Introduction

A precise measurements of greenhouse gases (water vapour, carbon dioxide, methane etc.) exchange between the surface and overlying air play a vital role in the understanding of their cycle in the environment and their influence on global warming. New measurements techniques, such as eddy covariance, allow obtaining the long-term measurements of net turbulent fluxes of these gases. The results of measurements allows analyzing of intensity and directions of greenhouse gases exchange in different time scales i.e. day, season, year or even multi-year periods. The appearance of commercially available measurement systems, that took place about 20-30 years ago, contributed to the many research campaigns, whereby the variability of water vapour and carbon dioxide turbulent fluxes has been fairly well understood. Nevertheless, the number of sites where turbulent methane flux is measured is still small. It is a result of low availability of fast-response gas analyzers that have been commercially available for a few years. Since wetlands of temperate and subpolar latitudes, except for rice fields placed in the tropics, are the largest source of methane in the world, most measurements campaigns have been conducted there. The aim of this paper is to present the results of net turbulent methane flux measurements by means of eddy covariance.

Site and instrumentation

Department of Meteorology and Climatology, University of Lodz started the measurements of net turbulent methane flux in fall of 2012. The measurement site is located in Kopytkowo (53°35’20”N, 22°53’31”E, 110 m asl) at the southern edge of Czerwone Bagno (fig. 1, left and middle), in the centre of Biebrza wetlands. Biebrza National Park was raised to protect the largest natural wetland inside the borders of Poland. The Park itself covers the area of about 592 sq km wherein 255 sq km is occupied by swamps, 182 sq km by grasslands and agriculture and 155 sq km is occupied by forests. In the surroundings of the measurement site the typical for whole Biebrza wetlands mixture of sedges and rushes (fig. 1, right) can be found. The surface is rather flat and homogeneous except for the three houses located in Kopytkowo about 500 m to the south from the site.

The measurements are conducted with typical eddy covariance system consisting of sonic anemometer RMYoung 81000 (RMYoung, USA), Li7500 (H₂O/CO₂) and Li7700 (CH₄) fast response open path gas analyzers (Li-cor, USA). The sensors are mounted at 3.7 m height and operate at 10 Hz frequency. Despite the eddy covariance, additional sensors for measurements of the radiation balance components and standard meteorological parameters have been deployed (fig. 1, right).

Results and discussion

All data covering the periods with precipitation and atmospheric sludge have been omitted in further calculations. This step was essential as open path sensors have been used. According to
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Fig. 2. Comparison of net turbulent methane flux without correction ($F_{CH_4}$), with WPL correction added ($F_{CH_4}$ + WPL) and WPL + spectroscopic correction added ($F_{CH_4}$ + WPL + S). All good data form the period November 2012 – February 2014 has been used.

Theoretical background of eddy covariance, turbulent methane flux is computed as a covariance between fluctuations of vertical wind speed component and methane concentration in the air. Despite the relative simplicity of measurements and flux calculations the expanded data postprocessing (spikes detection, covariance maximization, coordinate system rotations etc.) and data quality control is necessary. One of the most important steps in data processing is the application of correction for air density changes (so called WPL). The lack of WPL correction would result in a flux overestimation of about 1% (fig. 2, left).

In contrary to carbon dioxide and water vapour fluxes measurements, for methane flux the additional correction connected with spectroscopic influence of temperature, air pressure and water vapour (Li7700 manual) is vital. The lack of this correction results in flux overestimation of about 2% (fig. 2, right). Another important issue is the choice of averaging period. The most commonly used intervals cover the range from 15 to 60 minutes, however, the choice is based on subjective decisions. The different averaging times applied for the same dataset may result in a great difference in the ultimate fluxes (fig. 3). The comparison of nearly 1-year time series, averaged with different periods, indicates that shortening of time interval results in the flux overestimation.

Except for the choice of the proper averaging period while processing eddy covariance data, one must answer the question what kind of average should be use. For ideally homogeneous turbulence in space and time the choice is not a matter, however, in real conditions the turbulence intensity alters simultaneously with diurnal course of thermal heating of the surface and air, the surface influence on wind speed etc. For such conditions the classical average, for instance may be replaced with running average. The cut-off of some signal frequencies and decrease of time series length is a disadvantage of such an approach. On the other hand the trend that

Fig. 3. $F_{CH_4}$ flux measured with different averaging periods in the period 4 – 8 August 2013
is present in fluctuations data is eliminated. In figure 4 (left) the time series of FCH₄ flux from several days derived from classical average and with application of detrending (moving average) are shown. Application of the detrending results in more regular course of FCH₄. In figure 4 (right) the comparison between FCH₄ from the period November 2012-February 2014 computed with classical and running averages is shown. It appears that the detrending results in flux underestimation of about 25%.

Additional problems are introduced during the data quality control. The most important procedure of data quality control is raw data testing for steady-state conditions. It is performed via computation of the tests statistics that are next compared with limiting values. So data are rejected if a test statistic exceeds those values. The most frequently used is the test presented by Foken; however the tests by Mahrt and Dutuar (modified by Affre) are applied as well. The essential issue is the choice of the test boundary value. Some researchers apply the values proposed by tests authors. On the other hand, many researchers use their own limits, as those previously published seem to be too restrictive and reject even proper data. Additional difficulty results from the fact that above mentioned tests frequently gives completely different results.

In figure 6 the course of FCH₄ in the period 4 – 8 August 2013 is shown (dotted line). Data for which at least one stationarity tests indicated steady-state conditions have been drawn with solid line and data which passed all stationarity tests was drawn with bold solid line. It can be clearly seen that too restrictive approach to the data quality control results in significant decrease of the number of data available for further analyses. In the period November

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**Fig. 4.** Comparison of FCH₄ calculated 1 hour and 30 minutes averaging periods (left) and 15 minutes averaging period (right)

**Fig. 5.** Methane net flux FCH₄ calculated with block averaging (black line) and with detrending (red line) in the period 4 – 8 August 2013 (left) and comparison of FCH₄ calculated with block averaging and with detrending in the period November 2012 – February 2014
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2012-February 2014 about 85% passed at least one stationarity tests, but only about 38% passed positively all of the tests.

Summary

Despite the fact, that the methodology of eddy covariance is well developed, selected issues of the measurements described above, indicates that in case of turbulent fluxes of greenhouse gases, methane especially, still need to be systematized. Some of the considered methodological issues are connected with relatively small (1-2 %) errors in flux computation (the lack of WPL and spectroscopic correction, averaging period), while the others can be combined with significantly larger errors (detrending, stationarity tests of 10Hz raw data). Since any of the problems discussed above cannot be avoided, the ultimate results reflect their combined impact.

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