July 2000 ECN-C--00-079

NH_3 FLUX MEASUREMENTS AT SCHAGERBRUG AND OOSTVAARDERSPLASSEN, THE DUTCH CONTRIBUTION TO THE GRAMINAE EXPERIMENT

J. Mosquera
A. Hensen
W.C.M. van der Bulk
A.T. Vermeulen
J.W. Erisman
J.J. Möls

<table>
<tr><td colspan="3">Revisions</td></tr>
<tr><td>A</td><td colspan="2"></td></tr>
<tr><td>B</td><td colspan="2"></td></tr>
<tr><td>Made by:

J. Mosquera</td><td>Approved:

J.W. Erisman</td><td rowspan="2">ECN-Clean Fossils
Environmental Analysis and Technology</td></tr>
<tr><td>Checked by:</td><td>Issued:

C.A.M. van der Klein</td></tr>
</table>

Acknowledgement/Preface

The work described in this report was done within the GRAMINAE framework (EU contract ENV4-CT98-0722). We thank the Spanish Commission of Advanced Education and Scientific Research (Dirección General de Enseñanza Superior e Investigación Científica) who provided funding for J. Mosquera to come to the Netherlands Energy Research Foundation ECN as a postdoctoral fellow. We also thank R. Meester and our colleagues H. Möls, R. Otjes, P. Jongejan and P. Fonteijn for their helping hands on the experimental work.

Abstract

Ammonia concentration gradients at a grassland in an agricultural region were measured from July 1998 to July 2000 by three annular denuders (AMANDA) at the location Schagerbrug in the Netherlands. Concentration gradients were used to calculate the surface-atmosphere exchange of ammonia by means of the aerodynamic gradient technique. Measurements of the ammonia exchange were also performed at a grassfield that is part of a major wetland reserve in the centre of the Netherlands (Oostvaardersplassen), during the period June 1994-September 1995. At Schagerbrug, low net emissions or small depositions were measured during the winter months, with a net emission per month up to 5 kg $NH_3.ha^{-1}$ in summer. The net annual emission was 23 kg N/ha, with manure application contributing for about 50% to this level. At the Oostvaardersplassen mainly deposition occurs, but large emissions were measured in autumn. The measured exchange fluxes are compared to model evaluations that take into account plant physiological data like apoplast NH_4^+ concentrations and pH. Results show a good agreement between field observations and model simulations, although some improvements have to be made during nighttime periods.

Key words: Ammonia fluxes, long-term measurements, resistance modelling

CONTENTS

SUMMARY

1. INTRODUCTION

Ammonia is the major gaseous base in the atmosphere and the principal neutralising agent for atmospheric acids. But, at the same time, the deposition of gaseous ammonia (NH_3) and ammonium (NH_4^+) in aerosol or rain can contribute to terrestrial acidification and eutrophication, and, potentially, eutrophication of fresh and salt waters. Animal wastes produced in livestock breeding, together with fertilisation, provide the most important contribution to ammonia emissions. The major part of NH_3 evaporation takes place within two weeks after manure spreading or the application of fertiliser, decreasing almost exponentially as a function of time following the application (Beauchamp et al., 1982; van der Molen et al., 1990). But it also shows large diurnal variations and becomes very low during rain. Grazed pastures can contribute to the emissions not only by animal wastes deposed of during grazing, but also via application to the land of wastes excreted in the animal houses and via fertiliser application. The bi-directional nature of NH_3 exchange makes it necessary to use long-term data to develop and validate appropriate models for a real and temporal calculation of long-term fluxes from short periods of campaign measurements.
In this contribution we report 2 years of continuous measurements of NH_3 concentrations at a grassland in Northwestern Netherlands (Schagerbrug), together with 16 months of measurements at a semi-natural area in the middle of the Netherlands (Oostvaardersplassen). These measurements are evaluated in relation to meteorological parameters and the land use management (fertilization and/or grass cutting), and used to make a comparison between ammonia exchange over grasslands and semi-natural areas. A resistance model is evaluated to describe bi-directional NH_3 fluxes and applied to the measurements obtained at the site Schagerbrug. The measurements are used in the GRAMINAE project, which is a 2nd tranche project of EC TERI. Figure 1.1 shows the European scale transect of GRAMINAE, highlighting the Dutch site Schagerbrug.

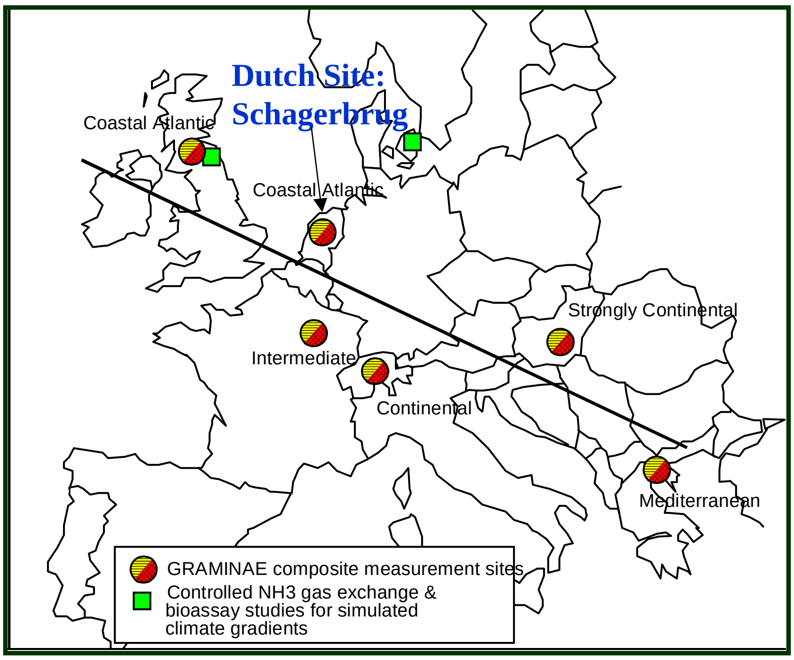


Figure 1.1. *The European scale transect of GRAMINAE*

2. MATERIALS AND METHODS

2.1 Description of the measurement sites

Schagerbrug

The Schagerbrug location (N 52°47', E 4°47') is situated about 4 km to the North West of the city of Schagen in an agricultural region (figure 2.1). The location is close to the North Sea with the coast at about 7 km to the west. Predominant wind direction for this area is West or Southwest. Low concentrations of NH_3 can be expected from this wind sector. The climate is mild and marine.

The fields surrounding the measurement location consist of flat pasture and some with ditches for water regulation. The average water table in the field is at -60 cm and the soil consists of clay. The soil moisture contents were measured twice at this site. On the field there are 5 drainage ditches that are about 50 cm below the highest level of the field. Water from the ditches flows into the canal that is the border of the field. The farm to which the field belongs is no longer active so there are no local NH_3 sources on the site. The farm to the east however is in operation and houses about 60 cows. The grass on the site is harvested about 4 times a year, after which manure spreading occurs. Until three years ago the field was used for grazing by cattle, now it is used for grass production.

Measurements were started in July 1998 with the tower located in the southern part of the field, and the denuders at 0.95, 2.17 and 3.84 m height (position 1 in figure 2.2). Just before the experiment the field was harvested. A few days later, on July 1, manure spreading took place on two plots (50 m diameter) Northwest of the measurement tower (figure 2.2). The core of the two plots was approximately at 290^o (injection into the soil) and 0^o (surface spreading) relative to the position of the tower. In September 1 the tower was replaced on the field and moved to the Northeast corner (position 2 in figure 2.2), but no changes in the measurement heights were applied. On September 4 manure spreading took place on two plots (50 m diameter) South of the measurement tower. In this case the core of the two plots was at about 180^o and 220^o (injection and surface spreading techniques applied, respectively). From 23 December 1998 to 21 January 1999 measurements were performed with the tower placed on the field at the position 3 (figure 2.2), with no changes in the measurement heights. From 21 January 1999 to June 2000 the tower was maintained in position 3 (figure 2.2), but with denuders at heights of 0.52, 0.92 and 2.17 m. The whole field was manured 4 times since then with organic manure (5 May, 16 June, 2 August and 13 September 1999) to study the effect of manure application on the measured NH_3 concentrations and fluxes.

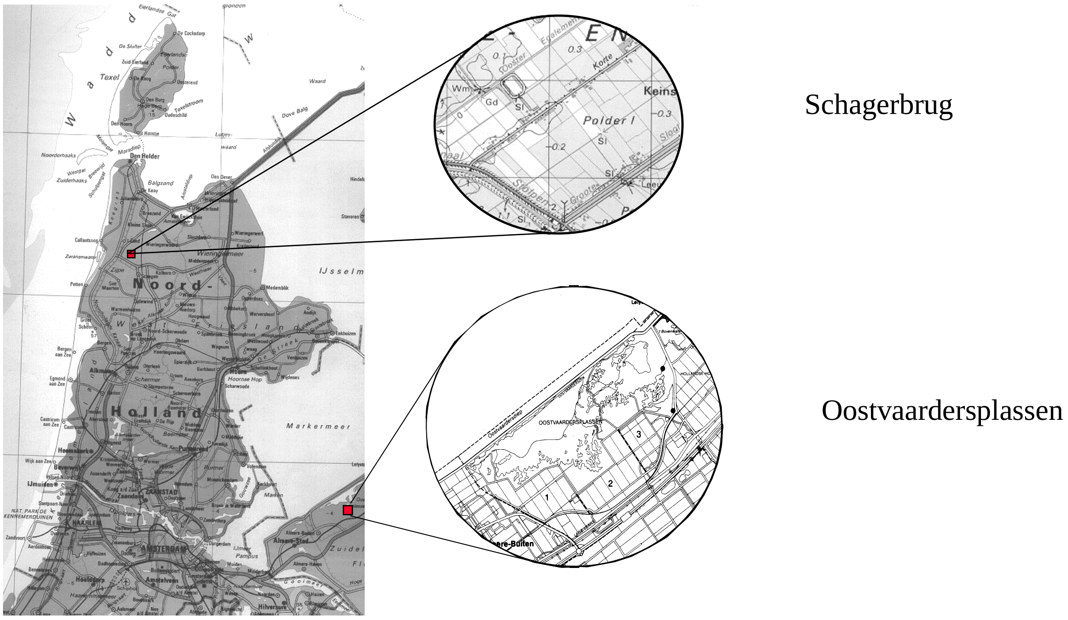


Figure 2.1 *Measurement sites location*

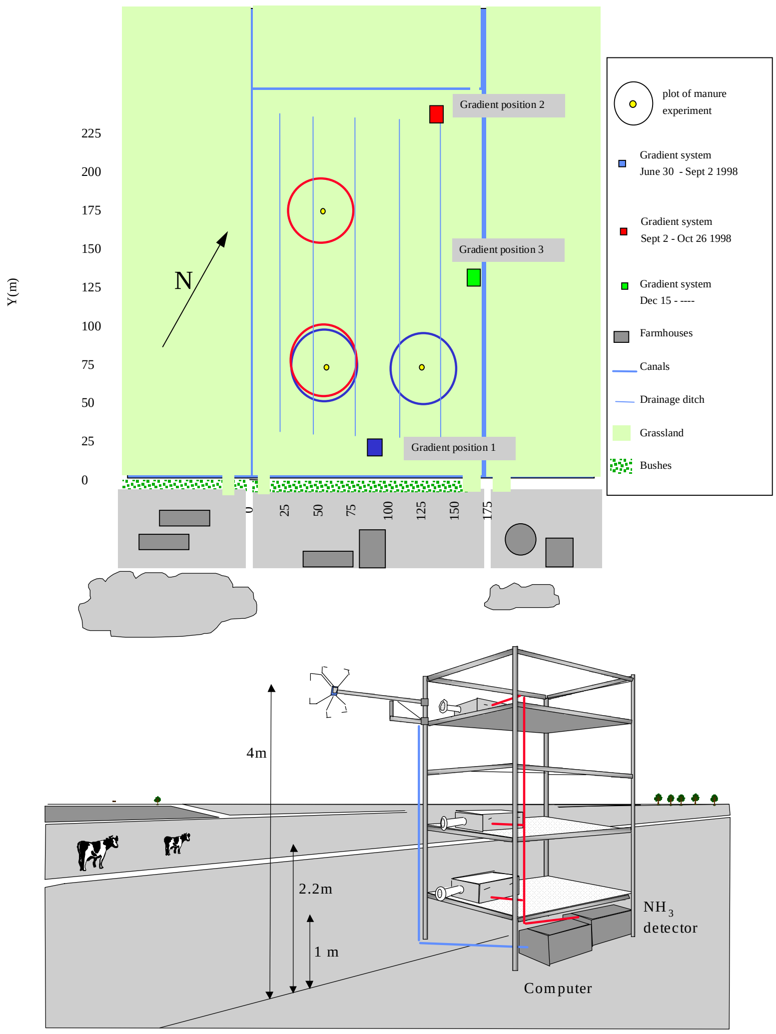


Figure 2.2 *Description of the measurement site at Schagerbrug*

Oostvaardersplassen
The Oostvaardersplassen area is the largest of the wetland reserves in Flevoland, close to the lake IJssel situated almost in the center of the northern part of the Netherlands, with a area of approximately 5600 ha. Water management and grazing are considered to be the most important management measures in the area. A large number of birds have been identified in the Oostvaardersplassen area for breeding, feeding, roosting, moulting or wintering. Large grazing animals (cattle, wild horses, red deer) are also found in the area. Measurements of NH_3 at Oostvaardersplassen covered the period June 1994-September 1995, with concentrations measured at heights of 0.9, 2.1 and 4.1 m.

2.2 Instrumentation

The measurement setup consists of an open frame tower on which three continuous flow annular denuders AMANDA (Wyers et al., 1993) were located to measure NH_3 concentrations at three different levels. These instruments are fully automated and feature on-line detection of ammonia. Ambient air is pumped through an annular denuder using a sample flow of 30 $l\ min^{-1}$. The denuder is rotated around its axis at a speed of 30 $rotations\ min^{-1}$. Ammonia is collected in a $NaHSO_4$ absorption solution, which covers the walls of the annular space in the rotating denuder and is continuously pumped into and out of the denuder by two peristaltic pumps, in counterflow with the sampled air. The resistance of the solution film inside the denuder is measured with two Pt-electrodes and used to adjust the flow rate of absorption solution into the denuder to keep the volume of solution inside the annulus at a constant level and compensate for evaporation losses. The solution is pumped out of the denuder at a fixed but adjustable rate of 0.5-4 $ml\ min^{-1}$.
Downstream of the denuder a NaOH solution containing NH_4^+, is merged with the absorption solution in a mixing chamber/debubbler at a rate of 0.08 $ml\ min^{-1}$, causing a shift of the NH_4^+ / NH_3 equilibrium towards NH_3, which is separated from the solution by diffusion through a semi-permeable membrane. Approximately 30% of the ammonia permeates the membrane and is dissolved in a stream of double-demineralized water (0.08 $ml\ min^{-1}$), from which all traces of (bi)carbonate have been previously removed on an ion exchange column. The ammonium concentration in the water stream is determined conductimetrically and compared with calibration standards, corrected for temperature variations. The detector is calibrated with solutions containing typically 50 and 500 *ppb* NH_4^+ and a blank solution. The instrument cannot be used at ambient temperatures below the freezing point, unless special precautions are taken.
For the profile measurements, the three denuders were connected to a single detector. The solution stream from each denuder is led through the detector for 2 minutes. The conductivity is measured for 1 min, starting after a 1-min pause to avoid memory effects. Thus, the analysis of the effluents of the three denuders will be completed in 6 min. Afterwards, the 6 minutes measurement cycles are averaged to 30 minutes values.
A sonic anemometer (ATI) was used for high-speed measurements (10 Hz) of the wind velocity in the three orthogonal directions (u, v, w) and of temperature (T), obtaining 6-minute averages continuously. This raw data was processed to obtain 30-minute averages, and used to calculate the average wind speed ($\bar{u}$), wind direction (WD), friction velocity (u*), sensible heat flux (H) and Monin-Obukhov length (L). Other sensors were used to obtain information of relative humidity (rh, %), rainfall (mm rain), soil temperature (T_s), global radiation (Glrad) and net radiation (netrad) on the same time basis, and averaged to 30-minute periods. Table 2.1 shows the different sensors and instruments used to provide meteorological conditions and NH_3 concentrations on a routine basis.

Table 2.1 *Overview of the instrumentation used at the site Schagerbrug*

Variable	Units	Period start	Type	
Data logger		6-1998	Micrologger	21X Campbell micro logger
NH_3 gradient	µg/m^3	6-1998	Wet denuder	ECN – AMANDA
CO_2 conc.	ppm	3-2000	NDIR	Licor 6262
Wind speed	m/s	6-1998	Sonic anemometer	ATI SWS-211/3K
Wind direction	degrees	6-1998	Sonic anemometer	ATI SWS-211/3K
Relative Humidity	%	3-1999		Rotronic MPS40 - 001683
Air temperature	^oC	3-1999	Thermocouple (E-type)	Campbell Scientific TCBR-3
Soil temperature	^oC	3-1999	Thermocouple (E-type)	Campbell Scientific TCAV
Soil heat flux	W/m^2	3-1999	Flux platelets (thermopile)	Radiation and Energy Balance Systems (HFT 1)
Net radiation	W/m^2	3-1999	Net-radiometer (thermopile)	REBS (Q*6)
Global radiation	W/m^2	3-1999	Solarimeter	Casella W6500
Rain intensity	mm/h	3-1999	Tipping bucket	Casella
Grass height	mm	3-1999	NMI	
LAI	m^2/m^2	3-1999		
Apoplast NH_4^+	mmol/l	3-1999		

2.3 Resistance model of NH_3 exchange

To describe the bi-directional exchange of NH_3, a resistance model was used based on the canopy compensation point-cuticular capacitance model developed by Sutton et al. (1998). This model (figure 2.3) allows both the atmosphere and the different parts of the canopy to behave as sinks (cuticular uptake, stomatal uptake) or sources of NH_3 (stomatal emission, soil emission). The net flux is derived as the result of the exchange between air concentrations (χ\{z-d\}) and the canopy compensation point (χ_c) as

$$F_t = \frac{\chi_c - \chi\left(z-d\right)}{R_a + R_b} \tag{1}$$

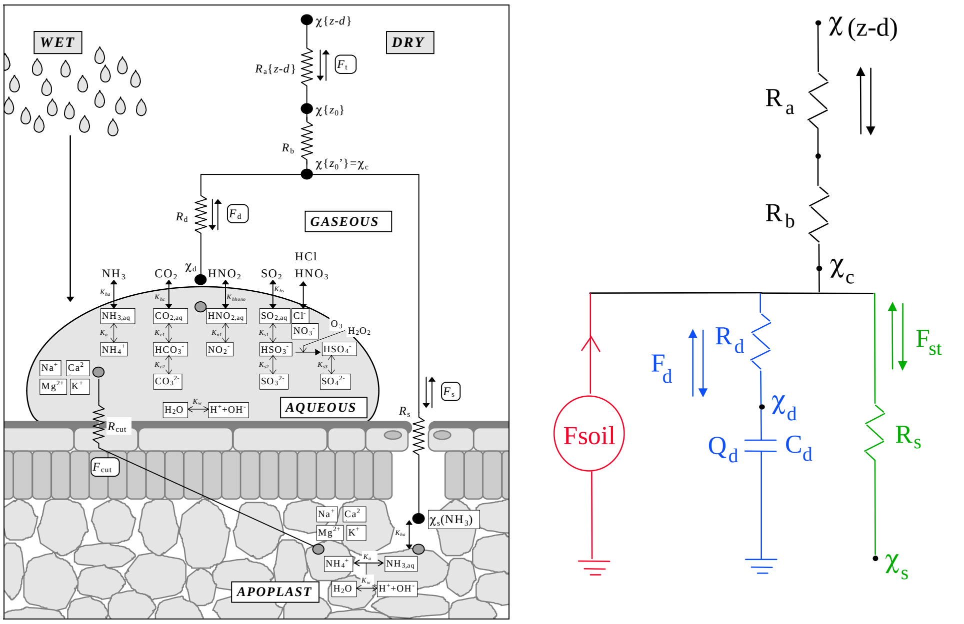


Figure 2.3 Resistance model of plant-atmosphere exchange of NH_3. In the figure, F_{st} refers to the exchange through the stomata, F_d to the exchange through water-films on leaf surfaces, and F_{soil} to the increased soil emission after manure application onto the field. R_a and R_b are the aerodynamic and quasi-laminar resistances, respectively, and R_d the resistances to transfer of NH_3 through the stomata. R_d, C_d and Q_d represent the resistance, capacitance and charge of the capacitor analogy used into the model to show the contribution of cuticular water films to the net NH_3 exchange. The NH_3 concentrations in air, stomata and water films are represented by χ(z-d), χ_c and χ_d, respectively

The term R_a represents the aerodynamic resistance above the surface, and depends mainly on the local atmospheric turbulence intensities. R_a is approximated following the procedures used by Garland (1978):

$$R_a(z-d) = \frac{1}{\kappa \cdot u^*} \cdot \left[\ln\left(\frac{z-d}{z_o}\right) - \psi_h\left(\frac{z-d}{L}\right) + \psi_h\left(\frac{z_o}{L}\right) \right] \tag{2}$$

in which κ is the Von Karman constant (0.4), u* is the friction velocity, which is calculated from the output of the meteorological model , L is the Monin-Obukhov length, *d* is the displacement height and z_o is the roughness length, which is defined independently for each land use and season category. $\psi_h[(z-d)/L]$ is the integrated stability function for heat. These can be estimated using procedures described in Beljaars and Holtslag (1990).
The second atmospheric resistance component R_b is associated with transfer through the quasi-laminar layer in contact with the surface and is governed by diffusivity of the gaseous species and air viscosity. R_b is approximated by the procedure presented by Hicks et al. (1987):

$$R_b = \frac{2}{\kappa \cdot u^*} \cdot \left(\frac{Sc}{\Pr}\right)^{2/3} \tag{3}$$

where Sc and Pr are the Schmidt and Prandtl number, respectively. Pr is 0.72 and Sc is defined as $Sc = \upsilon / D_i$, with υ being the kinematic viscosity of air (0.15 cm^2 s^{-1}) and D_i the molecular diffusivity of pollutant *i* and thus component specific.

The canopy compensation point may be written as

$$\chi_c = \frac{\dfrac{\chi\{z-d\}}{R_a\{z-d\}+R_b} + \dfrac{\chi_s}{R_s} + \dfrac{\chi_d}{R_d} + F_{soil}}{\dfrac{1}{R_a\{z-d\}+R_b} + \dfrac{1}{R_s} + \dfrac{1}{R_d}} \tag{4}$$

where F_{soil} is included to explain increased soil emissions following fertilisation. NH_3 exchange through the stomata is assumed to be related with the stomatal compensation point χ_s, leading to stomatal emission for $\chi\{z\text{-}d\}<\chi_s$, and deposition for $\chi\{z\text{-}d\}>\chi_s$. χ_s is expressed as

$$\chi_s = \frac{2}{T}\cdot \exp\left(-10.378\cdot\left(\frac{1}{T}-\frac{1}{T+25}\right)\right)\frac{[NH_4^+]}{[H^+]} \tag{5}$$

where T is in K and all the concentrations are in $mol\cdot l^{-1}$. The bulk stomatal resistance R_s depends on leaf morphology, leaf area index (*LAI*), photosyntetically active radiation (*PAR*), temperature (*T*), and vapour pressure deficit (*VPD*). According to Jarvis (1976) (see also Baldocchi et al., 1987), the stomatal conductance ($g_s=1/R_s$) for a leaf is computed as

$$g_s = LAI\cdot f(PAR)\cdot f(T)\cdot f(VPD)\cdot D_v/D_i \tag{6}$$

where *f(PAR)*, *f(T)* and *f(VPD)* are the functional relationships of the stomatal conductance for *PAR*, *T* and *VPD*, respectively. The response of stomatal resistance to PAR is estimated following Turner and Begg (1974) as

$$\begin{aligned} R_s(PAR) &= r_s(\min)\cdot(1+b_{rs}/PAR) \\ f(PAR) &= 1/R_s(PAR) \end{aligned} \tag{7}$$

where $r_s(min)$ is the minimum stomatal resistance under optimal conditions and b_{rs} is a constant equal to the PAR flux density at twice the minimum stomatal resistance. The response of stomatal conductance to temperature is computed using the relationship presented by Jarvis (1976)

$$\begin{aligned} f(T) &= [(T-T_{\min})/(T_o-T_{\min})]\cdot[(T_{\max}-T)/(T_{\max}-T_o)]^{\beta} \\ \beta &= (T_{\max}-T_o)/(T_{\max}-T_{\min}) \end{aligned} \tag{8}$$

where T_{min} and T_{max} are the minimum and maximum temperatures at which stomatal closure occurs, and T_o is the optimum temperature for stomatal opening. Finally, stomatal conductance is linearly related to vapor pressure deficit following the expression

$$f(VPD) = 1 - b_v\cdot VPD \tag{9}$$

where VPD is calculated according to Monteith (1973).
The NH_3 concentration in equilibrium with the cuticle is now $\chi_d>0$, associated with a resistance R_d , a capacitance C_d and a charge Q_d. This allows cuticular films to behave as capacitors, charging up with NH_3 when $\chi_d<\chi_c$, and releasing NH_3 to the air when $\chi_d>\chi_c$, at rates regulated by R_d. According to Sutton et al. (1998), χ_d (µg m^{-3}), C_d (m), Q_d (µg m^{-2}) and R_d (s m^{-1}) are described as

$$C_d = 20\cdot LAI\cdot \exp([Rh-60]/10)\cdot\left\{\frac{[H^+]}{10^{1.6035-4207.6/T}} + 10^{1477.7/T-1.6937}\right\} \tag{10}$$

$$Q_d^{i+t} = Q_d^i - F_d\cdot t \tag{11}$$

$$\chi_d^i = Q_d^i / C_d \tag{12}$$

$$R_d = \frac{5000}{C_d} \tag{13}$$

where $F_d = \left(\chi_d^i - \chi_c^i\right)/ R_d$ is the flux in or out of the adsorption capacitor, *LAI* is the canopy leaf area index, *Rh* the relative humidity (%), *T* the temperature in Kelvin, and *t* the number of seconds (time step) used to calculate the new charging resistance of the capacitor. A leaf surface pH of 5 ($[H^+]=10^{-5}$) will be assumed in the model calculations.

3. RESULTS

3.1 Data availability

Before the calculation of fluxes started, the measurements of the individual instruments were validated. Results that were unreliable due to traceable instrumental failures were removed from the set of input data for the flux calculations. Data coverage considering the total length of the experiment in Oostvaardersplassen was 41% for meteorological observations, 41% for concentration measurements, but only 25% when considering periods where both concentrations and meteorological observations were available. For Schagerbrug, data coverage was 79% for meteorological observations, 71% for concentrations, and 69% for those periods including both meteorological conditions and concentrations. In appendices A and B the data availability for fluxes, concentrations and some meteorological parameters are reported for Schagerbrug and Oostvaardersplassen.
Some selection criteria were defined in order to avoid artifacts by conditions that are outside the domain where micrometeorological methods are applicable. They concern the precision of the concentration profiles and meteorological conditions during the measurement. If all these criteria are met, the flux-profile method is applicable and results are reliable. The following meteorological parameters were used to reject conditions with poor fetch or uncertain flux-profile relations:

- *Wind direction*. To satisfy fetch requirements.
- *Wind speed*. At low wind speeds, the validity of flux-profile relations becomes uncertain. In stable, nocturnal atmosphere, at low wind speeds, transport is often dominated by very large eddies with long intervals which may be described less accurately by flux-profile relations. The same applies if at low wind speeds in an unstable atmosphere, convective transport completely dominates the transport. Partly for this reason, it is common practice in similar experiments to reject flux measurements if wind speed is below 1 to 2 m s^{-1}.
- *Stability*. This criterion is applied for similar reason as the previous one. The stability corrections are less certain under very stable or very unstable conditions. Therefore, again in the line with common practice, measurements with a value of L between -10 and 5 m ($-0.5 < z / L < 1$) were rejected.

The results of the selection according to the criteria explained above are presented in table 3.1. Slightly less than 35% of the total data collected at Schagerbrug remains after selection, most of the time due to instrumentation failure and incorrect wind direction. At Oostvaardersplassen, only 19% of the data can be used for flux calculation, once again due mainly to instrumentation failure. The concentration profiles that passed the validation were combined with the corresponding values of the relevant meteorological parameters. The fluxes and deposition velocities were calculated using the aerodynamic gradient method.

Table 3.1 *Selection criteria for flux measurements*

Criteria	% of remaining NH_3 data, Schagerbrug	% of remaining NH_3 data, Oostvaardersplassen
Concentrations and meteorological data available	72.9	27.1
$\bar{u} > 1$ m s^{-1} $u_* > 0.1$ m s^{-1}	60.5	21.3
$L < -10$ m or $L > 5$ m	59.8	18.6
Wind direction:	34.4	(not applied here)

3.2 Ammonia concentrations

The concentrations measured at Schagerbrug depend strongly on wind direction as a consequence of the presence of a number of local agricultural sources close to the measurement site. The wind sector dependence of NH_3 concentration can readily be seen in figure 3.1(a), where NH_3 concentrations measured at the 2.17 m height level are plotted for the three different positions of the measurement tower (figure 2.2). At the beginning of the study, when the measurement tower was placed on the field at the position 1 (figure 2.1), higher NH_3 concentrations were found for north-western wind directions (in the 240-360 and 0-30 wind sectors). This is clearly in agreement with the location of the two plots that were manured on the 1st of July 1998. On average, concentrations measured with air coming from the plot manured using the surface spreading technique are higher than those observed from the manure injected plot. After moving the tower to position 2, higher concentrations were measured from eastern wind directions, as expected from the location of the two plots manured in September 4, 1998. The fact that easterly winds were predominant in September, together with the low wind speed values measured in that period from the east, could explain this particular dependency observed. The farm located to the south east, still in operation, is also an important factor to explain this particular dependency of concentrations with wind direction. The concentration pattern observed with the tower at the position 3 also reflects the presence of other sources of ammonia east/south-east relative to the position of the measurement tower. Higher concentration values compared to those measured when the tower was at position 2 were measured during this period, which is related to the fact that manure spreading took place on the whole field four times with the tower at the position 3.

This effect is also shown in figure 3.1b, where average ammonia concentrations are plotted per season and per wind direction sector of 30^o. Limitations of the manure application period (prohibition of manure spreading in winter), together with the possibility of manure application in summer using low-emission techniques, have led to generally lower ammonia concentrations measured during wintertime compared to those measured during the rest of the year. In general higher concentration values were measured during spring and summer (table 3.2), but there was a close coupling between daily weather and NH_3 concentrations. Windy, rainy conditions favoured low concentrations; warm and dry, or cold and calm conditions were generally characterized by larger concentrations. Appendix A shows a complete report of monthly fluxes, concentrations and meteorological parameters for Schagerbrug.

Table 3.2 *Monthly variations in half-hourly measurements of ammonia concentrations at 2.17 m above ground level at Schagerbrug*

CONCENTRATIONS (MIDDLE LEVEL, μgM^{-3})							
Month	Max	Min	Mean	Median	STDV	Data available [%)]	level [m]
Jul-98	23.3	0.0	3.3	2.0	3.5	72.8	2.17
Aug-98	25.5	0.2	3.2	2.4	2.6	80.9	2.17
Sep-98	65.2	0.1	6.3	5.4	4.9	59.5	2.17
Oct-98	9.7	0.3	3.1	3.0	2.0	72.3	2.17
Nov-98							
Dec-98	25.6	0.8	5.6	3.1	5.4	94.9	2.17
Jan-99	27.5	0.1	4.0	2.6	3.8	53.6	2.17*
Feb-99	22.3	0.1	3.2	2.0	3.0	49.0	0.92
Mar-99	18.0	0.0	3.0	1.6	3.4	54.5	0.92
Apr-99	137.1	0.4	7.4	4.1	12.4	51.8	0.92
May-99	109.1	-0.3	9.4	6.9	12.0	98.9	0.92
Jun-99	113.8	-0.3	9.1	3.2	19.4	73.0	0.92
Jul-99	53.0	-0.1	9.4	5.8	8.8	92.4	0.92
Aug-99	146.2	0.3	13.8	8.2	17.6	98.9	0.92
Sep-99	64.1	-0.6	13.1	12.4	9.9	90.5	0.92
Oct-99	25.0	0.0	4.5	3.3	4.0	81.4	0.92
Nov-99	13.6	-0.1	2.0	1.3	2.1	91.9	0.92
Dec-99	8.0	-0.1	0.6	0.3	0.8	80.0	0.92
Jan-00	9.2	0.0	0.9	0.6	1.0	86.0	0.92
Feb-00	10.9	-0.1	0.7	0.4	1.0	95.9	0.92
Mar-00	214.5	-0.1	10.7	0.4	21.6	93.2	0.92
Apr-00	70.2	0.0	10.3	7.3	11.0	87.1	0.92
May-00	46.8	0.0	9.0	8.4	7.9	45.9	0.92
Jun-00							0.92
Jul-00							0.92

* after 21 January, 0.92 m

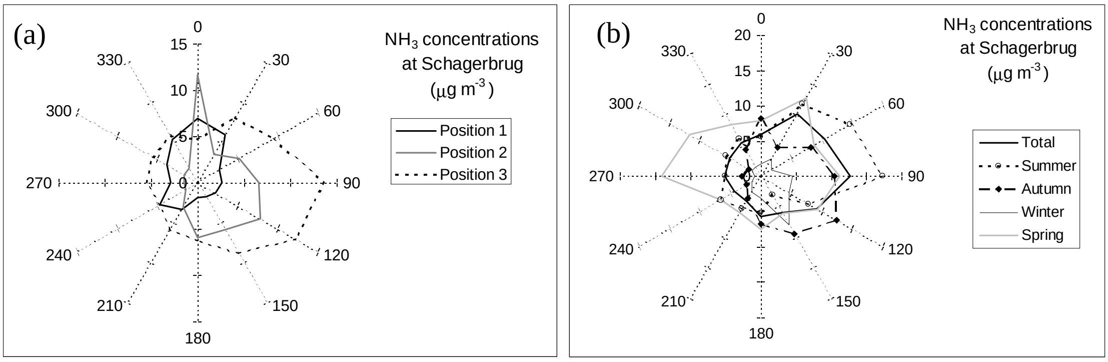


Figure 3.1 *Sector dependence of average NH_3 concentrations ($\mu g\ m^{-3}$) at Schagerbrug, at the 2.22 m height level, per wind direction sector of 30^o, regarding the different locations of the measurement tower at Schagerbrug during the whole measurement period (figure 2.2)*

Ammonia concentrations measured at Oostvaardersplassen depend also on wind direction, as shown in figure 3.2. Due to the presence of the IJssel lake to the north-northwest of the measurement site, generally low concentration values are measured in that wind sector range, while higher concentrations are observed from southeasterly wind directions. Besides, since Oostvaardersplassen is located in a semi-natural area with no local ammonia sources in the immediate vicinities, concentrations measured at Oostvaardersplassen are generally much lower than those observed in Schagerbrug (an intensively managed grassland), with the only exception of autumn where similar concentration values were measured at both sites. The presence of up to 200 horses in November 1994, and a large amount of geese (up to 50000 individuals) staying in that area in wintertime, could partially explain the high concentration values observed in November-December 1994, and January 1995. Appendix B shows the monthly averages calculated for fluxes, concentrations and meteorological parameters at Oostvaardersplassen.

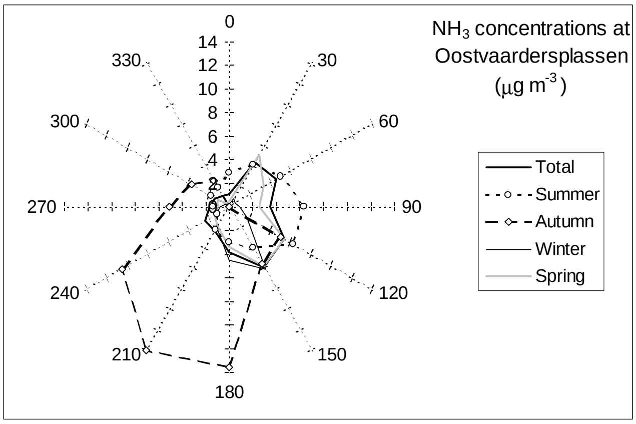


Figure 3.2 *Wind direction dependency and seasonal variation of average NH_3 concentrations ($\mu g\ m^{-3}$) at Oostvaardersplassen (at the 2.1 m height level), per wind direction sector of 30^o*

Concentration depends strongly on dilution and dispersion of the ammonia after its release from the surface or by other sources. This is reflected in the average ammonia concentration diurnal patterns shown in figure 3 for the concentrations measured in Schagerbrug (a) and Oostvaardersplasen (b) at the 2.1 m height level. At Schagerbrug, a build up of concentrations is observed during periods of low wind speed, low mixing layer heights and stable atmosphere, which occur mainly during nighttime. During daytime, after breakup of the inversion, more efficient mixing results in lower concentrations. Notice the increase of the concentration value in the early morning which marks the starting point of decreasing concentrations during daytime. For each season, this peak appears in a different position (hour of the day), earlier as we move on to the summer months. Oostvaardersplassen is located in a background area, so nighttime concentrations do not build up. But when the inversion layer breaks in the early morning, long-range transport of NH_3 reaches the site, producing the morning peak observed in figure 2b. Concentrations measured at Oostvaardersplassen are generally much lower than those observed in Schagerbrug, with the only exception of autumn where similar concentration values were measured at both sites. The presence of up to 200 horses in the field in November 1994, and a large amount of geese (up to 50000 individuals) staying in the Oostvaardersplassen area in December 1994 and January 1995, could partially explain the high concentration values observed in autumn and winter.

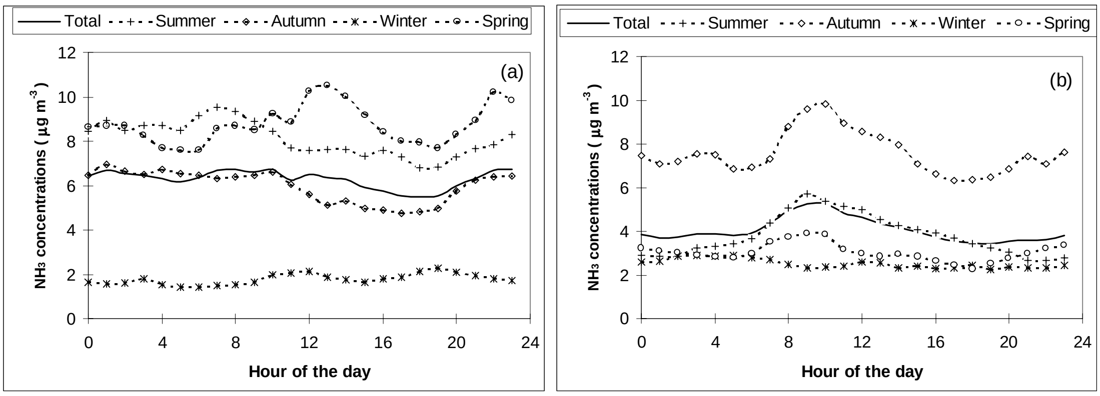


Figure 3.3 *Average diurnal pattern of ammonia concentrations measured at (a) Schagerbrug over the period July 1998-July 2000, and (b) Oostvaardersplassen over the period June 1994-September 1995*

3.3 Ammonia exchange fluxes

Using the information available for the three vertical NH_3 concentrations and meteorological parameters (on a 30-minute average basis), ammonia exchange fluxes and deposition velocities were calculated using the aerodynamic gradient method. The set of data obtained in this way was corrected by selection of those periods during which the theoretical demands for the aerodynamic gradient technique were fulfilled and there was no loss of necessary measurements due to technical problems. Ammonia fluxes measured at Schagerbrug show a diurnal pattern with higher emissions during daytime, and lower emissions (or even deposition in the winter season) during nighttime (figure 3.4). Generally higher emissions are observed in summertime, with deposition being the main pattern during the winter season (figure 3.4a). As expected, an emission peak is observed in the early afternoon, related to a peak in temperature and a peak in turbulence, both favouring higher emissions. The second peak observed in the early morning during spring and summer is expected to be related with manure spreading, that took place in the measurement field many times between May and September 1999. To show this, the average diurnal pattern for the NH_3 flux measured during the whole period of measurements with and without a period of 3 days after manure application, was calculated. Figure 3.4b shows the results of this analysis. As expected, the emission peak observed in the early morning for the complete set of measurements, disappears when only periods with no manure spreading are being considered in the flux calculation. Besides, more than 50% of the NH_3 that was emitted (on average) during the measurements period was observed to be due to these manure spreading events occurred in the measurement field studied at Schagerbrug. This effect is even more pronounced if we consider only those months where manure spreading took place. In this situation, more than 90% of the NH_3 net emission during the month is observed to come from the 3-day periods after manure application into the field.

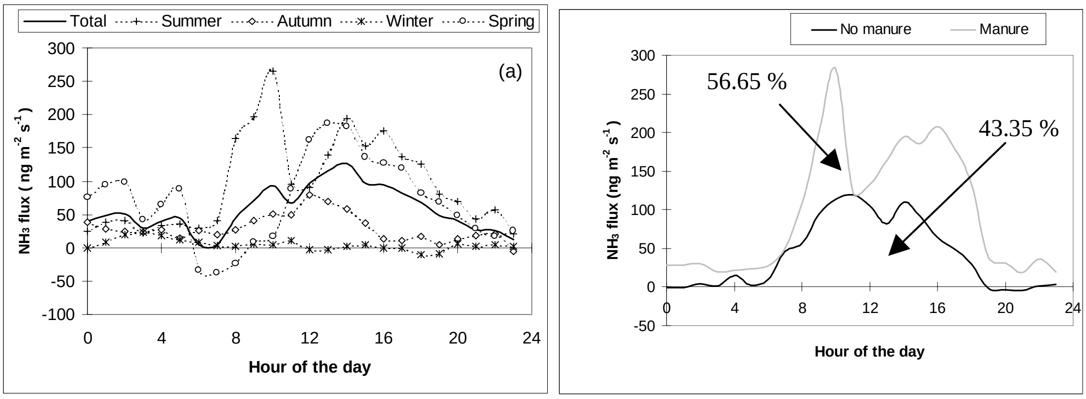


Figure 3.4 *Average diurnal pattern of ammonia exchange fluxes measured at Schagerbrug (a) per season, and (b) over the complete measurement period (July 1998-July 2000). In (b), the gray and dark lines denote flux calculations with and without considering a period of 3 days after manure application occurring in the measurement field*

Figure 3.5a shows in more detail the seasonal pattern observed for the NH_3 flux measured at Schagerbrug, with higher emissions in summertime, and lower emissions or even deposition in wintertime. An accumulated net emission of approximately 23 kg NH_3 ha^{-1} is obtained during the complete period of measurements at Schagerbrug. This pattern is clearly related with manure application into the field, which is not allowed in the Netherlands in winter, but also reflects the interaction between meteorological conditions and the measured flux. To show this, we have plotted both the effect of manure events occurring in the measurement field, and the effect of manure spreading observed in the neighboring field (figure 3.5b). Two examples will illustrate more clearly this dependence of measured fluxes with meteorological conditions. In April 1999 no manure spreading activities were performed in our field. However, a large flux was measured during that month. Meteorological conditions showed wind blowing from the east in the last part of the month, where manure spreading took place in the neighboring field located to the east of the measurement tower. So the large flux measured during that month was in fact related with events happening in fields other than the one used in our study. In the other hand, the net flux measured during August 1999 reflects the manure application event occurred in our field at the beginning of the month, with wind blowing from our measurement site.

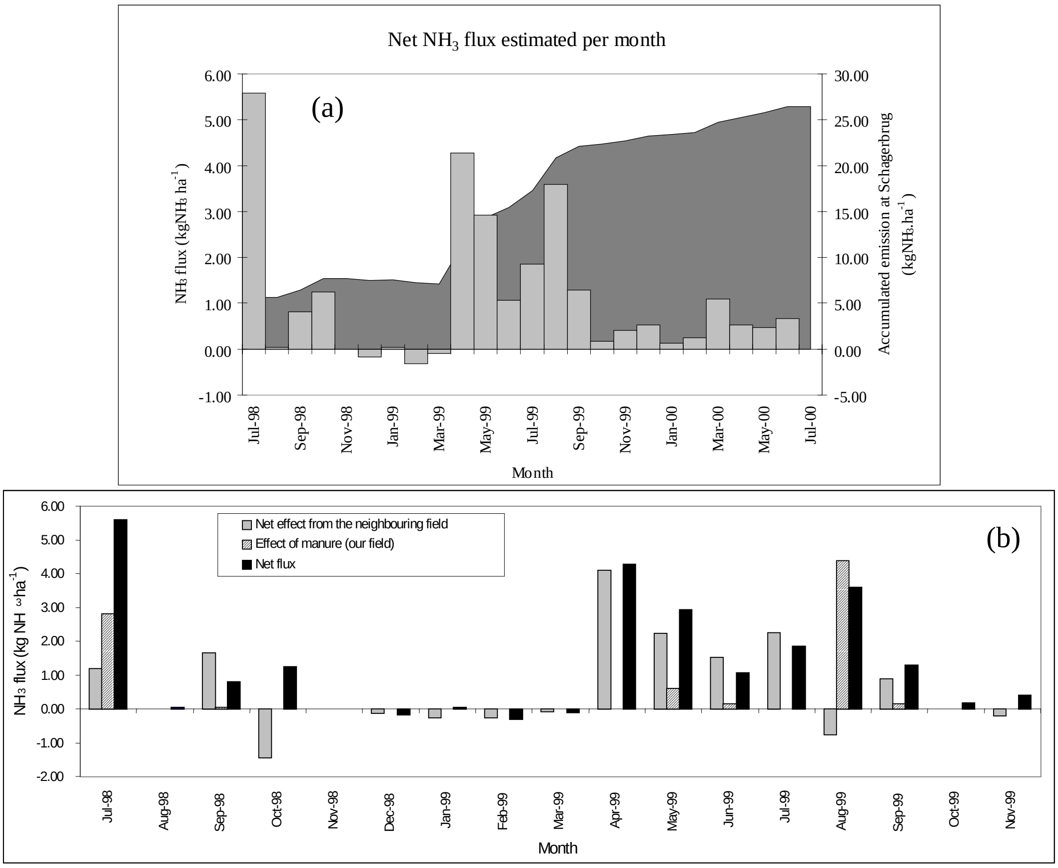


Figure 3.5 *(a) Net flux estimated per month at the site Schagerbrug during the period July 1998-July 2000. (b) Effect of manure application and meteorological conditions determining the net flux observed in our measurement site during the period July 1998-November 1999. Both the events occurring in our field (gray), and in the neighboring field located to the east (shaded pattern) are considered to affect the net flux measured at Schagerbrug*

Ammonia fluxes measured at Oostvaardersplassen, a semi-natural area, also reflect a diurnal pattern which differs to the one observed at Schagerbrug, an intensively managed area. Generally, lower fluxes are observed during nighttime, with the exception of the pattern observed in autumn. Deposition to the surface is the main pattern at Oostvaardersplassen in spring, with deposition occurring on average during the whole day, as reflected in the average diurnal pattern observed in figure 3.6a, and in the net flux showed in figure 3.6b. In summertime, an average emission occurred during daytime, but with values much lower to those observed at Schagerbrug. In autumn the pattern is reversed, with emissions during the whole day, and large emissions measured during nighttime. In the winter season, the average diurnal pattern showed in figure 3.6a reflects emission as the only issue, but some deposition events were also observed which lower the average emission calculated.

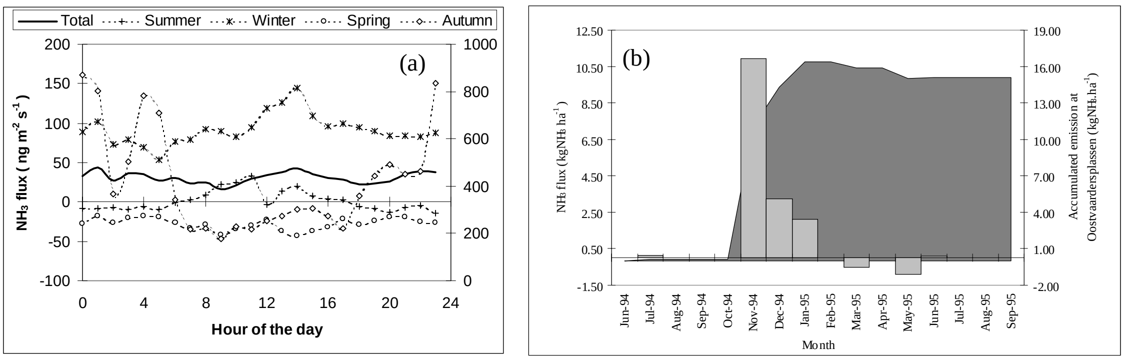


Figure 3.6 *a) Average diurnal pattern of NH_3 exchange fluxes and b) net NH_3 fluxes measured at Oostvaardersplassen during the period June 1994-September 1995*

This dependency of the seasonal pattern observed for the NH_3 flux measured at Schagerbrug and at Oostvaardersplassen on the meteorological conditions, particularly on wind direction, is reflected in the wind sector plot shown in figure 3.7. For Schagerbrug (figure 3.7a), it can be seen that most of the net ammonia flux measured in the measurement tower located in our field comes from events happening not in our field, but in the neighboring field belonging to the farm located to the east of our measurement site. However, figure 3.7a also shows a large flux from the southwest direction, partially influenced by the manure experiments performed when the tower was located in position 2 at the field (see figure 3.2). For Oostvaardersplassen, the presence of the IJssel lake in the northeast-west sector gives low NH_3 fluxes in that direction, as shown in figure 3.7b. High emissions are observed in the 150^o-240^o wind sector in autumn and wintertime, probably related with the presence of a large number of geese (up to 50000 individuals) during the winter months, and some horses (up to 200 individuals) in autumn, at the Oostvaardersplassen area.

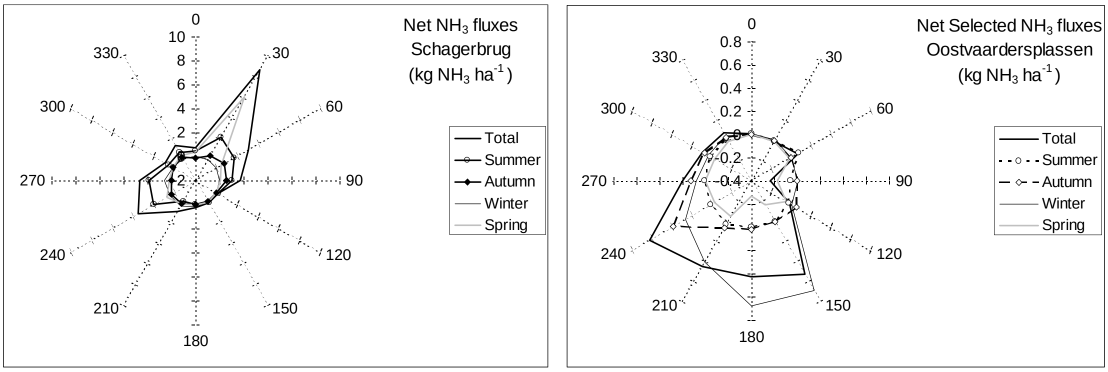


Figure 3.7 *Wind sector dependency of the net NH_3 flux measured at a) Schagerbrug during the period July 1998-July 2000, and b) Oostvaardersplassen during the period June 1994-September 1995, per season and wind sector of 30º*

3.4 Model validation and results.

To obtain good estimates of the parameters used in the resistance model described in section 2.3, some measurements were started in April 1999 to characterize the measurement field site, which included grass height and length, leaf area index (after October 1999), and NH_4^+ apoplast concentration and pH. Figure 3.8 shows the results of these measurements (a more complete record is reported in appendix C). With respect to grass height, figure 3.8a shows clearly the periods where grass was harvested just before manure application. LAI shows no large variations during the weeks where this analysis was performed. Apoplast measurements (figure 3.8b) show a rather constant pH (around 6), while apoplast NH_4^+ concentration increases rapidly both after harvesting and after manure application (over two orders of magnitude, in the range 0-6 mmol/l).

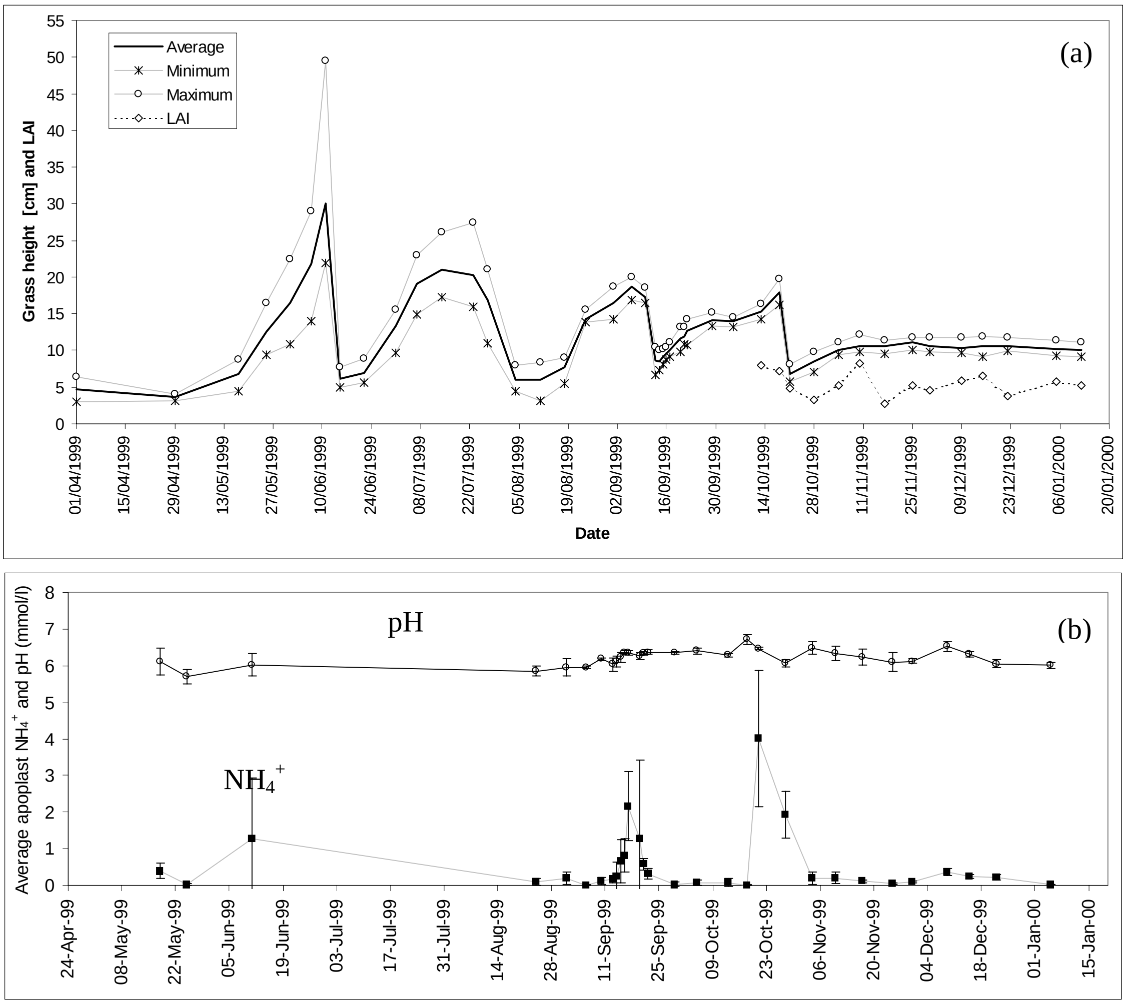
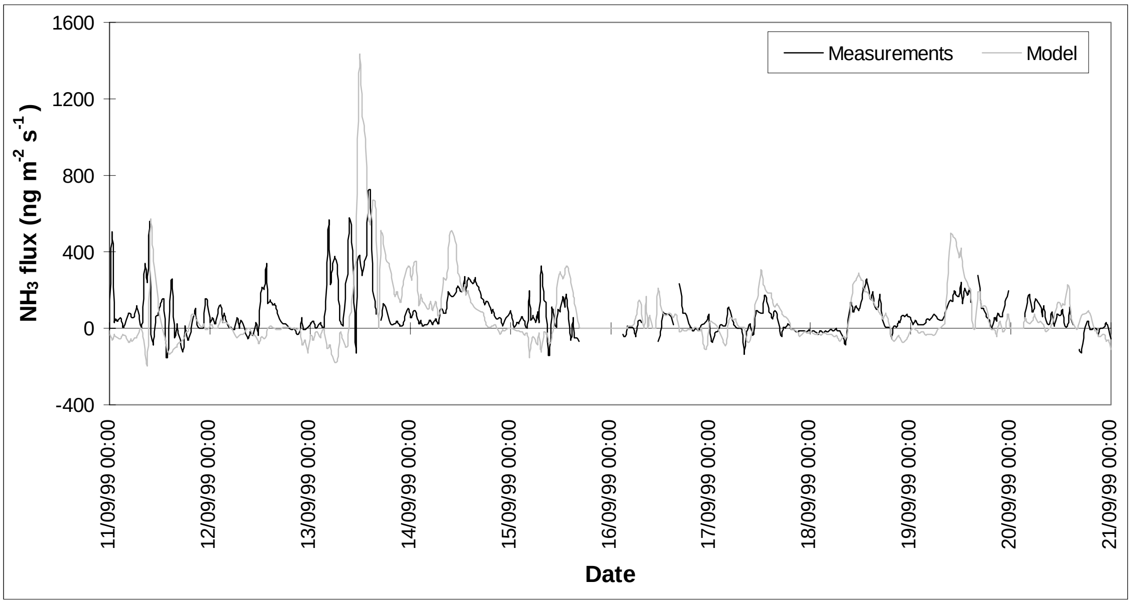


Figure 3.8 *Measurements performed at the site Schagerbrug to characterize the field. a) Grass height and LAI. b) Apoplast NH_4^+ and pH*

Since enough information about grass height and apoplast NH_4^+ concentration and pH was available in the period 11/09/99-21/09/99, we have considered this period to estimate the parameters used in the resistance model. Besides, manure was applied on September 13 on the whole field, so this study provides also a good test for the application of the model when manure takes place. The results of this analysis are plotted in figure 3.9a. The model is able to reproduce the measurements during most of the time, showing the bi-directional fluxes and following the diurnal emission pattern measured at the field during that time. However, it seems to overestimate the emission after manure application on September 13. The same parameterization was applied on a different period (11/07/99-21/07/99, figure 3.9b) to check the validity of the model under different conditions. The model is again able to predict the bi-directional fluxes observed during that time, but generally tending toward deposition at night compared with measurements.



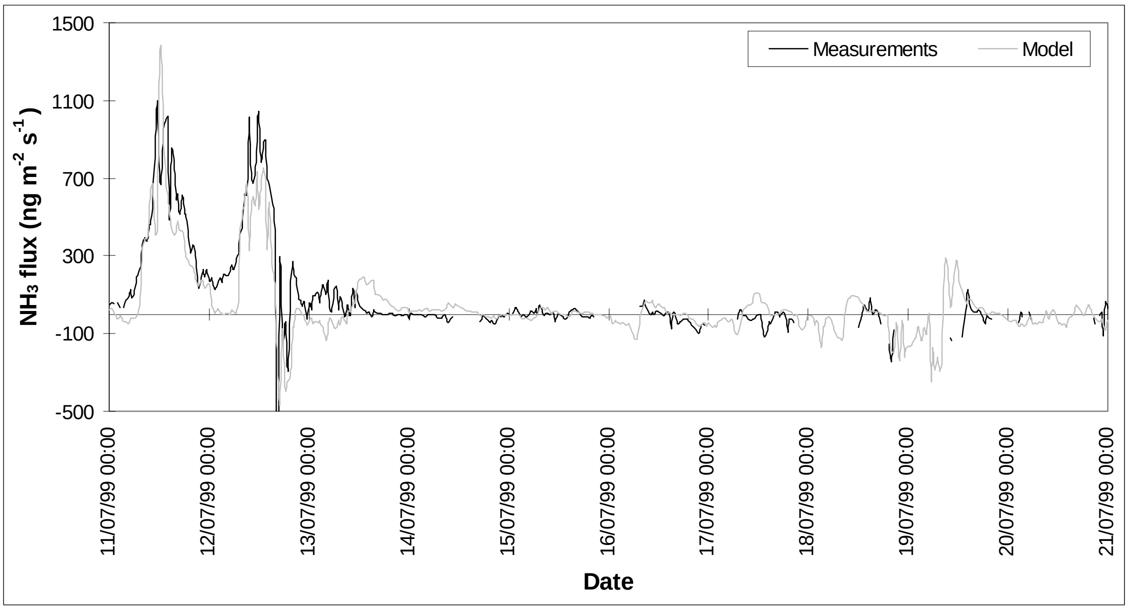


Figure 3.9 *Comparison of measured ammonia flux over grassland (Schagerbrug) with the estimated by the resistance model described in section 2.3. a) Period of 10 days (11/09/99-21/09/99) used to estimate the parameters of the resistance model. Manure was applied on september 13. b) Period of 10 days (11/07/99-21/07/99) used to check the validity of the model using the parameterization obtained from a)*

4. CONCLUSIONS

NH_3 concentrations at three heights and meteorological conditions were measured at Oostvaardersplassen during the period June 1994-September 1995, and in Schagerbrug during the period July 1998-July 2000. Concentration data were measured about 41% and 77% of the time at Oostvaardersplassen and Schagerbrug, respectively, while the flux data coverage was substantially lower, about 19% at Oostvaardersplassen and 31% at Schagerbrug. Instrumentation failures and incorrect wind direction were the main reasons for this reduction on the data available for flux calculation using the aerodynamic gradient method.

Clear seasonal and diurnal trends in the data were observed and interpreted in relation to meteorological and land use management variations at both sites. Generally lower concentrations were measured at Oostvaardersplassen, in a semi-natural region, compared to those measured at Schagerbrug, an intensively managed area. However, high concentration values, similar to the ones measured at Schagerbrug, are observed in Oostvaardersplassen in Autumn 1994, which could be related to the presence of a large amount of horses in that region in November 1994. At Oostvaardersplassen, the presence of the Ijssel lake leads to generally low NH_3 concentrations when the wind comes from that direction. At Schagerbrug, higher concentrations values were observed from easterly wind directions because of the farms that are still in operation and which are located in that direction. Generally higher concentrations are measured during nighttime, with a concentration peak in the early morning after which concentrations start to decrease. This pattern is observed both in Schagerbrug and Oostvaardersplassen.

Ammonia fluxes measured at Schagerbrug show a diurnal pattern with higher emissions during daytime, and lower emissions during nighttime. Generally higher emissions are observed in summertime, with deposition being the main pattern during the winter season. This pattern was shown to be related with manure application into the field. An accumulated net emission of approximately 23 kg NH_3 ha^{-1} was obtained during the complete period of measurements at Schagerbrug. At Oostvaardersplassen, generally lower emissions were found during nighttime, with the exception of the pattern observed in autumn. Deposition to the surface is the main pattern in spring, with emission observed in the winter and summer season, but with values much lower to those observed at Schagerbrug. In autumn generally large emissions were measured during nighttime.

To describe the bi-directional exchange of NH_3, a modified version of the resistance model described in Sutton et al. (1998), including an extra soil emission after manure application into the field, was used. Some measurements, which included grass height and length, leaf area index (after October 1999), and NH_4^+ apoplast concentration and pH, were performed to characterise the field at Schagerbrug and to obtain a good parameterisation for the model. This parameterisation was applied on different conditions to check the validity of the resistance model. The model was shown to be able to predict the diurnal pattern of emission/deposition observed, but leading generally to deposition compared with measurements. In order to get a better estimate of the parameters used on the resistance model applied in this study, and to establish the contribution of cuticular water films to the final flux pattern measured at the field, more measurements of the leaf surface chemistry are needed.

REFERENCES

Baldocchi, D.D., B.B. Hicks and P. Camara (1987): A canopy stomatal resistance model for gaseous deposition to vegetated surfaces. *Atmospheric Environment* **21**, 91-101.

Beauchamp, T.G., G.E. Kidd and G. Thurtell (1982): Ammonia volatilization from liquid dairy cattle manure in the field. *Can. J. Soil. Sci.* **62**, 11-19.

Beljaars, A.C.M. and A.A.M. Holtslag(1990): Description of a software library for the calculation of surface fluxes. *Environ. Software* **5**, 60-68.

Garland, J.A. (1978): Dry and wet removal of sulfur from the atmosphere. *Atmospheric Environment* **12**, 349.

Hicks, B.B., D.D. Baldocchi, T.P. Meyers, R.P. Hosker Jr and D.R. Matt (1987): A preliminary multiple resistance routine for deriving dry deposition velocities from measured quantities. *Water Air Soil Pollut.* **36**, 311-330.

Jarvis, P.G. (1976): The interpretation of the variation in leaf water potential and stomatal conductance found in canopies in the field. *Phil. Trans. R. Soc. London* **B273**, 593-610.

Montheith, J.L. (1973): Principles of Environmental Physics. American Elsevier, New York.

Sutton, M.A., J.K. Burkhardt, D. Guerin, E. Nemitz and D. Fowler (1998): Development of resistance models to describe measurement of bi-directional ammonia surface-atmosphere exchange. *Atmospheric Environment* **32**, 473-480.

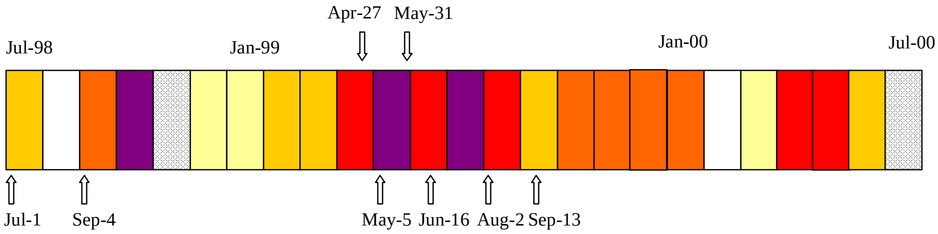
Turner, N.C. and J.E. Begg (1973): Stomatal behavior and water status of maize, sorghum and tobacco under field conditions, I: at high soil water potential. *Plant Physiol.* **51**, 31-36.

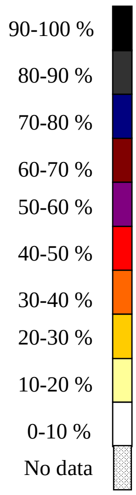
Van der Molen, J. H.G. van Faasen, M.Y. Leclerc, R. Vriesema and W.J. Chardon (1990): Ammonia volatilization form arable land after application of cattle slurry. 1. Field estimates. *Neth. J. Agri. Sci.* **38**, 145-148.

Wyers, G.P., R.P. Otjes and J. Slanina (1993): A continuous-flow denuder for the measurement of ambient concentrations and surface-exchange fluxes of ammonia. *Atm. Env.* **27A(13)**, 2085-2090.

APPENDIX A: SEASONAL VARIATIONS IN METEOROLOGICAL PARAMETERS, CONCENTRATIONS AND FLUXES, SCHAGERBRUG

This appendix shows the results of the calculations made with the complete data set obtained for the site Schagerbrug during the whole period of measurements. Monthly and seasonal average values were calculated in order to have an overview of the behaviour observed in the NH_3 exchange over an intensively managed grassland. As a starting point, a summary of the measurement period covered in the study, together with the average data availability for the fluxes, concentrations and meteorological parameters measured, is presented.





(1)Measurement period covered:	Jul ‘98 - Jul ‘00
(2)Meteo available:	73.5 %
(2)Concentration available:	76.7 %
(2)Meteo and concentration available (%):	62.5 %
(2)Selected flux (%):	31.1 %

(1) Measurements still in progress

(2) Average of the whole period studied

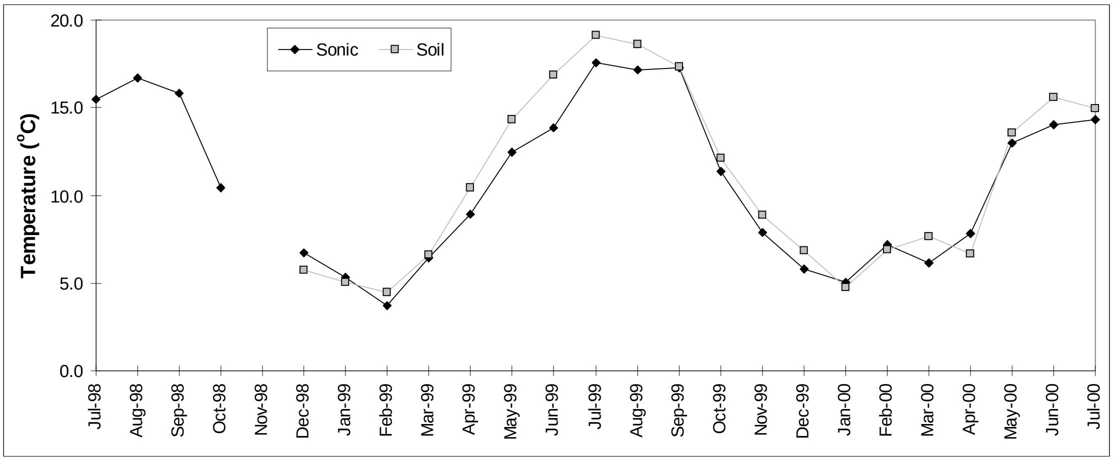
⇧ Manure applied in our field

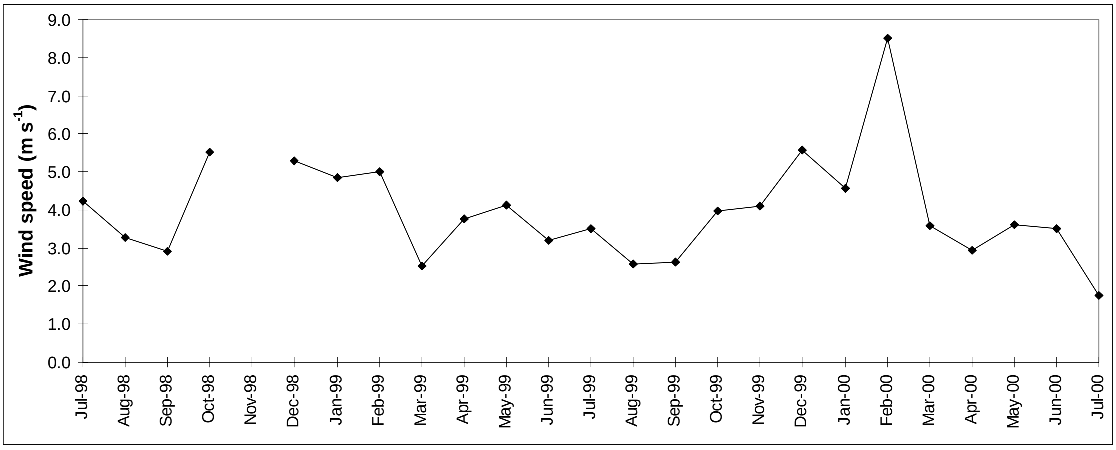
⇩ Manure applied in the neighbouring field

TEMPERATURE (SONIC, °C)						
Month	MAX	MIN	MEAN	MEDIAN	STDV	Data available (%)
Jul-98	27.2	10.5	15.5	15.5	2.6	72.8
Aug-98	27.3	9.1	16.7	16.8	2.7	80.9
Sep-98	20.6	9.7	15.8	16.1	2.2	59.6
Oct-98	16.8	3.5	10.4	10.3	2.9	72.3
Nov-98						
Dec-98	11.0	2.9	6.7	6.7	1.9	87.9
Jan-99	12.4	-3.3	5.4	5.8	3.5	93.8
Feb-99	9.3	-5.6	3.7	4.5	3.2	92.3
Mar-99	16.3	-0.3	6.5	6.1	2.8	89.0
Apr-99	18.0	1.3	8.9	8.9	3.1	90.3
May-99	23.5	5.0	12.5	12.5	3.0	97.2
Jun-99	21.6	7.2	13.8	13.7	2.6	97.8
Jul-99	27.2	9.7	17.5	17.2	3.0	98.1
Aug-99	27.6	9.0	17.1	16.7	3.2	95.8
Sep-99	27.0	11.2	17.3	17.0	2.5	97.8
Oct-99	17.8	2.4	11.4	12.2	3.3	94.5
Nov-99	17.0	-1.5	7.9	8.7	3.4	86.5
Dec-99	14.7	-0.9	5.8	5.9	2.7	75.9
Jan-00	10.9	-3.9	5.1	5.4	2.4	86.6
Feb-00	9.2	2.5	7.2	7.6	1.1	5.0
Mar-00	15.0	1.3	6.2	6.2	2.0	39.7
Apr-00	18.0	-0.8	7.8	7.6	3.7	81.7
May-00	25.4	5.7	13.0	11.8	4.2	88.3
Jun-00	27.9	7.6	14.0	13.2	3.6	96.1
Jul-00	19.2	8.1	14.3	14.0	2.7	6.7

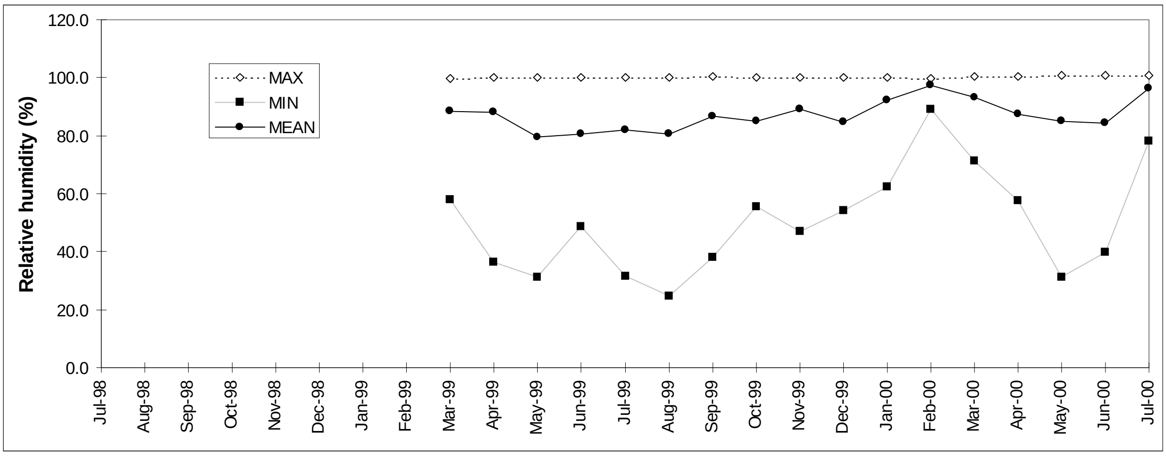
TEMPERATURE (SOIL, °C)						
Month	MAX	MIN	MEAN	MEDIAN	STDV	Data available (%)
Jul-98						
Aug-98						
Sep-98						
Oct-98						
Nov-98						
Dec-98	7.5	4.1	5.8	5.6	0.9	99.7
Jan-99	8.6	1.2	5.1	5.1	1.9	97.6
Feb-99	7.3	1.3	4.4	4.7	1.5	30.8
Mar-99	12.7	3.3	6.6	6.4	1.5	97.8
Apr-99	14.6	6.4	10.4	10.1	1.5	59.3
May-99	21.2	10.1	14.3	14.1	2.2	87.2
Jun-99	22.2	13.8	16.9	16.6	1.7	99.6
Jul-99	24.8	15.4	19.1	18.9	1.8	100.0
Aug-99	25.6	14.5	18.6	18.2	2.3	97.9
Sep-99	20.3	15.3	17.4	17.4	1.1	100.0
Oct-99	15.5	7.6	12.1	12.3	1.7	98.9
Nov-99	12.6	3.1	8.9	8.5	2.0	85.6
Dec-99	8.7	3.8	6.9	7.2	1.2	52.4
Jan-00	7.2	2.0	4.8	5.0	1.1	84.9
Feb-00	7.0	6.7	6.9	6.9	0.1	5.0
Mar-00	9.2	6.6	7.6	7.5	0.6	21.7
Apr-00	12.0	0.0	6.7	7.3	3.3	84.5
May-00	17.4	5.4	13.6	13.5	1.6	84.8
Jun-00	20.5	12.9	15.6	15.4	1.5	100.0
Jul-00	16.6	13.7	15.0	14.7	0.8	7.8

WIND SPEED (m s-1)						
Month	MAX	MIN	MEAN	MEDIAN	STDV	Data available (%)
Jul-98	10.3	0.0	4.1	4.2	2.4	72.8
Aug-98	9.5	0.0	3.5	3.3	2.4	80.9
Sep-98	10.9	0.2	3.5	2.9	2.3	59.6
Oct-98	14.2	0.6	5.7	5.5	2.8	72.3
Nov-98						
Dec-98	17.0	1.5	6.3	5.3	3.5	87.9
Jan-99	15.6	0.2	5.3	4.9	3.3	93.8
Feb-99	13.5	0.2	5.2	5.0	3.1	92.1
Mar-99	12.6	0.1	3.0	2.5	2.1	89.0
Apr-99	10.5	0.1	4.0	3.8	2.2	90.2
May-99	9.0	0.2	4.2	4.1	2.0	97.2
Jun-99	12.3	0.1	3.5	3.2	2.1	97.8
Jul-99	10.1	0.3	3.7	3.5	2.0	97.9
Aug-99	8.8	0.1	2.9	2.6	1.8	95.6
Sep-99	9.1	0.2	3.0	2.6	1.8	96.9
Oct-99	11.6	0.1	4.1	4.0	2.1	91.0
Nov-99	17.2	0.2	4.1	4.1	2.4	82.3
Dec-99	24.0	0.3	6.1	5.6	3.5	75.6
Jan-00	13.7	0.4	4.7	4.6	2.5	86.6
Feb-00	14.7	3.2	8.3	8.5	1.9	5.0
Mar-00	39.5	0.2	4.9	3.6	5.5	39.7
Apr-00	16.2	0.2	3.4	2.9	2.2	81.4
May-00	25.3	0.1	3.9	3.6	2.8	88.4
Jun-00	11.0	0.1	3.8	3.5	2.1	96.1
Jul-00	4.0	0.3	1.7	1.8	0.9	6.7





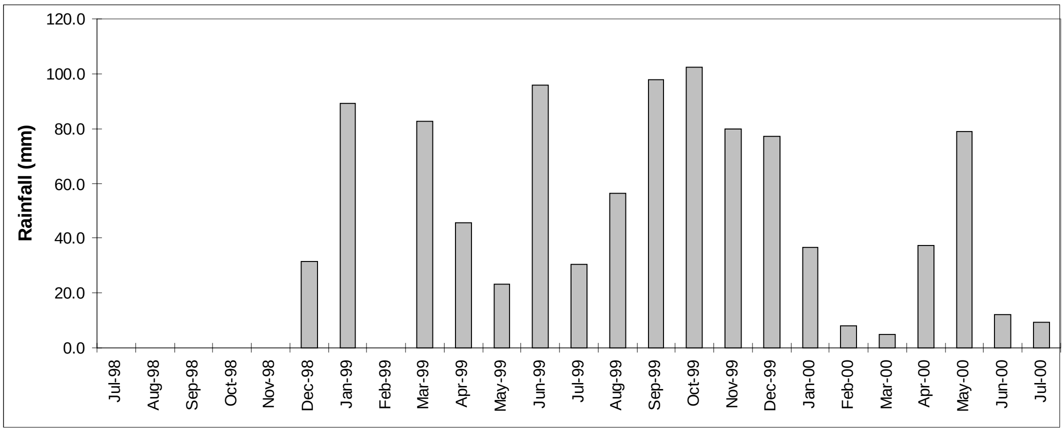
RELATIVE HUMIDITY (%)						
Month	MAX	MIN	MEAN	MEDIAN	STDV	Data available (%)
Jul-98						
Aug-98						
Sep-98						
Oct-98						
Nov-98						
Dec-98						
Jan-99						
Feb-99						
Mar-99	99.9	57.8	88.3	90.5	8.7	97.8
Apr-99	100.0	36.3	88.0	91.6	11.7	59.4
May-99	100.0	31.3	79.7	83.2	13.5	87.3
Jun-99	100.0	48.9	80.5	82.4	12.3	99.6
Jul-99	100.1	31.7	81.8	83.4	13.4	100.0
Aug-99	100.0	24.7	80.5	83.3	14.0	97.9
Sep-99	100.4	38.1	86.8	88.6	10.9	100.0
Oct-99	100.0	55.5	85.1	87.0	10.2	98.9
Nov-99	100.0	46.9	89.3	90.2	8.0	85.9
Dec-99	100.0	54.1	84.8	85.8	9.2	52.4
Jan-00	100.0	62.2	92.2	93.2	6.8	84.9
Feb-00	99.9	89.2	97.4	99.0	3.3	5.0
Mar-00	100.4	71.3	93.2	95.7	7.6	21.7
Apr-00	100.6	57.8	87.5	90.9	12.5	84.5
May-00	100.8	31.2	85.2	89.0	16.0	84.8
Jun-00	101.0	39.7	84.4	86.2	14.0	100.0
Jul-00	100.7	78.2	96.4	100.2	6.1	7.8

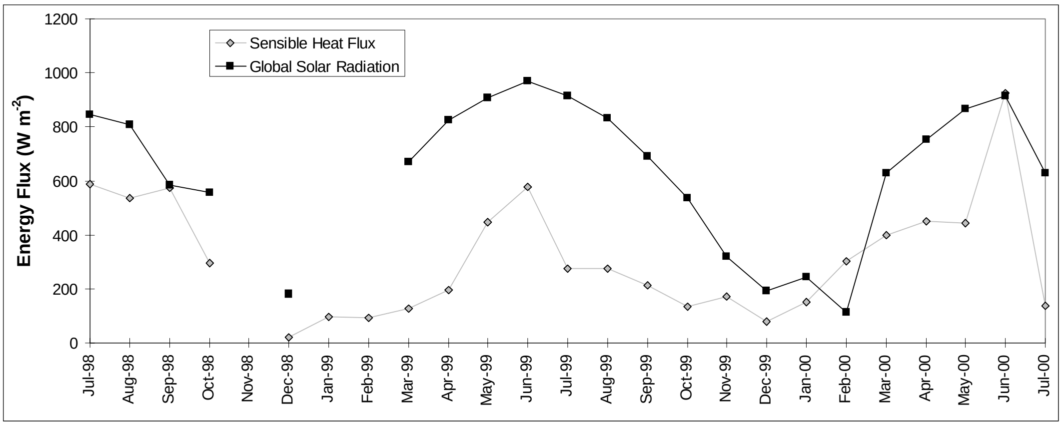


SENSIBLE HEAT FLUX (W m^{-2})						
Month	MAX	MIN	MEAN	MEDIAN	STDV	Data available (%)
Jul-98	586	-94	23	2	63	72.8
Aug-98	537	-100	32	6	73	80.9
Sep-98	575	-99	6	-2	52	59.1
Oct-98	295	-99	-3	-11	62	68.1
Nov-98						
Dec-98	22	-223	-40	-35	34	79.4
Jan-99	95	-150	-23	-19	26	85.3
Feb-99	92	-127	-12	-10	30	78.2
Mar-99	128	-94	5	-2	29	83.3
Apr-99	196	-75	20	2	49	87.4
May-99	447	-79	25	1	58	92.7
Jun-99	577	-65	29	2	62	93.3
Jul-99	275	-79	26	1	58	96.6
Aug-99	277	-71	16	-1	50	93.5
Sep-99	214	-133	3	-5	37	95.1
Oct-99	133	-99	-14	-15	26	88.3
Nov-99	173	-292	-24	-20	33	78.5
Dec-99	80	-173	-33	-33	27	65.1
Jan-00	150	-192	-16	-16	24	74.6
Feb-00	302	-17	7	-11	58	2.7
Mar-00	400	-70	18	-2	58	35.8
Apr-00	450	-70	17	-1	52	76.6
May-00	444	-71	23	0	59	85.7
Jun-00	926	-119	28	1	69	94.7
Jul-00	137	-79	17	3	34	6.7

GLOBAL RADIATION (W m^{-2})						
Month	MAX	MIN	MEAN	MEDIAN	STDV	Data available (%)
Jul-98	844	0	192	83	236	100.0
Aug-98	808	0	187	56	233	100.0
Sep-98	586	0	97	6	142	100.0
Oct-98	558	0	49	0	95	100.0
Nov-98						
Dec-98	181	0	16	0	35	100.0
Jan-99						
Feb-99						
Mar-99	670	0	76	1	132	100.0
Apr-99	826	0	142	24	208	59.4
May-99	907	0	237	100	274	87.2
Jun-99	968	0	234	116	272	99.9
Jul-99	913	0	226	104	264	99.9
Aug-99	833	0	172	55	222	98.0
Sep-99	690	0	122	11	174	100.0
Oct-99	538	0	70	1	116	98.9
Nov-99	320	0	31	1	61	86.2
Dec-99	191	0	19	1	38	52.4
Jan-00	245	0	24	1	46	85.0
Feb-00	113	1	20	1	34	5.0
Mar-00	630	0	87	12	141	21.7
Apr-00	752	0	110	1	194	95.3
May-00	868	0	219	79	265	84.9
Jun-00	916	0	230	101	267	100.0
Jul-00	628	0	124	33	164	7.8

RAINFALL (mm)	
Month	Net amount
Jul-98	
Aug-98	
Sep-98	
Oct-98	
Nov-98	
Dec-98	31.4
Jan-99	89.2
Feb-99	0.0
Mar-99	82.6
Apr-99	45.6
May-99	23.0
Jun-99	95.8
Jul-99	30.6
Aug-99	56.4
Sep-99	97.8
Oct-99	102.2
Nov-99	80.0
Dec-99	77.2
Jan-00	36.6
Feb-00	7.8
Mar-00	4.8
Apr-00	37.2
May-00	79.0
Jun-00	12.2
Jul-00	9.4



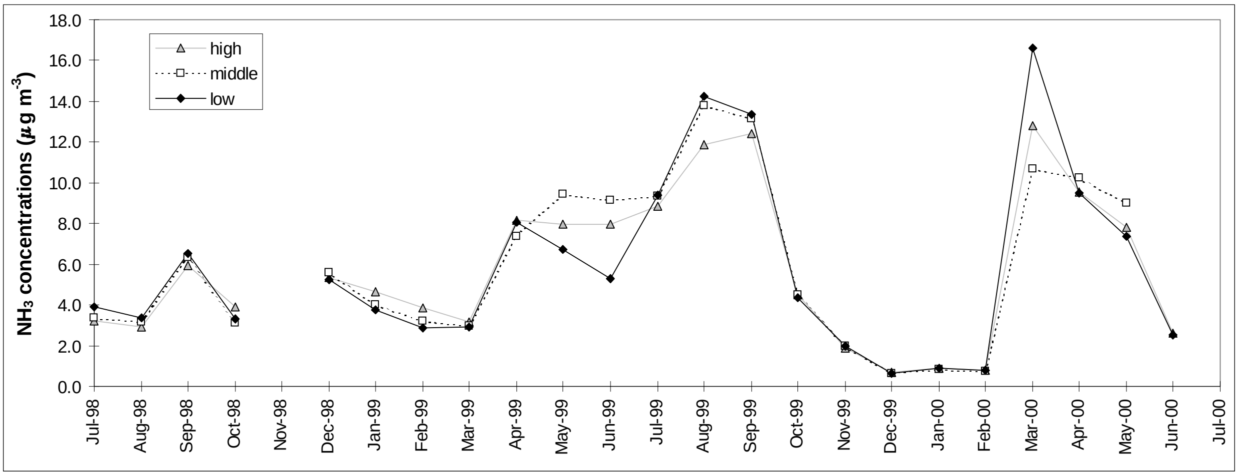


CONCENTRATIONS (LOW LEVEL, µg m^{-3})							
Month	MAX	MIN	MEAN	MEDIAN	STDV	Data available (%)	level (m)
Jul-98	32.5	0.0	3.9	2.1	4.7	72.8	0.95
Aug-98	21.8	0.2	3.4	2.6	2.7	80.9	0.95
Sep-98	59.1	0.1	6.5	5.8	4.9	50.2	0.95
Oct-98	9.8	0.5	3.3	2.6	2.0	72.3	0.95
Nov-98							
Dec-98	23.7	0.8	5.2	2.8	5.1	94.6	0.95
Jan-99	25.8	0.2	3.8	2.5	3.6	59.5	0.95*
Feb-99	16.6	0.7	2.9	1.9	2.8	27.4	0.52
Mar-99	16.0	0.1	2.9	1.6	3.1	73.4	0.52
Apr-99	132.5	0.4	8.1	5.2	10.3	91.3	0.52
May-99	56.7	-0.3	6.7	5.3	6.6	91.6	0.52
Jun-99	48.1	-0.6	5.3	3.5	5.7	56.8	0.52
Jul-99	52.9	-0.1	9.4	5.9	8.9	91.1	0.52
Aug-99	171.0	0.1	14.3	8.0	20.9	99.1	0.52
Sep-99	54.3	-0.7	13.4	12.9	10.0	84.9	0.52
Oct-99	21.5	0.0	4.3	3.2	3.6	81.4	0.52
Nov-99	12.0	-0.1	2.0	1.2	2.1	91.9	0.52
Dec-99	5.8	0.0	0.7	0.4	0.8	78.5	0.52
Jan-00	8.2	0.0	0.9	0.6	1.0	86.1	0.52
Feb-00	10.8	-0.1	0.8	0.4	1.0	95.9	0.52
Mar-00	464.3	-0.1	16.6	0.5	45.4	98.8	0.52
Apr-00	59.2	0.0	9.5	7.2	9.6	87.3	0.52
May-00	129.4	-1.2	7.4	5.0	9.6	95.9	0.52
Jun-00	11.8	-1.3	2.5	1.3	3.4	24.5	0.52
Jul-00							0.52
* after 21 January, 0.52m							

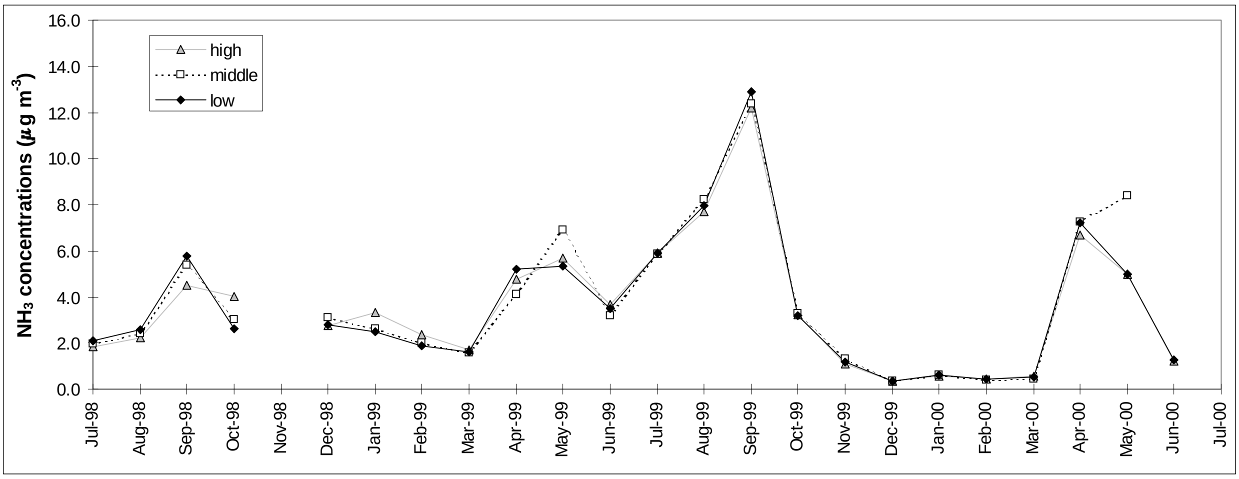
CONCENTRATIONS (MIDDLE LEVEL, µg m^{-3})							
Month	MAX	MIN	MEAN	MEDIAN	STDV	Data available (%)	level (m)
Jul-98	23.3	0.0	3.3	2.0	3.5	72.8	2.17
Aug-98	25.5	0.2	3.2	2.4	2.6	80.9	2.17
Sep-98	65.2	0.1	6.3	5.4	4.9	59.5	2.17
Oct-98	9.7	0.3	3.1	3.0	2.0	72.3	2.17
Nov-98							
Dec-98	25.6	0.8	5.6	3.1	5.4	94.9	2.17
Jan-99	27.5	0.1	4.0	2.6	3.8	53.6	2.17*
Feb-99	22.3	0.1	3.2	2.0	3.0	49.0	0.92
Mar-99	18.0	0.0	3.0	1.6	3.4	54.5	0.92
Apr-99	137.1	0.4	7.4	4.1	12.4	51.8	0.92
May-99	109.1	-0.3	9.4	6.9	12.0	98.9	0.92
Jun-99	113.8	-0.3	9.1	3.2	19.4	73.0	0.92
Jul-99	53.0	-0.1	9.4	5.8	8.8	92.4	0.92
Aug-99	146.2	0.3	13.8	8.2	17.6	98.9	0.92
Sep-99	64.1	-0.6	13.1	12.4	9.9	90.5	0.92
Oct-99	25.0	0.0	4.5	3.3	4.0	81.4	0.92
Nov-99	13.6	-0.1	2.0	1.3	2.1	91.9	0.92
Dec-99	8.0	-0.1	0.6	0.3	0.8	80.0	0.92
Jan-00	9.2	0.0	0.9	0.6	1.0	86.0	0.92
Feb-00	10.9	-0.1	0.7	0.4	1.0	95.9	0.92
Mar-00	214.5	-0.1	10.7	0.4	21.6	93.2	0.92
Apr-00	70.2	0.0	10.3	7.3	11.0	87.1	0.92
May-00	46.8	0.0	9.0	8.4	7.9	45.9	0.92
Jun-00							0.92
Jul-00							0.92
* after 21 January, 0.92m							

CONCENTRATIONS (HIGH LEVEL, μg m^{-3})							
Month	MAX	MIN	MEAN	MEDIAN	STDV	Data available (%)	level (m)
Jul-98	24.8	0.0	3.2	1.8	3.3	66.8	3.84
Aug-98	27.4	0.0	2.9	2.2	2.8	58.3	3.84
Sep-98	57.0	0.0	6.0	4.5	5.2	51.2	3.84
Oct-98	6.6	1.5	3.9	4.0	1.2	12.1	3.84
Nov-98							
Dec-98	25.9	0.7	5.3	2.7	5.4	94.9	3.84
Jan-99	28.0	0.2	4.6	3.3	4.2	44.5	3.84*
Feb-99	38.2	0.3	3.9	2.3	4.1	33.1	2.17
Mar-99	18.8	0.1	3.1	1.7	3.5	75.4	2.17
Apr-99	85.2	0.3	8.1	4.8	9.1	91.2	2.17
May-99	91.3	-0.3	7.9	5.7	9.3	95.8	2.17
Jun-99	110.7	-0.5	7.9	3.7	13.1	88.0	2.17
Jul-99	50.3	-0.2	8.8	5.9	8.0	92.3	2.17
Aug-99	102.8	0.3	11.9	7.7	12.7	98.8	2.17
Sep-99	62.8	-0.6	12.4	12.2	8.9	90.4	2.17
Oct-99	26.1	0.0	4.5	3.2	4.0	81.4	2.17
Nov-99	16.5	-0.1	1.9	1.1	2.3	84.6	2.17
Dec-99	12.8	0.0	0.7	0.4	1.0	76.0	2.17
Jan-00	9.9	0.0	0.9	0.6	1.2	86.0	2.17
Feb-00	12.1	-0.1	0.8	0.4	1.2	95.9	2.17
Mar-00	290.3	-0.1	12.8	0.6	29.2	98.8	2.17
Apr-00	66.6	0.0	9.6	6.7	10.2	87.2	2.17
May-00	77.7	-1.1	7.8	5.0	9.5	95.9	2.17
Jun-00	12.8	-1.4	2.6	1.2	3.8	24.5	2.17
Jul-00							2.17
* after 21 January, 2.17m							

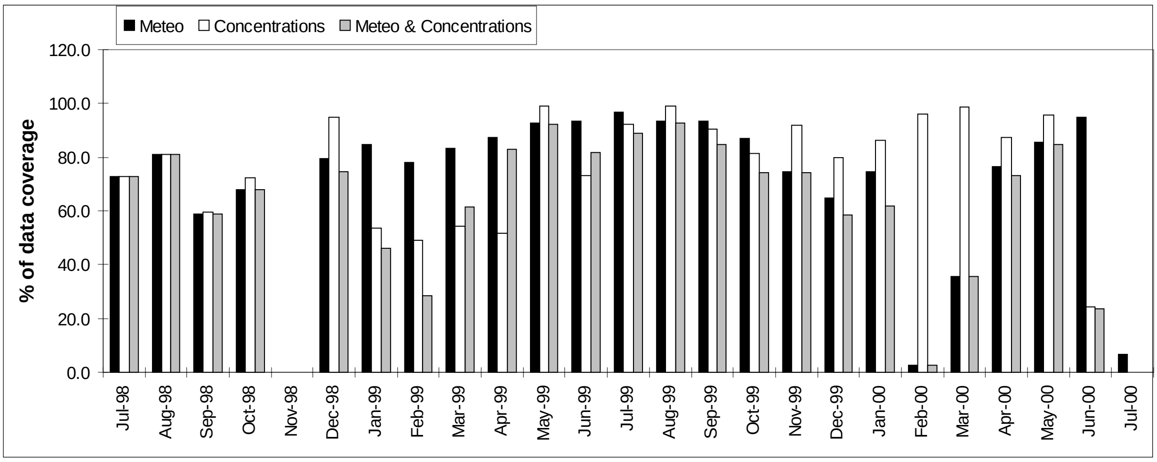
MEAN CONCENTRATION VALUES



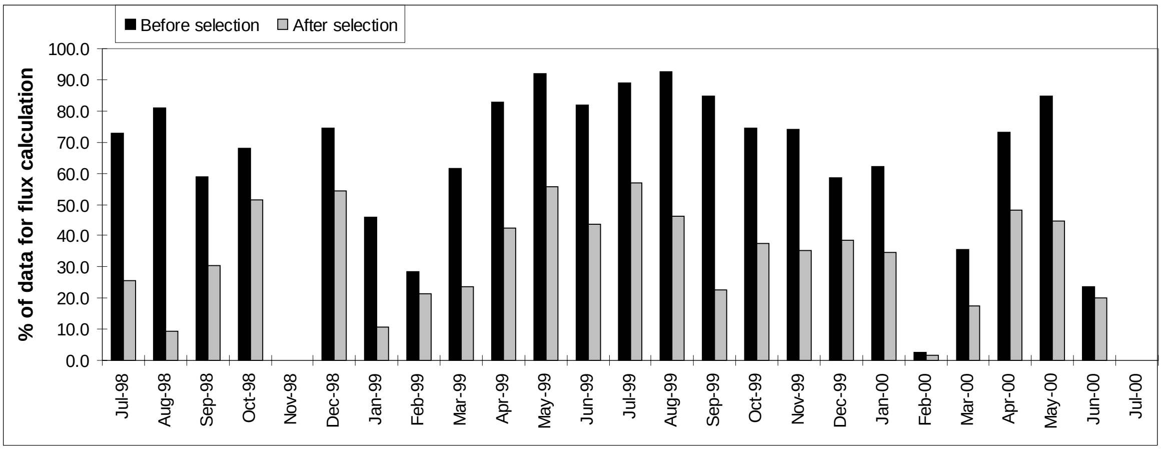
MEDIAN CONCENTRATION VALUES



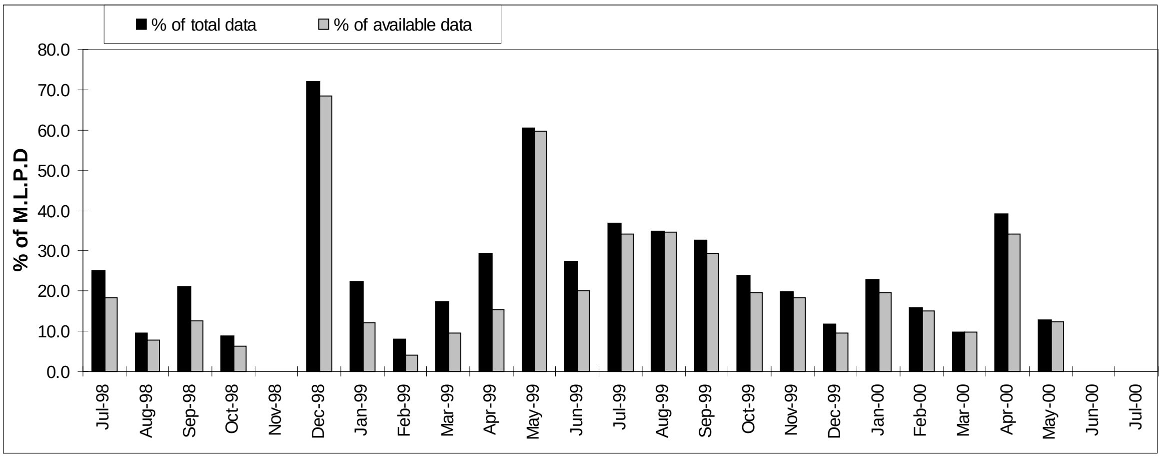
DATA COVERAGE			
Month	Meteo available (%)	Concentration available (%)	Meteo+concentration available (%)
Jul-98	72.7	72.8	72.7
Aug-98	80.9	80.9	80.9
Sep-98	58.9	59.5	58.9
Oct-98	67.8	72.3	67.8
Nov-98			
Dec-98	79.4	94.9	74.6
Jan-99	84.9	53.6	46.1
Feb-99	78.1	49.0	28.4
Mar-99	83.3	54.5	61.6
Apr-99	87.4	51.8	82.8
May-99	92.7	98.9	92.1
Jun-99	93.3	73.0	81.8
Jul-99	96.6	92.4	89.0
Aug-99	93.3	98.9	92.7
Sep-99	93.4	90.5	84.9
Oct-99	86.9	81.4	74.3
Nov-99	74.6	91.9	74.1
Dec-99	64.8	80.0	58.6
Jan-00	74.6	86.1	62.0
Feb-00	2.7	95.9	2.7
Mar-00	35.8	98.8	35.6
Apr-00	76.4	87.2	73.2
May-00	85.6	95.8	84.7
Jun-00	94.7	24.5	23.6
Jul-00	6.7	0.0	0.0



DATA COVERAGE			
Month	No selection (%)	Selected Flux (%)	Selected Vd (%)
Jul-98	72.7	25.6	25.6
Aug-98	80.9	9.5	9.5
Sep-98	58.9	30.5	30.5
Oct-98	67.8	51.5	51.5
Nov-98			
Dec-98	74.6	54.5	54.5
Jan-99	46.1	10.7	10.7
Feb-99	28.4	21.4	21.4
Mar-99	61.6	23.7	16.5
Apr-99	82.8	42.3	27.2
May-99	92.1	55.5	55.5
Jun-99	81.8	43.6	35.6
Jul-99	89.0	57.0	57.0
Aug-99	92.7	46.2	46.2
Sep-99	84.9	22.7	22.4
Oct-99	74.3	37.6	37.5
Nov-99	74.1	35.3	35.2
Dec-99	58.6	38.5	37.3
Jan-00	62.0	34.6	34.6
Feb-00	2.7	1.5	1.5
Mar-00	35.6	17.4	15.6
Apr-00	73.2	48.1	48.0
May-00	84.7	44.5	23.1
Jun-00	23.6	20.2	12.4
Jul-00	0.0	0.0	0.0



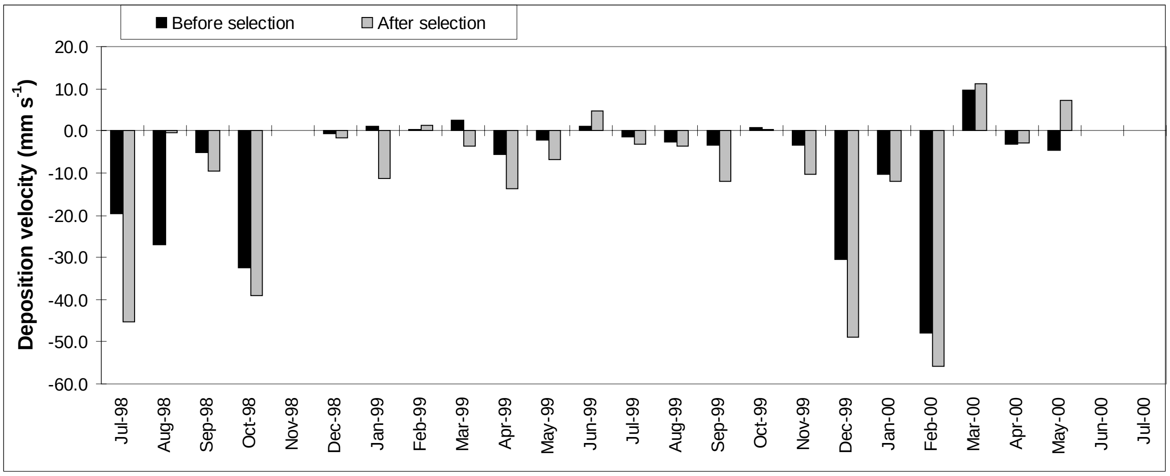
DATA COVERAGE		
Month	Knik (% of total data)	Knik (% of available data)
Jul-98	25.1	18.3
Aug-98	9.6	7.8
Sep-98	21.1	12.6
Oct-98	8.8	6.4
Nov-98		
Dec-98	72.0	68.4
Jan-99	22.3	12.0
Feb-99	8.1	4.0
Mar-99	17.3	9.4
Apr-99	29.4	15.2
May-99	60.4	59.7
Jun-99	27.4	20.0
Jul-99	36.9	34.1
Aug-99	35.0	34.6
Sep-99	32.5	29.4
Oct-99	23.9	19.4
Nov-99	19.9	18.3
Dec-99	11.8	9.4
Jan-00	22.8	19.6
Feb-00	15.7	15.1
Mar-00	9.8	9.7
Apr-00	39.2	34.2
May-00	12.8	12.3
Jun-00	0.0	0.0
Jul-00	0.0	0.0



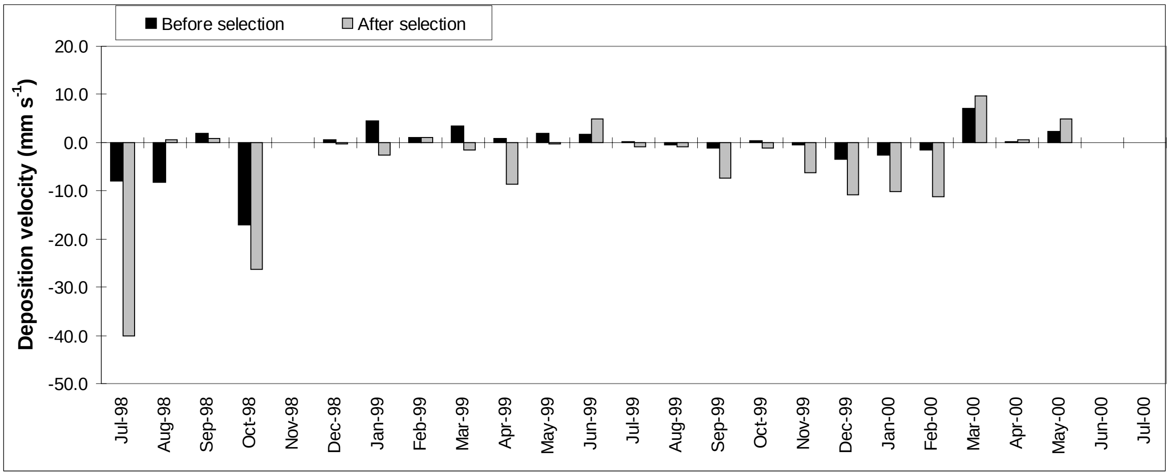
DEPOSITION VELOCITY (mm s^{-1})						
Month	MAX	MIN	MEAN	MEDIAN	STDV	Data available (%)
Jul-98	68.0	-211.0	-19.5	-8.0	33.6	72.8
Aug-98	112.2	-349.7	-26.9	-8.3	53.5	80.9
Sep-98	84.1	-299.4	-5.1	1.8	32.6	59.0
Oct-98	152.7	-943.6	-32.4	-17.0	90.2	68.1
Nov-98						
Dec-98	25.6	-39.8	-0.8	0.6	10.1	74.6
Jan-99	110.9	-150.2	0.9	4.5	30.4	46.1
Feb-99	132.9	-89.7	0.3	1.0	28.3	28.3
Mar-99	63.2	-69.9	2.5	3.5	12.5	44.9
Apr-99	114.5	-281.6	-5.7	0.9	28.0	46.5
May-99	75.0	-336.3	-2.3	2.0	26.9	92.1
Jun-99	336.4	-111.3	1.0	1.7	28.2	67.2
Jul-99	755.9	-322.9	-1.3	0.1	29.6	89.0
Aug-99	112.9	-141.5	-2.6	-0.5	16.6	92.6
Sep-99	383.0	-963.0	-3.4	-1.1	48.2	84.4
Oct-99	169.0	-41.6	0.7	0.4	13.8	74.2
Nov-99	775.2	-618.6	-3.4	-0.5	52.6	74.1
Dec-99	261.2	-980.1	-30.5	-3.4	113.0	57.7
Jan-00	288.2	-675.2	-10.2	-2.7	59.8	61.9
Feb-00	24.1	-368.3	-47.9	-1.6	93.2	2.7
Mar-00	465.5	-362.4	9.6	7.0	49.8	30.1
Apr-00	150.1	-97.1	-3.1	0.2	19.1	73.3
May-00	203.0	-90.9	-4.5	2.3	29.9	43.9
Jun-00						
Jul-00						

DEPOSITION VELOCITY SELECTED (mm s^{-1})						
Month	MAX	MIN	MEAN	MEDIAN	STDV	Selected data available (%)
Jul-98	23.7	-211.0	-45.1	-40.0	39.3	25.6
Aug-98	73.2	-86.1	-0.5	0.6	18.9	9.5
Sep-98	84.1	-299.4	-9.5	0.8	40.6	30.5
Oct-98	152.7	-943.6	-39.2	-26.4	101.0	51.5
Nov-98						
Dec-98	25.6	-39.8	-1.7	-0.3	11.2	54.5
Jan-99	101.1	-150.2	-11.3	-2.6	31.9	10.7
Feb-99	132.9	-89.7	1.3	1.1	31.5	21.4
Mar-99	43.0	-69.9	-3.5	-1.6	14.0	16.5
Apr-99	58.0	-135.9	-13.7	-8.6	27.9	27.2
May-99	75.0	-336.3	-6.9	-0.2	32.2	55.5
Jun-99	336.4	-111.3	4.6	5.0	31.1	35.6
Jul-99	755.9	-322.9	-3.1	-0.9	36.2	57.0
Aug-99	112.9	-80.6	-3.7	-0.9	20.5	46.2
Sep-99	246.8	-963.0	-11.9	-7.4	64.7	22.4
Oct-99	169.0	-41.6	0.3	-1.1	17.7	37.5
Nov-99	201.8	-169.1	-10.3	-6.3	36.6	35.2
Dec-99	261.2	-980.1	-49.0	-10.9	136.4	37.3
Jan-00	288.2	-321.7	-11.9	-10.2	39.3	34.6
Feb-00	24.1	-368.3	-55.7	-11.1	109.5	1.5
Mar-00	181.3	-362.4	11.1	9.7	44.2	15.6
Apr-00	150.1	-54.4	-2.9	0.5	16.7	48.0
May-00	203.0	-80.9	7.2	4.9	24.6	23.1
Jun-00						
Jul-00						

MEAN VALUES



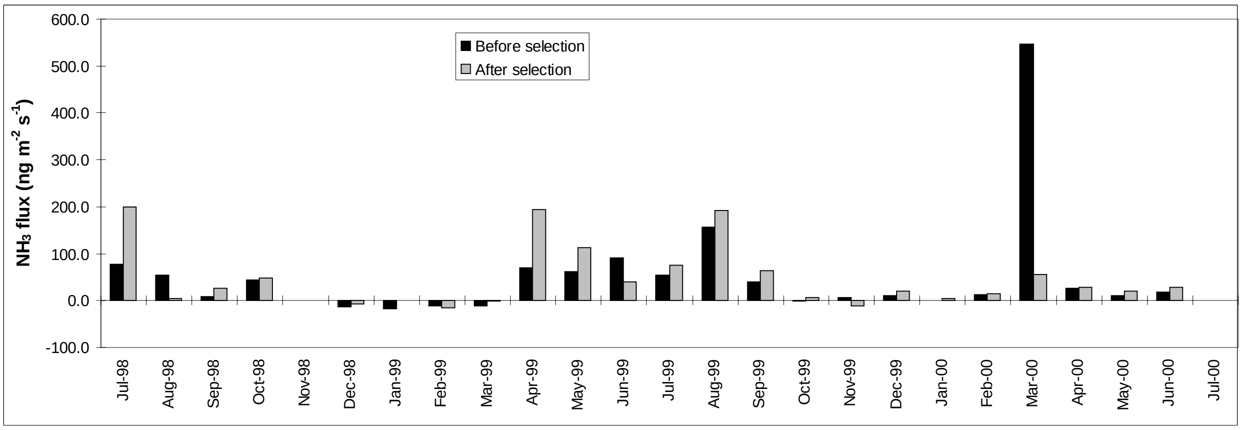
MEDIAN VALUES



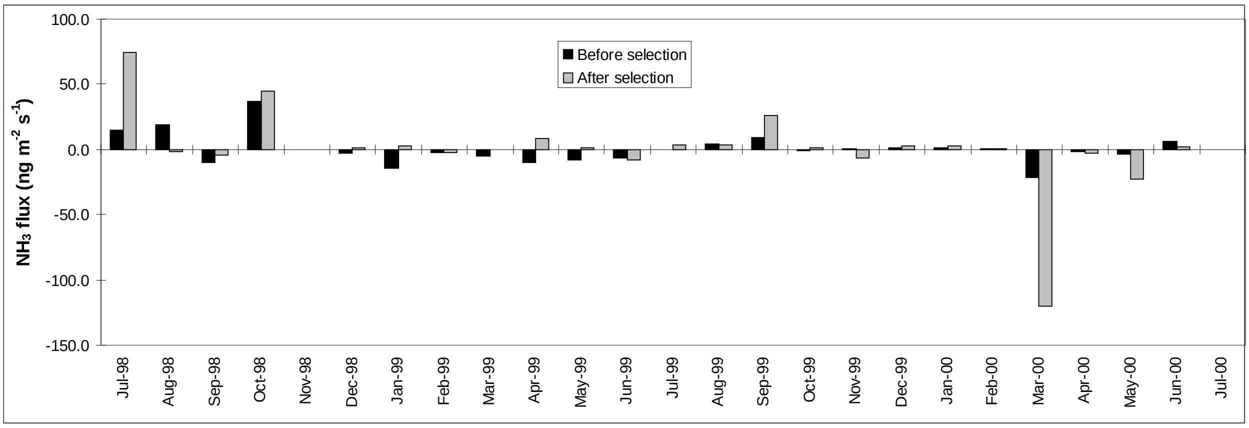
NH_3 FLUX (ng m^{-2} s^{-1})						
Month	MAX	MIN	MEAN	MEDIAN	STDV	Total data available (%)
Jul-98	3834.6	-264.0	77.8	14.5	324.4	72.8
Aug-98	1391.5	-502.6	53.9	18.8	151.3	80.9
Sep-98	1669.9	-506.0	8.0	-10.0	152.0	59.1
Oct-98	848.0	-561.1	43.7	37.0	147.8	68.1
Nov-98						
Dec-98	166.5	-291.3	-13.9	-2.9	48.3	74.6
Jan-99	489.4	-310.1	-17.7	-14.1	93.4	46.1
Feb-99	244.0	-847.0	-10.4	-2.3	101.7	28.3
Mar-99	100.7	-301.3	-11.0	-5.4	32.8	61.5
Apr-99	9375.0	-910.3	70.2	-9.9	648.7	82.8
May-99	7590.5	-894.3	60.9	-8.2	414.4	92.1
Jun-99	8951.4	-2382.2	91.4	-6.2	634.2	81.7
Jul-99	1100.0	-1050.5	52.9	-0.4	167.1	89.0
Aug-99	9427.6	-519.1	157.3	4.0	726.4	92.6
Sep-99	792.1	-236.9	39.8	8.9	108.7	84.9
Oct-99	181.7	-188.7	-2.1	-0.9	36.6	74.3
Nov-99	640.7	-426.2	6.2	0.4	56.4	74.1
Dec-99	824.0	-128.8	10.8	1.1	57.7	58.8
Jan-00	245.1	-144.6	0.7	0.9	23.3	62.0
Feb-00	88.6	-13.5	12.0	0.5	25.8	2.7
Mar-00	36273.7	-6761.2	545.8	-21.3	3319.9	35.6
Apr-00	1650.6	-708.2	27.1	-1.5	166.8	73.4
May-00	1027.3	-1163.3	10.5	-3.5	172.4	84.5
Jun-00	245.8	-173.0	18.7	6.0	71.0	23.6
Jul-00						

NH_3 FLUX SELECTED (ng m^{-2} s^{-1})						
Month	MAX	MIN	MEAN	MEDIAN	STDV	Selected data available (%)
Jul-98	3834.6	-241.9	200.3	74.4	495.9	25.6
Aug-98	218.9	-136.3	3.9	-1.8	64.9	9.5
Sep-98	1669.9	-506.0	27.0	-4.2	189.3	30.5
Oct-98	848.0	-561.1	47.0	44.5	161.7	51.5
Nov-98						
Dec-98	60.8	-291.3	-8.3	1.1	40.6	54.5
Jan-99	91.8	-147.1	1.4	2.7	38.2	10.7
Feb-99	202.1	-847.0	-14.9	-2.5	106.9	21.4
Mar-99	72.6	-104.0	-2.3	0.0	20.9	23.7
Apr-99	9375.0	-450.8	193.7	8.4	884.4	42.3
May-99	3016.5	-576.7	113.6	1.0	401.9	55.5
Jun-99	5098.5	-2382.2	40.7	-7.8	525.1	43.6
Jul-99	1100.0	-1050.5	76.3	3.6	191.0	57.0
Aug-99	8446.2	-519.1	191.7	3.2	823.1	46.2
Sep-99	724.9	-163.7	63.2	26.4	123.3	22.7
Oct-99	88.9	-81.8	6.4	1.5	22.2	37.6
Nov-99	201.8	-169.1	-10.3	-6.3	36.6	35.2
Dec-99	824.0	-67.7	19.4	2.7	67.6	38.5
Jan-00	64.3	-61.8	4.6	2.9	12.1	34.6
Feb-00	88.6	-13.5	14.2	0.7	30.0	1.5
Mar-00	8431.1	-6761.2	56.3	-120.4	1627.4	17.4
Apr-00	1650.6	-708.2	27.7	-3.0	180.7	48.1
May-00	1027.3	-1163.3	20.4	-22.6	211.9	44.5
Jun-00	245.8	-173.0	27.9	1.9	92.2	12.4
Jul-00						

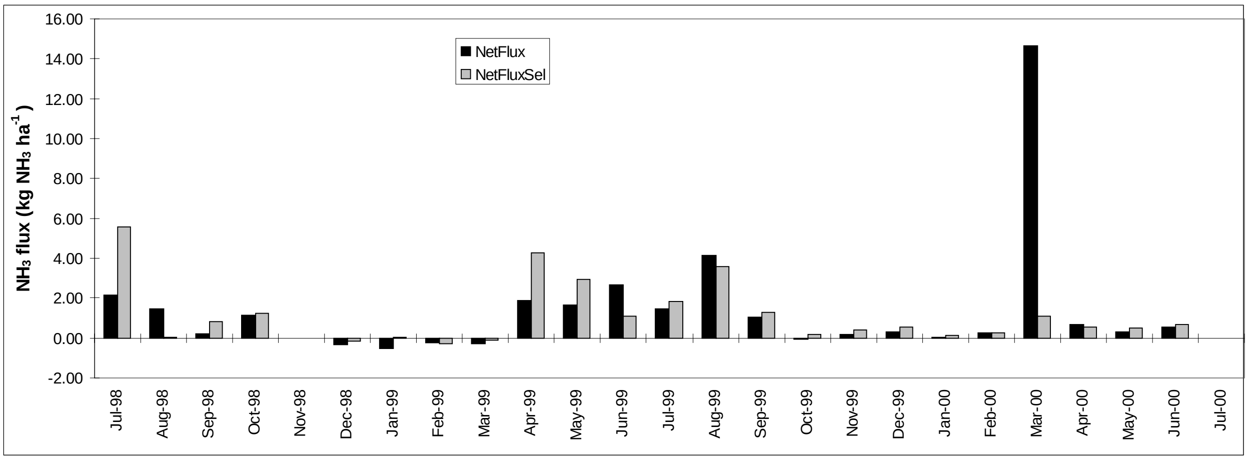
MEAN VALUES

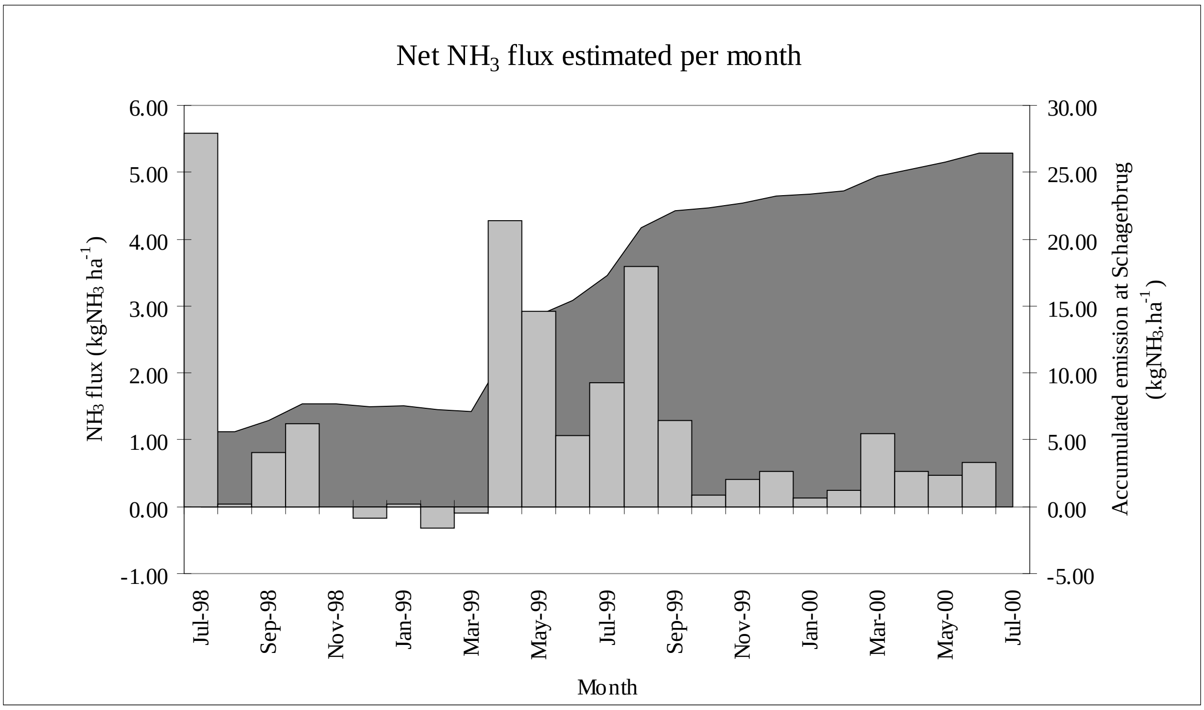


MEDIAN VALUES



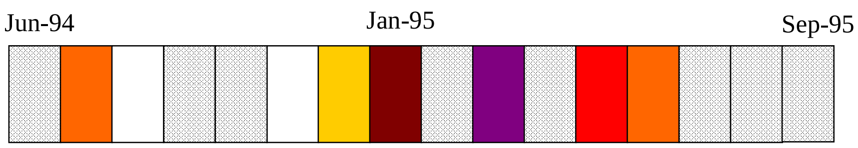
NET FLUX (kg NH_3 ha^{-1})			
Month	NetFlux	NetFluxSel	Accumul.
Jul-98	2.14	5.59	5.59
Aug-98	1.47	0.04	5.63
Sep-98	0.22	0.81	6.44
Oct-98	1.14	1.24	7.68
Nov-98			7.68
Dec-98	-0.32	-0.17	7.51
Jan-99	-0.54	0.04	7.55
Feb-99	-0.24	-0.31	7.24
Mar-99	-0.29	-0.10	7.14
Apr-99	1.86	4.28	11.42
May-99	1.65	2.93	14.35
Jun-99	2.65	1.07	15.42
Jul-99	1.45	1.85	17.27
Aug-99	4.12	3.59	20.86
Sep-99	1.03	1.29	22.15
Oct-99	-0.05	0.17	22.32
Nov-99	0.18	0.41	22.73
Dec-99	0.30	0.53	23.26
Jan-00	0.02	0.13	23.39
Feb-00	0.26	0.25	23.64
Mar-00	14.64	1.09	24.73
Apr-00	0.67	0.53	25.26
May-00	0.30	0.47	25.73
Jun-00	0.54	0.67	26.40
Jul-00			26.40

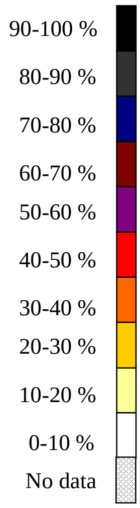

NetFlux
NetFluxSel
NH3 flux (kg NH3 ha-1)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
Jul-98
Aug-98
Sep-98
Oct-98
Nov-98
Dec-98
Jan-99
Feb-99
Mar-99
Apr-99
May-99
Jun-99
Jul-99
Aug-99
Sep-99
Oct-99
Nov-99
Dec-99
Jan-00
Feb-00
Mar-00
Apr-00
May-00
Jun-00
Jul-00


Net NH3 flux estimated per month
NH3 flux (kgNH3 ha-1)
Accumulated emission at Schagerbrug (kgNH3.ha-1)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
Jul-98
Sep-98
Nov-98
Jan-99
Mar-99
May-99
Jul-99
Sep-99
Nov-99
Jan-00
Mar-00
May-00
Jul-00
Month

APPENDIX B: SEASONAL VARIATIONS IN METEOROLOGICAL PARAMETERS, CONCENTRATIONS AND FLUXES, OOSTVAARDERSPLASSEN

This appendix shows the results of the calculations made with the complete data set obtained for the site Oostvaardersplassen during the whole period of measurements. Monthly and seasonal average values were calculated in order to have an overview of the behaviour observed in the NH_3 exchange over a semi-natural grassland. As a starting point, a summary of the measurement period covered in the study, together with the average data availability for the fluxes, concentrations and meteorological parameters measured, is presented.





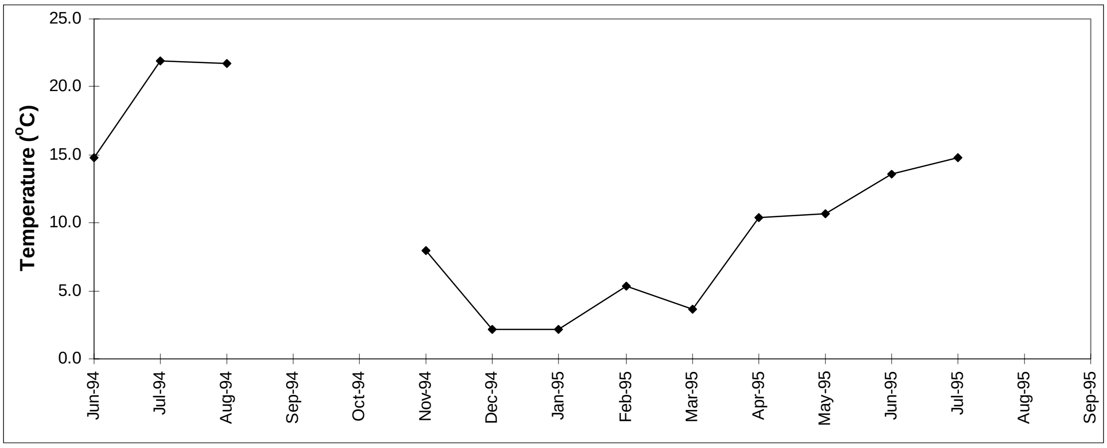
(*)Measurement period covered:	Jun ‘94 - Sep ‘95
(*)Meteo available:	40.8 %
(*)Concentration available:	41.5 %
(*)Meteo and concentration available (%):	24.9 %
(*)Selected flux (%):	16.8 %

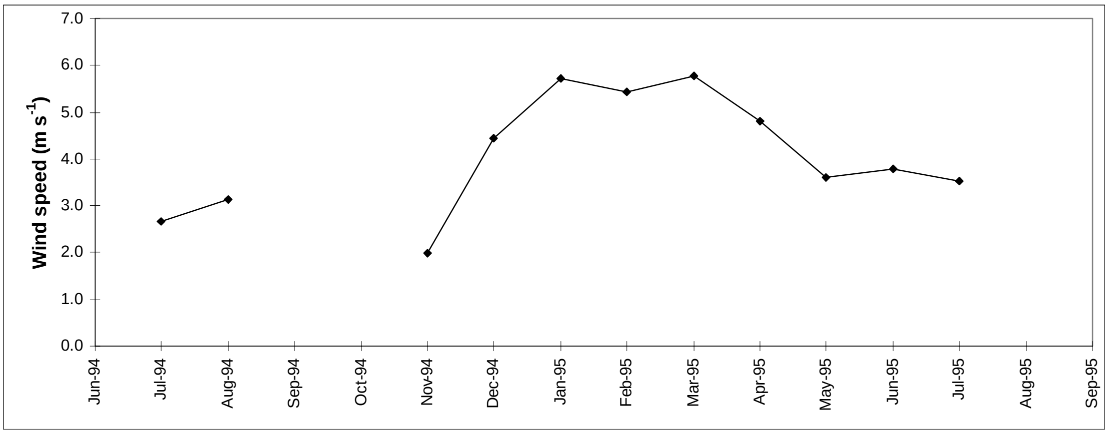
(*) Average of the whole period studied

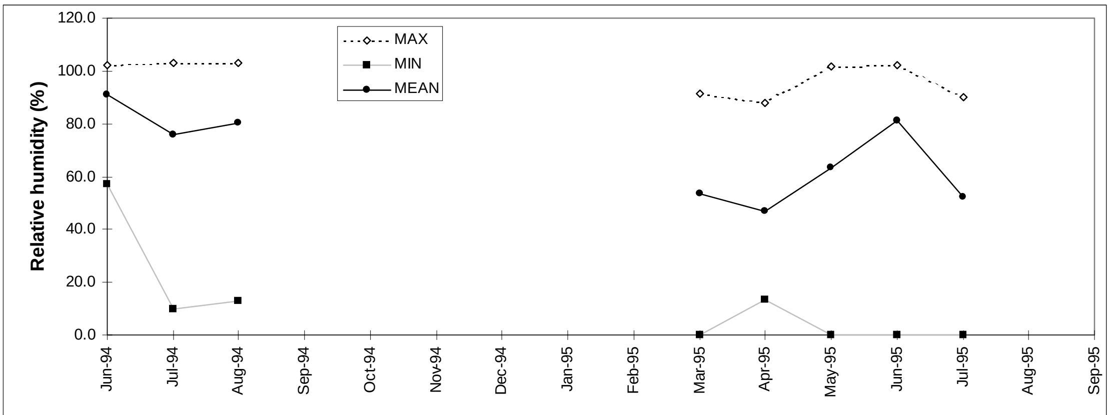
TEMPERATURE (SONIC, °C)						
Month	MAX	MIN	MEAN	MEDIAN	STDV	Data available (%)
Jun-94	23.8	6.7	14.8	14.9	3.3	33.5
Jul-94	37.1	7.9	21.9	21.7	5.9	79.7
Aug-94	37.3	13.1	21.7	21.3	4.6	46.2
Sep-94						
Oct-94						
Nov-94	11.3	0.1	8.0	8.8	2.7	20.6
Dec-94	12.6	-8.6	2.1	2.4	4.8	59.3
Jan-95	10.8	-10.7	2.1	2.8	4.1	93.0
Feb-95	10.5	-2.3	5.3	6.1	3.1	46.1
Mar-95	12.6	-2.2	3.7	3.5	3.1	83.3
Apr-95	12.0	7.1	10.4	10.6	1.3	1.9
May-95	24.5	-1.0	10.7	10.0	4.8	75.1
Jun-95	28.3	5.5	13.6	12.6	4.2	99.3
Jul-95	24.1	9.0	14.8	14.3	3.4	14.4
Aug-95						
Sep-95						

WIND SPEED (m s^{-1})						
Month	MAX	MIN	MEAN	MEDIAN	STDV	Data available (%)
Jun-94						
Jul-94	9.6	0.2	2.8	2.7	1.5	79.7
Aug-94	10.4	0.1	3.6	3.1	2.3	46.2
Sep-94						
Oct-94						
Nov-94	5.0	0.3	2.3	2.0	1.4	20.6
Dec-94	12.4	0.2	4.9	4.4	3.1	59.3
Jan-95	14.9	0.3	6.0	5.7	3.2	93.0
Feb-95	17.5	0.2	5.8	5.4	3.2	69.2
Mar-95	14.6	0.6	6.3	5.8	3.2	94.5
Apr-95	5.9	3.7	4.7	4.8	0.7	1.9
May-95	9.9	0.1	3.9	3.6	2.2	75.1
Jun-95	9.8	0.2	3.8	3.8	1.9	99.3
Jul-95	8.1	0.7	3.7	3.5	1.4	14.4
Aug-95						
Sep-95						

RELATIVE HUMIDITY (%)						
Month	MAX	MIN	MEAN	MEDIAN	STDV	Data available (%)
Jun-94	102.0	57.2	91.1	94.8	10.6	33.5
Jul-94	103.0	10.0	75.8	89.2	30.9	79.7
Aug-94	103.0	13.0	80.3	96.6	31.2	46.2
Sep-94						
Oct-94						
Nov-94						
Dec-94						
Jan-95						
Feb-95						
Mar-95	91.5	0.0	53.6	63.2	28.8	83.3
Apr-95	87.8	13.2	47.1	33.9	27.1	1.9
May-95	101.9	0.0	63.2	81.3	35.2	75.1
Jun-95	102.0	0.0	81.4	91.4	24.5	99.3
Jul-95	90.0	0.0	52.3	68.0	34.3	14.4
Aug-95						
Sep-95						

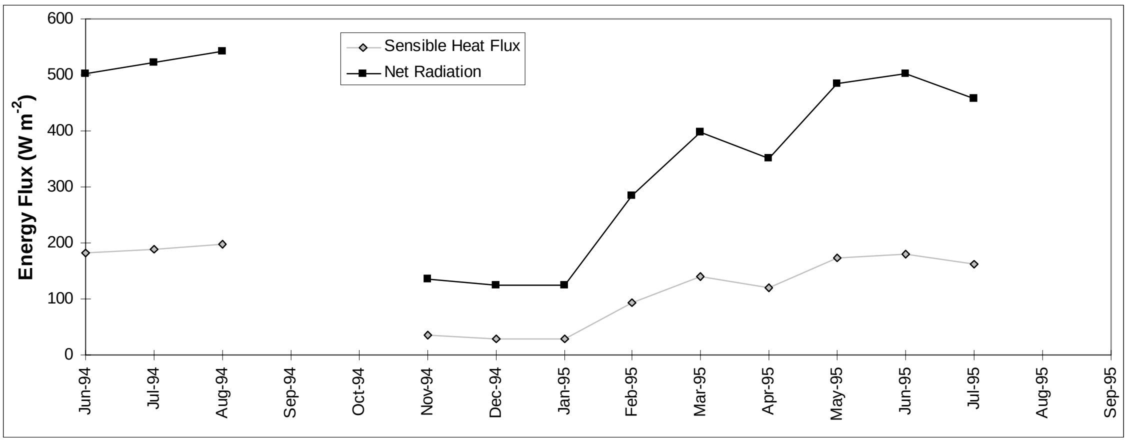

Temperature (°C)
25.0
20.0
15.0
10.0
5.0
0.0
Jun-94
Jul-94
Aug-94
Sep-94
Oct-94
Nov-94
Dec-94
Jan-95
Feb-95
Mar-95
Apr-95
May-95
Jun-95
Jul-95
Aug-95
Sep-95


Wind speed (m s-1)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Jun-94
Jul-94
Aug-94
Sep-94
Oct-94
Nov-94
Dec-94
Jan-95
Feb-95
Mar-95
Apr-95
May-95
Jun-95
Jul-95
Aug-95
Sep-95


Relative humidity (%)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
MAX
MIN
MEAN
Jun-94
Jul-94
Aug-94
Sep-94
Oct-94
Nov-94
Dec-94
Jan-95
Feb-95
Mar-95
Apr-95
May-95
Jun-95
Jul-95
Aug-95
Sep-95

SENSIBLE HEAT FLUX (W m^{-2})						
Month	MAX	MIN	MEAN	MEDIAN	STDV	Data available (%)
Jun-94	181	-44	16	0	52	33.5
Jul-94	189	-45	45	15	73	79.7
Aug-94	197	-30	35	6	63	46.2
Sep-94						
Oct-94						
Nov-94	35	-31	-18	-21	11	20.6
Dec-94	30	-45	-21	-21	10	59.3
Jan-95	30	-45	-22	-23	13	93.0
Feb-95	94	-48	-15	-23	26	69.2
Mar-95	139	-49	-4	-23	44	94.5
Apr-95	120	-28	14	3	49	1.9
May-95	174	-46	19	-9	58	75.1
Jun-95	181	-45	22	-4	60	99.3
Jul-95	163	-43	15	-11	61	14.4
Aug-95						
Sep-95						

NET RADIATION (W m^{-2})						
Month	MAX	MIN	MEAN	MEDIAN	STDV	Data available (%)
Jun-94	503	-60	91	50	131	33.5
Jul-94	522	-62	162	87	183	79.7
Aug-94	543	-25	138	66	158	46.2
Sep-94						
Oct-94						
Nov-94	136	-29	6	-2	26	20.6
Dec-94	125	-62	-3	-4	25	59.3
Jan-95	125	-63	-4	-7	33	93.0
Feb-95	284	-69	12	-7	66	69.2
Mar-95	397	-71	39	-9	109	94.5
Apr-95	350	-19	84	56	121	1.9
May-95	484	-66	97	28	145	75.1
Jun-95	502	-64	104	40	151	99.3
Jul-95	458	-57	89	22	152	14.4
Aug-95						
Sep-95						

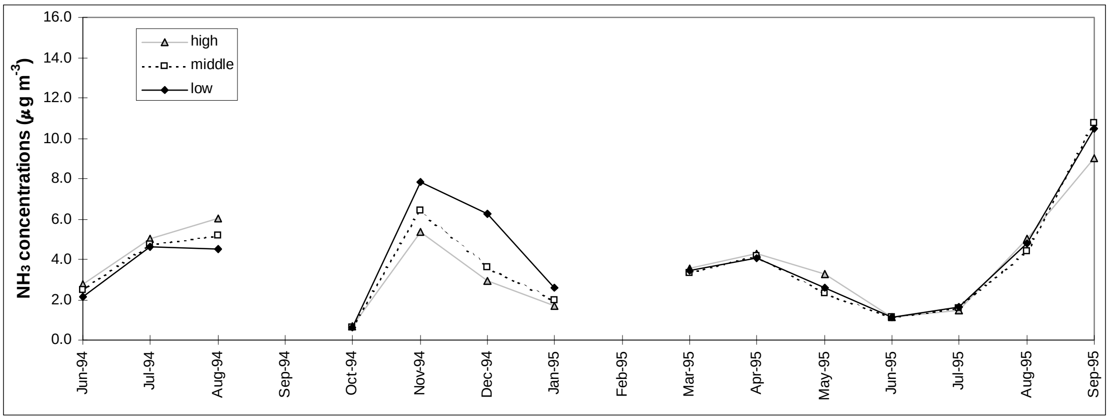


CONCENTRATIONS (LOW LEVEL, μg m^{-3})							
Month	MAX	MIN	MEAN	MEDIAN	STDV	Data available (%)	level (m)
Jun-94	9.2	-0.1	2.2	1.7	1.7	13.3	0.9
Jul-94	14.4	-0.4	4.6	4.1	2.9	87.5	0.9
Aug-94	12.3	1.1	4.5	3.9	2.6	4.6	0.9
Sep-94							0.9
Oct-94	2.5	0.0	0.6	0.5	0.5	14.0	0.9
Nov-94	30.5	0.4	7.8	6.7	5.8	56.4	0.9
Dec-94	20.7	0.3	6.2	6.0	3.9	25.8	0.9
Jan-95	11.5	0.0	2.6	1.2	2.8	50.8	0.9
Feb-95							0.9
Mar-95	40.7	-0.2	3.5	2.2	4.2	81.7	0.9
Apr-95	12.0	-0.1	4.0	3.8	2.9	24.7	0.9
May-95	21.1	-0.2	2.6	1.5	3.2	98.7	0.9
Jun-95	5.3	0.0	1.1	0.8	0.9	41.1	0.9
Jul-95	7.6	-0.1	1.6	1.2	2.0	1.9	0.9
Aug-95	48.7	0.0	4.8	3.0	5.5	62.9	0.9
Sep-95	38.6	0.6	10.5	7.6	8.6	45.6	0.9

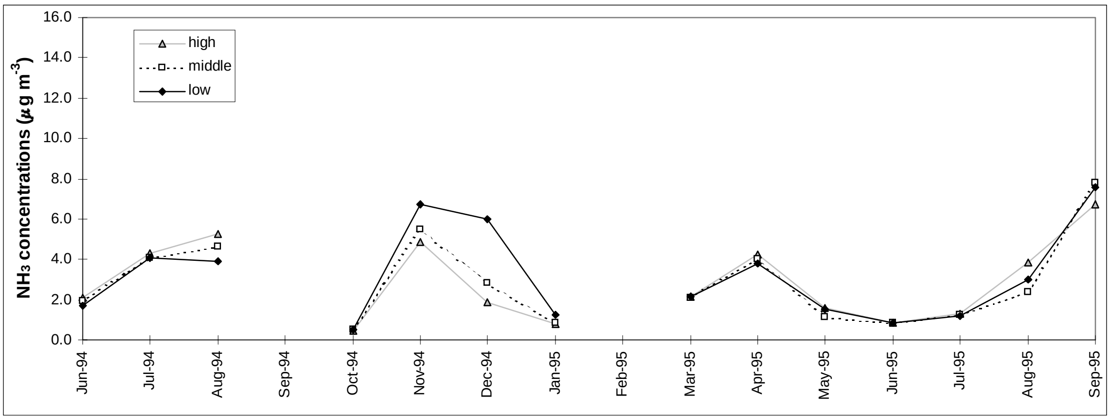
CONCENTRATIONS (MIDDLE LEVEL, μg m^{-3})							
Month	MAX	MIN	MEAN	MEDIAN	STDV	Data available (%)	level (m)
Jun-94	10.9	0.2	2.5	1.9	1.9	13.3	2.1
Jul-94	14.6	-0.5	4.8	4.1	3.0	87.5	2.1
Aug-94	12.5	1.3	5.2	4.6	2.7	4.6	2.1
Sep-94							2.1
Oct-94	2.5	0.0	0.6	0.5	0.6	14.0	2.1
Nov-94	22.5	0.3	6.4	5.5	4.4	56.4	2.1
Dec-94	17.9	0.1	3.6	2.9	3.1	35.6	2.1
Jan-95	9.5	0.0	2.0	0.9	2.2	70.3	2.1
Feb-95							2.1
Mar-95	41.1	-0.2	3.3	2.1	4.2	93.4	2.1
Apr-95	12.6	-0.1	4.2	4.0	2.9	24.7	2.1
May-95	21.5	-0.2	2.3	1.2	3.1	80.4	2.1
Jun-95	5.5	-0.1	1.1	0.9	1.0	41.1	2.1
Jul-95	6.9	-0.2	1.6	1.3	1.9	1.9	2.1
Aug-95	52.1	-0.1	4.4	2.4	5.8	55.2	2.1
Sep-95	45.6	0.5	10.8	7.8	9.8	51.0	2.1

CONCENTRATIONS (HIGH LEVEL, μg m^{-3})							
Month	MAX	MIN	MEAN	MEDIAN	STDV	Data available (%)	level (m)
Jun-94	11.6	0.0	2.8	2.1	2.2	13.3	4.1
Jul-94	17.3	-0.7	5.0	4.3	3.4	87.5	4.1
Aug-94	13.4	1.5	6.0	5.3	2.8	4.6	4.1
Sep-94							4.1
Oct-94	2.6	0.0	0.7	0.4	0.7	14.0	4.1
Nov-94	17.7	0.2	5.4	4.9	3.5	56.4	4.1
Dec-94	18.6	0.0	3.0	1.9	3.0	31.9	4.1
Jan-95	8.6	0.0	1.7	0.8	2.0	69.9	4.1
Feb-95							4.1
Mar-95	44.3	-0.2	3.6	2.1	4.5	98.5	4.1
Apr-95	12.8	-0.1	4.3	4.2	3.0	24.7	4.1
May-95	31.3	-0.1	3.3	1.6	4.4	94.2	4.1
Jun-95	6.0	-0.1	1.1	0.8	1.0	41.1	4.1
Jul-95	6.2	-0.2	1.5	1.3	1.7	1.9	4.1
Aug-95	30.6	0.1	5.0	3.8	4.6	32.4	4.1
Sep-95	48.6	0.4	9.0	6.8	9.0	41.8	4.1

MEAN CONCENTRATION VALUES



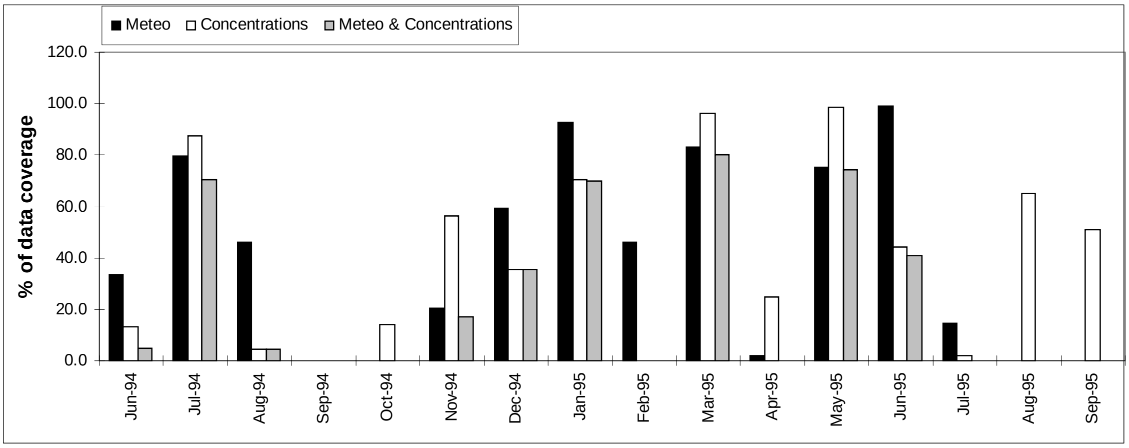
MEDIAN CONCENTRATION VALUES

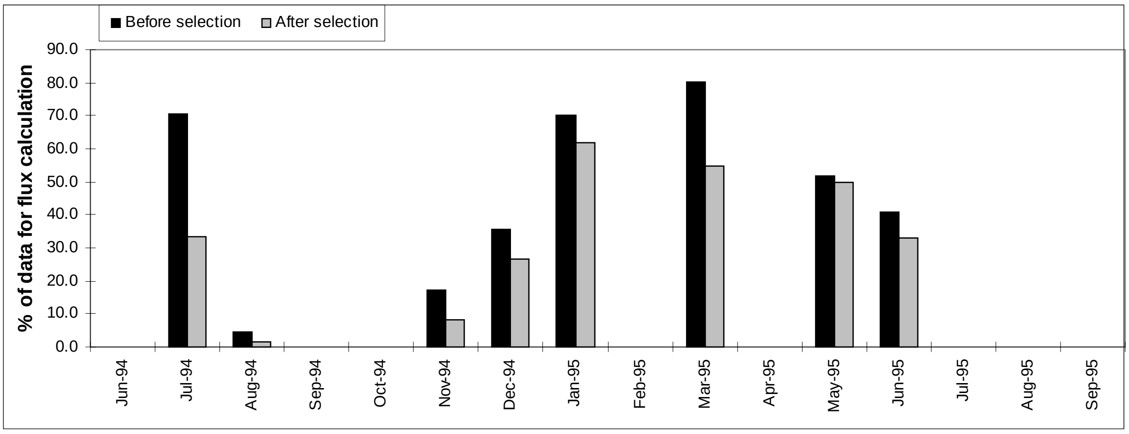


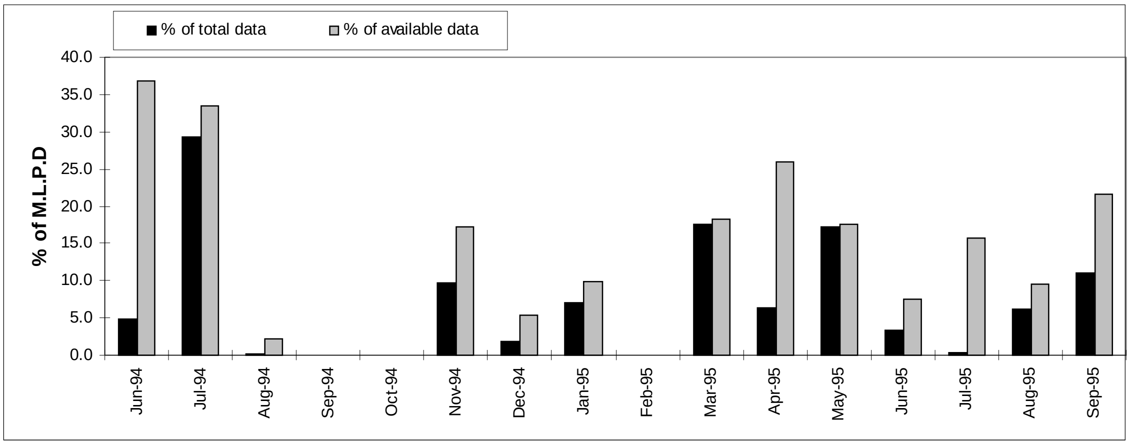
DATA COVERAGE			
Month	Meteo available (%)	Concentration available (%)	Meteo+concentration available (%)
Jun-94	33.5	13.3	5.1
Jul-94	79.7	87.5	70.4
Aug-94	46.2	4.6	4.6
Sep-94			
Oct-94	0.0	14.0	0.0
Nov-94	20.6	56.4	17.2
Dec-94	59.3	35.6	35.6
Jan-95	93.0	70.3	70.2
Feb-95	46.1	0.0	0.0
Mar-95	83.3	96.2	80.1
Apr-95	1.9	24.7	0.0
May-95	75.1	98.7	74.1
Jun-95	99.3	44.1	41.0
Jul-95	14.4	1.9	0.0
Aug-95	0.0	65.1	0.0
Sep-95	0.0	51.1	0.0

DATA COVERAGE			
Month	No selection (%)	Selected Flux (%)	Selected Vd (%)
Jun-94			
Jul-94	70.4	33.5	33.5
Aug-94	4.6	1.6	1.6
Sep-94			
Oct-94			
Nov-94	17.2	8.1	8.1
Dec-94	35.6	26.6	26.6
Jan-95	70.2	61.7	59.4
Feb-95			
Mar-95	80.1	54.6	51.9
Apr-95			
May-95	51.9	49.9	37.8
Jun-95	41.0	33.1	32.8
Jul-95			
Aug-95			
Sep-95			

DATA COVERAGE		
Month	Knik (% of total data)	Knik (% of available data)
Jun-94	4.9	36.8
Jul-94	29.3	33.5
Aug-94	0.1	2.2
Sep-94		
Oct-94	0.0	0.0
Nov-94	9.7	17.2
Dec-94	1.9	5.3
Jan-95	7.0	10.0
Feb-95		
Mar-95	17.5	18.2
Apr-95	6.4	25.9
May-95	17.3	17.5
Jun-95	3.3	7.5
Jul-95	0.3	15.8
Aug-95	6.2	9.5
Sep-95	11.0	21.5


Meteo
Concentrations
Meteo & Concentrations
% of data coverage
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Jun-94
Jul-94
Aug-94
Sep-94
Oct-94
Nov-94
Dec-94
Jan-95
Feb-95
Mar-95
Apr-95
May-95
Jun-95
Jul-95
Aug-95
Sep-95

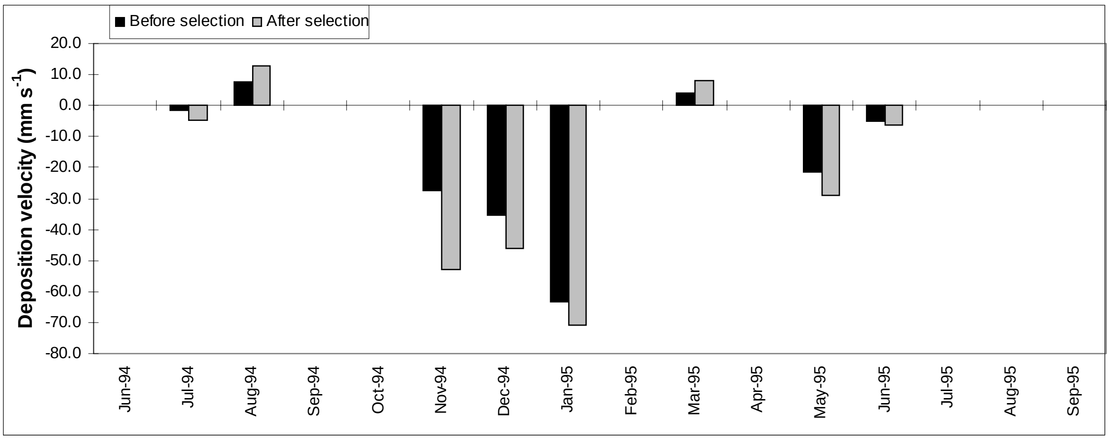

Before selection
After selection
% of data for flux calculation
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Jun-94
Jul-94
Aug-94
Sep-94
Oct-94
Nov-94
Dec-94
Jan-95
Feb-95
Mar-95
Apr-95
May-95
Jun-95
Jul-95
Aug-95
Sep-95


% of total data
% of available data
% of M.L.P.D
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Jun-94
Jul-94
Aug-94
Sep-94
Oct-94
Nov-94
Dec-94
Jan-95
Feb-95
Mar-95
Apr-95
May-95
Jun-95
Jul-95
Aug-95
Sep-95

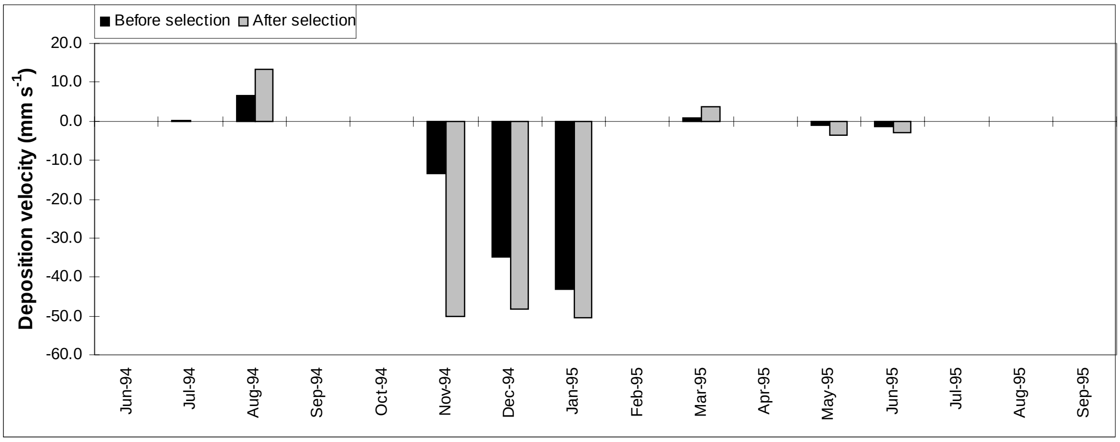
DEPOSITION VELOCITY (mm s^{-1})						
Month	MAX	MIN	MEAN	MEDIAN	STDV	Data available (%)
Jun-94						
Jul-94	79.0	-98.4	-1.5	0.2	15.7	70.4
Aug-94	25.9	-2.4	7.5	6.6	7.3	4.6
Sep-94						
Oct-94						
Nov-94	-0.4	-151.0	-27.6	-13.6	29.4	17.2
Dec-94	942.2	-245.3	-35.2	-34.7	75.5	35.6
Jan-95	92.1	-751.4	-63.2	-43.2	79.3	66.9
Feb-95						
Mar-95	628.3	-732.3	3.9	0.9	53.7	86.6
Apr-95						
May-95	87.8	-618.3	-21.6	-1.0	75.9	50.7
Jun-95	22.7	-103.7	-5.1	-1.4	14.6	40.3
Jul-95						
Aug-95						
Sep-95						

DEPOSITION VELOCITY SELECTED (mm s^{-1})						
Month	MAX	MIN	MEAN	MEDIAN	STDV	Selected data available (%)
Jun-94						
Jul-94	42.8	-98.4	-4.8	-0.2	17.1	33.5
Aug-94	25.9	5.9	12.9	13.2	5.7	1.6
Sep-94						
Oct-94						
Nov-94	-16.9	-151.0	-53.0	-50.1	24.6	8.1
Dec-94	942.2	-245.3	-46.0	-48.2	84.6	26.6
Jan-95	92.1	-751.4	-71.0	-50.5	80.9	59.4
Feb-95						
Mar-95	628.3	-732.3	7.9	3.9	68.4	51.9
Apr-95						
May-95	87.8	-618.3	-29.1	-3.5	86.5	37.8
Jun-95	22.7	-103.7	-6.4	-3.1	15.8	32.8
Jul-95						
Aug-95						
Sep-95						

MEAN VALUES



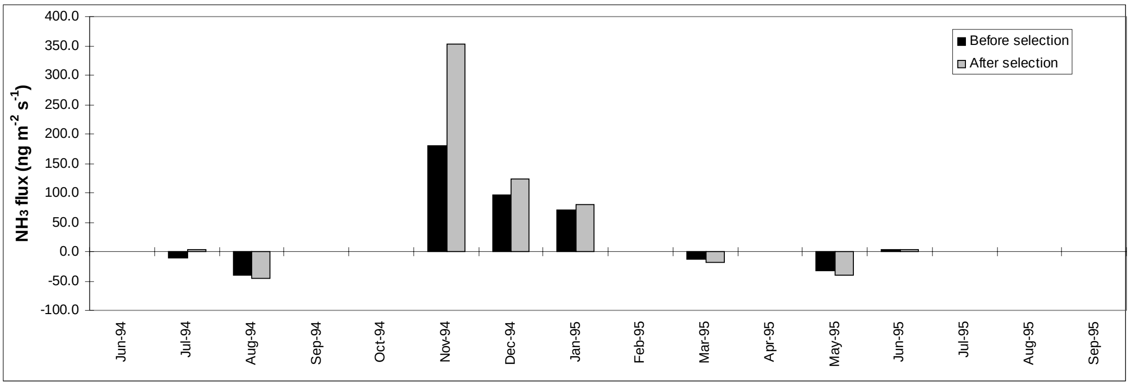
MEDIAN VALUES



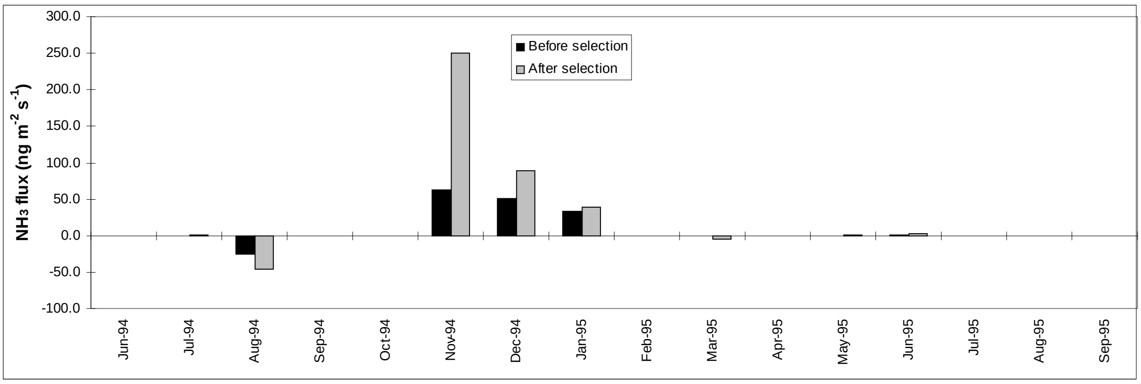
NH_3 FLUX (ng m^{-2} s^{-1})						
Month	MAX	MIN	MEAN	MEDIAN	STDV	Total data available (%)
Jun-94						
Jul-94	168.5	-740.4	-11.7	-0.5	96.8	70.4
Aug-94	11.2	-230.0	-40.5	-25.9	51.0	4.6
Sep-94						
Oct-94						
Nov-94	961.3	3.9	180.6	63.1	243.0	17.2
Dec-94	507.4	-369.5	95.8	51.5	116.2	35.6
Jan-95	473.3	-60.1	71.1	33.5	98.5	69.2
Feb-95						
Mar-95	149.4	-278.8	-12.3	-1.0	39.7	89.5
Apr-95						
May-95	58.0	-905.2	-33.0	-0.3	115.5	69.0
Jun-95	58.7	-45.9	3.5	0.6	13.4	40.6
Jul-95						
Aug-95						
Sep-95						

NH_3 FLUX SELECTED (ng m^{-2} s^{-1})						
Month	MAX	MIN	MEAN	MEDIAN	STDV	Selected data available (%)
Jun-94						
Jul-94	168.5	-471.6	4.0	0.4	60.6	33.5
Aug-94	-18.0	-75.7	-46.0	-45.9	21.4	1.6
Sep-94						
Oct-94						
Nov-94	961.3	43.3	352.5	250.5	263.3	8.1
Dec-94	507.4	-369.5	124.4	89.4	121.7	26.6
Jan-95	473.3	-60.1	79.2	39.2	101.4	61.7
Feb-95						
Mar-95	113.0	-278.8	-18.4	-5.3	43.4	54.6
Apr-95						
May-95	58.0	-783.9	-39.7	0.8	120.1	49.9
Jun-95	58.7	-45.9	4.5	2.5	14.6	33.1
Jul-95						
Aug-95						
Sep-95						

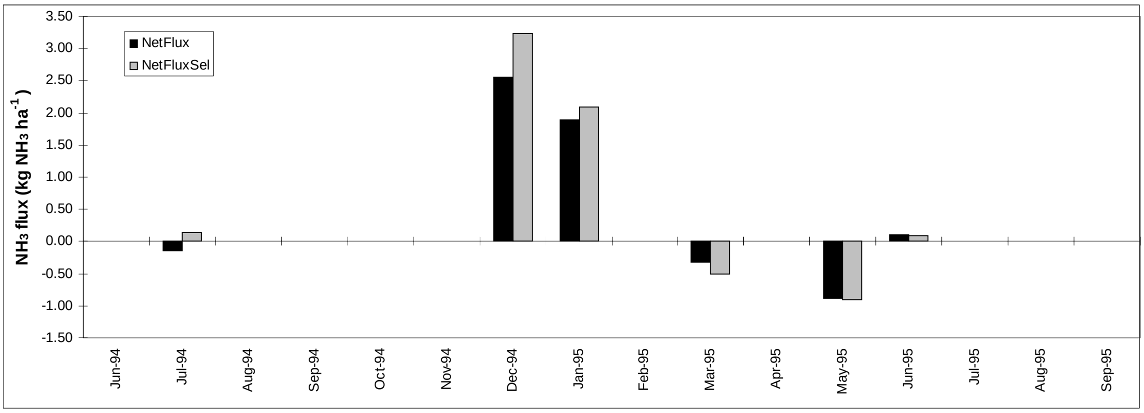
MEAN VALUES

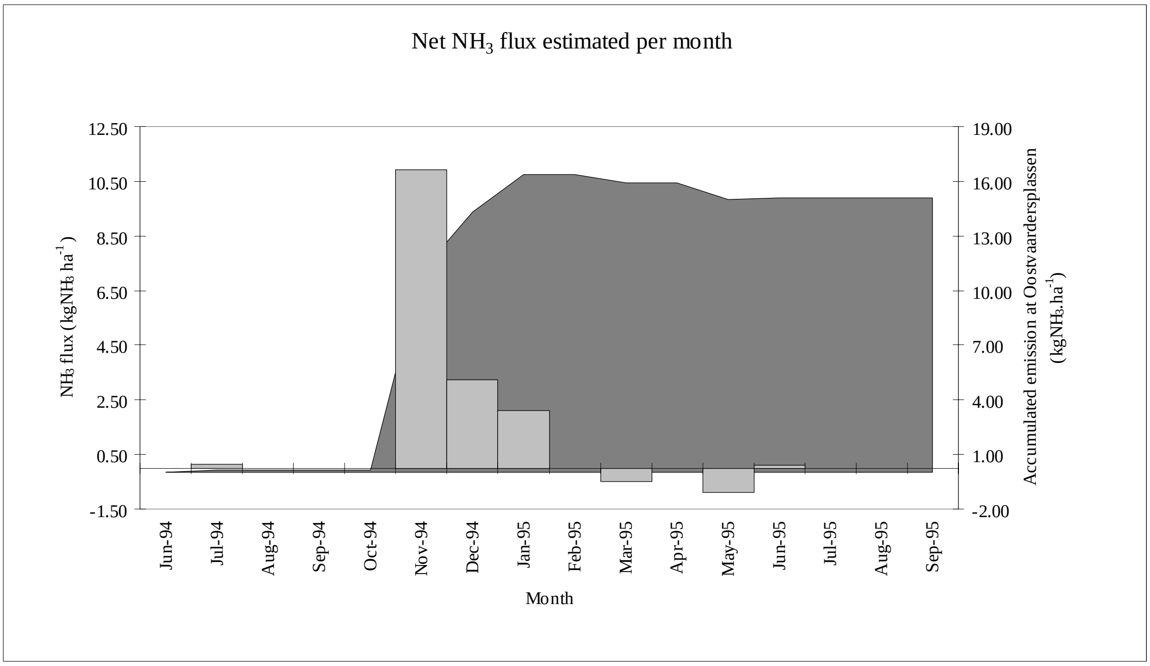


MEDIAN VALUES



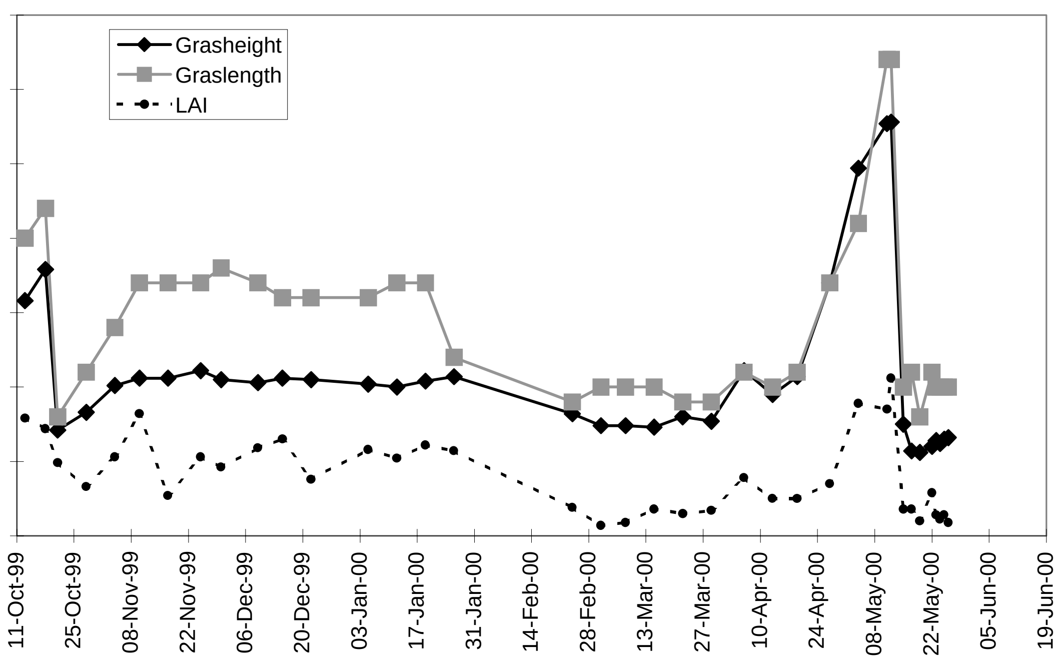
NET FLUX (kg NH_3 ha^{-1})			
Month	NetFlux	NetFluxSel	Accumul.
Jun-94			0.00
Jul-94	-0.14	0.14	0.14
Aug-94			0.14
Sep-94			0.14
Oct-94			0.14
Nov-94	4.65	10.93	11.07
Dec-94	2.55	3.23	14.30
Jan-95	1.90	2.10	16.40
Feb-95			16.40
Mar-95	-0.32	-0.51	15.89
Apr-95			15.89
May-95	-0.89	-0.90	14.99
Jun-95	0.10	0.09	15.08
Jul-95			15.08
Aug-95			15.08
Sep-95			15.08



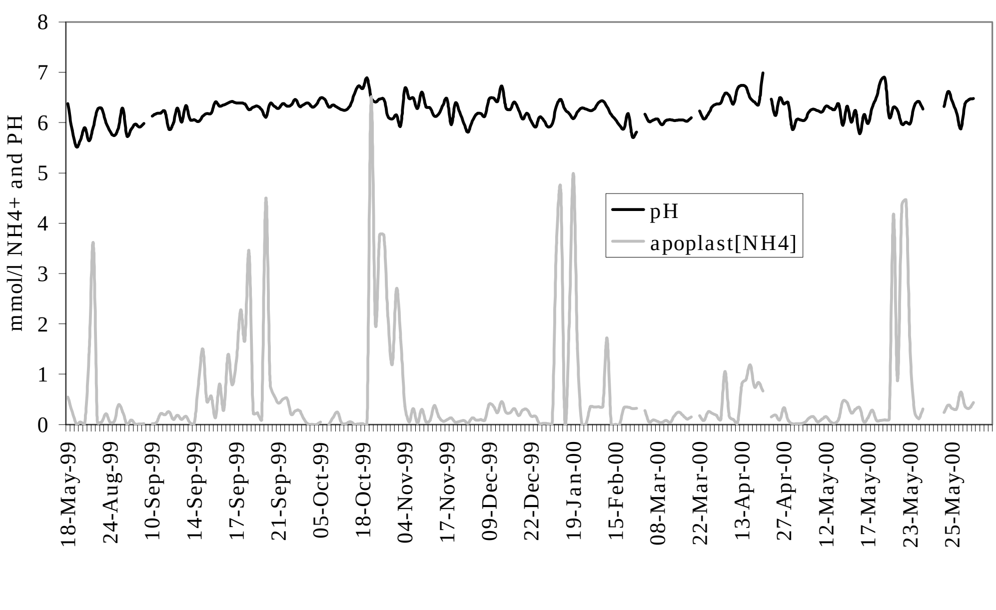


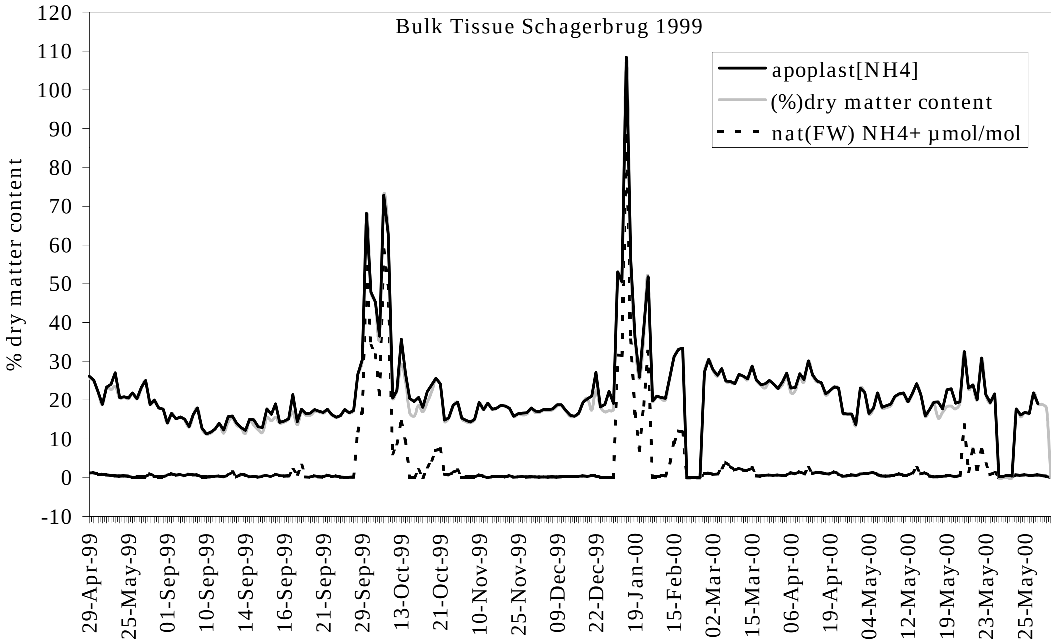
APPENDIX C: FIELD CHARACTERIZATION OF THE SITE SCHAGERBRUG

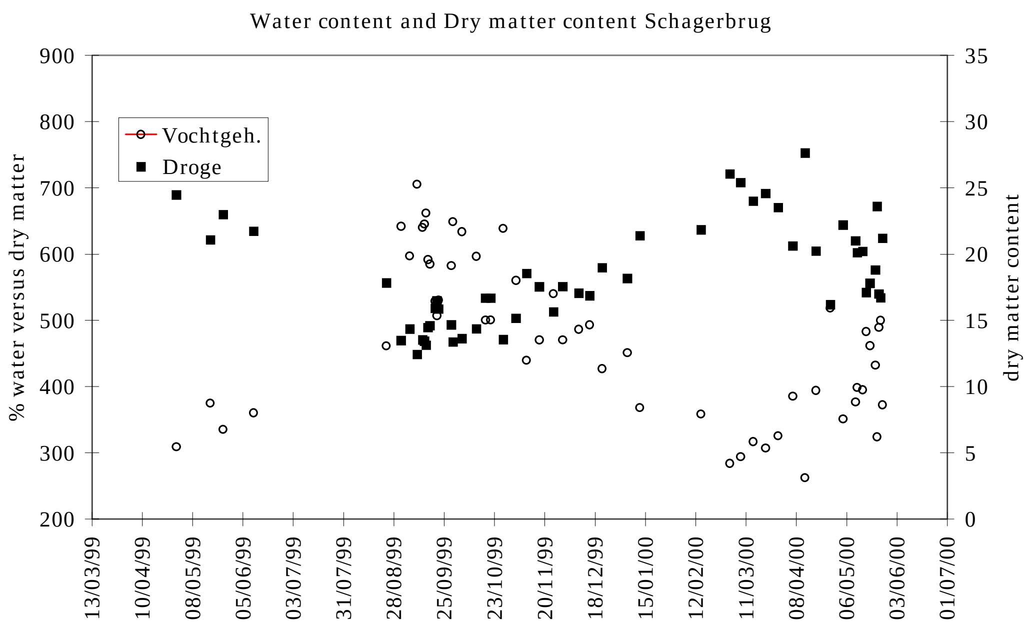
This appendix reports the results of the measurements performed at the site Schagerbrug to characterise the field. These measurements included grass height and length, leaf area index (LAI), apoplast NH_4^+ concentration and pH, water content and dry matter content, total C, total N and total H. Measurements of grass height and length started in April 1999, although here we present the results after October 1999, where measurements of LAI started at Schagerbrug. The main goal of these measurements was to have enough information about the field used at Schagerbrug, mainly focusing on the parameters characterising apoplast of leaves. This information is needed to get a good estimation of the parameters used to describe the stomatal resistance in the resistance model described in section 2.3.

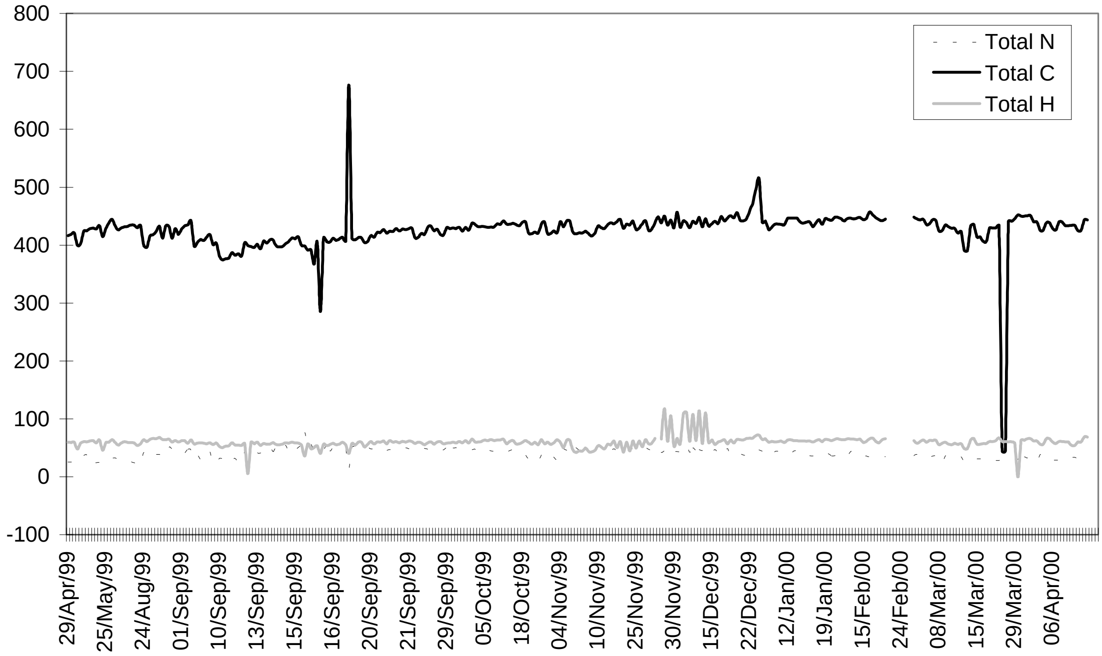


Apoplast measurements Schagerbrug




Bulk Tissue Schagerbrug 1999
apoplast[NH4]
(%)dry matter content
nat(FW) NH4+ µmol/mol
% dry matter content
29-Apr-99
25-May-99
01-Sep-99
10-Sep-99
14-Sep-99
16-Sep-99
21-Sep-99
29-Sep-99
13-Oct-99
21-Oct-99
10-Nov-99
25-Nov-99
09-Dec-99
22-Dec-99
19-Jan-00
15-Feb-00
02-Mar-00
15-Mar-00
06-Apr-00
19-Apr-00
04-May-00
12-May-00
19-May-00
23-May-00
25-May-00


Water content and Dry matter content Schagerbrug
Vochtgeh.
Droge
% water versus dry matter
dry matter content
13/03/99
10/04/99
08/05/99
05/06/99
03/07/99
31/07/99
28/08/99
25/09/99
23/10/99
20/11/99
18/12/99
15/01/00
12/02/00
11/03/00
08/04/00
06/05/00
03/06/00
01/07/00


800
700
600
500
400
300
200
100
0
-100
Total N
Total C
Total H
29/Apr/99
25/May/99
24/Aug/99
01/Sep/99
10/Sep/99
13/Sep/99
15/Sep/99
16/Sep/99
20/Sep/99
21/Sep/99
29/Sep/99
05/Oct/99
18/Oct/99
04/Nov/99
10/Nov/99
25/Nov/99
30/Nov/99
15/Dec/99
22/Dec/99
12/Jan/00
19/Jan/00
15/Feb/00
24/Feb/00
08/Mar/00
15/Mar/00
29/Mar/00
06/Apr/00