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In-Borehole Monitoring of Greenhouse Gas Fluxes from Upland Peat

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Abstract: Greenhouse gases (CH_4 and CO_2) constitute a risk both to human health and the environment because they are complicit in global warming. There is, therefore, often a requirement to monitor them especially to understand their concentration and flux rate. Whilst concentration helps to determine the direct effect to human health; flux rate deals directly with their emission into the atmosphere, hence their global warming effect. The in-situ measurement of CH_4 and CO_2 concentration was done with the aid of the Gasclam (an in-borehole monitor). They were monitored alongside their controls to determine how they will change in future. The average rates of production of CH_4 and CO_2 at shallow peat varied from 0.19% to 0.50% and 0.1% to 1.28% in deep peat during the entire monitoring period. More CH_4 than CO_2 concentration was produce in deep borehole and vice versa, thereby validating the result of Holden (2005). The R^2 values of the gas concentration with the barometric pressure is averagely small implying that atmospheric pressure – the acclaimed major control on ground-gas variability, is not usually so. The effects of permeability and hysteresis were also observed. The above shows that with the knowledge of the concentration of greenhouse gases and their environmental control, their flux can be predicted. Ex-situ flux measurement is not presently able to do this as it does not take into consideration, their associated environmental parameters.

Key words: Gasclam · Greenhouse · Flux · Concentration · Environmental parameters · Peatland

INTRODUCTION

Greenhouse driven climate change is recognised to be risk to human health [1-6], as a result, extensive research efforts and huge investments are directed into quantification of greenhouse gas emissions into the atmosphere. The carbon content of the soil is many times greater than that of the atmosphere; nearly twice that of biota and atmosphere combined [6-8]. Also, any variation to and from the soil is likely to be important in controlling atmospheric greenhouse concentrations.

There are two main types of greenhouse gases with widely different warming potential. Though the concentration of CH_4 in the atmosphere is lower than CO_2 but it has 22 times the warming potential of CO_2 on a 100-yr time scale, therefore, it may have significant impacts on global climate change [9]. The present CO_2 concentration in the atmosphere is 384.8 ppm while the present CH_4 concentration is 1.74 to 1.86 ppm [10]. The annual increase rate of the concentration of CO_2 and CH_4 in the atmosphere is 0.5% and 0.8%, respectively [11].

Though most portion of global carbon is concentrated in soils, but not all soils are important reservoir of carbon. Peat soils play important roles in global greenhouse budget because; they act as carbon sink storing huge amount of carbon [12]. They are rich in carbon due to their extremely organic matter content [13]; [14]. These organic matter content of peat are mainly broken down into CH_4 and CO_2, hence, the two major greenhouse gases generated by peat are methane and CO_2 [15]. The breakdown process is being accelerated by anthropogenic activities such as soil erosion, drainage and deforestation [13] and with the realisation that climate change is associated with these activities as they cause carbon to be emitted into the atmosphere and reduces carbon storage capability of the soil which again triggers

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climate change [16]. Moreover, peat soils are more susceptible to soil erosion than other soil types because of the higher organic content of peat soils [13].

Peat erosion has a special relevance and importance for UK where about 350,000 ha are believed to be in the eroding state and where the rate of peat lands erosion is unprecedentedly fast [17]. An observation that up to 75% of blanket peat bogs in Peak District National Park was eroded already in 1980s [18].

Although a lot of research has been done to quantify the concentration and flow of these gases in peat soils [19], it has not been well quantified (CL: AIRE). This is because; the data is not enough to be able to prove as the worst case of these gases since sufficient data gives sufficient confidence about the conditions of these gases. There is, therefore, the need to incorporate continuous monitoring by ensuring that sampling interval is as short and the monitoring period as long as possible.

Importance of peat: In summary, peat soil is a significant source of greenhouse gas, hence climate change. Also peat is likely to be subject to change (aerobic and anaerobic) and need to be studied. There is therefore the requirement to accurately quantify greenhouse fluxes from peat soil.

Aim: Quantification of greenhouse gas (CH_4 and CO_2) fluxes from peat soil.

Current Methods: Many works have been done to quantify the amount of carbon present in soil. However, more emphasis has been given on flux measurement of CO_2 and CH_4 in recent years due to climate change [19]. There are many methods such as chamber technique, incubation experiment in a laboratory (ex-situ analysis) and in-situ time series measurement used to measure CO_2 and CH_4 fluxes. Chamber technique has various limitations like physical disturbance of the chamber itself, need multiple visits for periodic sample [20].

Ex-situ (incubation experiment in a laboratory) measurement is important because temperature and pressure can be controlled and easy to conduct because it requires just periodic sample and less time requirement. However, periodic sample or static measurement cannot quantify the carbon budget accurately given an under or over estimates of the gases present in the soils. The ex-situ measurement does not consider the atmospheric variables like temperature, humidity, atmospheric pressure which influences the temporal and spatial variability of greenhouse gas production. For instance, CH_4 which is also produced by microbial activity [21], ;[22] is emitted due to the diffusion, ebullition (release of gas bubbles from waterlogged peat) and from root tissues [23]. It is very difficult to account all of these phenomena through single measurement or static sample.

In-situ continuous measurement gives data on both spatial and temporal variations. So ex-situ measurement can be validated by in-situ measurement. Ex-situ measurement can be validated by comparing the ratio of gas concentration between in-situ and ex-situ. Furthermore, in-situ measurement also gives information of greenhouse gas fluxes on different depths and locations by comparing ex-situ and in-situ data. A significant difference between in-situ and ex-situ data indicate incubated samples are not applicable because production are influenced by environmental factors while little difference gives the validity of ex-situ method for measuring gas fluxes from peat soils. However, in-situ measurement cannot measure the amount of greenhouse gas content per unit of solid soil. So, ex-situ measurement is needed to measure the amount of gas content per unit of solid soil.

Gas fluxes are fluctuated because the factors controlling the fluxes are changeable. So, to understand about temporal and spatial variability of gas flux, long-term continuous data is needed. Moreover, continuous data gives an idea about both surface and underground fluxes which is very important to predict future changes of greenhouse gas fluxes due to erosion and land use changes. So, to improve understanding of the factors influencing the fluxes in peat soils, experiments will be monitored for longer periods of time with the following objectives:

Objectives: i) To quantify CH_4 and CO_2 gas fluxes from peat through ex-situ measurement. This would allow the quantification of greenhouse emissions from a known weight of soil (per kg soil). However, the ex-situ measurement does not consider the atmospheric variables like temperature, humidity, atmospheric pressure which influence the temporal and spatial variability of greenhouse gas production [24]. Determining whether these variables have an influence will establish whether flux can be predicted. Also, there is need to understand the effects peat soil depth and erosion would have on the gas flux.

- In-situ measurement will also be conducted to validate the ex-situ measurement because it considers the environmental variables like temperature and pressure. *This study concentrated on the second objective*.

Methodology: In the peat soil under investigation, two sites were considered; they are the eroded and uneroded sites at the Crowden Great Brook, near Manchester, UK. It has a total surface area of 7km^2 [25] with a mound topography and belongs to the Peak District National Park. All the waters of the catchment are collected by stream systems which originate from Black Hill into Torside reservoir [25]. Gritstone and Shale are dominant rocks in this place while moorlands and bogs are the dominated peat lands and the depth of these peats up to four meters from the surface [26]. In the Peak District, about 27% of the moorland has been degraded due to air pollution from industrial activity, overgrazing, excessive walking and climate change [26]. The peat has developed from decayed of sphagnum moss over thousands of years. The eroded site has a greater surface area of bare peat compared to the uneroded. The uneroded site tells us the present condition of the peat while the eroded gives us a picture of what it would be like in future. Therefore, collection of a good data from the two sites would give us reliable information on the possible future changes of these gases and the processes. In both sites, Gasclam units were installed in two boreholes which were considered as shallow or deep depending on the depth. In order to determine the control pressure has on the gas variability/migration [24], the data was analysed in terms of rising and falling trend of barometric pressure. Firstly, the whole of rising/falling trend was considered before individual rising and falling trend of the pressure. The essence is to know whether pressure wholly or partially drives the ground-gases as it may be possible for it not to be the driver from time to time. The reason for comparing the gas variability/flux with individual rising and dropping barometric pressure is to see if there is hysteresis effect. In this chapter, the uneroded part of the peat soil will be considered as more work is yet to be done on the eroded counterpart.

RESULTS AND DISCUSSION

Figures 1 – 2 and 3 – 4 describe the relationship between ground-gas concentration (CH_4 and CO_2 concentration) and atmospheric pressure variability in shallow and deep boreholes respectively in May and August, while fig. 5(i -iii) shows the effect of hysteresis on them.

Variability in gas concentration and atmospheric pressure was observed in shallow boreholes (Figures 1 & 2). The pressure differential of the shallow borehole in May, ranges from 2 to -51 (Figure 3), whereas in August, it was between 23 to -34. This high difference in pressure shows that the soil was relatively impermeable during the two periods; however, it was more in August.

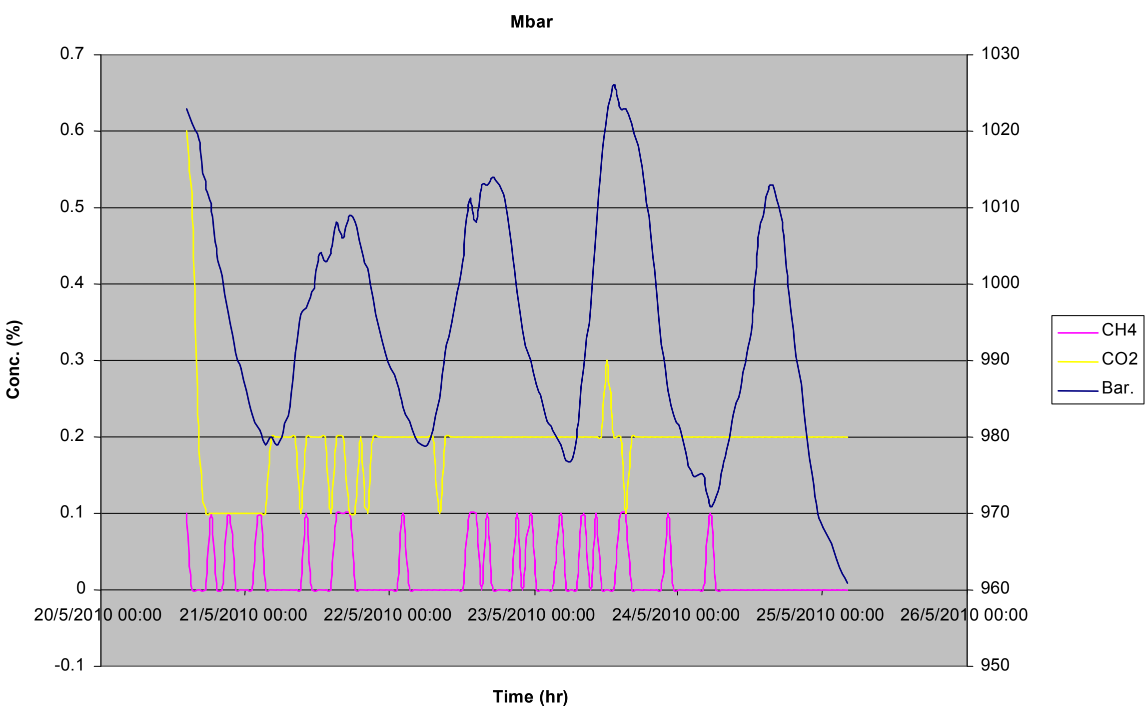

Fig. 1: Gas concentration and barometric pressure data as time series of increasing duration for shallow borehole (May, 2010)

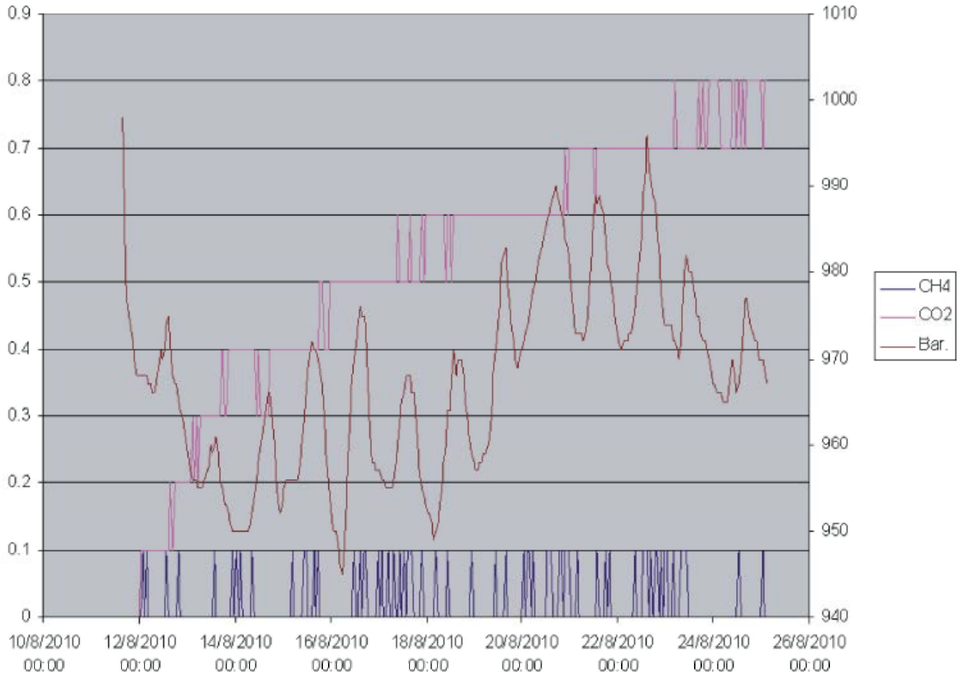

Fig. 2: Gas concentration and barometric pressure data as time series of increasing duration for shallow borehole (August, 2010)

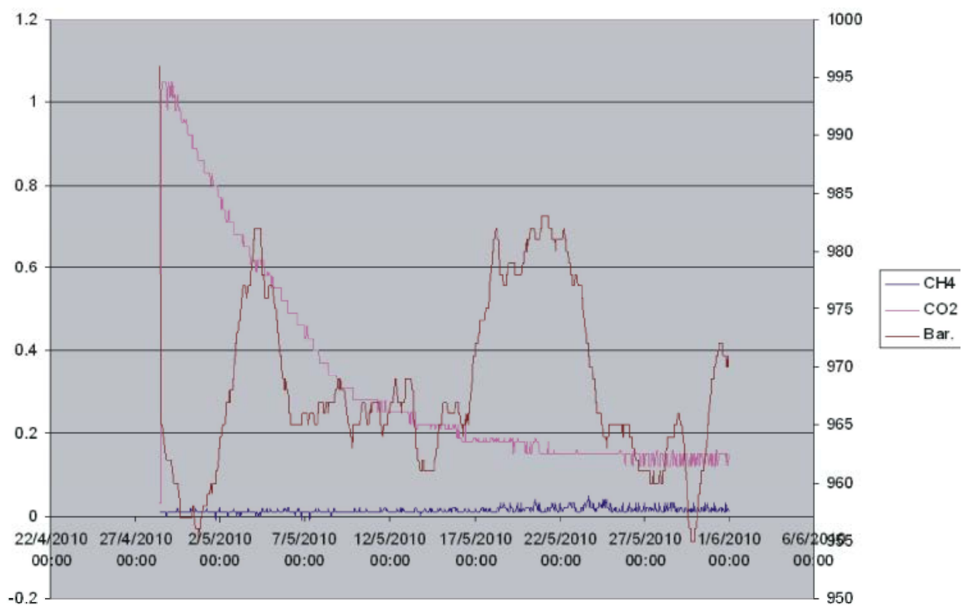

Fig. 3: Gas concentration and barometric pressure data as time series of increasing duration for deep borehole (May, 2010)

In deep boreholes, there is variability in gas concentration and atmospheric pressure (Figures 3 – 4) as observed in shallow counterparts. Unlike the shallow boreholes, the differential pressure of the deep boreholes reveals high permeability of the soil, but this drops as winter approaches. For example, the pressure differential was between 0 and 1 in May, 0 and 3 in July and between 0 and 4 in August. The difference in pressure of shallow borehole is much higher than that of the deep. This means that permeability may be increasing with depth, but can this be true?

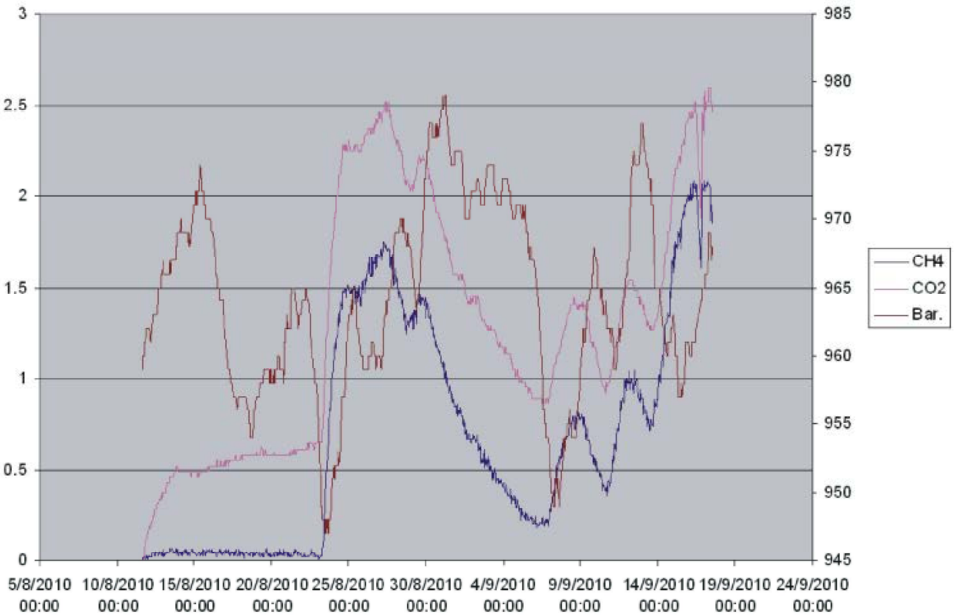

Fig. 4: Gas concentration and barometric pressure data as time series of increasing duration for deep borehole (August 11th – Sept. 17th, 2010)

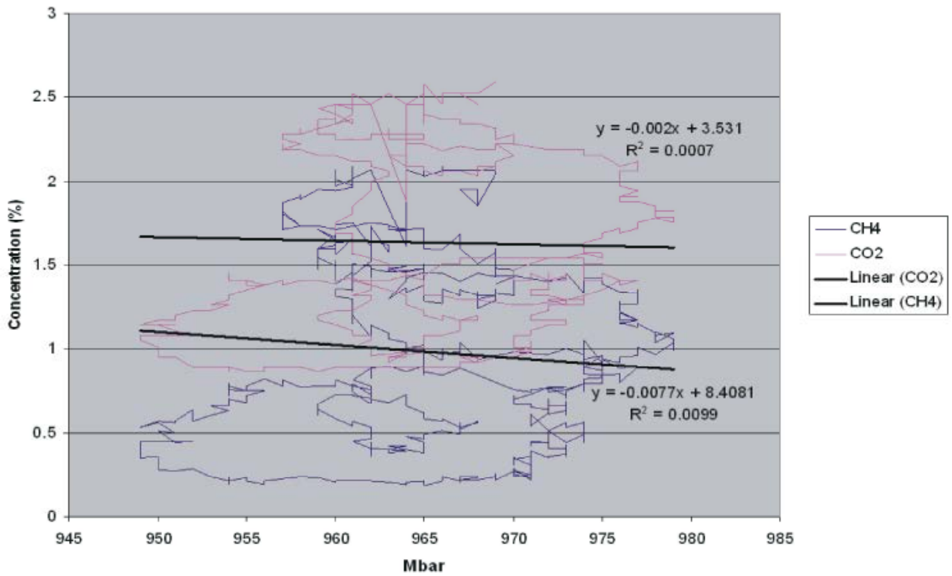

Fig. 5(i): Relationship b/w gas concentration and barometric pressure variability in deep borehole (August 25th – Sept. 17th, 2010)

In the in-situ measurement, the average rates of production of CH_4 and CO_2 at shallow peat in May 2010 were 0.019% and 0.191%, respectively and in August/September 2010 were 0.020% and 0.520% respectively; while at deep peat the average production rate of CH_4 and CO_2 in May were 0.014% and 0.332%, respectively and in August/September were 0.628% and 1.282%. Production rate of CH_4 and CO_2 is comparatively higher at deep peat than at shallow peat.

A comparison of Figures 1 and 3 shows that the concentration of CO_2 decreased with depth. This is due to the presence of O_2 in more concentration at shallower depth. The concentration of CO_2 started to increase because of oxidation and it reached peak and after that the concentration of CO_2 decreased because of the creation of anaerobic condition due to the lack of O_2 and the proportion of CH_4 started to increase [21], although was not reasonably large which could be attributed to their

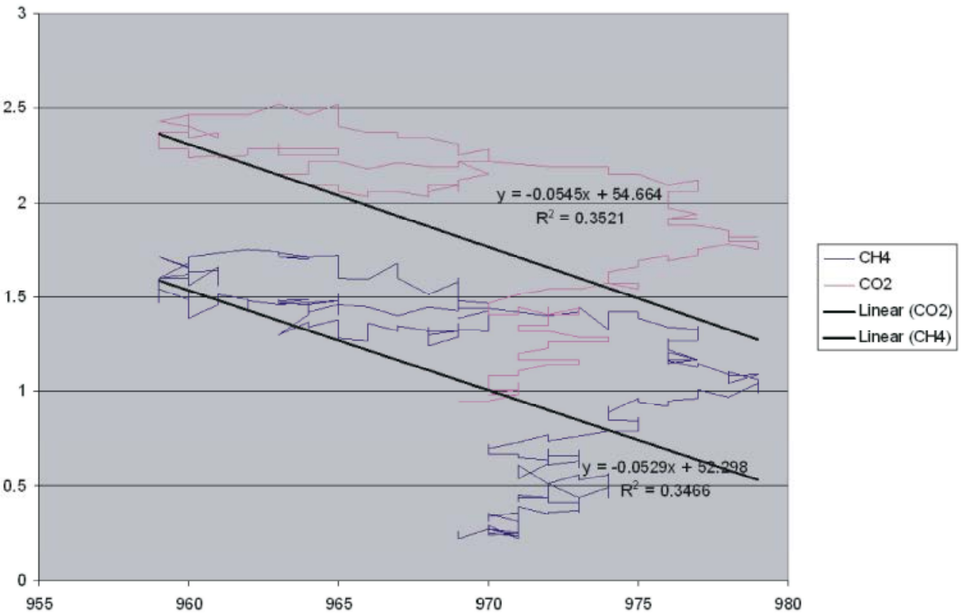

Fig. 5(ii):Relationship b/w gas concentration and barometric pressure variability in deep borehole (August 25th – Sept. 5th, 2010)

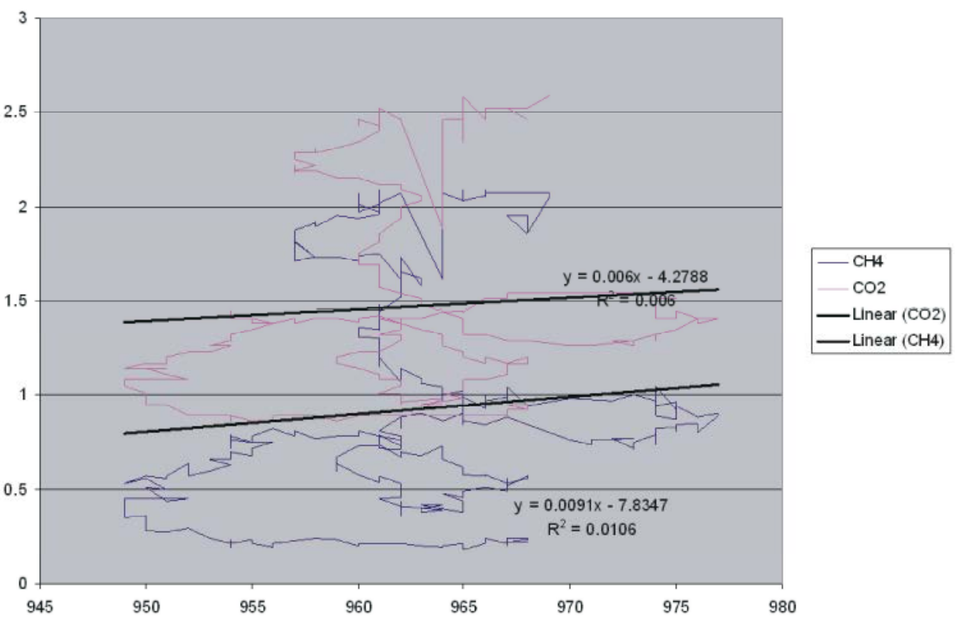

Fig. 5(iii): Relationship b/w gas concentration and barometric pressure variability in deep borehole (Sept. 5th – Sept. 17th, 2010)

availability. Here we found a negative correlation between depth and production of CO_2 gas. The concentration of CO_2 decreased as depth increased.

On the contrary, there was not much difference of CH_4 concentration between shallow and deep uneroded peat. However, the higher concentration was found at shallow peat soil in August/ September. The fluctuation of CH_4 flux is not only determined by anoxic condition but also the can be regulated by methanogenesis in anaerobic peat and/or methanotrophy in drier surface soils [27]. However, methanogenesis can be controlled by acidic condition because neutral pH is optimal for methanogenesis [27].

The in-situ measurement would be used to validate the CO_2 and CH_4 flux of ex-situ measurement. This would be reflected in the next report, the result of which will be used to determine whether ex-situ measurement is also a valid method for measuring gas production from peat soil.

If data can be temporally resolved, the variability in the relationship may be recognized as a hysteresis and therefore can provide further information on system behaviour. The effects of hysteresis were observed both in shallow and deep boreholes. An example can be seen in Figures 5 (i –iii) of deep borehole. The data set was divided into two equal parts to improve the possibility of getting a temporal resolution of the gas concentration (Figure 5i –iii) and if there is hysteresis effect. Figure 5 (i) showed the hysteresis between atmospheric pressure and gas production which revealed loops of data. Different gas concentrations were found in the same atmospheric pressure (Figure 5i).

However, from the loop diagram (Figure 5i) the relationship between gas production from soil and atmospheric pressure could not be described properly. Figure 5 (ii-iii) described the hysteresis which considered the temporal resolution and used to describe the relationship between atmospheric pressure and gas production. A somewhat better correlation between the two parameters was observed in Figure 5 (ii) of deep borehole from 25th of August to 5th of September, 2010.However, if we look at Figure 5 (iii) then we will find that atmospheric pressure did not change with the change in gas concentration.

CONCLUSION

Over the entire monitoring period within the two boreholes, gas production in deep borehole is higher than that of the shallow. The correlation, R^2 of the gas concentration with the barometric pressure is averagely small, accounting to the fact that pressure is not the major driver of the gases in peat soil. The pressure differential across the boreholes shows that the soil was not very permeable and that the permeability reduces as winter approaches. Also, a comparison of the permeability between shallow and deep boreholes reveals that it may be increasing with depth. The effect of delay by the gas to respond to changes in barometric pressure (i.e. hysteresis) which depends on the gas availability was equally observed. It could be that the water table was responsible for large amount of gases observed during the monitoring period since peat soil is known for high content of water.

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