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Ammonia Concentration and Modeled Emission Rates from a Beef Cattle Feedyard

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Abstract. *Ambient NH_3 concentrations were measured at a beef cattle CAFO during the spring and summer months of 2007. Concentrations were measured every five minutes, 24-hours per day at a sample intake height of 3.3 m using a chemiluminescence analyzer. On site weather data was collected concurrently. Emission rates were estimated using a backward Lagrangian Stochastic model (WindTrax 2.0.7.8). Mean 24-hr concentrations for spring were 0.498, 0.597 and 0.568 ppm for March, April and May, respectively. Corresponding fluxes for March, April and May were 57.76, 123.10 and 86.34 $\mu g\ m^{-2}\ sec^{-1}$, respectively. Summer mean ambient concentrations were 0.684, 0.702 and 0.568 ppm for June, July and August, respectively. Summer fluxes were 85.27, 75.06 and 71.56 $\mu g\ m^{-2}\ sec^{-1}$ for June, July and August, respectively.*

Keywords. ammonia, emissions, beef feedyard, bLs model, CAFO, chemiluminescence, WindTrax®

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Introduction

The practice of concentrating large numbers of beef cattle into animal feeding operations (AFOs) has been well established in the Texas Panhandle. The economy of scale, coupled with the development of infrastructure to move commodities into the feeding operations, as well as moving animals to harvesting facilities has an economic impact in the billions of dollars annually nationwide. The Texas Panhandle alone saw an impact of 7 billion dollars in 2007 (TCFA, 2008).

This streamlined movement of commodities and animals has proven an effective means for preparing animals for harvest and has been emulated in other countries. However, agriculturalists and consumers recognize a need not only for an inexpensive, safe and abundant supply of animal based protein, but also for an awareness of how current practices of food production affect the environment. The movement of commodities into an area also moves the associated nutrients into that same area. This necessitates an understanding of the fate of those nutrients.

Most beef feedyards in the Texas Panhandle feed some form of a corn based diet, balanced to about a 13.5% crude protein (CP) based on dry matter intake. This has proven to be easily mixed and delivered to the animals via feed delivery trucks. Although high energy diets are a more efficient than roughage diets, it may be possible to decrease NH_3 emissions by diet modification. Cole et al. (2005) found that as CP was decreased from 13% to 11.5 %, in vitro NH_3 emissions were reduced about 50% in a laboratory setting. Todd et al. (2006), in a controlled field study, found that reduction of CP intake from 13 to 11.5% reduced annual NH3 emissions by 28%.

Ammonia Production

Ammonia volatilization depends on several factors, including pH, surface and air temperature, wind speed, moisture content of the source area, and N concentration in the source (Duyson et al., 2003; Freney et al., 1983; Watkins et al., 1972). Several researchers have established that the majority of NH_3 produced in CAFOs is volatilized from urine spots, as opposed to feces (Ball et al., 1979; Cole et al., 2005; Harper et al., 2004; Hutchinson et al., 1982; Koziel et al., 2005; Stewart, 1970; Vallis et al., 1982; Whitehead & Raistrick, 1991). Vallis et al., (1982) reported that up to 80% of the urea in urine can be hydrolyzed to ammonium (NH_4^+) within two hours of urination. Ammonium is then easily converted to NH_3 and available for volatilization.

The pathway for conversion of urea to NH_3 is shown in Eq. 1 (Hausinger, 2004). As the pH increases, the reactions move toward an increased release of NH_3, whereas at low pH (<6.5), most of ammonical N is found in NH_4^+. As pH increases (> 8), a molecule of urea, in the presence of water and urease, hydrolyzes into two molecules of NH_3, although this is bi-directional as the pH lowers.

$$CO(NH_3)_2 + H_2O \xrightarrow{\text{urease}} 2NH_3 + CO_2 \qquad [pK = 9.4] \qquad \text{(Eq. 1)}$$

While the method and source of NH_3 volatilization has been well established, there have been little data published on long term concentration measurements in CAFOs. This paper presents 24-hour measurements for the spring and summer months at a commercial feedyard. The objectives were to quantify NH_3 concentrations over an extended period of time and to estimate emission rates based on local climate measurements.

Methods and Materials

Ammonia Sampling

Ambient concentrations of NH_3 were measured with a continuous analyzer located inside a temperature-controlled instrument shelter. A TEI 17C chemiluminescence NH_3 analyzer (Thermo Environmental Instruments, Franklin, MA*) was used to measure NH_3 concentrations. The NH_3 analyzer is a combination of NH_3 converter and an NO-NO_2-NOx analyzer. The analyzer was calibrated using instrument-grade air, certified standard span NH_3 gas in air (98 ppmv - diluted to 4.66 ppmv with instrument-grade air) and NO in nitrogen (50 ppmv – diluted to 4.55 ppmv with instrument-grade air) (AirGas Southwest, Amarillo, TX*). Calibrations were done weekly.

The instrument shelter was a modified 1.5 m $\times$ 2.1 m box trailer with a 3.95 KW air-conditioning unit. Data were collected by a Campbell Scientific CR23X* data logger using analog outputs from the analyzer every five minutes. Data were downloaded weekly.

Ammonia concentrations were sampled at a height of 3.3 m beginning in February 2007 and continuing through July 2007.

Weather Data Collection

An onsite weather station (Unidata, Inc*) was located on the prevailing upwind side of the feedyard. Data were collected for 2-m wind speed, wind direction, air temperature, solar radiation, rainfall, and 5-cm and 15-cm soil temperatures. A 10 m tower was located on the prevailing downwind side of the feedyard beginning in May 2007. The tower was instrumented at both 2- and 10- m with identical wind speed, wind direction and $\pm$0.1 °C thermistors. Data were collected from both data loggers weekly. Selected data (wind speed, temperature and rainfall) are summarized in Table 1.

Table 1: Wind speed, air temperature, and precipitation summary by month.

Month	Wind Speed (km/h)		Ambient Temperature (°C)		Precipitation (mm)
	Mean	Max	Mean	Max	Total
March	16.8	55.0	10.5	28.9	88.2
April	20.7	73.8	11.5	28.8	20.2
May	18.0	60.6	18.2	33.1	39.8
June	18.0	79.8	22.7	36.5	86.2
July	13.6	51.2	24.8	36.2	59.4
August	14.6	43.9	25.1	41.3	14.0

Emissions Modeling

WindTrax® ver. 2.0.7.8 (Thunder Beach Scientific, 2007*) was selected as the modeling software for emissions estimation. WindTrax® is a backward Lagrangian Stochastic (bLs) model that predicts emissions based on random particle placement upwind of a concentration sensor. The simulations presented here are based on 50,000 particles limited to 500 m length (i.e. the edge of the feedyard pens). The reader is referred to Sommer et al. (2005) for a description of the mathematics of WindTrax®. Models were run on 5-min intervals for all data points. Therefore, for a complete month, a total of 8,630 emission models were run, assuming no missing data.

Model input data consisted of wind speed, wind direction, ambient temperature, NH_3 concentration, and Pascal-Gifford (P-G) stability class. Barometric pressure was estimated from

elevation above sea level (1162 M). Todd et al. (2007) calculated a surface roughness length (z_o) of 0.10 m using sonic anemometer data. The Environmental Protection Agency (EPA) has also classified terrains in terms of effective z_o. A z_o of 0.10 m is terrain described as low crop with occasional large obstacles, where the typical distance to the upwind obstacle divided by the height of the obstacle is > 20 (EPA, 2000). While not perfect, this seems to be the most accurate description available for a beef CAFO.

Windtrax operates under the Monin-Obuhkhov Similarity Theory, which is only applicable to steady-state horizontally homogenous conditions in the surface layer. Therefore, the temperature and wind speed measurements must be representative of a layer that is both high enough to be outside the influence of the surface roughness elements and low enough to be within the surface layer. Typically, the measurements should be taken from $20z_o$ to $100z_o$ above the surface. For a Z_o of 0.10 m, measurements should be taken 2 – 10 m above the surface.

The pen source area mapped into Windtrax was defined by Google Earth*. A satellite photo was obtained and polygons were drawn over the pen surface and retention pond. The scale was verified by GPS at the feedyard. The pen source area was defined as fenced manure surfaces either occupied or recently occupied with cattle. All service roads and feed alleys were excluded from the source map.

The stability class input was determined by use of the solar radiation/delta-T (SRDT) method as described by the EPA (2000). Daytime stability classes are determined by a matrix combining wind speed and solar radiation (Table 2). Nighttime stability classes are determined by a matrix using a vertical temperature gradient and wind speed (Table 2). The vertical temperature gradient is determined by the differences air temperature at recommended heights of 2 m and 10 m (EPA, 2000).

Table 2: Pasquill-Gifford stability classes as determined by the SRDT method.

Daytime				
	Solar Radiation (W/m^{-2})			
Wind Speed (m/s)	≥ 925	925-675	675-175	< 175
< 2	A	A	B	D
2 – 3	A	B	C	D
3 – 5	B	B	C	D
5 – 6	C	C	D	D
≥ 6	C	D	D	D

Nighttime		
	Vertical Temperature Gradient	
Wind Speed (m/s)	< 0	≥ 0
< 2.0	E	F
2.0 – 2.5	D	E
≥ 2.5	D	D

The P-G stability classes range from very unstable (A) to neutral (D) to very stable (G). WindTrax tends to operate best when the stability is in the B to F range, and does not work well under very unstable conditions, i.e. very sunny and low wind speeds. Figure 1 shows the frequency of stability classes that were used as inputs.

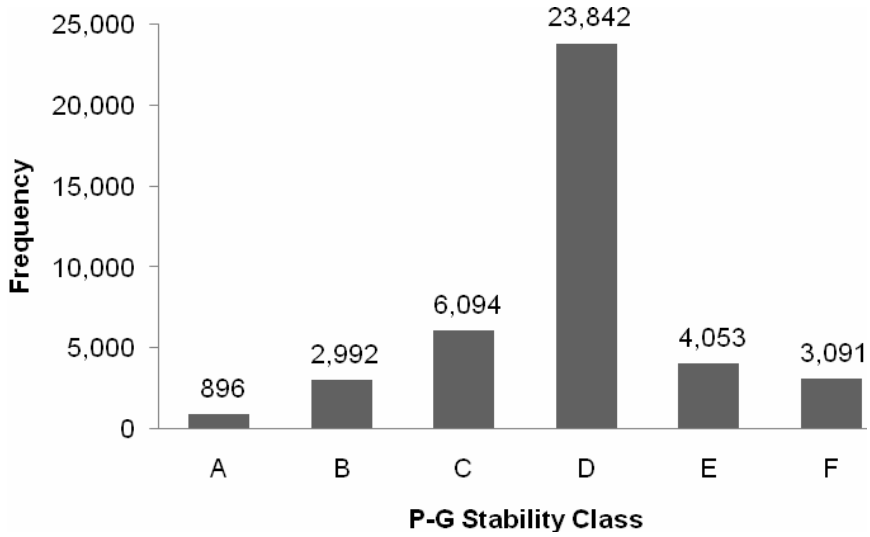

Figure 1: Frequency histogram of Pasquill-Gifford Stability classes used in emission estimations.

Approximately 2% of the inputs into WindTrax occurred under very unstable conditions (Fig. 1). These were not removed from the data set, as it was believed that they would have little impact on the overall mean estimated emission rates.

Feedyard

The participating feedyard (Fig. 2) in this study is a sprinkled yard with a one-time feeding capacity of 24,000 head located in the Texas Panhandle. This area is a semi-arid region receiving approximately 480 mm precipitation, annually. The yard is equipped with big gun sprinklers that are typically operated on an as-needed basis to control dust. Unfortunately, at the time of this study, the sprinkler system was not operational due to computer hardware and software updates. The sprinklers had been operational the previous year.

Results and Discussion

Ammonia monitoring commenced in mid-February 2007 and will be on-going through August 2009. Data from February 2007 were discarded as they were used for programming and instrument adjustment purposes. Data presented here are from March through August 2007, and are labeled spring (March – May) and summer (June – August). Emission rates of NH_3-N were compared to nitrogen fed to cattle (Table 5).

Ambient Concentration

Ammonia concentrations were measured at a height of 3.3 m 24-h per day. Concentrations were logged every 10-seconds and averaged over 5-min intervals to match with the weather data logs. All data loggers were time-synchronized weekly.

Table 3: Mean monthly NH_3 concentrations (ppm)

Month	n	Mean Concentration (ppm)	Standard Deviation (ppm)
March	8160	0.498	0.309
April	5663	0.597	0.350
May	6077	0.568	0.254
June	8172	0.684	0.676
July	8123	0.702	0.318
August	2456	0.772	0.487

Mean ambient concentrations for the summer months were higher than for the spring months (Table 3; Figs. 3 and 4). Mean monthly concentrations averaged by 5-min intervals followed observed daily trends of lower concentration in the early morning hours increasing to maxima in the early afternoon hours (Figs 3 and 4). The summer months exhibited a greater variation in concentration than did the spring months, probably due to an increased variation in climatic conditions. McGinn et al. (2007) found ambient NH_3 concentrations at a comparably sized beef cattle feedyard in Canada during the month of September to average about 0.800 ppm, which is very similar to the August concentrations (Table 3).

NH_3 Emissions

Figure 2 shows the Windtrax schematic used to define the model surface source and inputs. Table 4 gives the mean monthly flux densities. April fluxes were substantially greater than all other months, including during summer, even though ambient concentrations were not greater. April was a very dry, windy month, receiving only 20 mm of precipitation. Air temperature ranged from -3.33 to 28.89 °C, with an overall monthly mean of 11.44 °C. Wind speed more than likely offered the greatest influence to elevated fluxes. Winds ranged from 0 to 74 km/h with a mean of 20.7 km/h, with a total of 15 days having winds greater than 40 km/h (Table 1).

Table 4: Mean monthly NH_3 Flux Densities.

Month	n	Mean Flux Density ($\mu g\ m^{-2}\ sec^{-1}$)	Standard Deviation ($\mu g\ m^{-2}\ sec^{-1}$)
March	8160	57.76	36.32
April	5663	123.10	118.81
May	6077	86.34	66.95
June	8172	85.27	88.58
July	8123	75.06	54.39
August	2456	71.56	90.54

Ammonia flux rates followed the expected diel pattern, where rates are lowest in the early morning hours, then steadily increase to peak rates in the mid-afternoon (figs. 5 and 6). Mean spring flux rates were higher than summer fluxes, due to the high fluxes observed in April. The pen surfaces during March were very wet and muddy, with some partial freezing at night. There was a drying period during April, which may help to explain the higher flux densities during April. Flux densities averaged 85 and 79 $\mu g\ m^{-2}\ s^{-1}$ for the spring and summer months, respectively. This is very consistent with McGinn et al. (2007), who found average emission rates of 84 $\mu g\ m^{-2}\ s^{-1}$, and somewhat higher than Todd et al. (2005), who reported emission rates of 70 $\mu g\ m^{-2}\ s^{-1}$ for summer months.

Table 5: Comparison of NH_3-N emission to nitrogen fed, by month.

Month	NH_3 Flux Density ($\mu g\ m^{-2}\ sec^{-1}$)	NH_3-N Emission Rate ($kg\ d^{-1}$)	Fed N ($kg\ d^{-1}$)	NH_3-N flux density as % of fed N
March	57.76	1387	3330	34.3 %
April	123.10	2955	3260	74.7 %
May	86.26	2071	3472	49.1 %
June	85.53	2053	3629	46.6 %
July	75.26	1807	3465	42.9 %
August	71.55	1718	3385	41.8 %

The fraction of fed N lost as NH_3-N averaged 53% and 44% for the spring and summer months, respectively (Table 5). This is very similar to the 45% found by Todd et al. (2005), and lower than the 63 to 65% loss found by Flesch et al. (2007) for Texas feedlots and McGinn et al. (2007) for a 22,500 head capacity feedyard in Canada. Erickson et al. (1999) reported a range of 52 to 74% loss for Nebraska feedyards, which compares well with what we observed for the spring months, but is higher than the summer months

Conclusion

Although the pathway of urea to NH_3 is well understood, there are relatively few long-term data in the literature concerning NH_3 concentrations and emissions from area sources. Ammonia measurements were taken at a commercial cattle feeding operation in the Texas Panhandle to quantify concentrations and to estimate emissions. Ambient NH_3 concentrations during the spring months in 2007 were 0.498, 0.597 and 0.568 ppm for March, April and May, respectively. Concentrations during the summer months were 0.684, 0.702 and 0.772 ppm for June, July and August, respectively. Mean fluxes during spring were 57.8, 123.1 and 86.3 $\mu g\ m^{-2}\ sec^{-1}$ for March, April and May, respectively. Mean fluxes for summer were 85.3, 75.1 and 71.6 $\mu g\ m^{-2}\ sec^{-1}$ for June, July and August, respectively. Ammonia measurements are continuing throughout the fall and winter months and are expected to continue until August 2009.

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Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture

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Appendix

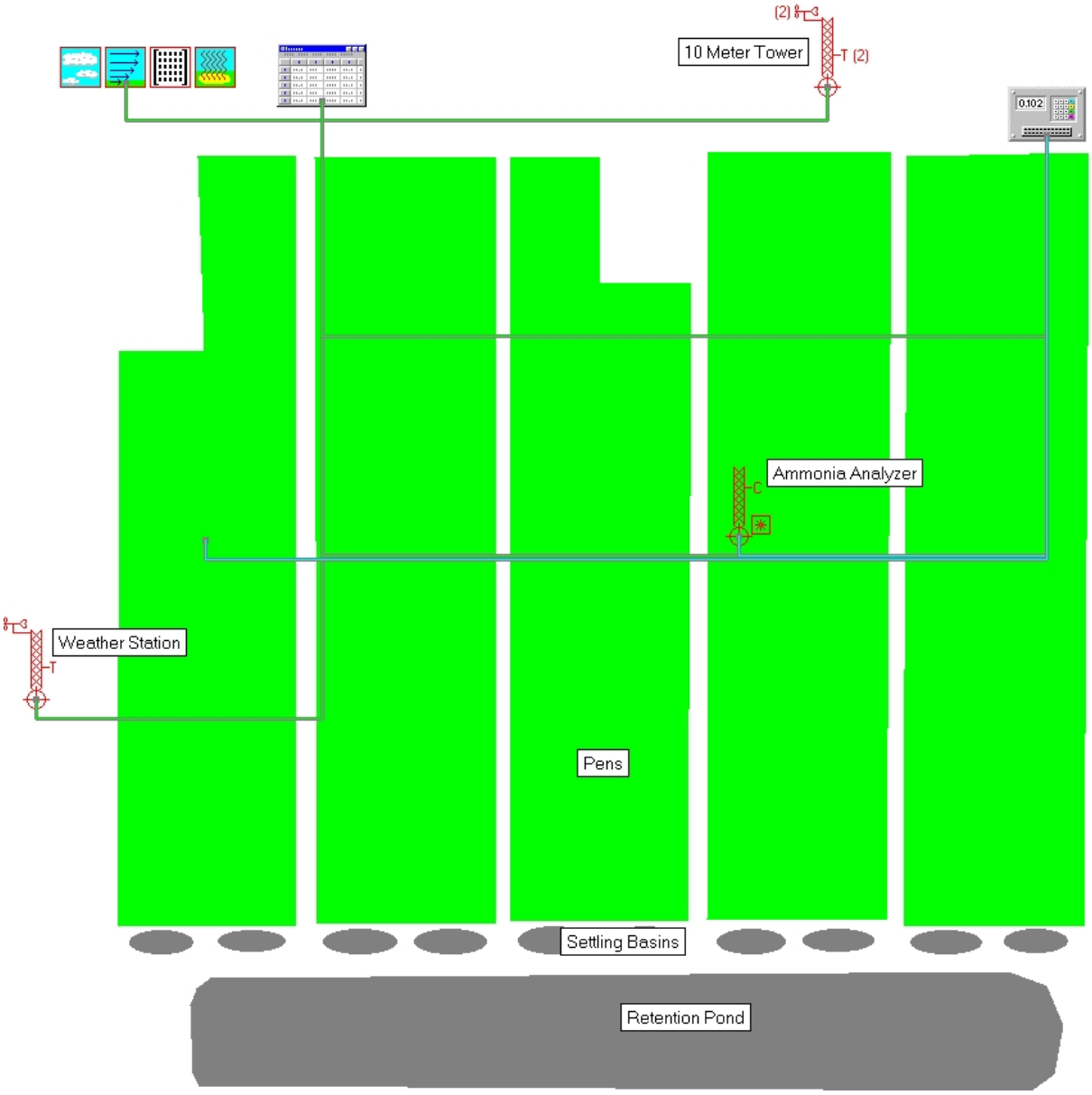

Figure 2: WindTrax® schematic of participating yard showing pen orientation and relative sensor locations. The 10-meter tower is located on the North side of the feedyard, while the weather station is located on the Southwest side, which is the prevailing upwind side.

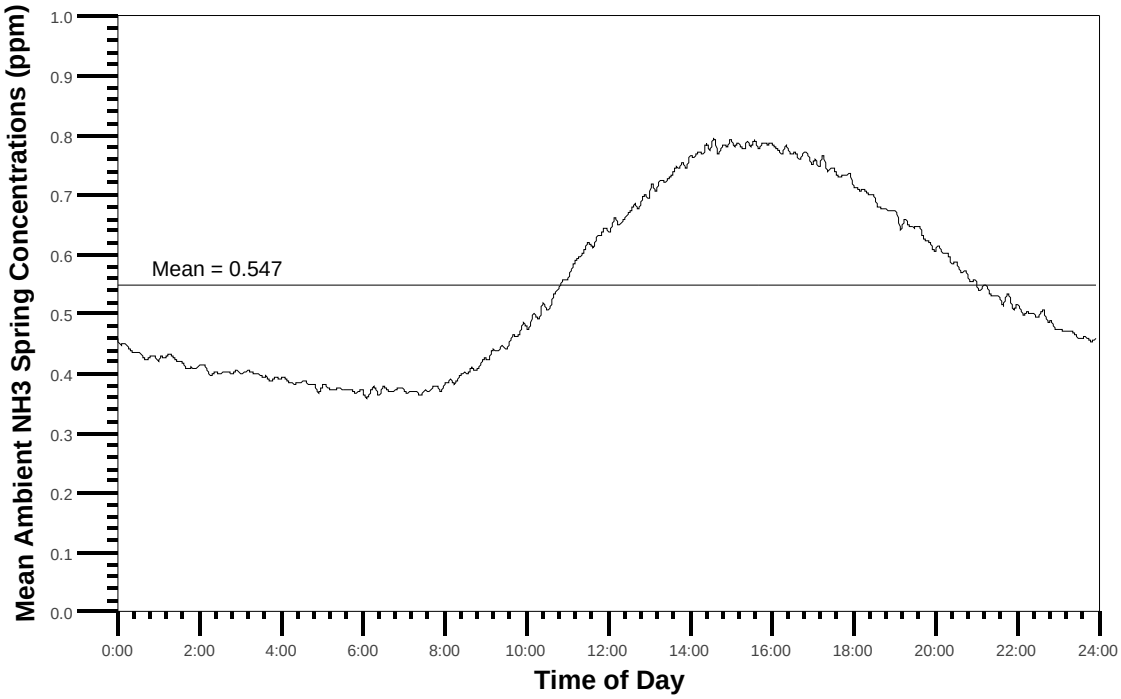

Figure 3: Mean NH_3 concentrations for March, April, and May 2007 combined averaged over time of day. The overall mean for the spring months was 0.547 ppm.

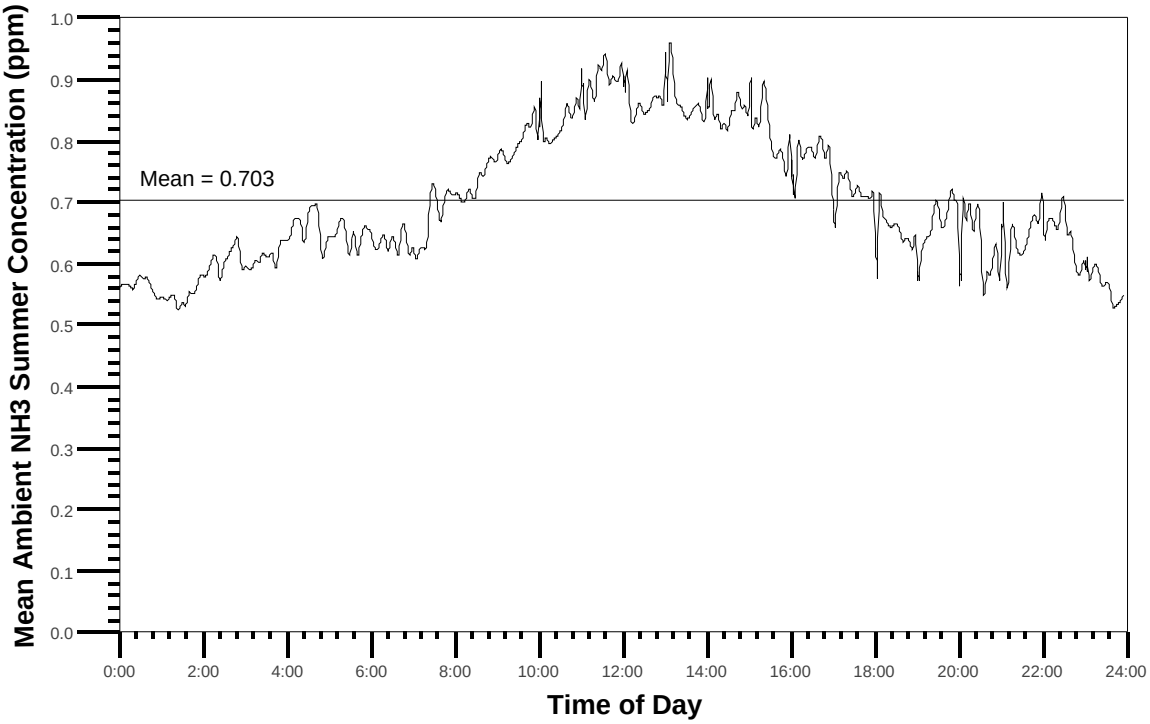

Figure 4: Mean NH_3 concentrations for June, July, and August 2007 combined averaged over time of day. The overall mean for the summer months was 0.703 ppm.

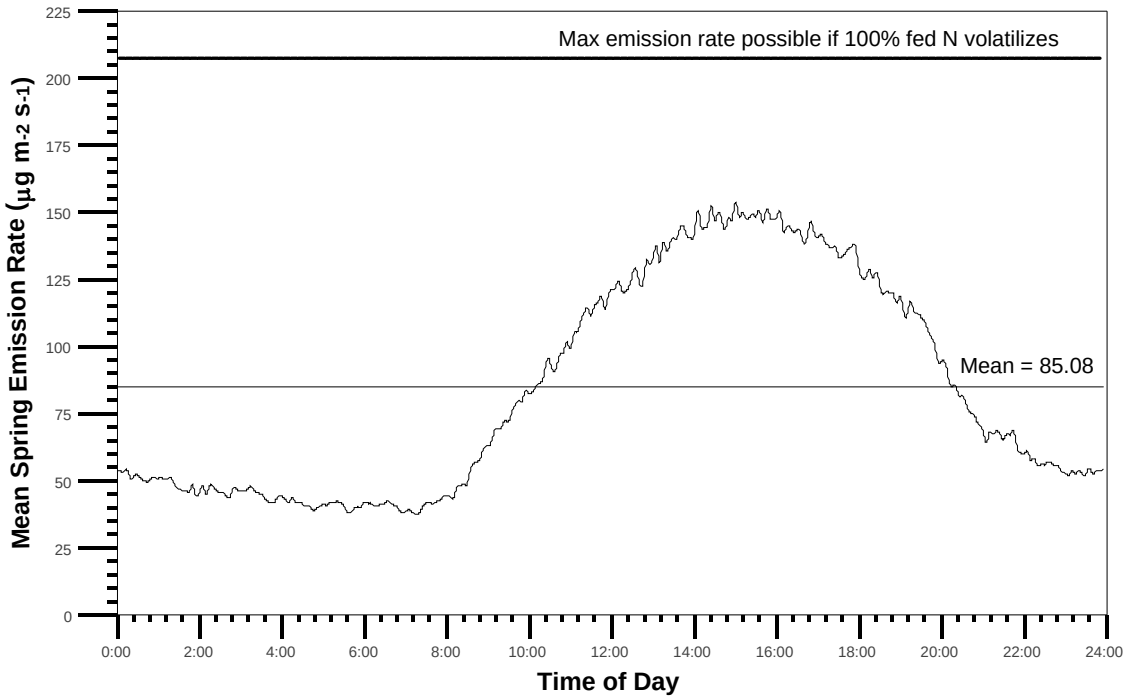

Figure 5: Mean flux density ($\mu g\ m^{-2}\ s^{-1}$) for March, April, and May 2007 by time of day. The overall mean for the spring months was 85.08 $\mu g\ m^{-2}\ s^{-1}$.

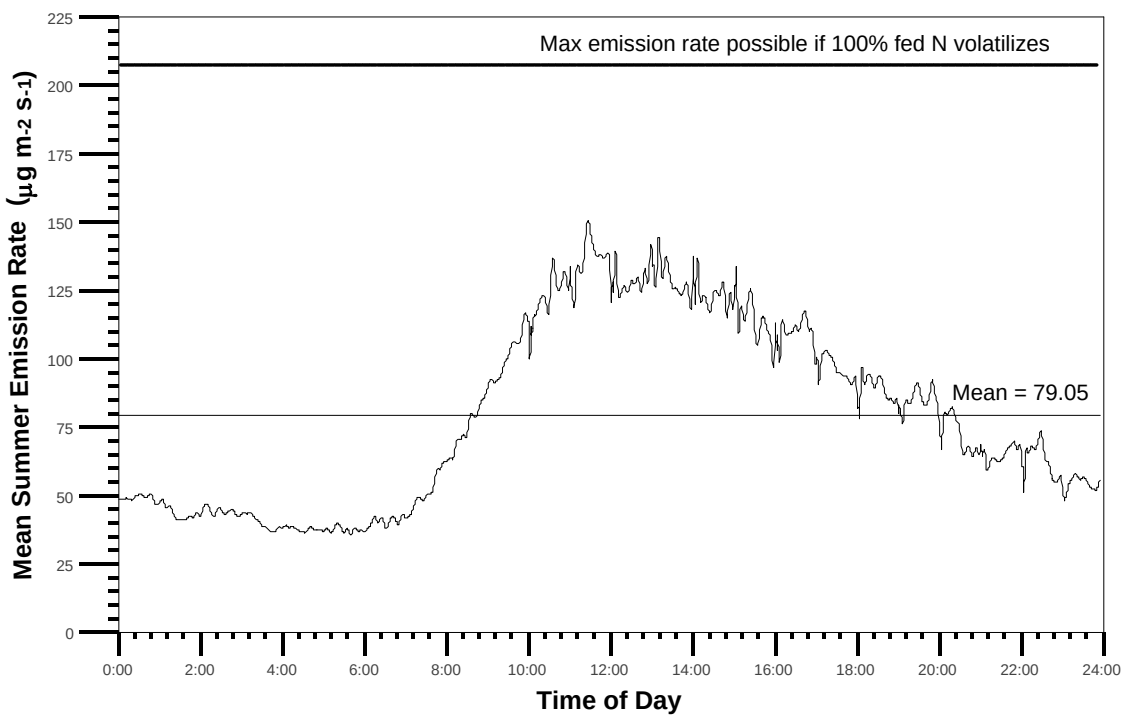

Figure 6: Mean flux density ($\mu g\ m^{-2}\ s^{-1}$) for June, July, and August 2007 by time of day. The overall mean for the summer months was 79.05 $\mu g\ m^{-2}\ s^{-1}$.