Energy Fluxes and Greenhouse Gas Emissions from a Waste Lagoon

Justin Rawley[1], Arturo Quintanar [2], Rezaul Mahmood[2], John Loughrin[3] and Nanh Lovanh[3]

[1]Department of Environmental Sciences, University of Virginia, Charlottesville, VA 22904

[2]Department of Geography and Geology and Kentucky Climate Center, Western Kentucky University, Bowling Green, KY 42101

[3]United States Department of Agriculture Animal Waste Management Research Unit, Bowling Green, KY 42101

Abstract

The sensible and latent heat fluxes, net radiation and lagoon heating from a waste lagoon located in South Central Kentucky are estimated for five days in February 2009 using the Bowen Ratio energy balance (BREB) method. Relationships between these fluxes, meteorological variables and greenhouse gas (GHG) emissions from the waste lagoon were also estimated. The GHG data collections days are characterized by mostly clear conditions. Because the raw data fluctuated greatly, a 15 minute moving average was utilized to smooth the data. The energy fluxes showed a definitive diurnal pattern expected of such fluxes. It is found that latent and sensible heat flux and temperatures could be a good predictor of GHG emissions.

Introduction

Agricultural practices comprise 6.8% of all greenhouse gas emissions in the United States. An important agricultural source of greenhouse gases is liquid/slurry waste lagoons, commonly implemented on swine farms. The anaerobic conditions in the lagoon treat the waste, but during this process, GHG are released. To accurately predict the emissions of these gases, the energy fluxes in and out of the lagoon must be known. The Bowen Ratio Energy Balance (BREB) method implements the differences in temperature and vapor pressure at two heights to compute energy fluxes such as the sensible and latent heat fluxes. Thus, the Bowen Ratio (β) is defined as the ratio of sensible and latent heat flux. The sensible heat flux represents the energy going into warming the air while the latent heat corresponds to the energy being used to evaporate water. The gases studied include nitrous oxide, sulphur hexafluoride, carbon dioxide, methane, water vapor and ammonia. The latter is not a GHG but an important gas to investigate. The purpose of this study is to examine the relationships between the gas concentrations and meteorological data.

Methods

Meteorological data were collected on two floating stations at heights of 0.5 and 1.5 m above the lagoon surface (Fig. 1) while ammonia and GHG data were measured at a height of 50 cm. The energy balance equation was used to compute net radiation and lagoon heating. Then the β was calculated using the differences in temperature and vapor pressure at two different heights. Three β (BR1, BR2 and BR3) were calculated using the BREB method. BR1 was calculated using the difference between 1.5 and 0.5 m, BR2 between 1.5 m and the surface and BR3 between 0.5 m and the surface. With values for the net radiation, lagoon heating and β, the sensible and latent heat fluxes could be calculated. Once these β and fluxes were calculated regressions were constructed for ammonia and each GHG.

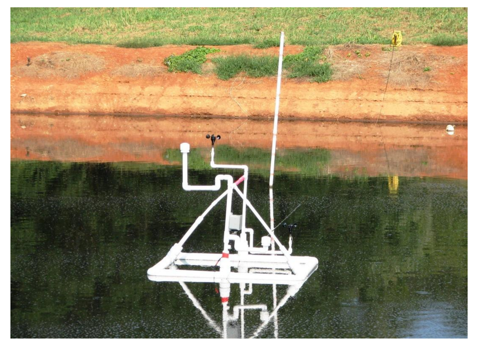


Figure 1. Floating raft containing instrumentation on lagoon surface

Results

BR3, using the differences in temperature and vapor pressure between 0.5 m and the lagoon surface, produced the best estimates of sensible and latent heat fluxes. Thus the following graphs all display results using BR3. Also, the ammonia and GHG data were normalized by dividing each data point for a specific gas by the maximum observed value for that gas. This was done so that each gas could be displayed on the same graph and compared.

Figure 2. Solar Radiation for specific February dates

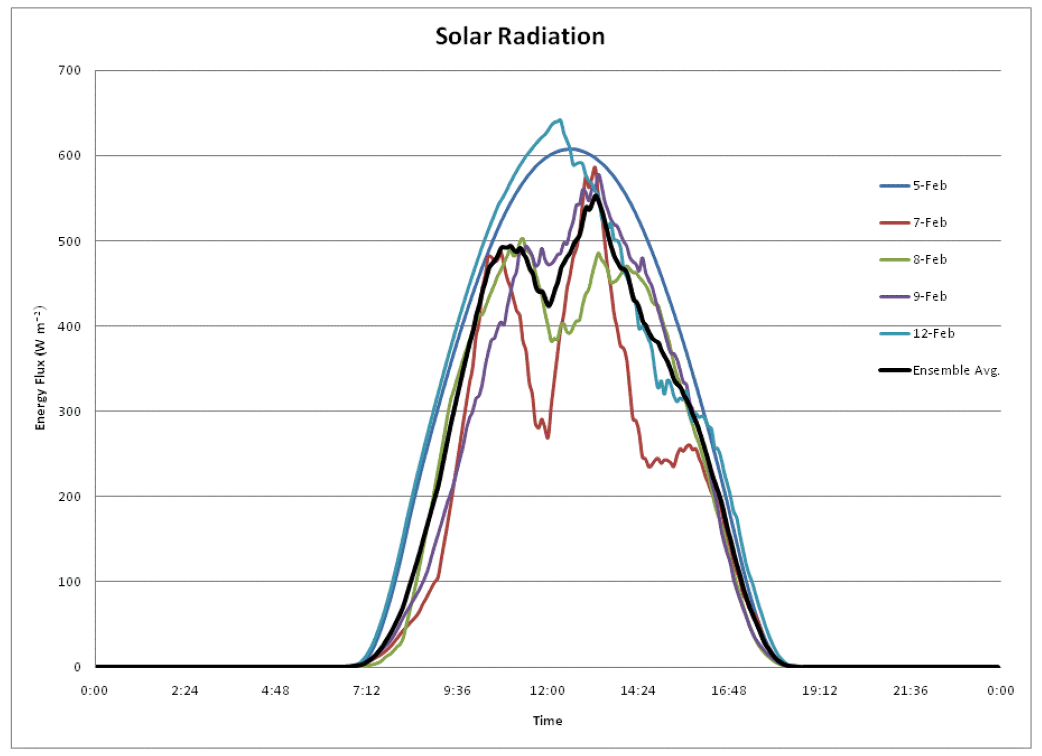
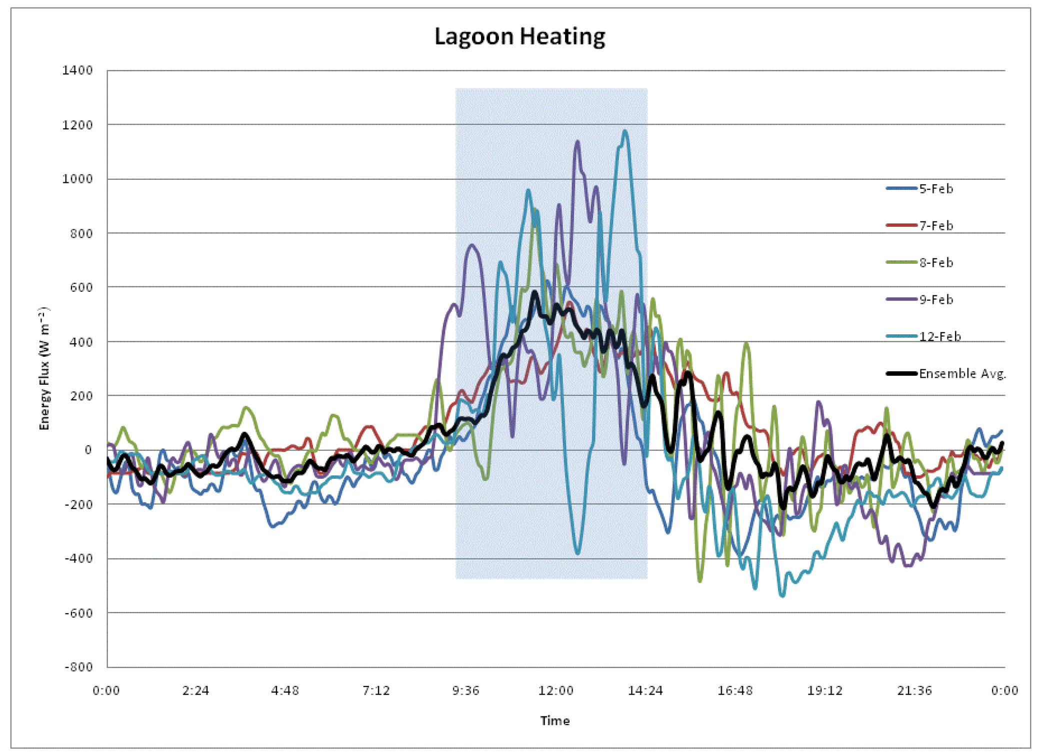


Figure 3. Lagoon heating for specific February dates



The solar radiation shows a clear diurnal pattern with peak values occurring between 12:00 and 13:00 local time (Fig. 2). Likewise, the lagoon heating displays a diurnal pattern and it varies significantly especially around 12:00 local time (Fig 3).

Figure 4. Gases and Energy Fluxes on February 7, 2009

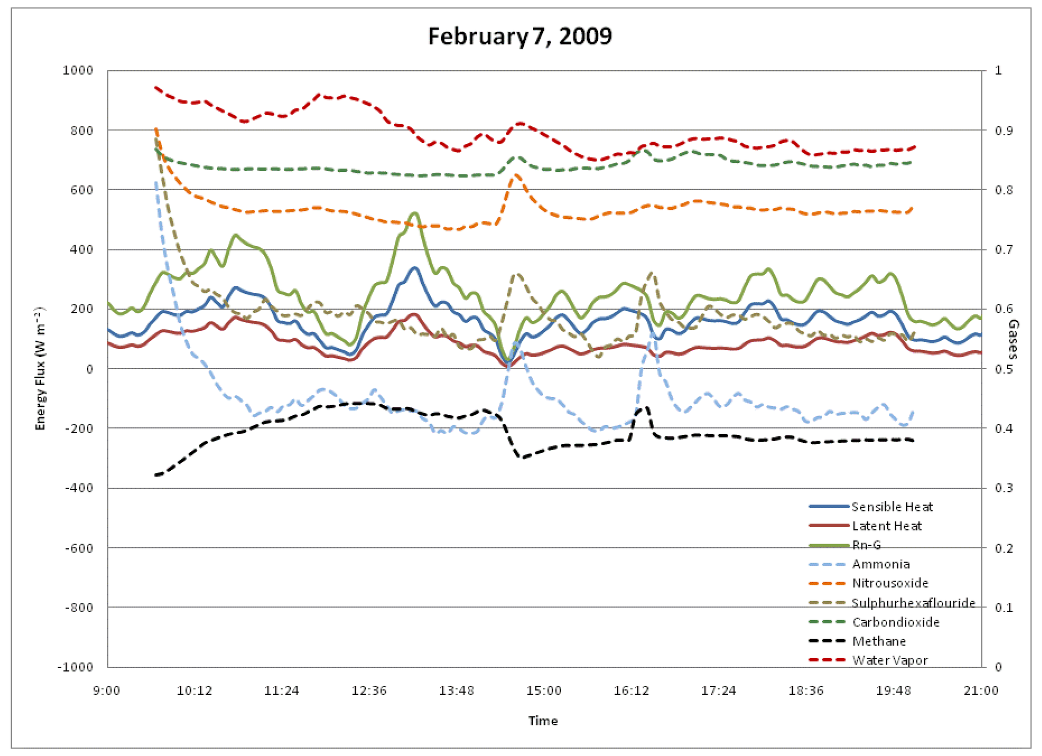
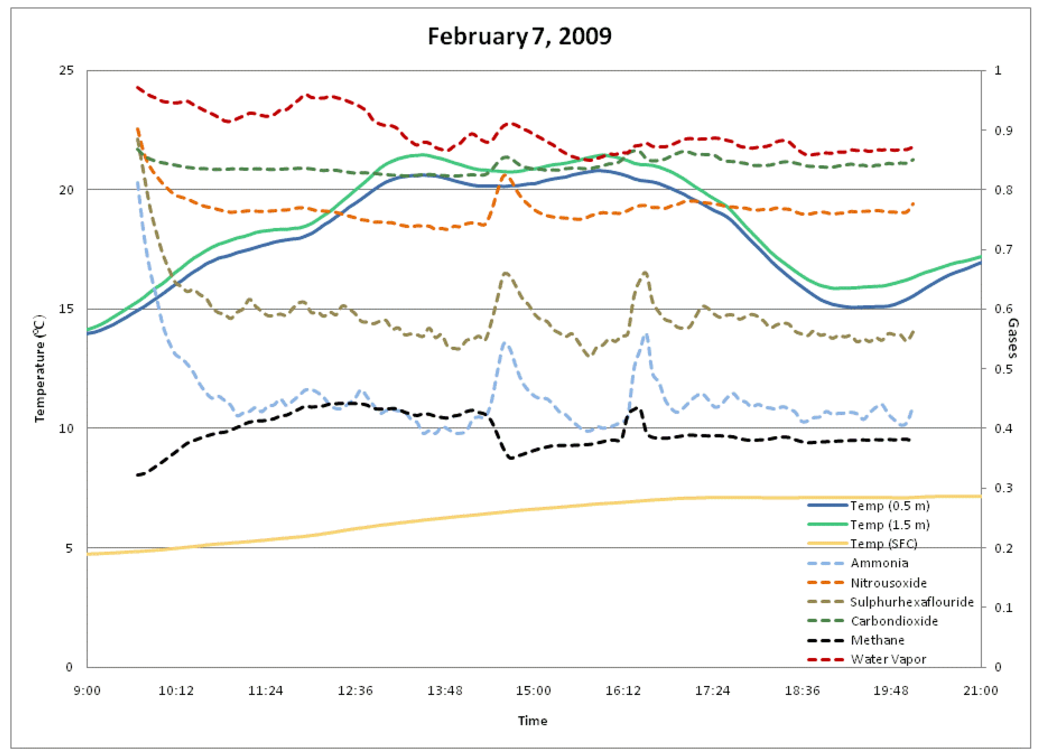


Figure 5. Gases and Temperatures for February 7, 2009



Clearly, most of the gases seem to spike an hour or two after the sensible or latent heat fluxes reach peak (Fig. 4). Also, small changes in the energy fluxes do not affect the gas concentrations. Peaks in gas concentrations also are delayed slightly after an increase in temperature at 0.5 and 1.5 m (Fig. 5). The surface temperature affects most of the gases. For example, the carbon dioxide levels show a small but steady increase at the same time that the surface temperature is steadily increasing throughout the day.

The following correlations were computed using a significance level of 0.05 and represent the best model for each gas.

Ammonia		
Model Summary		
	R^2	Significance
Model	0.275	2.53E-21
ANOVA		
	Unstandardized Coefficient B	Significance
Constant	3.977	4.13E-34
Sensible Heat	0.001	1.45E-03
Latent Heat	-0.002	2.62E-12
Temp (0.5 m)	-0.174	1.77E-22

This model is significant but only accounts for roughly 28% of total variance.

Carbon dioxide		
Model Summary		
	R^2	Significance
Model	0.857	3.04E-129
ANOVA		
	Unstandardized Coefficient B	Significance
Constant	377.263	5.76E-172
Temp (SFC)	14.542	3.09E-47
Sensible Heat	-0.194	4.61E-38
Latent Heat	0.238	1.55E-69

This model is significant and explains roughly 86% of total variance.

Sulphur hexafluoride		
Model Summary		
	R^2	Significance
Model	0.272	5.08E-21
ANOVA		
	Unstandardized Coefficient B	Significance
Constant	0.111000	1.06E-39
Temp (0.5 m)	-0.004000	1.04E-21
Sensible Heat	0.000021	5.89E-03
Latent Heat	-0.000054	2.39E-13

This model is significant but accounts for only 27% of total variance.

Water Vapor		
Model Summary		
	R^2	Significance
Model	.343	7.89E-29
ANOVA		
	Unstandardized Coefficient B	Significance
Constant	0.85173	6.37E-57
Temp (SFC)	0.00642	2.67E-02
Latent Heat	0.00042	5.50E-12

This model is significant but explains only 34% of total variance.

Nitrous Oxide		
Model Summary		
	R^2	Significance
Model	0.443	8.22E-40
ANOVA		
	Unstandardized Coefficient B	Significance
Constant	1.242	2.26E-174
Temp (0.5 m)	-0.0160	8.37E-40
Latent Heat	-0.0002	3.66E-18

This model is significant and accounts for 44% of total variance.

Methane		
Model Summary		
	R^2	Significance
Model	0.456	1.96E-41
ANOVA		
	Unstandardized Coefficient B	Significance
Constant	77.726	1.31E-82
Temp (SFC)	2.023	4.86E-09
Latent Heat	-0.045	7.98E-27

This model is significant and explains 46% of total variance.

Conclusions

- Ammonia is not correlated strongly with any of the parameters
- Nitrous oxide is negatively correlated with the temperature at 0.5 m but positively correlated with the surface temperature
- Because of sulphur hexafluoride's small concentration it cannot be reliably correlated to the energy fluxes nor temperature
- Carbon dioxide depends largely on the temperature, the latent heat flux and the sensible heat flux
  - By itself, the temperature at 0.5 m has the greatest influence on CO_2, but the combination of the surface temperature, latent heat flux and sensible heat flux has a greater control on CO_2 levels than the temperature at 0.5 m and the latent heat flux.
- Methane correlates fairly well with the temperature at the surface and the latent heat flux
- Water Vapor is obviously related to the latent heat flux, which affects evaporation, but is not closely correlated with the other parameters.
- For each gas with a significant correlation and large R^2 value, the temperatures at 0.5 m and 1.5 m are negatively correlated with the gas levels, but the lagoon surface temperature is positively correlated with the concentrations.
- For some days around noon, the estimates of lagoon heating exhibit large fluctuations which lead to abnormal values of energy fluxes, represented by the highlighted box in Figure 3. It is concluded that measurements of lagoon temperatures at this time are suspect.

Future Research

- Sample GHG concentrations for a longer time period
- Look into effects of clouds on energy fluxes and GHG levels.
- Study correlations in different seasons
- Look at effect of other variables such as wind or pH levels
- Investigate whether certain GHG concentrations affect the levels of other gases
- Examine the affects that the turbulent eddies, which are caused by roughness differences going from the land to the water, have on energy fluxes more thoroughly with sonic anemometry
- Use data from the land station to compare with calculations from the lagoon floating station data

Acknowledgements

- Research Experience for Undergraduates (REU) at Western Kentucky University (WKU)
- Ogden College of Science at WKU
- Dr. Cathleen Webb, Department of Chemistry at WKU
- Department of Geography and Geology at WKU
- Mammoth Cave National Park - National Park Service
- Kentucky Climate Center
- National Science Foundation REU grant # EAR-1004655
- USDA grant # 58-6445-6-068
- Mr. and Mrs. Jeffery Rawley
- Mr. and Mrs. Timothy Rawley