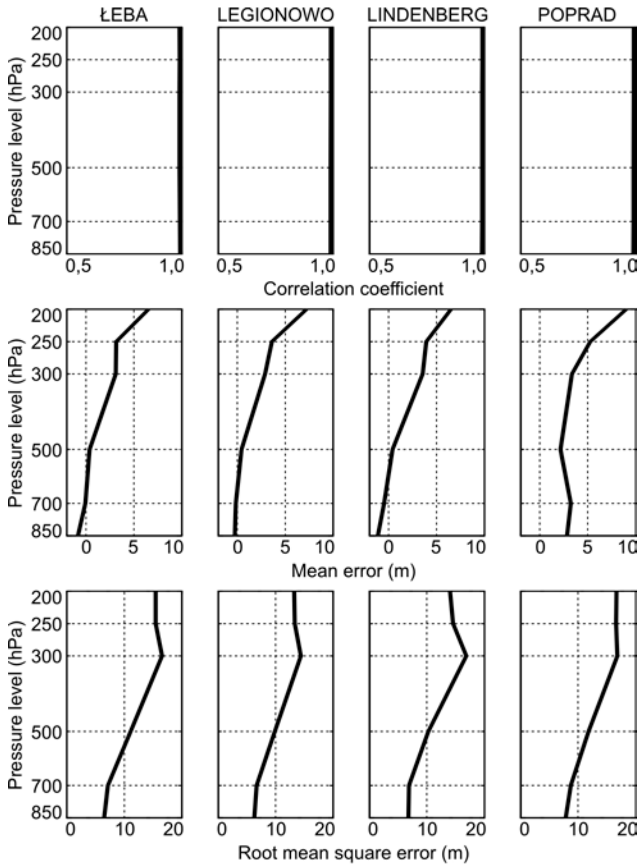

Figure 3. *As in Fig. 2, but for the geopotential height of isobaric levels.*

Above the level of 300 hPa, a slight decrease in correlation is observed, as well as an increase in the values of errors, which suggests less concordance between the two data series in this layer of the atmosphere. The lower concordance at the upper pressure levels was indicated earlier by Woyciechowska and Bąkowski (2006), who saw the reasons for it in the jet streams occurring there. The slight decrease in correlation coefficients, accompanied by an increase in RMSE, is also noticeable in the lower troposphere over Poprad, which is probably due to local conditions.

The results regarding geopotential height of isobaric levels reveal a very strong correlation between the reanalysis data and the radiosonde data at all the pressure levels studied (Fig. 3, top row). However, the analysis of the mean error and RMSE indicates less concordance, also varied depending on the isobaric level. The mean error takes the lowest values in the lower and middle troposphere and increases above the level of 500 hPa (Fig. 3, middle row). This is clearly visible in Łeba, Legionowo and Lindenberg. A slightly different vertical profile is characteristic of Poprad, over which the error discussed has relatively high values, already from the level of 850 hPa. RMSE also increases with altitude (Fig. 3, bottom row), reaching the highest values in the upper troposphere.

The comparative studies carried out for the wind speed show that the correlation coefficients between the data series under consideration reach the highest values in the upper troposphere and decrease with decreasing altitude (Fig. 4, top row).

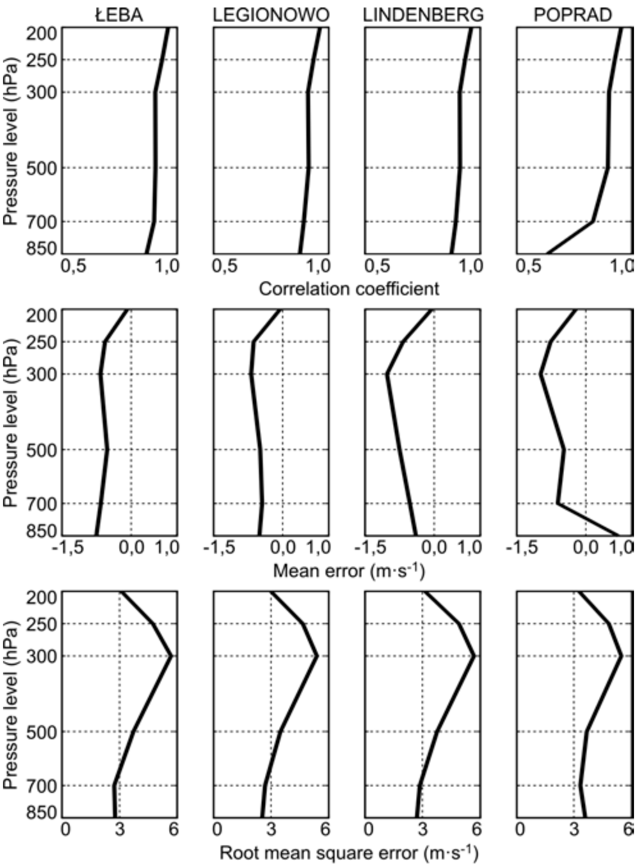

Figure 4. *As in Fig. 2, but for wind speed.*

High values of RMSE, at the level of 300 hPa, are worth noticing (Fig. 4, bottom row). They are most likely associated with the jet streams occurring at this altitude. Very high wind speeds accompanying jet streams are clearly underestimated by the reanalysis model, the evidence of which may be negative values of the mean error (Fig. 4, middle row). The level of 850 hPa over Poprad, where a big drop in the correlation coefficient and the simultaneous increase in the mean error are observed, is also worth noticing.

The final meteorological element examined in this study is the wind direction. The mean error values accompanying it amount to approximately zero in the upper and middle troposphere, rising only at the level of 850 hPa (Fig. 5, top row). A slightly different distribution is characteristic of RMSE, whose values increase gradually with the decreasing altitude (Fig. 5, bottom row). The increase in both errors, occurring at the level of 850 hPa, is particularly distinct in Poprad.

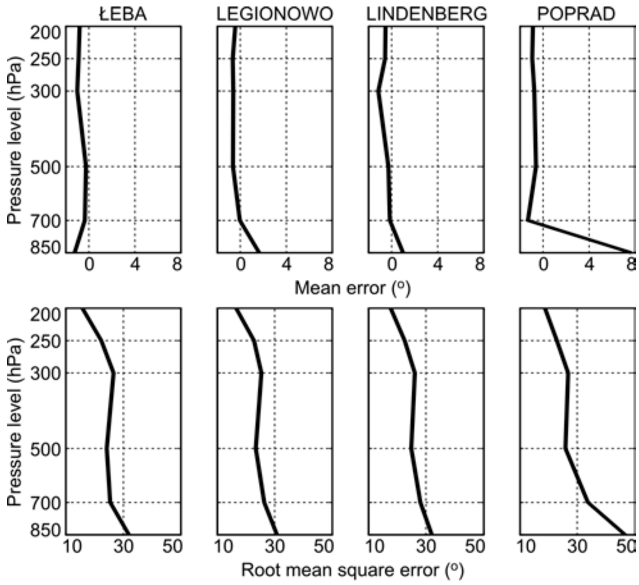

Figure 5. *As in Fig. 2, but for wind direction (note that the values of the correlation coefficient were omitted).*

In order to more closely define the concordance of the NCEP–NCAR data and the radiosonde data, the frequency of wind directions calculated on their basis was compared.

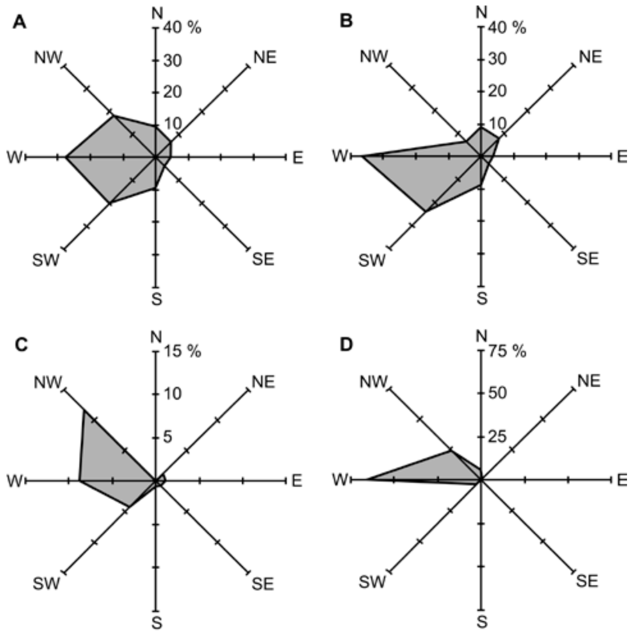

Figure 6. *The frequency of particular wind directions in Poprad at the 850 hPa pressure level in the period 2001–2010: according to the NCEP–NCAR data (A); according to the radiosonde data (B); the differences between A and B (C); according do the radiosonde data in the cases where the reanalysis indicates NW (D).*

It turns out that the average frequency difference is only 0.5%, with maximum differences reaching only 4%. These results do not take into account the level of 850 hPa in Poprad, which has been discussed separately. Figure 6 shows the frequency of wind directions in Poprad at the level of 850 hPa, obtained basing on the reanalysis data (A) and the radiosonde data (B). The differences between these frequencies are high, especially for the NW wind (Fig. 6C). As it can be seen in Fig. 6D, in the cases where the reanalysis indicates NW, the actual wind (from the radiosonde measurement) is mostly W. It should be noted that the aerological station in Poprad is situated in a valley enclosed from two sides by two mountain ranges (the Tatras and the Low Tatras). The NCEP–NCAR data, on the other hand, were interpolated to the position of this station from the grid points located in the areas with entirely different local conditions (see Fig. 1). It is therefore clear that the data obtained from the reanalysis cannot accurately reflect local atmospheric processes occurring in Poprad. This results in such large discrepancies in the case of both wind parameters.

Conclusions

Based on the studies carried out, it is concluded that the data from the NCEP–NCAR Reanalysis are characterised by a high concordance with the data from aerological measurements. This concordance is particularly distinct in the lower and middle troposphere, taking into account air temperature and the geopotential height of isobaric levels. In the case of wind speed and direction, the concordance discussed is high at all the isobaric levels examined. Poprad, where significant discrepancies are found in the lower troposphere, is an exception. The results regarding Poprad allow us to come to the conclusion that the reanalysis data, among others because of their low spatial resolution, are not suitable for analysing local atmospheric processes occurring in the lower troposphere over areas of high relief complexity. In conclusion, the NCEP–NCAR reanalysis is a valuable source of data that can be used to supplement or even replace radiosonde data. This applies to the entire troposphere, except for its lower layers over mountain areas, where reanalysis data should be verified every single time.

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