EASTMAIN EM-1

*Reservoirs' net greenhouse gas emissions research project*

# The Eddy Covariance Technique: Data Processing, Result Examples and Applications

## Brief reminder on the use of eddy covariance in the EM-1 greenhouse gas project

In August 2006, two eddy covariance systems were installed in a dominant pre-flooding ecosystem (black spruce forest) and in the post-flooding (reservoir) environment in the EM-1 area. A third system was installed in June 2008 in a peatland, which represents the second dominant terrestrial ecosystem of the flooded landscape. The eddy covariance (EC) technique uses specialized instrumentation to measure the net exchange of $CO_2$, water vapour and energy towards or from a given ecosystem. The main advantage of this micrometeorological technique is that measurements are made continuously at a very high frequency and represent the average exchange over a large upwind area. For $CO_2$, the surface-atmosphere exchange is referred to as the net ecosystem $CO_2$ exchange (NEE). A positive NEE represents a net emission to the atmosphere, whereas a negative NEE means a net uptake of $CO_2$ by the ecosystem.

## Processing of eddy covariance data

With the eddy covariance technique, measurements of $CO_2$ and water vapour concentrations are made using an infrared gas analyzer (IRGA), and wind speed is measured in three dimensions using a sonic anemometer. As variables are commonly recorded at 10 Hz (i.e. ten times per second), the amount of data generated over the lifetime of a project can be incredibly large. The processing of EC data is quite complex and requires a significant amount of programming using specialized software before the flux data can be used in a meaningful way. The two main steps in the EC data processing are the data quality control and handling of missing data.

As part of the data quality control, pre-established criteria following internationally agreed protocols help to tell if the data recorded are reliable or not. Data are first screened using the built-in diagnostic signal of the IRGA which indicates periods when the optical path was partially or fully obstructed – often corresponding to rain or snow events. Data are also rejected when the system indicates (usually small) physically improbable uptake of $CO_2$ at night or during wintertime. Fundamentally, the EC technique operates during turbulent conditions. On calm nights, the atmospheric conditions may be too stable for reliable data collection. These conditions are identified using a threshold value of the friction velocity - a measure of how turbulent the air flow is. Finally, instantaneous extreme values (caused by instrument noise) of the net ecosystem exchange (NEE) are eliminated based on the monthly averages and standard deviations of the $CO_2$ fluxes. An additional step is performed for the reservoir flux data, which consists of removing the data when the wind is coming from the direction of the island in order to retain only the fluxes from the water surface itself.

Gaps in time series of EC data can occur due to a variety of reasons (e.g. following quality control, power failure, instrument maintenance and repair, etc.). Data gaps are usually divided into gaps of short and long duration. Short data gaps of less than four half-hours are filled by linear interpolation. For terrestrial ecosystems, longer gaps are filled based on empirical models specific for day and night with respect to daytime and nighttime dominant physiological processes. NEE is comprised of biological activities resulting in ecosystem respiration (ER) and gross ecosystem productivity (GEP). Respiration is mainly driven by temperature, so an exponential relationship of nighttime NEE vs. soil temperature is usually used to fill gaps during the night and in the winter, i.e. when GEP is assumed to be zero so that ER is the only flux component. This relationship is derived from windy nighttime data and is also used to model daytime ER. During the daytime in the growing season, photosynthetic uptake is dominant and is largely controlled by light (photosynthetically active radiation or PAR). To fill daytime NEE gaps, a GEP vs. PAR hyperbolic relationship is used. The remaining NEE gaps are filled by subtracting GEP from ER. The gap filling procedure for the reservoir $CO_2$ fluxes is more complex as the source and processes driving the $CO_2$ emissions are disconnected spatially from the water surface and the transport processes in the atmosphere. Preliminary work indicates that relationships between $CO_2$ fluxes and wind speed, and maybe with water temperature and/or concentration of dissolved organic carbon, would help us estimate the reservoir fluxes for any missing periods.

## Examples of results obtained from EC

One of the major advantages of the EC technique is the fact that it allows scientists to investigate the $CO_2$ fluxes on different time scales, from minutes to years. For instance, the trends in $CO_2$ uptake and emission over the course of a day can be easily observed. Figure 1 shows an example of the diurnal average net $CO_2$ flux for August 2008 for the three main sites in the EM-1 region (i.e. reservoir, forest and peatland). It is interesting to notice that the reservoir is a small but constant net source of $CO_2$ to the atmosphere over the entire day, which is expected since there is no vegetation to absorb the $CO_2$ from the atmosphere. In contrast, the forest and the peatland show net daytime uptake of $CO_2$ from the atmosphere due to plant photosynthesis which converts the atmospheric $CO_2$ into plant biomass. Also to be noted is the larger daytime $CO_2$ uptake and larger nighttime $CO_2$ release at the forest compared to the peatland, which is due to the more productive vegetation in the forest compared to the moss-dominated peatland. Another way of presenting EC results is shown in Figure 2. Here, the average daily (24-hrs) net $CO_2$ fluxes over six consecutive days in August 2008 (Aug. 15-20) indicates that the forest was a larger daily net $CO_2$ sink than the peatland, and that the reservoir was a daily net source of $CO_2$. With this kind of analysis, the direction and magnitude of NEE for different sites, and over different time periods can be examined. Using the continuous record of EC data over longer time periods, such as a complete year, it is possible to identify the time of the year when a terrestrial ecosystem, like a forest, switches from being a net $CO_2$ source to the atmosphere (through fall and winter, when short days and cold temperatures allow little or no photosynthesis) to a net $CO_2$ sink (through the growing season, when photosynthesis becomes larger than respiration). The timing of this switch changes each year and for each ecosystem depending on climatic and biophysical ecosystem properties. Therefore EC's ability to measure continuously over long time scales is unique and essential for such analysis.

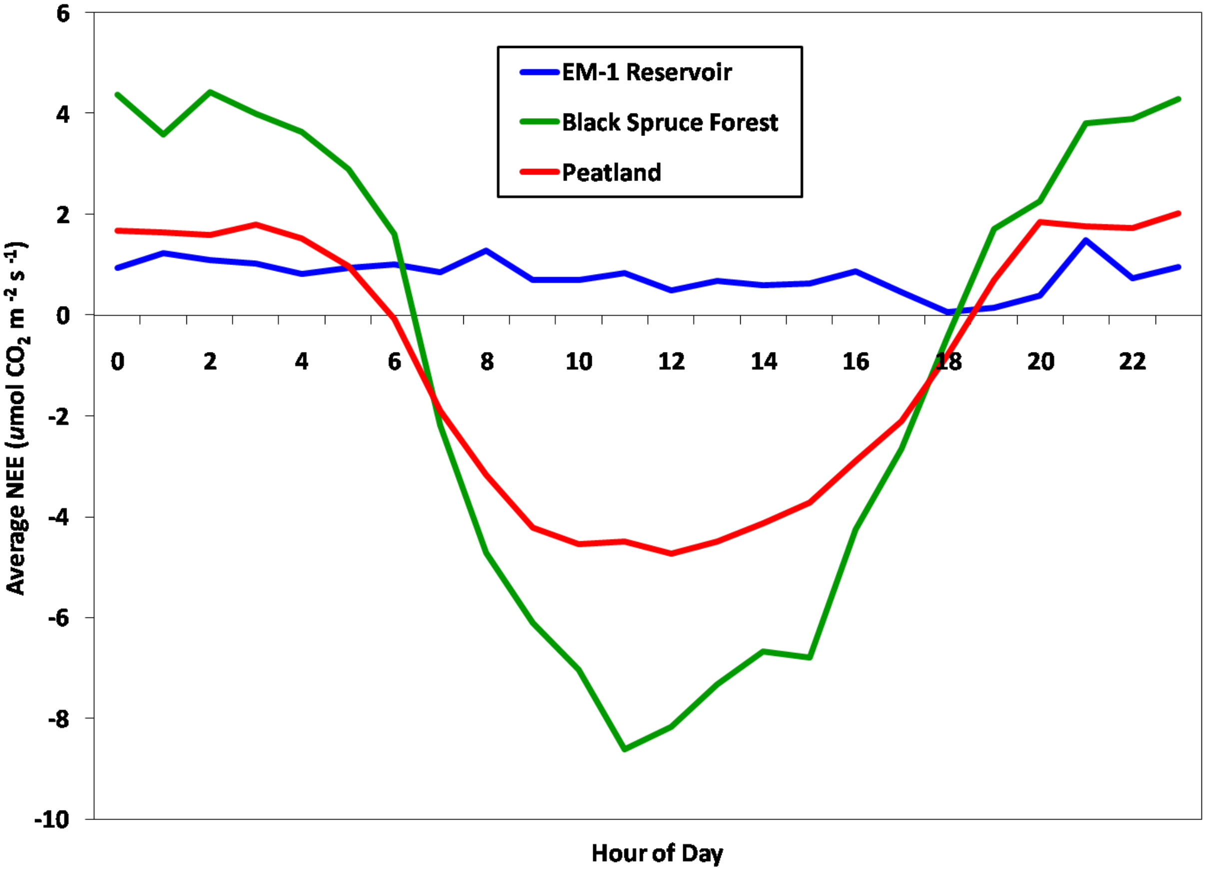

***Figure1 :*** *Diurnal trends of NEE for the three sites in the EM-1 region for August 2008. Negative NEE values indicate net $CO_2$ uptake by the ecosystems, and positive values indicate net release of $CO_2$ to the atmosphere. This graph has been created using preliminary data that have not been through final quality control and gap filling.*

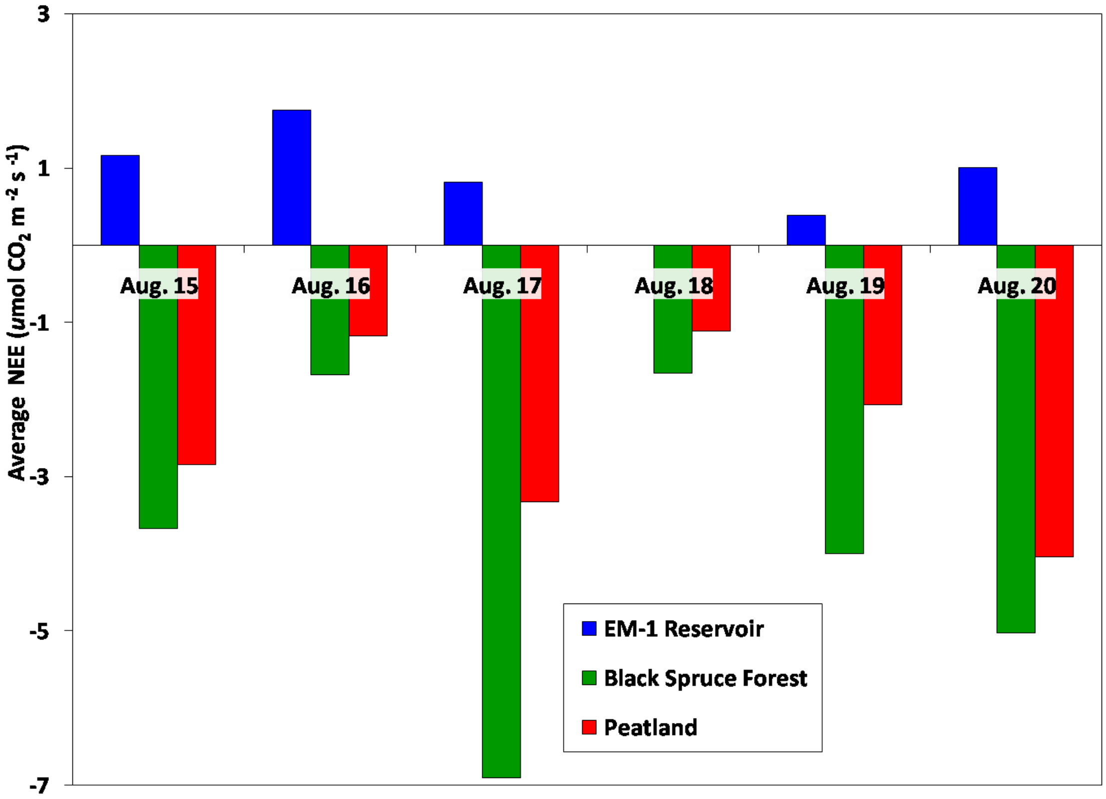

***Figure2 :*** *Daily NEE averages for the three study sites over six days in August 2008. Negative NEE values indicate net $CO_2$ uptake by the ecosystems, and positive values indicate net release of $CO_2$ to the atmosphere. This graph has been created using preliminary data that have not been through final quality control and gap filling.*

## Applications of EC to other components of the EM-1 GHG project

The EC technique offers the opportunity to get annual $CO_2$ budgets of the dominant pre-flooded ecosystems (forest and peatland) and of the EM-1 reservoir. By characterizing $CO_2$ exchanges over different ecosystems and integrating the results to the whole disturbed region based on the relative coverage of each ecosystem for which we have flux measurements, we will be better placed to estimate the net impact of the creation of EM-1 on greenhouse gas emissions. If the EC systems continue to function for multi-year periods, the interannual variability in NEE and carbon budgets can be investigated and relationships with biophysical variables can facilitate our understanding of the major controlling factors on $CO_2$ fluxes in reservoirs and natural ecosystems. Furthermore, one of the project goals is to compare the various techniques available for trace gas measurement from reservoirs and terrestrial ecosystems. Gas flux measurements obtained using EC, which provide continuous and spatially-averaged $CO_2$ flux data over a relatively large upwind area, can be compared to chamber measurements, which are used on smaller spatial and discrete temporal scales.

Finally, because it provides continuous records of measured fluxes over different areas, eddy covariance is an essential tool needed to validate GHG models (a primary objective of this project). Researchers will use the EC results within a multidisciplinary modeling approach in order to assess the present and future greenhouse gas contribution of hydroelectric reservoirs. The data obtained from EC systems will also be used in combination with the measured methane ($CH_4$) emissions to get a more complete assessment of the net carbon fluxes from the EM-1 reservoir.

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