Ammonia Reduction from Trees (ART) – Field Experiments

Tang Y.S., Braban C.F., Dick. J.D., Vanguelova E., Timmis R., Fisher B., Carnell, E., Martin Hernandez C., Arkle P., Brass, D., Gill, R., Davies R., Stephens A., Iwanicka A., Mullinger N.J., Cowan N., Simmons I., Jones R., Shutt M., Whyatt D., Benham S., Broadmeadow S., Mansfield P., and Bealey W.J.

January 28th, 2022

UK Centre for Ecology & Hydrology · Forest Research · Environment Agency · Cumbria Farm Environment Partnership · Lancaster University · The Lakes Free Range Egg Co · Natural England · Department for Environment Food & Rural Affairs

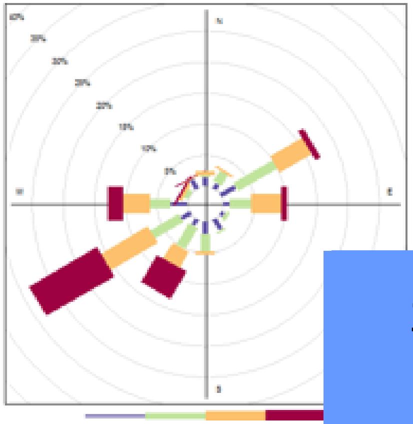
Programme

13.30	**Welcome**	Philippa Mansfield
13.35 – 14.20	ART field experiment results	
13.35 – 13.50	Field set up, ammonia monitoring and modelling	Sim Tang Bill Bealey
13.50 – 14.00	Tree measurements, lichen survey	Elena Vanguelova
14:00 – 14.10	Intensive measurements	Christine Braban
14.10 – 14.20	Directional Passive ammonia sampling	Roger Timmis
5 minute break		
14.25 – 14.30	Summary and Conclusions	Christine Braban
14.30 - 14.55	Q & A	All
14.55 – 15.00	Wrap up and Close	

EXPERIMENTAL DESIGN

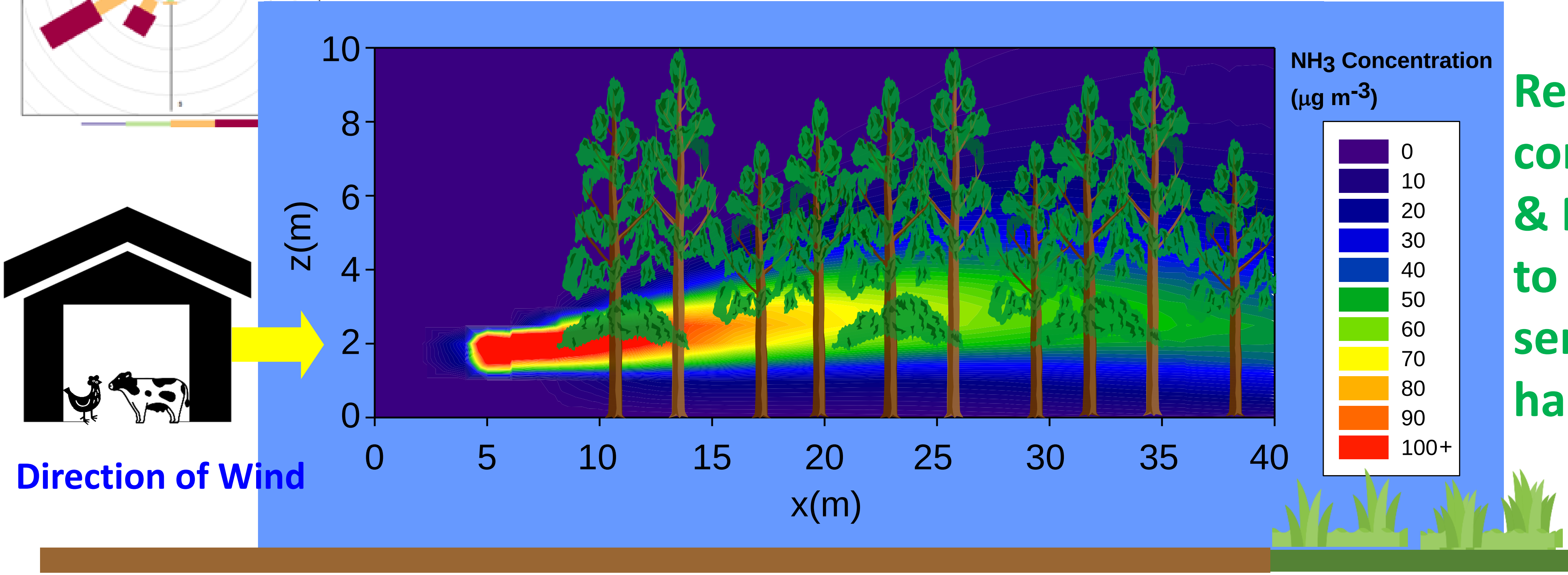
Five case study farms: 3 poultry, 1 dairy, 1 mixed (dairy + poultry)	
• **2-weekly NH_3 measurements (Aug - Nov 2020)** and comparison with model predictions	Sim Tang and Bill Bealey (UKCEH)
• **Tree parameters**: Girth, height, LAI, N uptake • **Lichen Survey**	Elena Vanguelova (Forest Research)
At a single farm: Poultry 3	
• **Intensive measurements (17/09 – 18/11/20)** Automatic NH_3 ,CO_2, CH_4 and PM On-site meteorology	Christine Braban (UKCEH)
• **2-weekly directional NH_3 (17/09 – 11/11/20):** **D**irectional **P**assive **Air S**ampler **(DPAS)** with **M**ini-**AN**nular **DE**nuders (MANDE)	Roger Timmis (EA)

Ammonia Mitigation by Tree Shelterbelts



1. Local recapture of NH_3 by trees ?% ↓

2. Increased mixing of the air increases plume dispersion ?% ↓

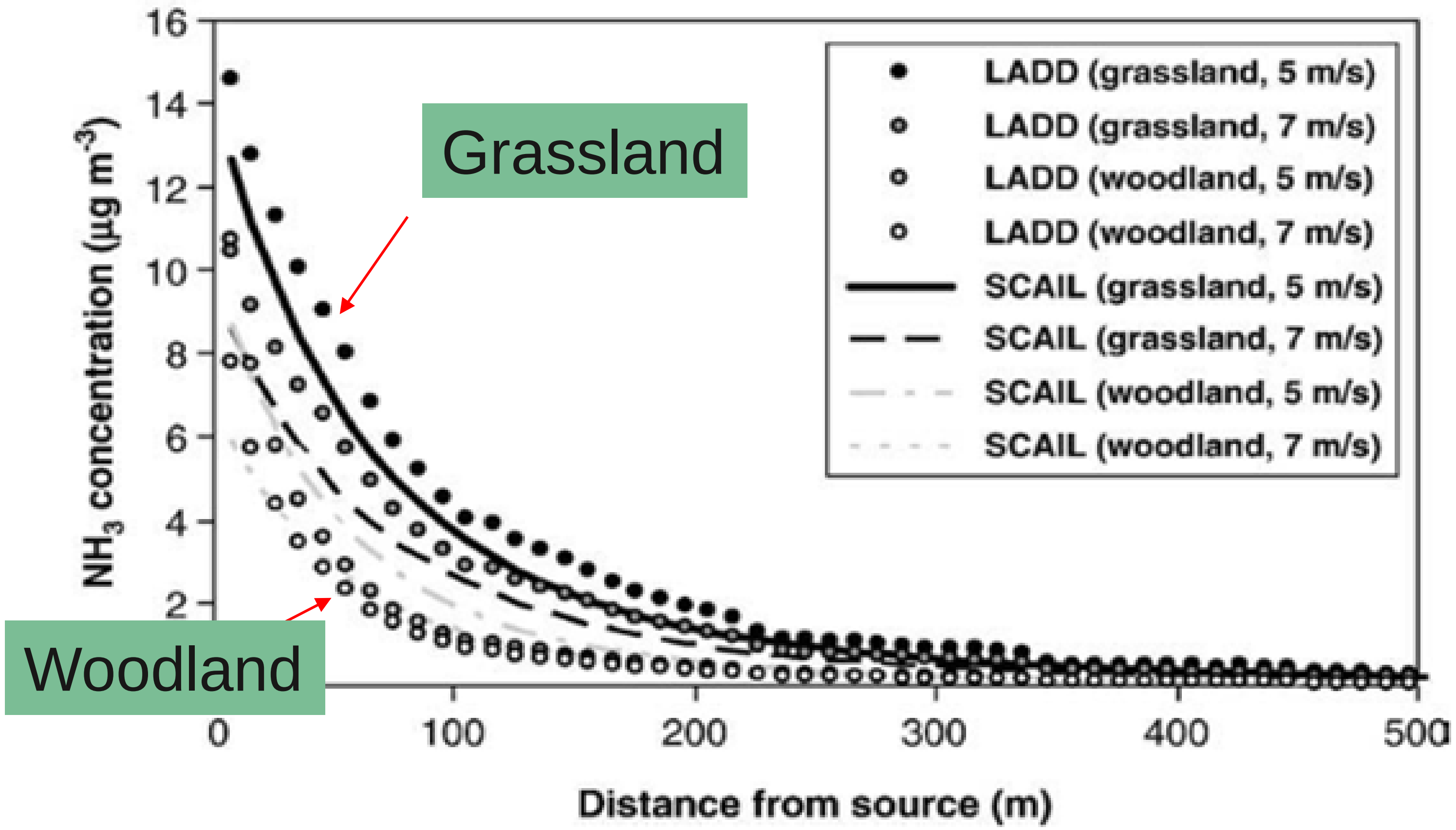


Reduced NH_3 concentrations & N deposition to nearby sensitive habitats

3. Recapture from livestock under trees ↓ ?%

https://www.farmtreestoair.ceh.ac.uk/

Ammonia: concentration gradient downwind of sources



Factors:

- Meteorology
- Landcover types

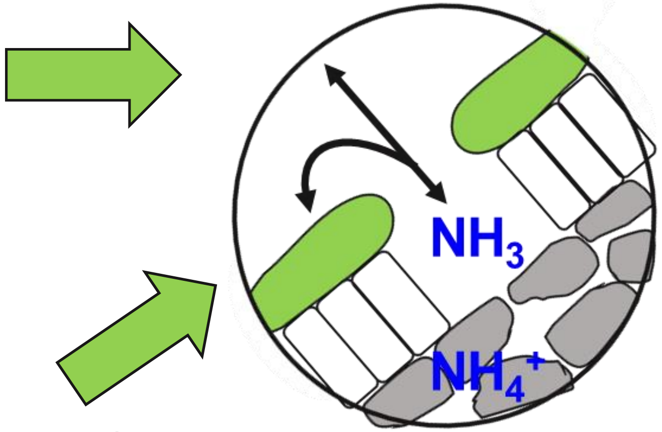
Example NH_3 concentration profiles from LADD and SCAIL models for different landcover types and wind speeds

(Theobald et al. Sci Total Env, 407(23), 6024-6033, 2009)

Ammonia Mitigation by Tree Shelterbelts

Stomatal uptake

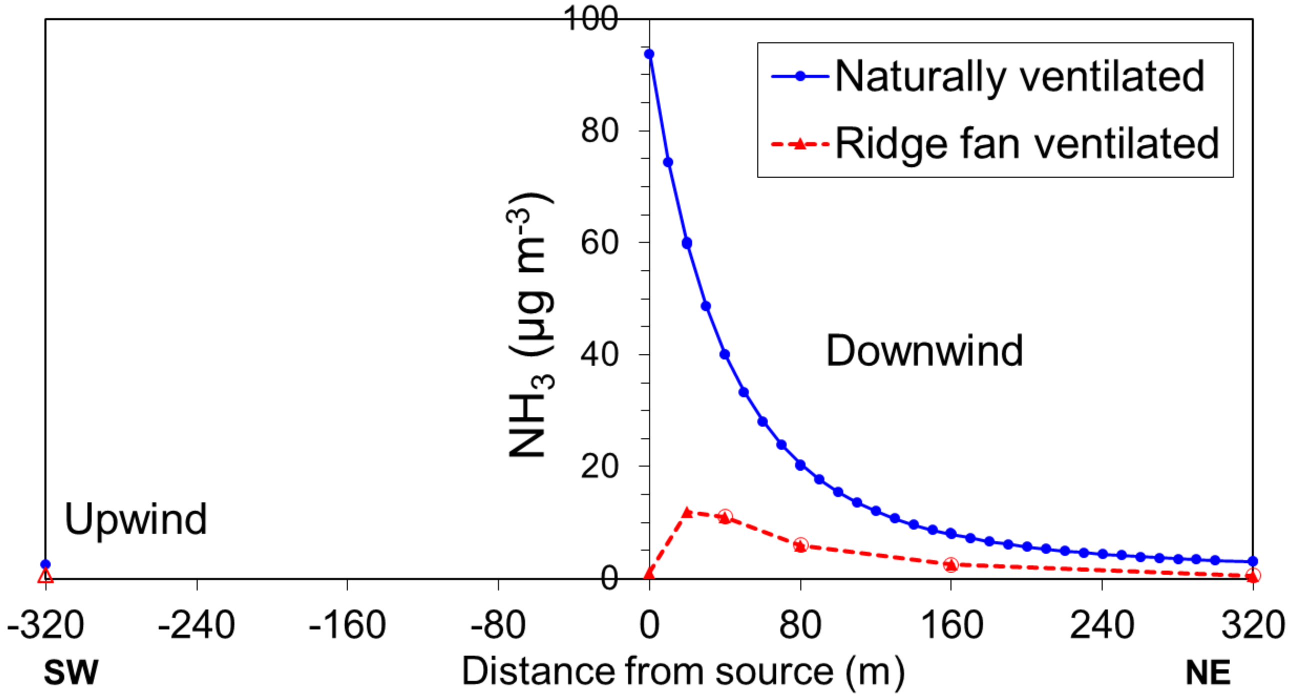
NH$_3$ enters leaves through stomata

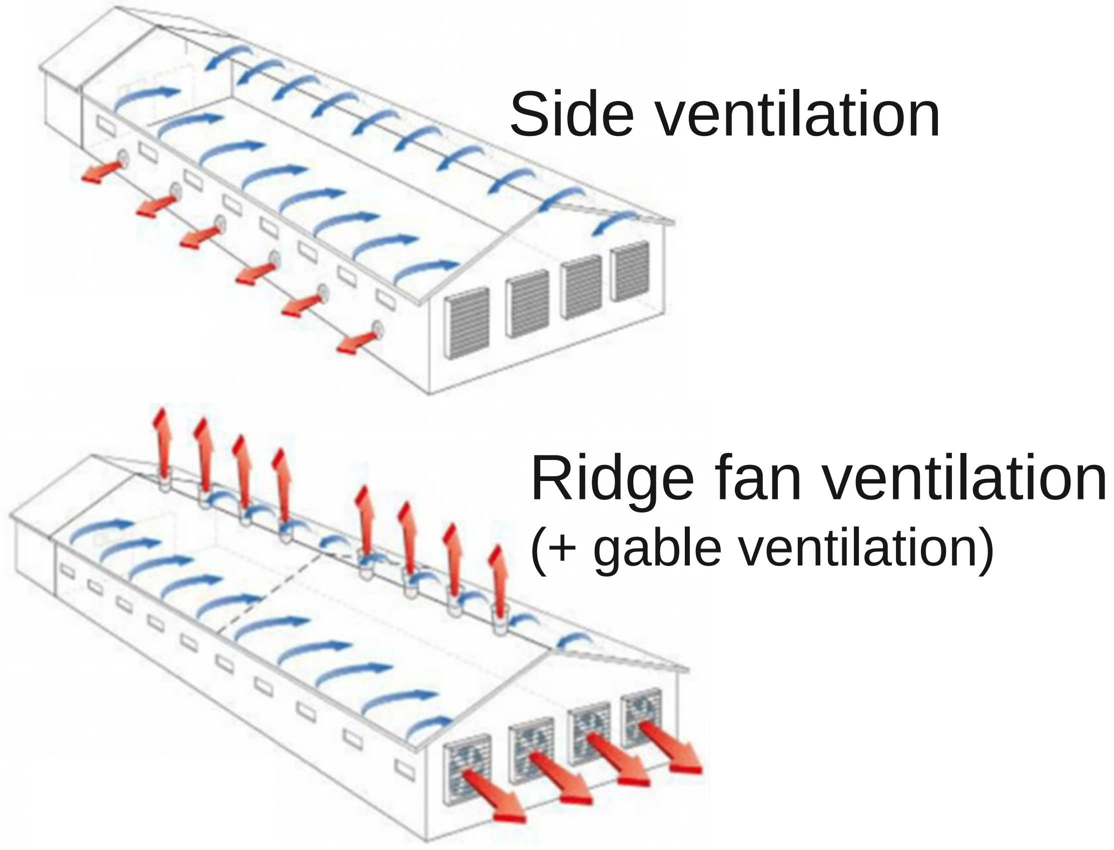


Non-stomatal uptake to leaf cuticles, stems, soil or any other material

"Surface wetness" important

Ammonia: concentration gradient downwind of sources





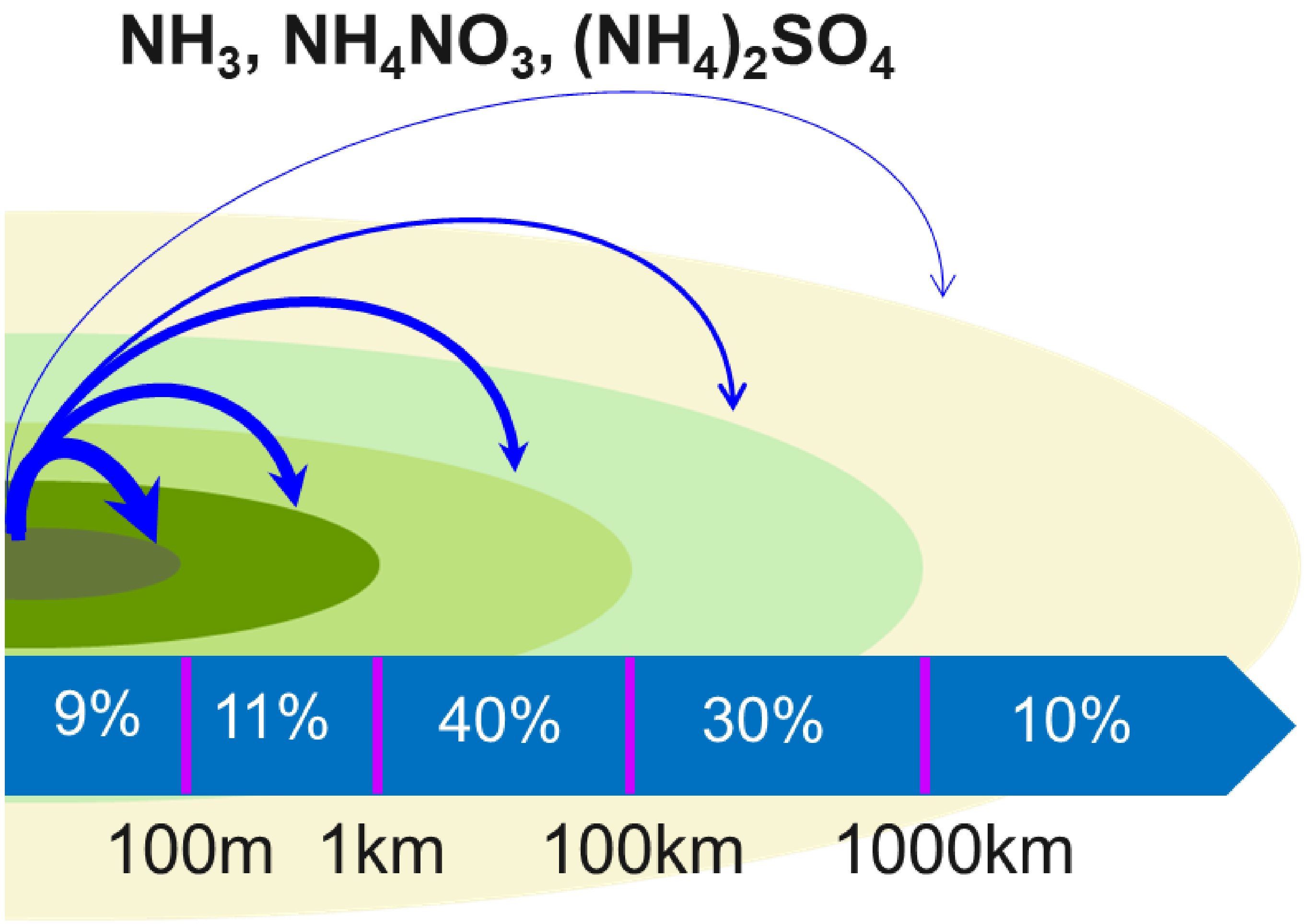
Example NH_3 concentration profiles from ADMS model for two types of ventilation on poultry housing

Tang et al. 2004. UKPIR04

Factors:

- Emission source height
- Exit velocity

Ammonia: deposition footprint



Reproduced from Hassouna and Eglin (2015)

Ammonia (NH_3) gas:

- Dry deposition
- ~ 2% - 60 % within 2 km of source

Ammonium aerosols:

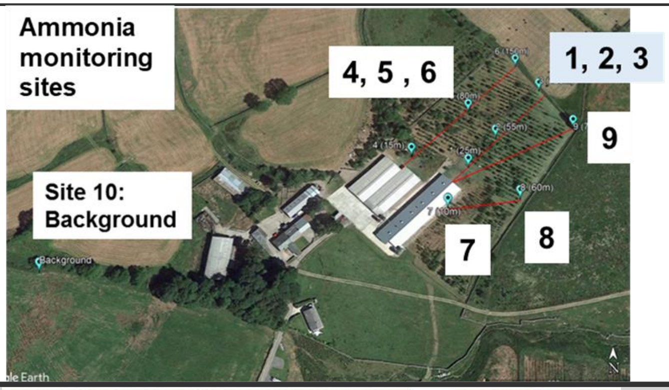
- Dry and wet deposition
- long-range transboundary pollution

5 case study farms
2-weekly ammonia measurements

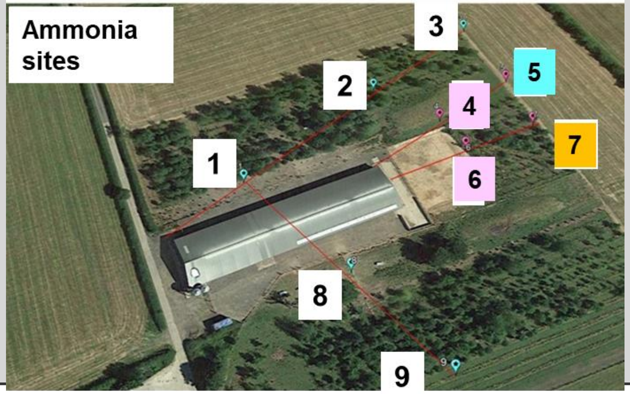
Sim Tang (yst@ceh.ac.uk)
Bill Bealey (bib@ceh.ac.uk)
UKCEH

Case study farms

Poultry 1
Tree-belt (100m)
11yrs
26k birds
(3 sheds)

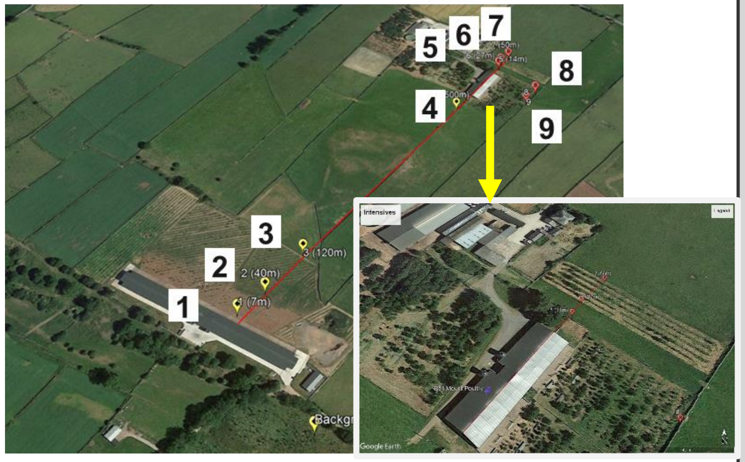


Poultry 2
Tree-belt (25 m)
11yrs
12k birds
(single shed)



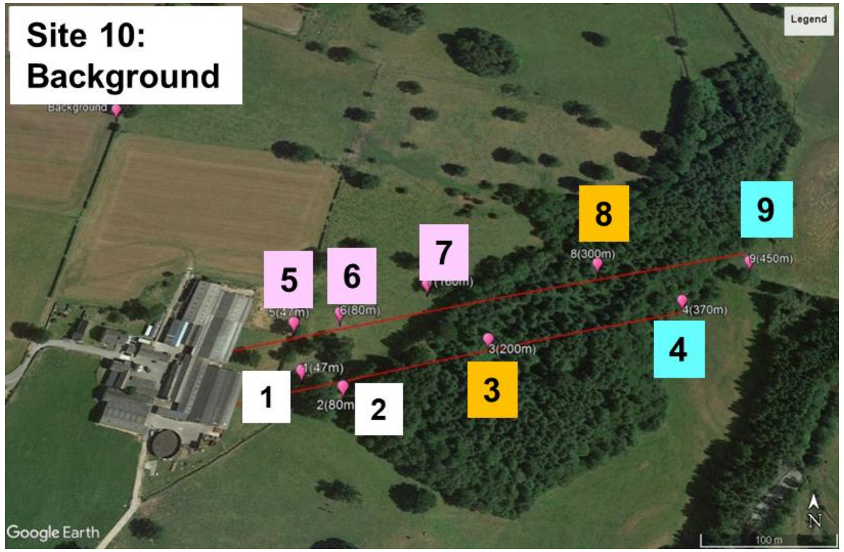
Poultry 4
Tree-belt (100m)
7yrs
32k birds

Poultry 3
Tree-belt (25 m)
12yrs
6k birds



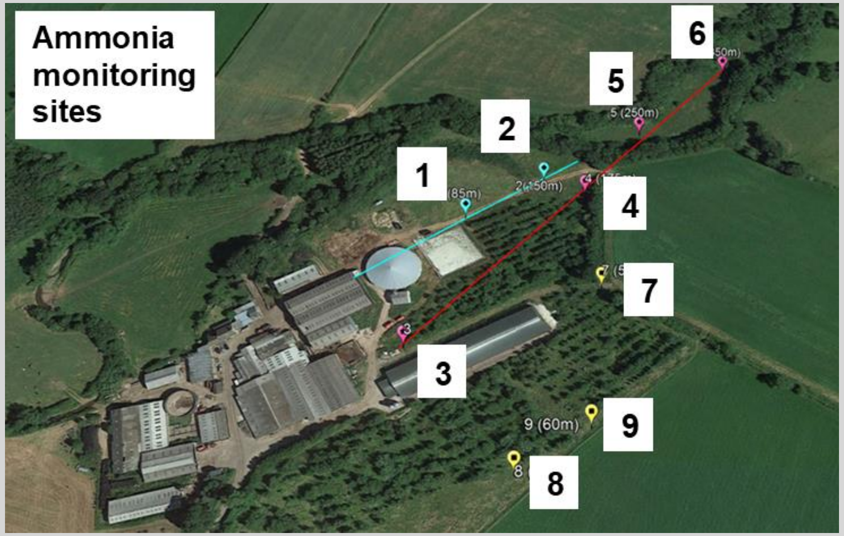
Dairy 2
Tree-belt (250m)
Replanted ancient woodland

350 dairy cows inc. followers



Dairy 1 (+poultry)
Tree-belt (~60m)
12yrs
Ancient woodland 300m NE

Mixed and complex sources



Ammonia ALPHA® Passive Samplers

UKCEH ALPHA® sampler

- Passive sampler
- 2-weekly exposure
- LOD = 0.06 µg NH_3 m^{-3}

https://www.ceh.ac.uk/services/air-samplers#alpha

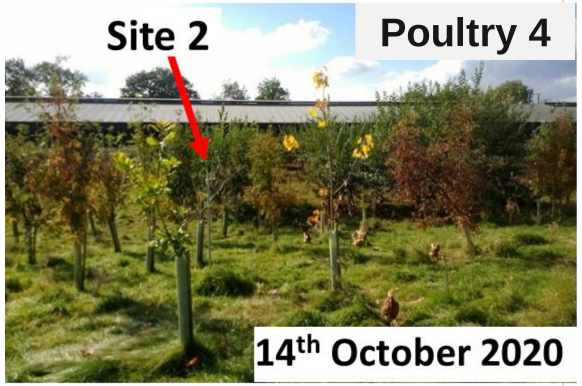
Monitoring strategy: Transects

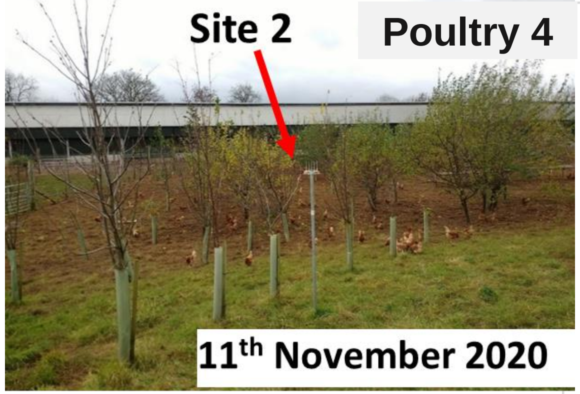
Transects downwind of source

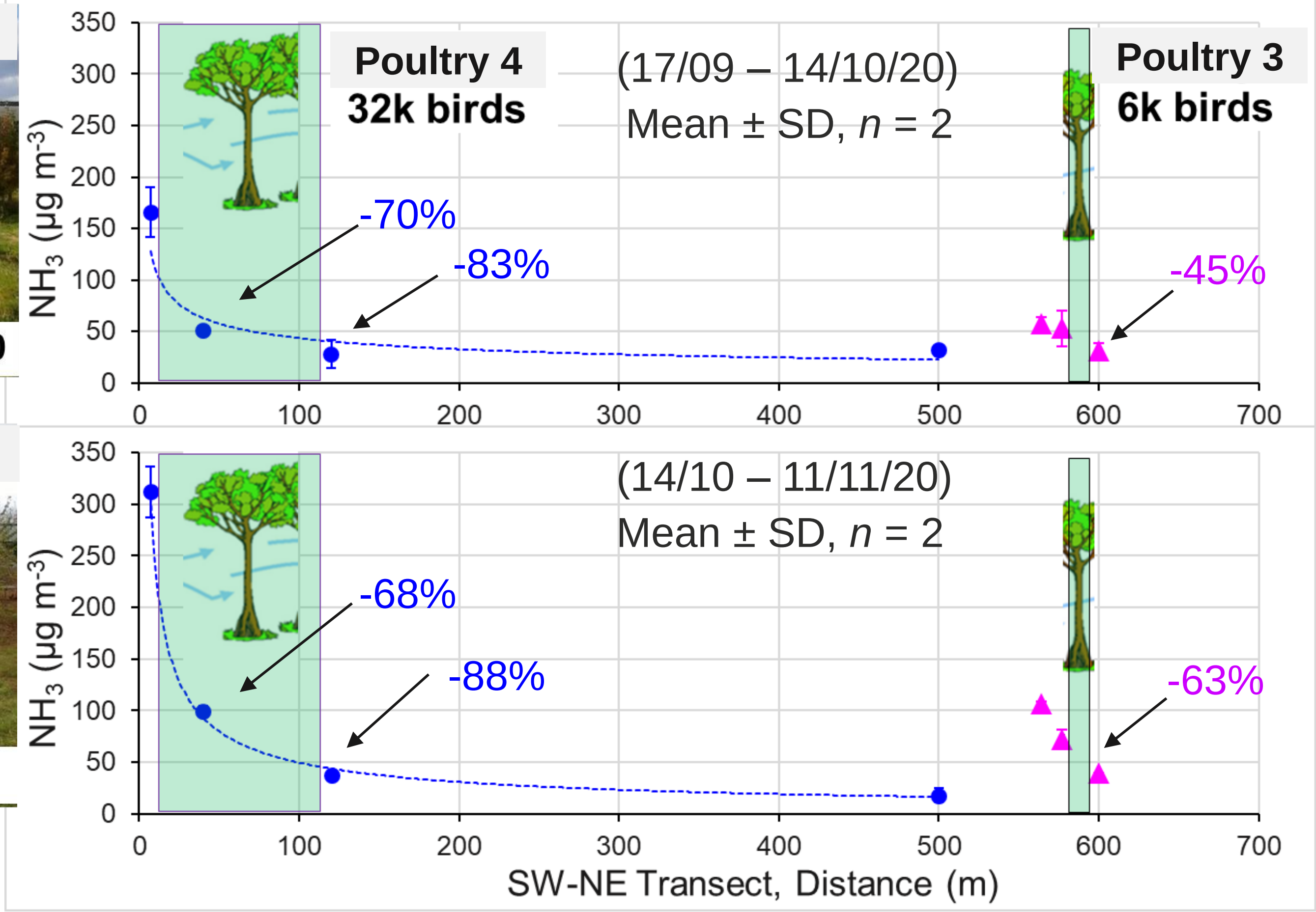
Measurement (with trees)

VS

SCAIL model (no trees)







Hypothesis

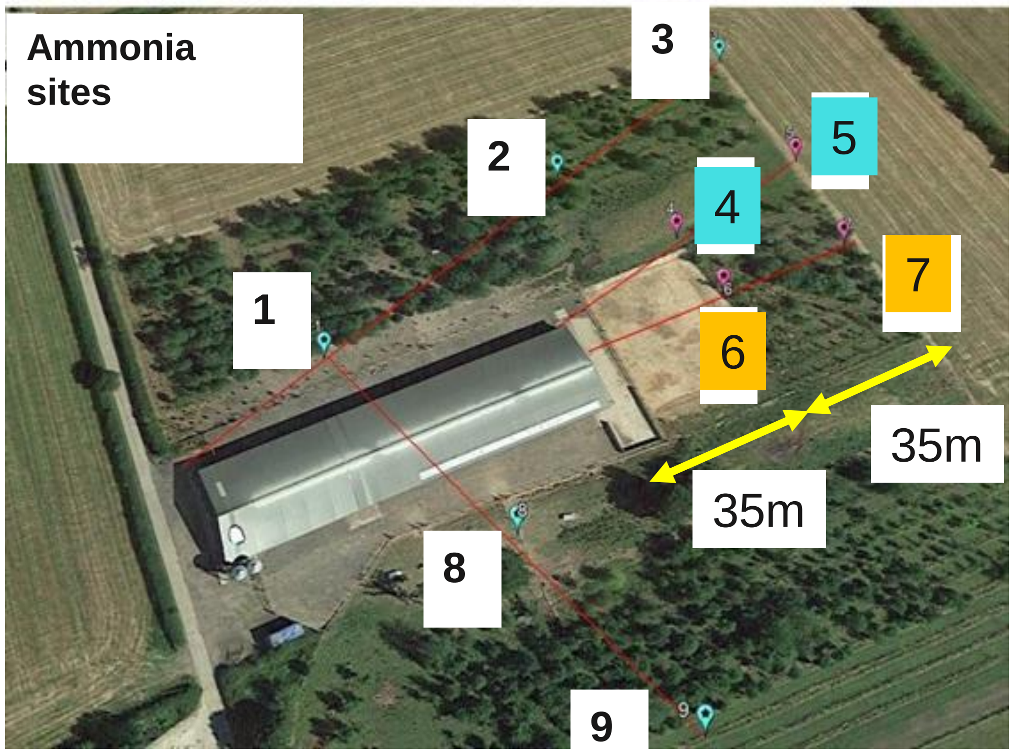
NH_3 reductions across treebelt

= larger than

Modelled (SCAIL – no trees)

Monitoring strategy: Open vs Treebelt

Poultry 2



Paired measurements:

NO TREES 4 and 5

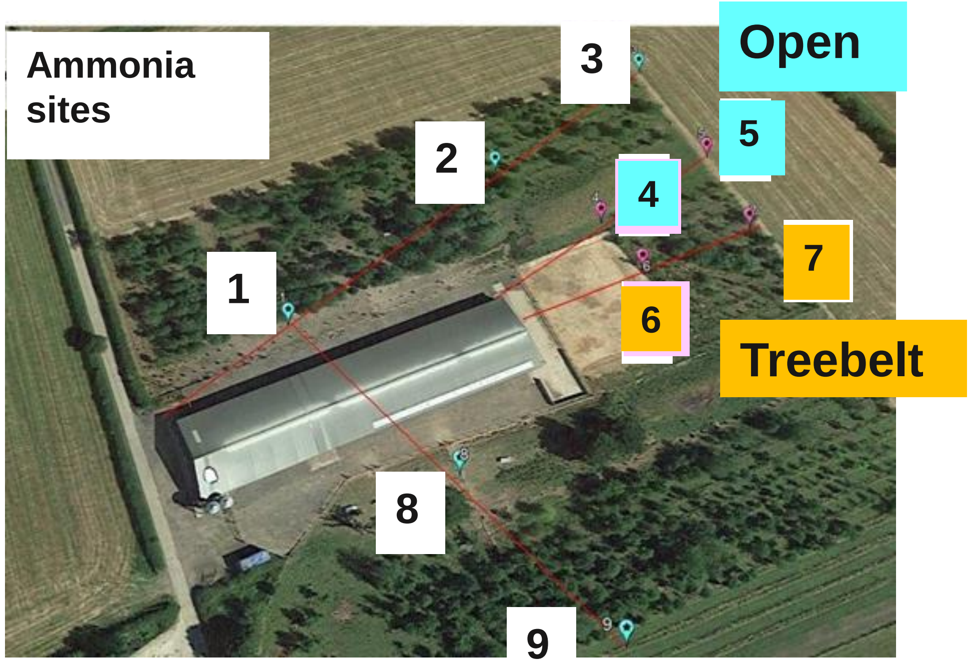
VS

WITH TREES 6 and 7

Hypothesis:

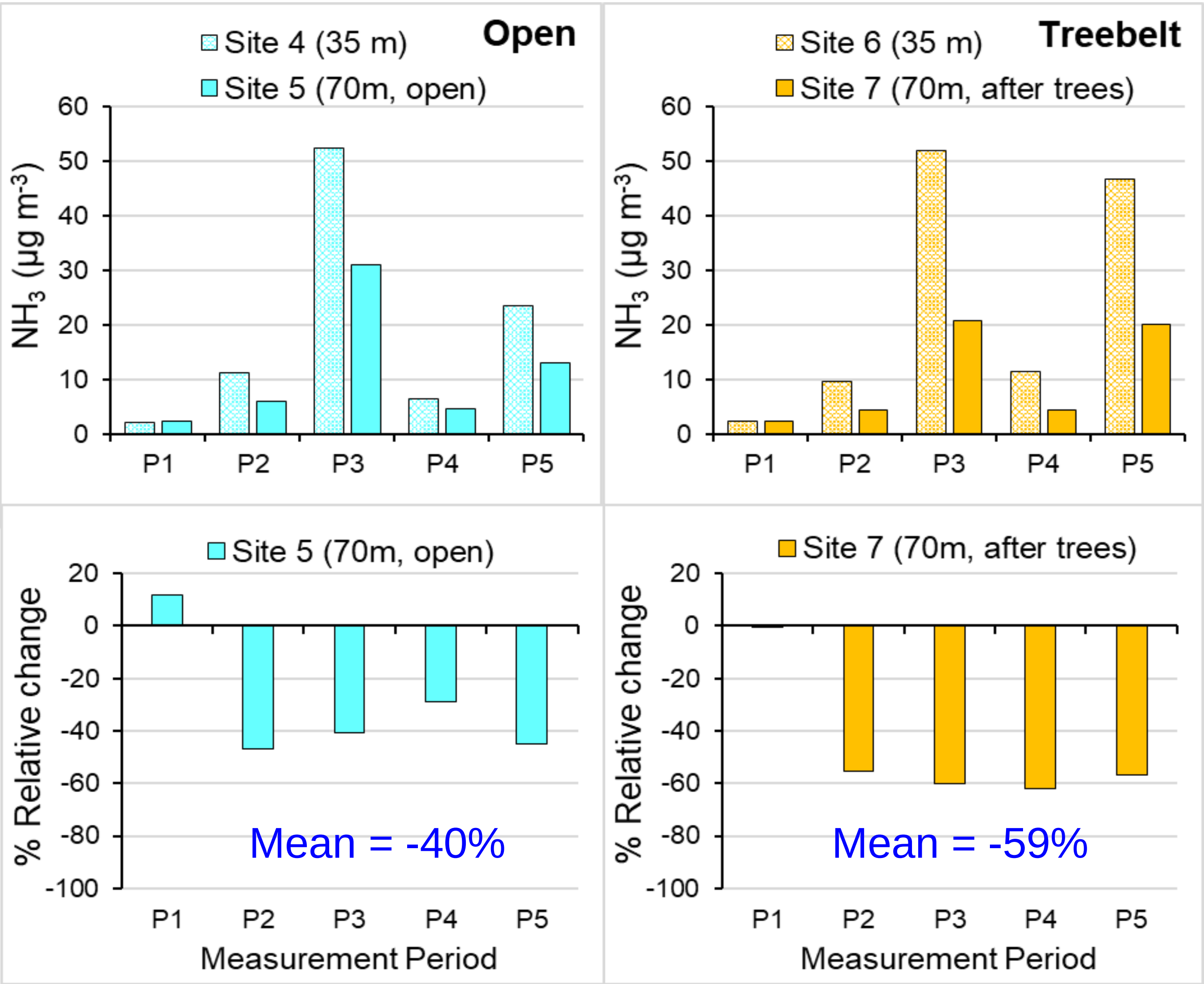
Larger reduction in NH_3 between 6 and 7

Monitoring strategy: Open vs Treebelt



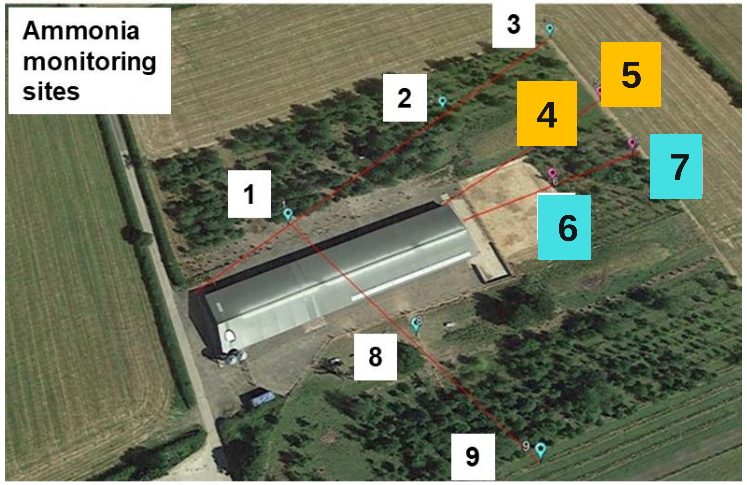
Ammonia reduction across 35 m of treebelt:
-19 % (p = 0.02)

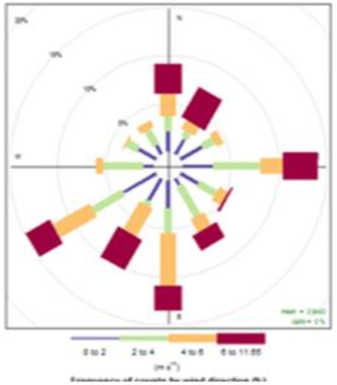
OPEN | **TREEBELT**

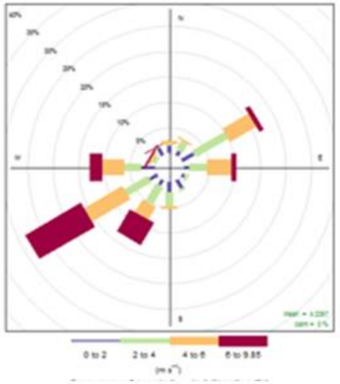


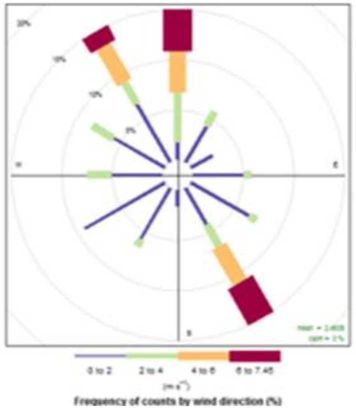
Poultry 2 – Measured vs Modelled (SCAIL)

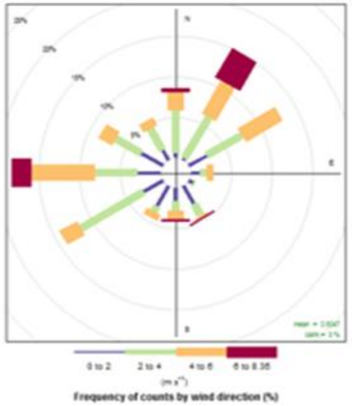
Period	Sampling Site	SCAIL µg NH_3 m^{-3}	ALPHA µgNH_3 m^{-3}	SCAIL % reduction	ALPHA % reduction	SCAIL vs ALPHA
2	4	5.50	11.14	49%	47%	Difference
2	5	2.79	5.92			-2%
2	6	5.38	9.71	46%	56%	Difference
2	7	2.91	4.32			10%
3	4	9.77	52.42	50%	41%	Difference
3	5	4.91	31.15			-9%
3	6	10.11	52.10	47%	60%	Difference
3	7	5.39	20.79			13%
4	4	16.56	6.45	46%	29%	Difference
4	5	9.02	4.60			-17%
4	6	15.88	11.43	44%	62%	Difference
4	7	8.90	4.34			18%
5	4	9.64	23.57	49%	45%	Difference
5	5	4.88	12.93			-4%
5	6	10.99	46.85	47%	57%	Difference
5	7	5.79	20.19			10%











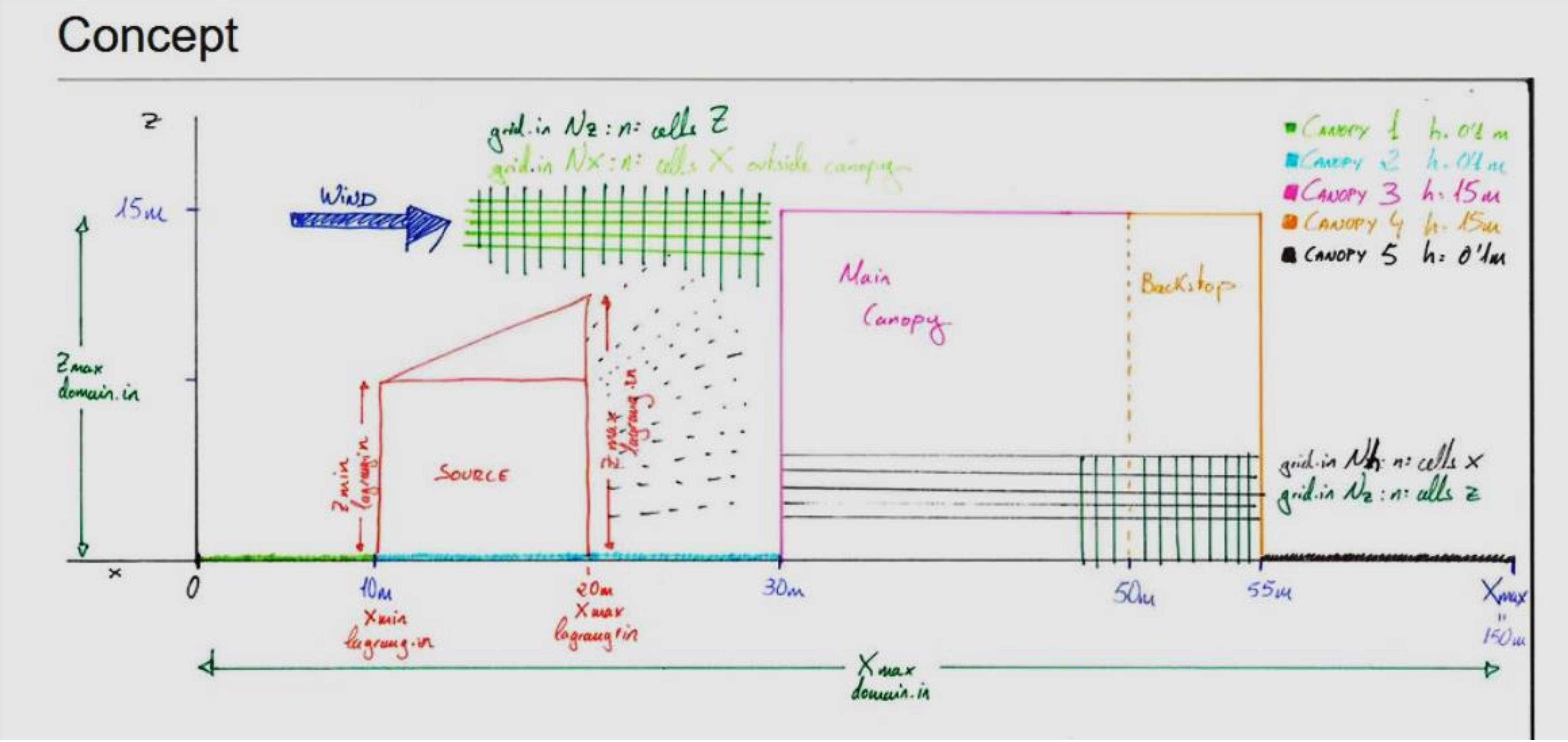
ALPHA® approach: 2-weekly measurements

Pros
Does not require power
Easy to set up: post + shelter
Locally trained person can change over samples
Ideal for transects, spatial surveys
12 x monthly measurements to provide annual mean concentrations – compare with Critical Levels of NH_3 – with models (e.g. SCAIL)

Cons
Time-integrated average concentrations: source apportionment not possible
Requires regular site visits to exchange samples
Laboratory costs can be high
Time delay between deployment and data

Question: Can concentration measurements give a quantitative measure of ammonia reduction by tree shelterbelts?

OpenFoam-MODDAS - Schema



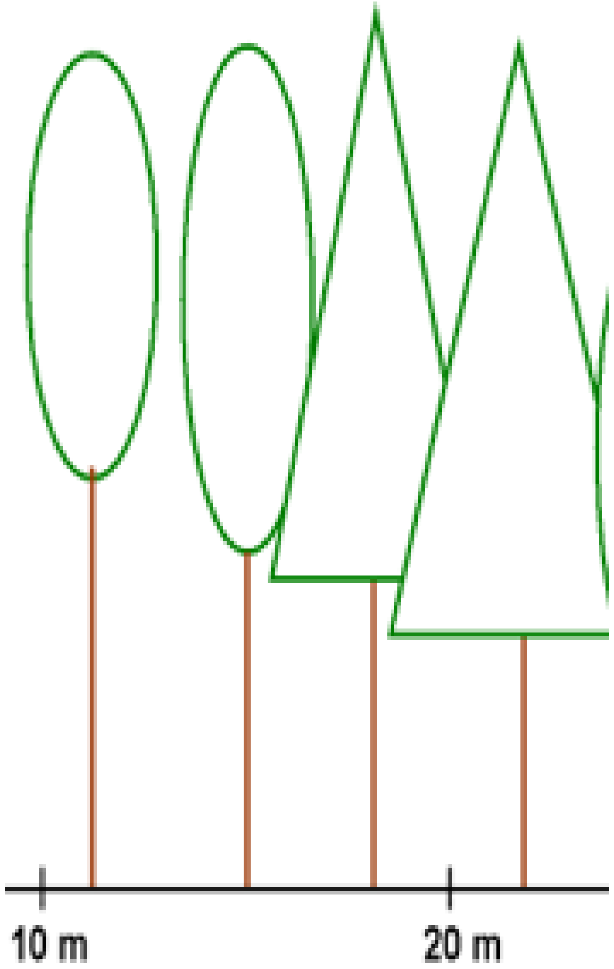
Rationale for choices – vertical shape and Leaf Area Index (LAI)

LAD - Vertical shape:

- main canopy "lollipop" type (deciduous)
- backstop canopy "Christmas tree" type (conifer)

LAI:

- tree spacing (main 2.5m) and (backstop 2m)
- LAI timeseries (advice from FR)
- increases to a max at 15yrs, min at 25yrs and increases again to 50yrs
- given this variation in LAI chose years (5, 15, 25 and 50)
- tested seasonal versus annual average LAI for deciduous trees



Rationale for choices – season/time variation

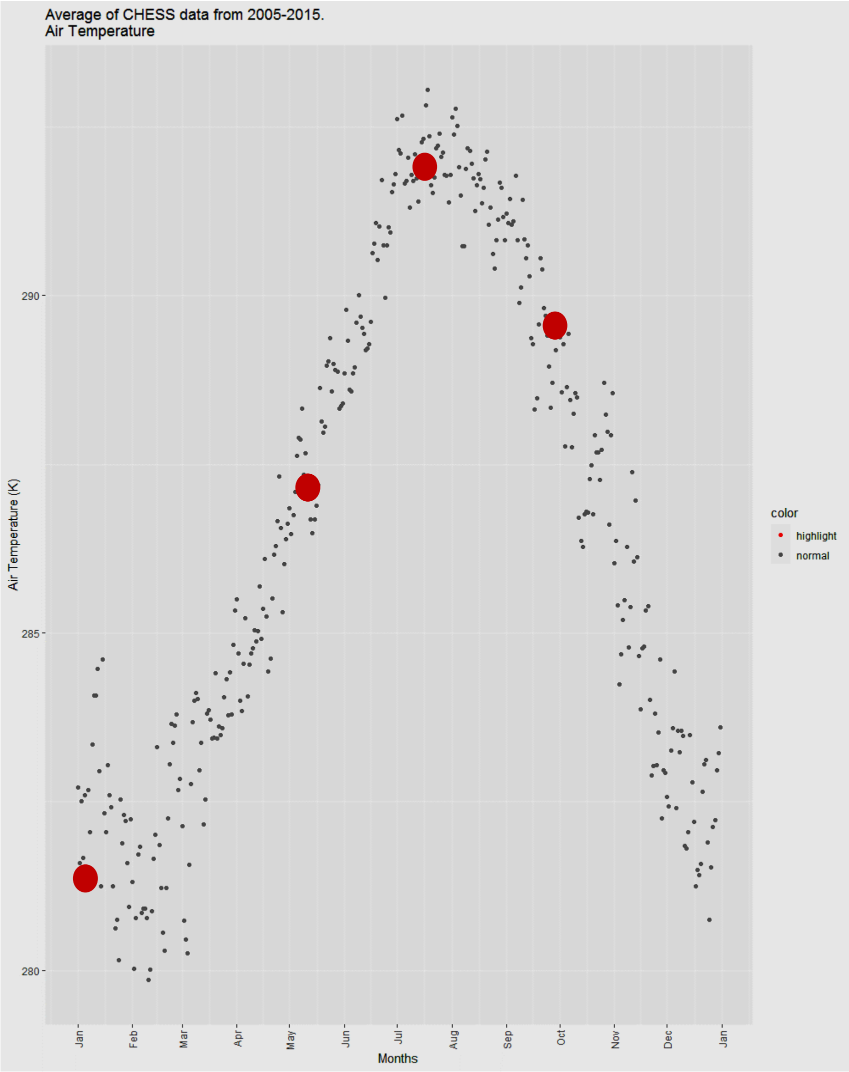
Seasonal cycle:

- 4 time-points in the year to represent the seasonal cycle.
- 16th Jan, 11th May 14th July and 30th Sep

Diurnal variation:

- two time points (day, night)
- air temperature: daily min/max
- relative humidity: calc depends on temp.
- solar radiation: imposed a cycle from position of the sun at the time of day (3am, 3pm)

Air Temperature



MODDAS Inputs/Outputs

INPUT DATA	Poultry 1 (Fans)	Poultry 1	Dairy 2	Poultry 2	Dairy 1 Dairy	Dairy 1 Poultry	Poultry 3	Poultry 4
Emission Strength (NH_3 tonnes per year)	3480	4060	7774	3480	10366	4640	1740	9280
Height of shed (m)	5	3.6	4	3.6	4	3.6	3.6	3.6
Length of shed (m)	80	50	50	80	45	100	65	20
Area of Shed (m^2)	1630	1800	5836	1772	1350	2000	1270	4400
Distance from shed to main canopy (metres)	25	15	36	35	40	7	26	45
Main canopy depth (m)	100	137	330	33	170	36	23	65
Main Canopy Height (m)	5.04	5.04	16.1	5.66	6.11	6.11	5.36	2.57
Main Canopy LAI (From FR - excpt. Dairy1)	0.79	0.79	3.10	0.45	0.83	0.83	0.95	0.06
Backstop (m) NO BACKSTOP => single main canopy	0	0	0	0	0	0	0	0
RESULTS								
TOTAL Recapture	**-1.0**	**-1.6**	**-80.6**	**-1.3**	**-4.2**	**-2.8**	**-1.7**	**-0.1**

Uncertainty Analysis

- Ran MODDAS 100 times per sample and took average to ensure variation due to parameters
- 100,000 runs in all
- Range of % recapture from 1000 sample 63%

Question: How can we improve uncertainty, especially through improved LAI by age of treebelt & by species

Title	Min	Mode	Max
Minimum Plant Cuticular Resistance s m^{-1}	0	10	230
Response Coefficient Cuticular Resistance to RH	1	7	35
Minimum Stomatal Resistance s m^{-1}	1	60	100
Response Coefficient Stomatal Aperture to PAR	1	7	35
Plant Emission Potential – Main $H^+/NH4^+$	3	1000	7000
Plant Emission Potential - Backstop $H^+/NH4^+$	3	20000	40000
Soil Emission Potential	20	13000	7000000

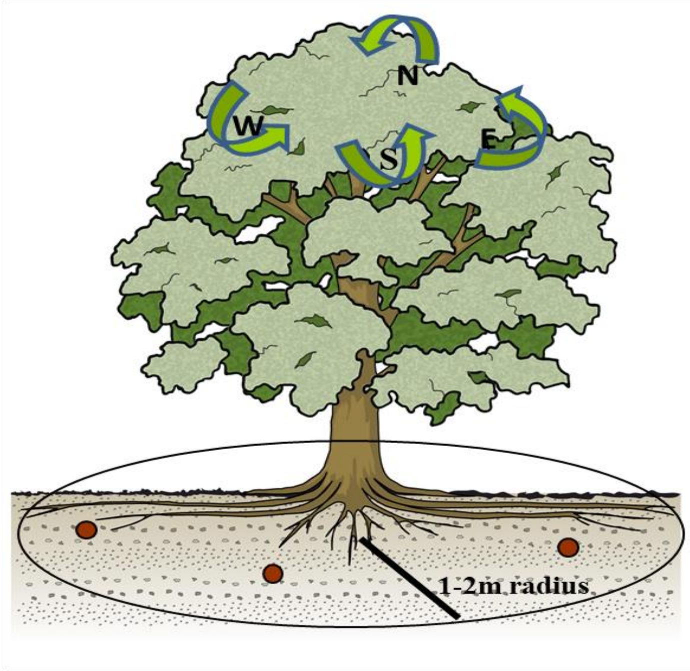
Ecosystem measurements: Assessing effects of NH_3 on trees

Elena Vanguelova
(Elena.vanguelova@forestresearch.gov.uk)
Forest Research

- **Tree parameters**: Girth, height, LAI, foliar nitrogen and chemistry, leaf area (**FR**)
- **Lichen Survey (King's College, London)**
- **Leaf Area Index (LAI) was calculated by using:**
- Measured Tree **S**pecific **L**eaf **A**rea (SLA) (m2/kg)
- Modelled tree canopy biomass (kg) using measured diameter(cm) and height (m) allometric relationships
- Tree density at farms (tree per ha)

Leaf Area Index (LAI)= SLA x canopy biomass x tree density

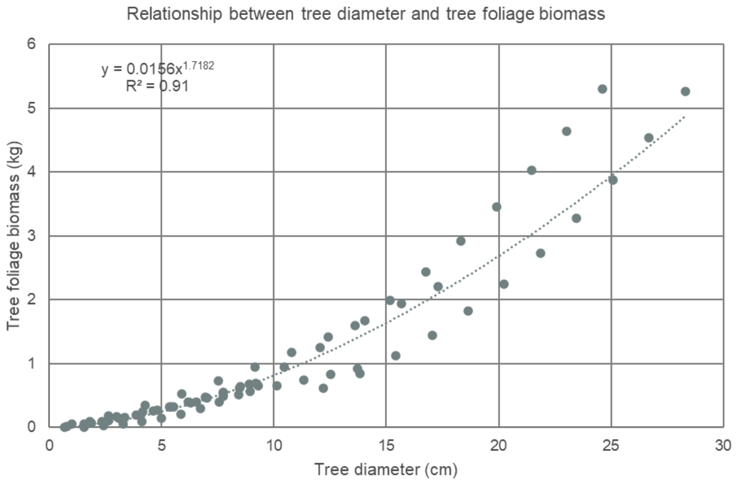
Foliar sampling cardinal direction facing the farms



Soil and root sampling – 3 points per tree

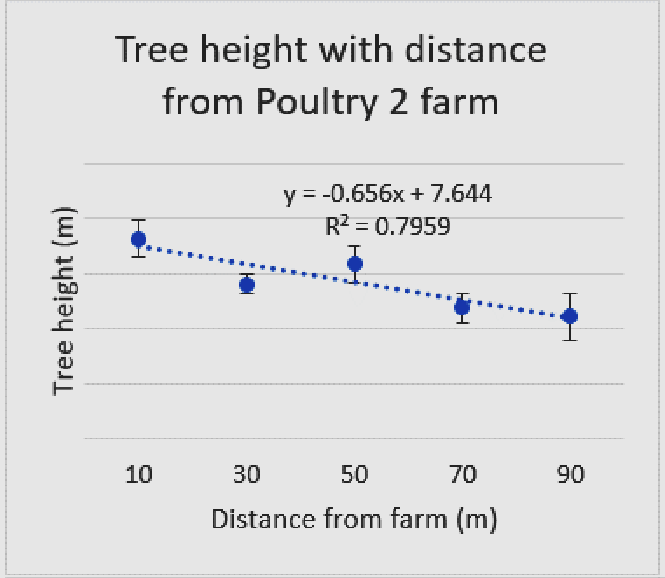
- **Canopy N uptake was calculated by using:**
- Measured Foliar N concentration
- Modelled canopy biomass (kg)
- Tree density at farms (trees per ha)

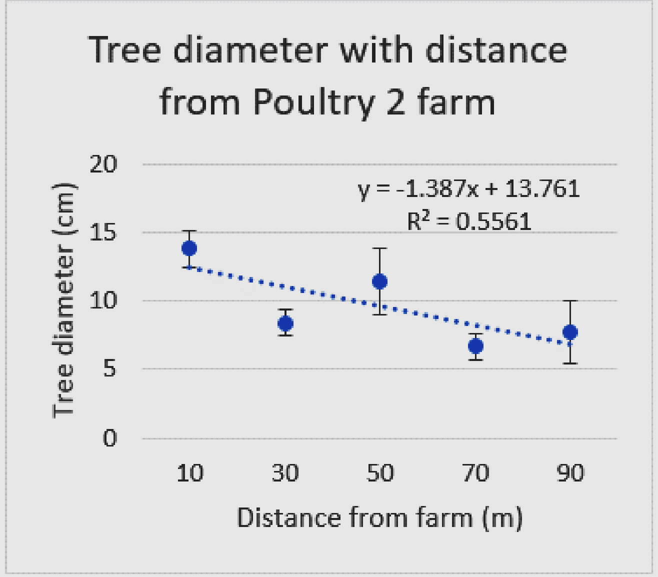
Canopy N uptake = measured foliar N% x canopy biomass x tree density

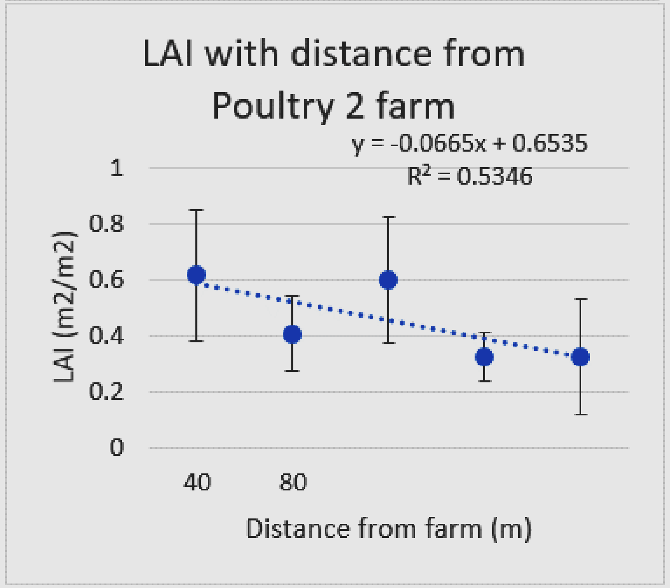


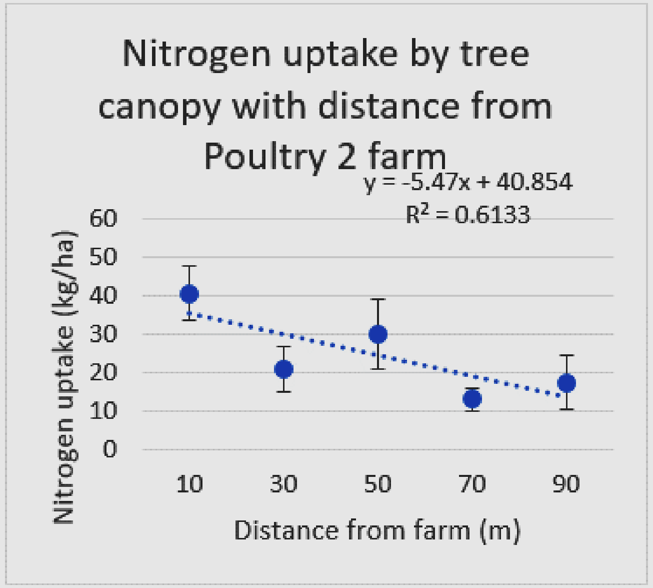
Diameter/canopy biomass allometric relationships were used to model canopy biomass as more accurate than tree height for younger trees (Zianis et al., 2005)

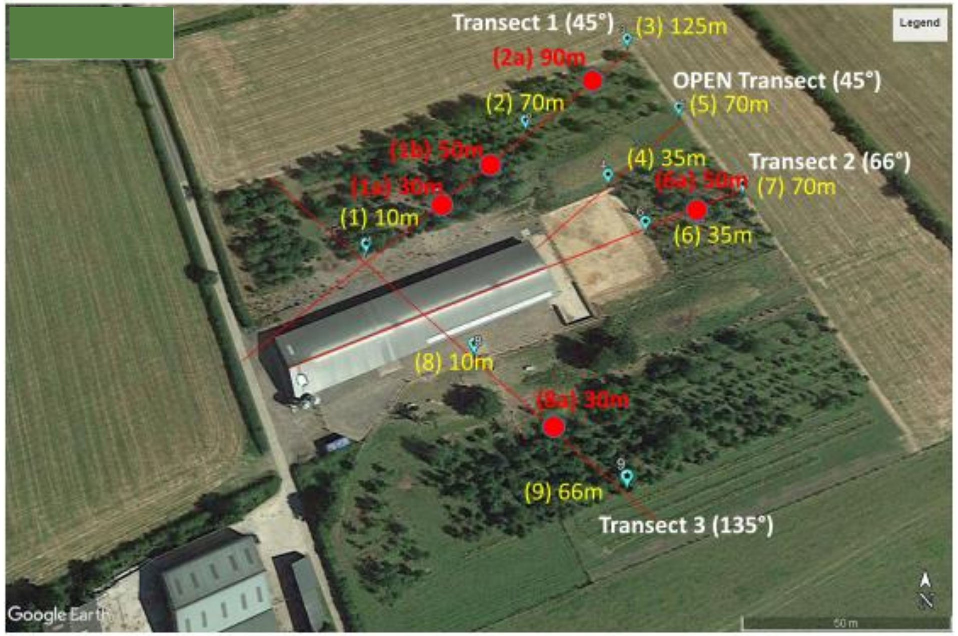
Poultry 2 - Ecology





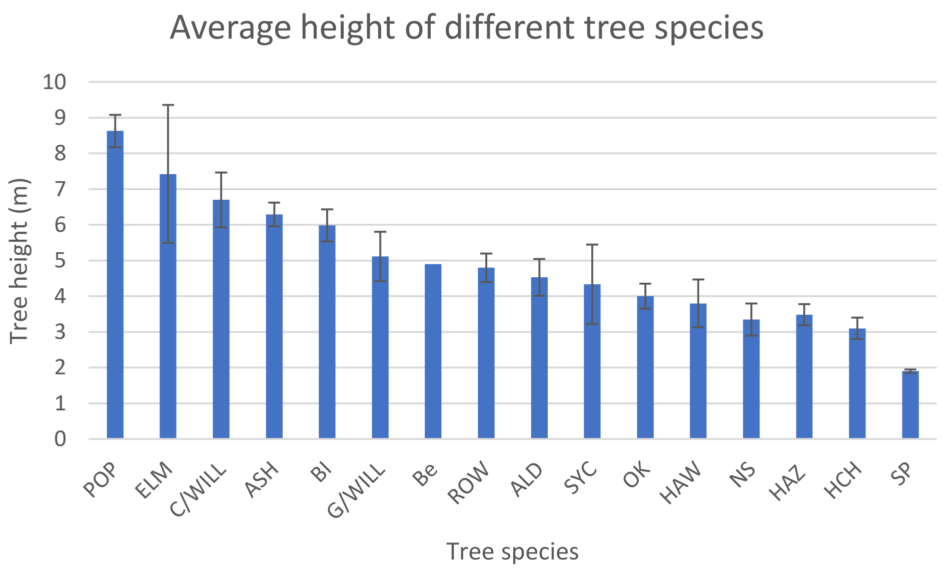


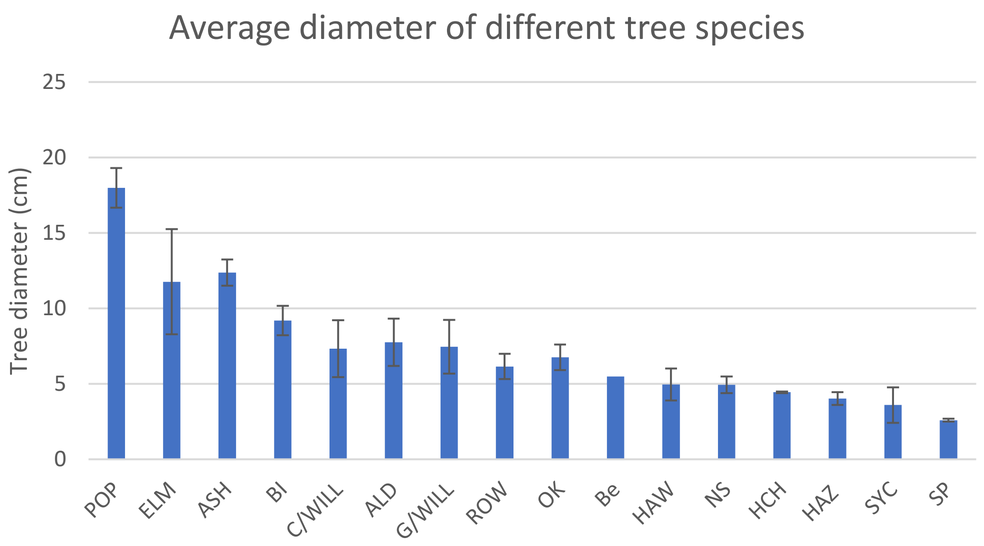


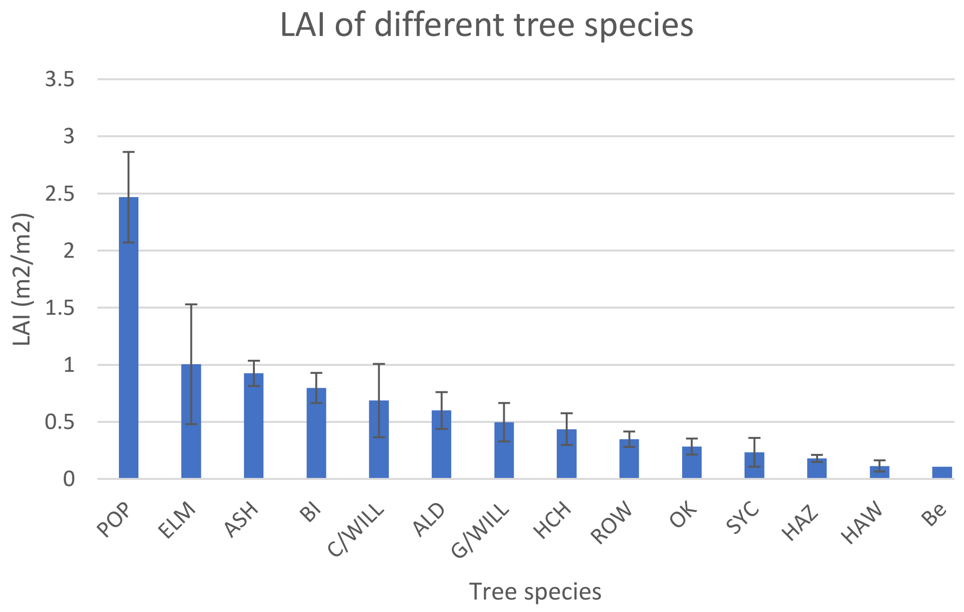


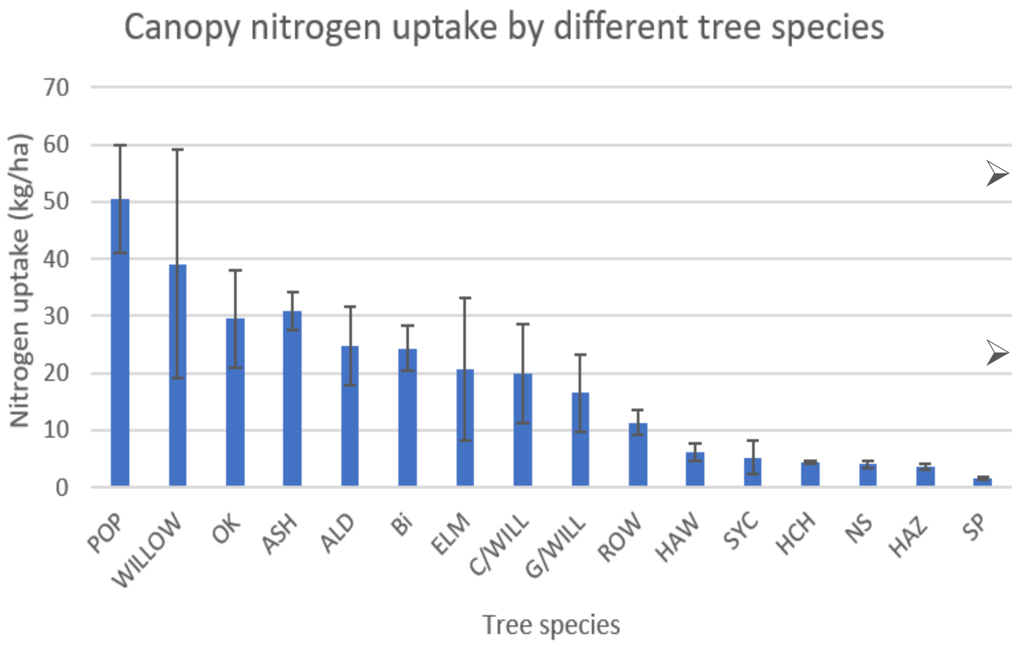
- Tree height, diameter, LAI (Leaf Area Index) and canopy nitrogen uptake all decrease linearly with distance away from farm.
- Clear evidence of higher tree growth and carbon and double N capture by trees near the farms than further away.
- **LAI is key for canopy N uptake calculations and NH_3 reduction models/tools. Need better tree allometric relationships, e.g. Age, time and tree species specific to reduce LAI and tree N uptake uncertainties.**
- **Next step to measure N capture/storage by soils along the transects.**

Across all farms – variation in tree species parameters









- Tree canopy uptake of nitrogen ranged between 1.5 to 50 kg N/ha
- Poplar, Willow, Oak, Ash, Alder, Birch and Elm canopy N uptake 20-50 kg N/ha
- Other tree species N uptake <20 kg N/ha
- Tree species choice for shelterbelts is important

Dairy 1 – Lichen Survey (Allan Pentecost, King's College London)

Xanthoria parietina from a birch branch - the most abundant and conspicuous N-tolerant species. Partially overgrown by a coccoid green alga, *Apatococcus*.

Physcia tenella. A small grey foliose N-tolerant species that is often associated with the yellow *Xanthorias*,

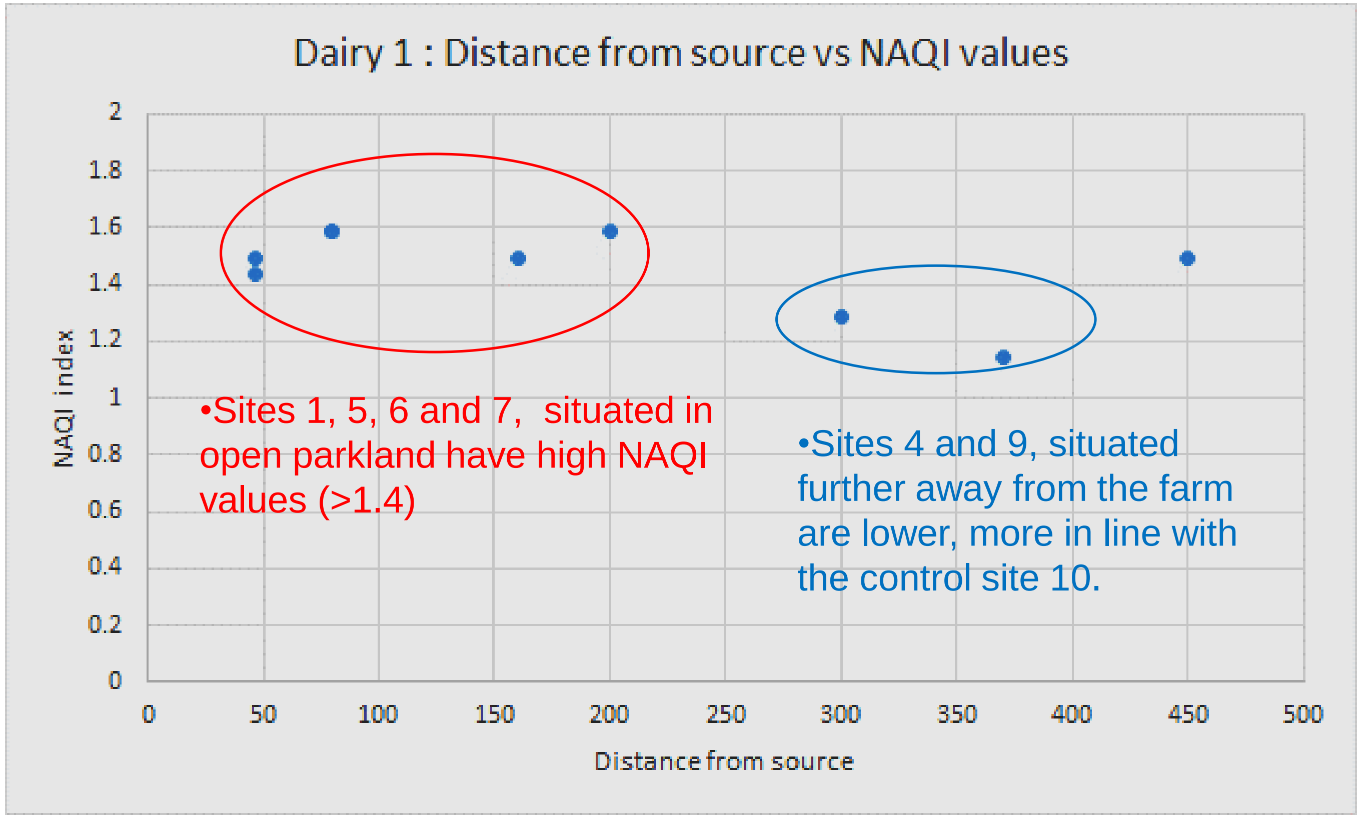
Dairy 1 – Lichen Survey (Allan Pentecost, King's College London)

NAQI (Nitrogen Air Quality Index)
NAQI 0 - 0.5, clean
NAQI > 0.5-0.85, at N risks
NAQI 0.86-1.25, N polluted
NAQI > 1.25, very N polluted

LIS (Lichen Indicator Scores)
On Oak and birch, but also on alder, larch, sycamore

NAQI – 1.14-1.59 N polluted to very N polluted

LIS – mostly N tolerant species



Sites 2, 3 and 8 situated adjacent to, or within woodland are more varied.

Findings across all farms

- ➢ Clear evidence that tree growth (diameter, height, LAI) is significantly higher nearer the farms and decline with distance away, likely due to the influence of ammonia concentrations.

- ➢ Tree uptake of nitrogen is up to double nearer the farms where ammonia emissions are higher compared to further away from the farms. Evidence for tree ammonia mitigation.

- ➢ Young age, fast growing tree species (with higher LAI) such as Poplar, Willow, Birch and Ash can take up significantly higher (at least double) amounts of nitrogen compared to slow growing tree species such as rowan, hazel, sycamore.

- Ø Tree height is a less variable measurement of tree growth compared to tree diameter at a young stage of tree growth. Thus, tree diameter is more representative parameter to be used in developing allometric relationships for models.

- ➢ Despite being young the tree shelterbelts show a clear potential for both nitrogen mitigation and higher carbon sequestration. Likely impacts of ammonia on lichens flora has been found.

Questions for further studies:

- **How aboveground N compares to belowground N capture, storage and cycling by different trees and soils?**

- **What is the influence of N on carbon capture above and belowground?**

- **What is the influence of N input on soil biodiversity, nitrogen leaching and soil GHG?**

Poultry 3 farm

Intensive measurements

Christine Braban (chri2@ceh.a.uk)
UKCEH

Intensive measurements at Poultry 3 farm

- Continuous real-time NH_3 ,CO_2, CH_4 and PM
- On-site meteorology
- Estimation of NH_3 reduction across tree belt

High time resolution measurements of NH_3

- Visual interpretation of plumes and source apportionment
- Back-trajectory emissions modelling

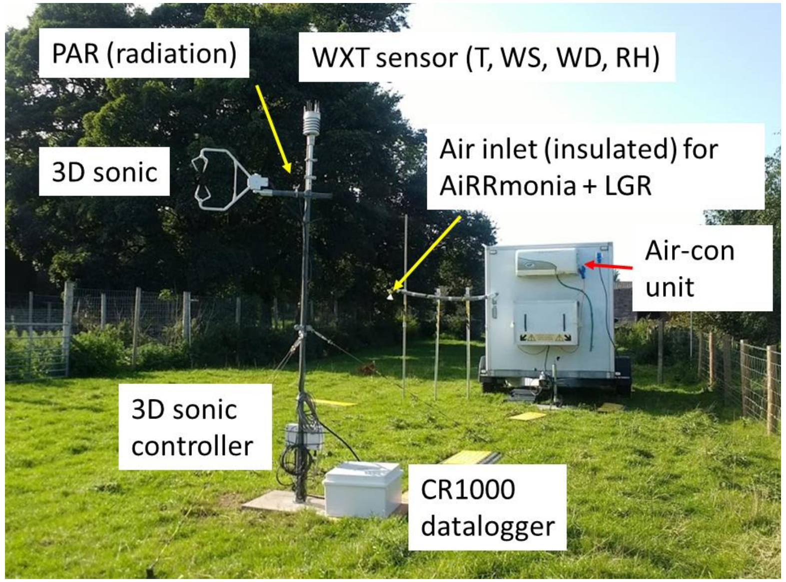
High resolution measurements of CH_4 and CO_2

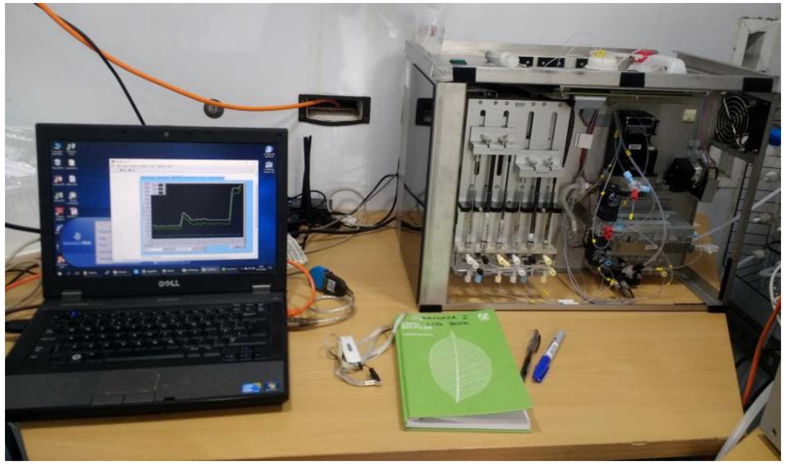
- Methane and carbon dioxide both air pollutants emitted from agriculture
- Tracer does not interact strongly with the surfaces of the landscape (trees/soild/grass)
- Depletion of NH3 relative to CH4/CO2 may be used to estimate capture by trees
- Science question will be at this very local scale can concentration measurements give quantitative identification of both the ammonia and greenhouse gas sources above background

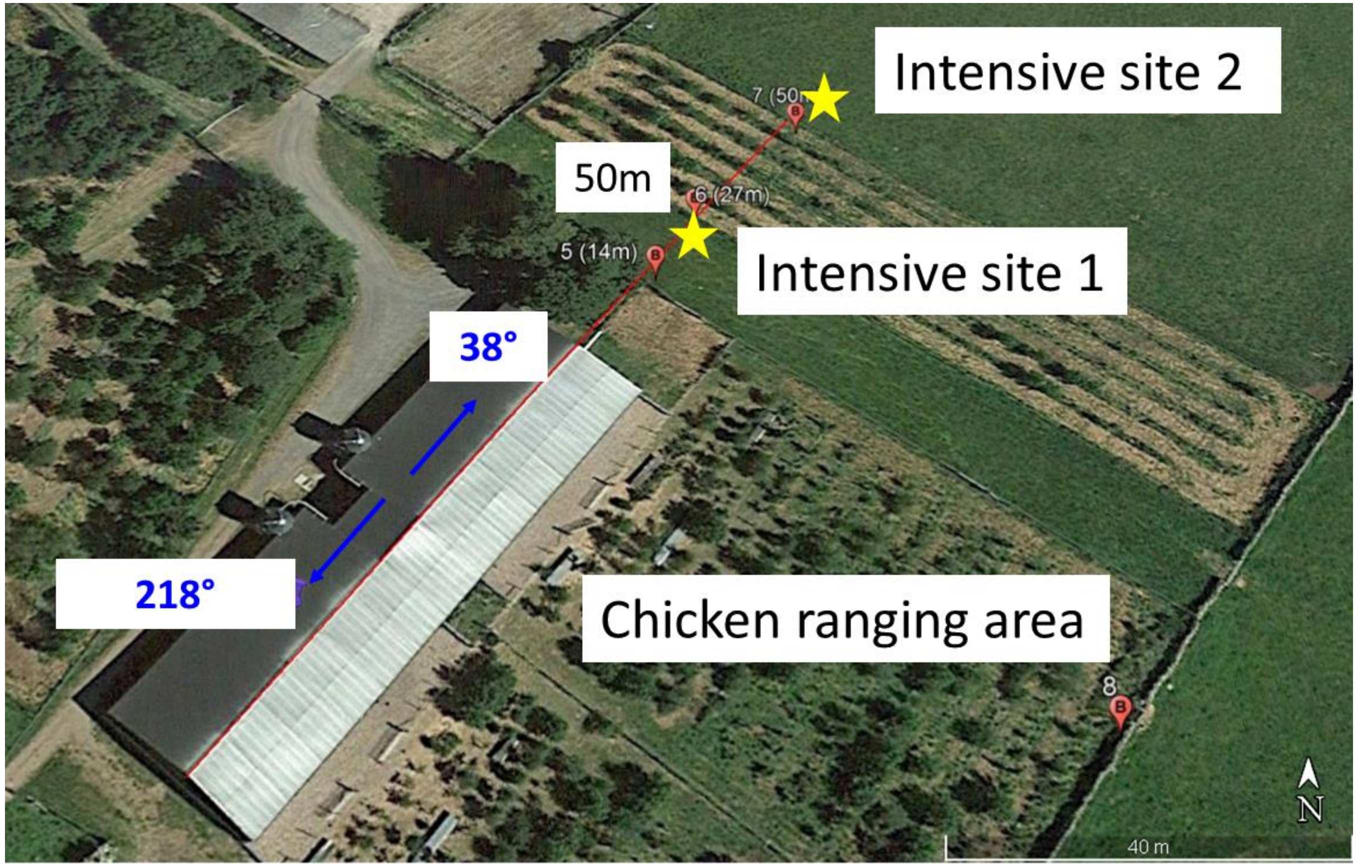
High time resolution measurements of PM

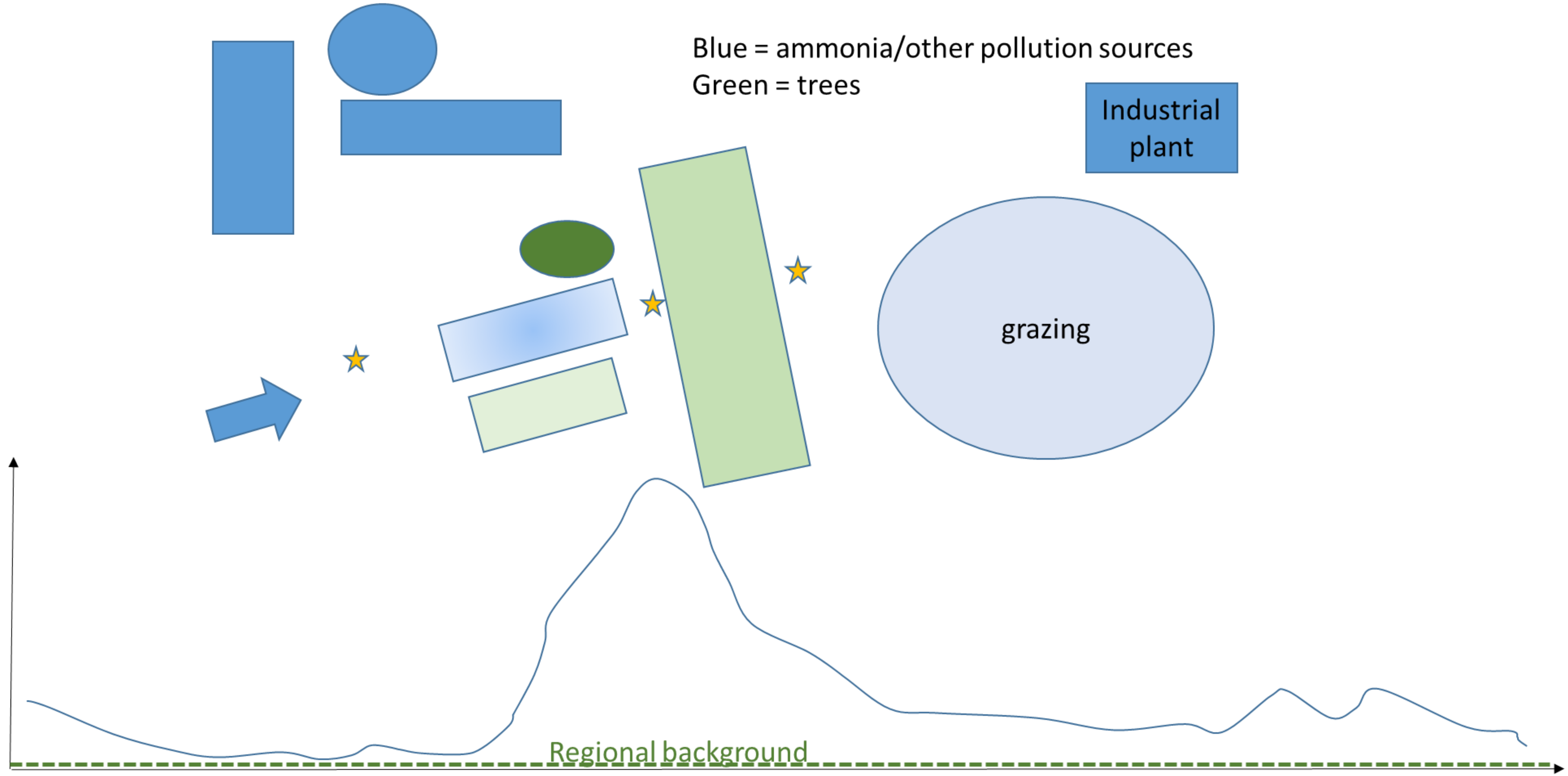
- Visual interpretation of plumes and source apportionment
- Co-emissions and combining with other air pollution source research

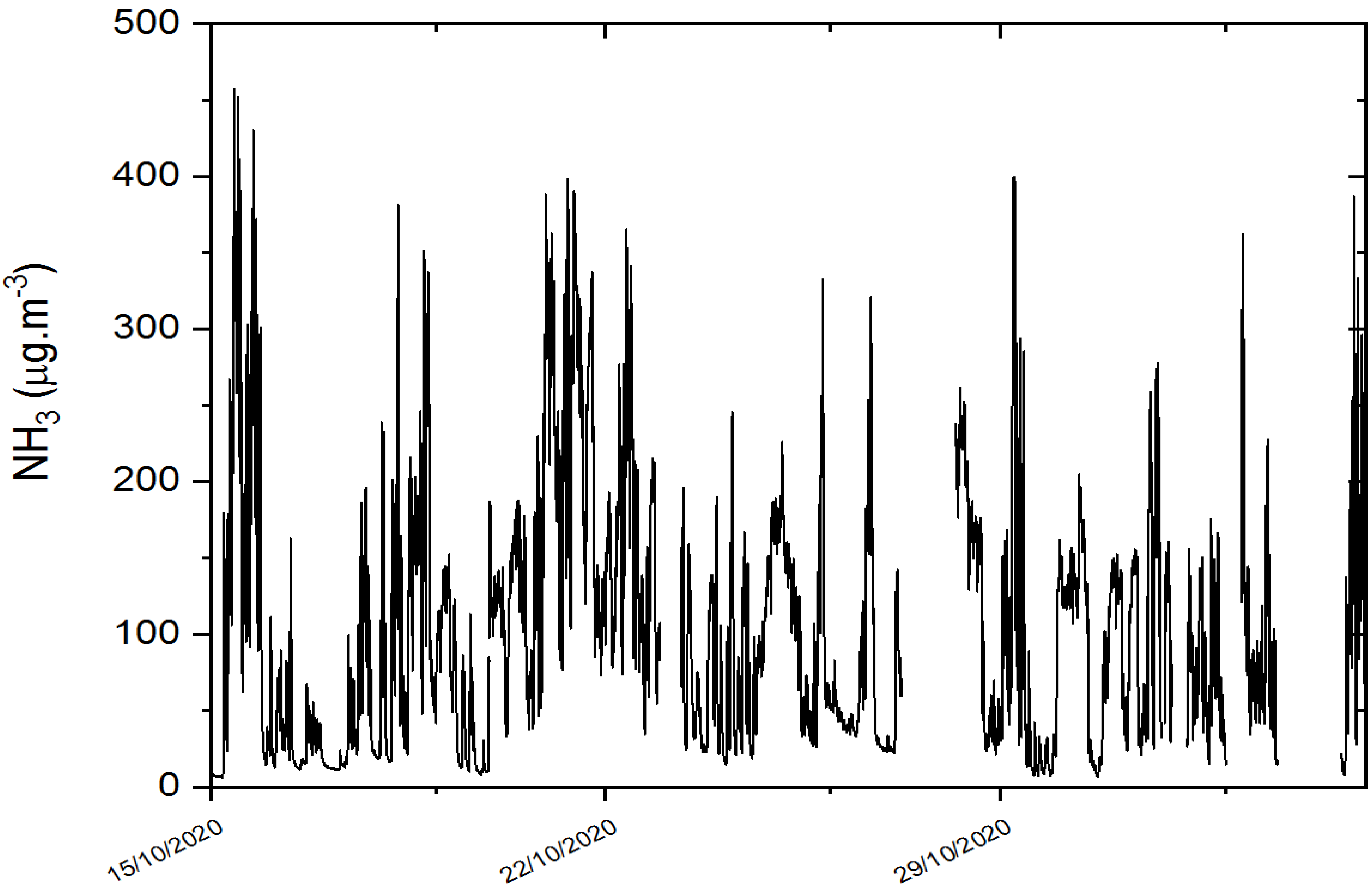
Intensive Campaign at Poultry 3







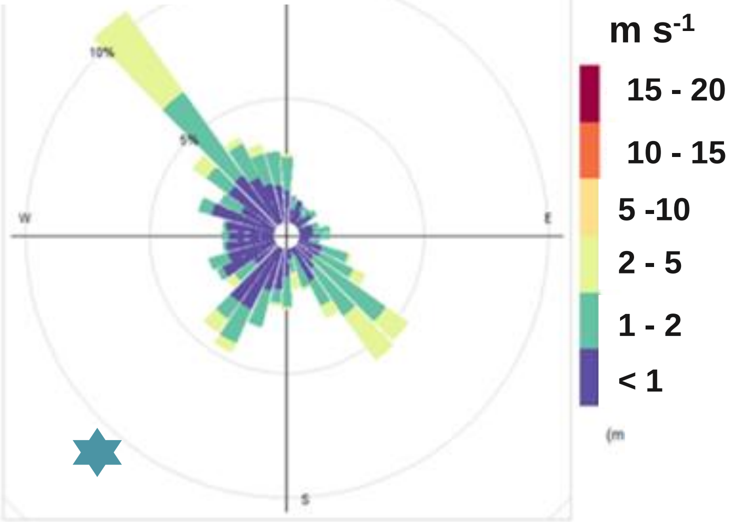

Blue = ammonia/other pollution sources
Green = trees
Industrial plant
grazing
Regional background



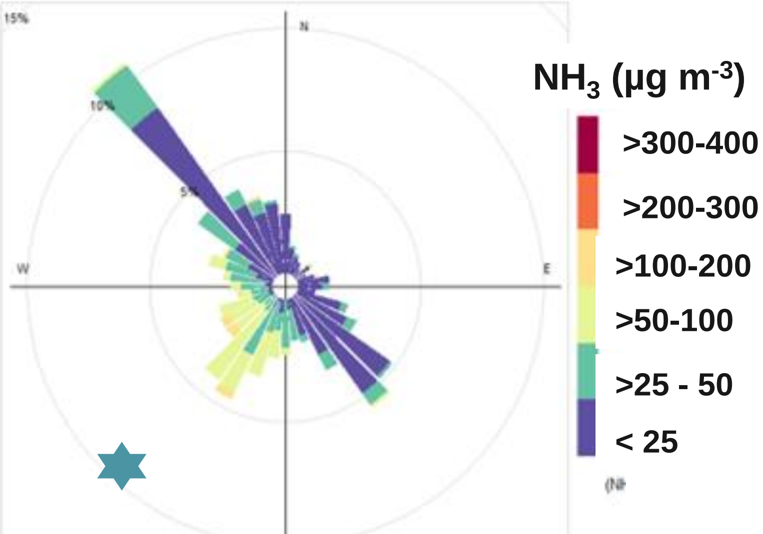
500
400
300
200
100
0
NH3 (µg.m-3)
15/10/2020
22/10/2020
29/10/2020

Intensive Campaign at Poultry 3 - Source apportionment with the wind rose

Site 1 Wind rose



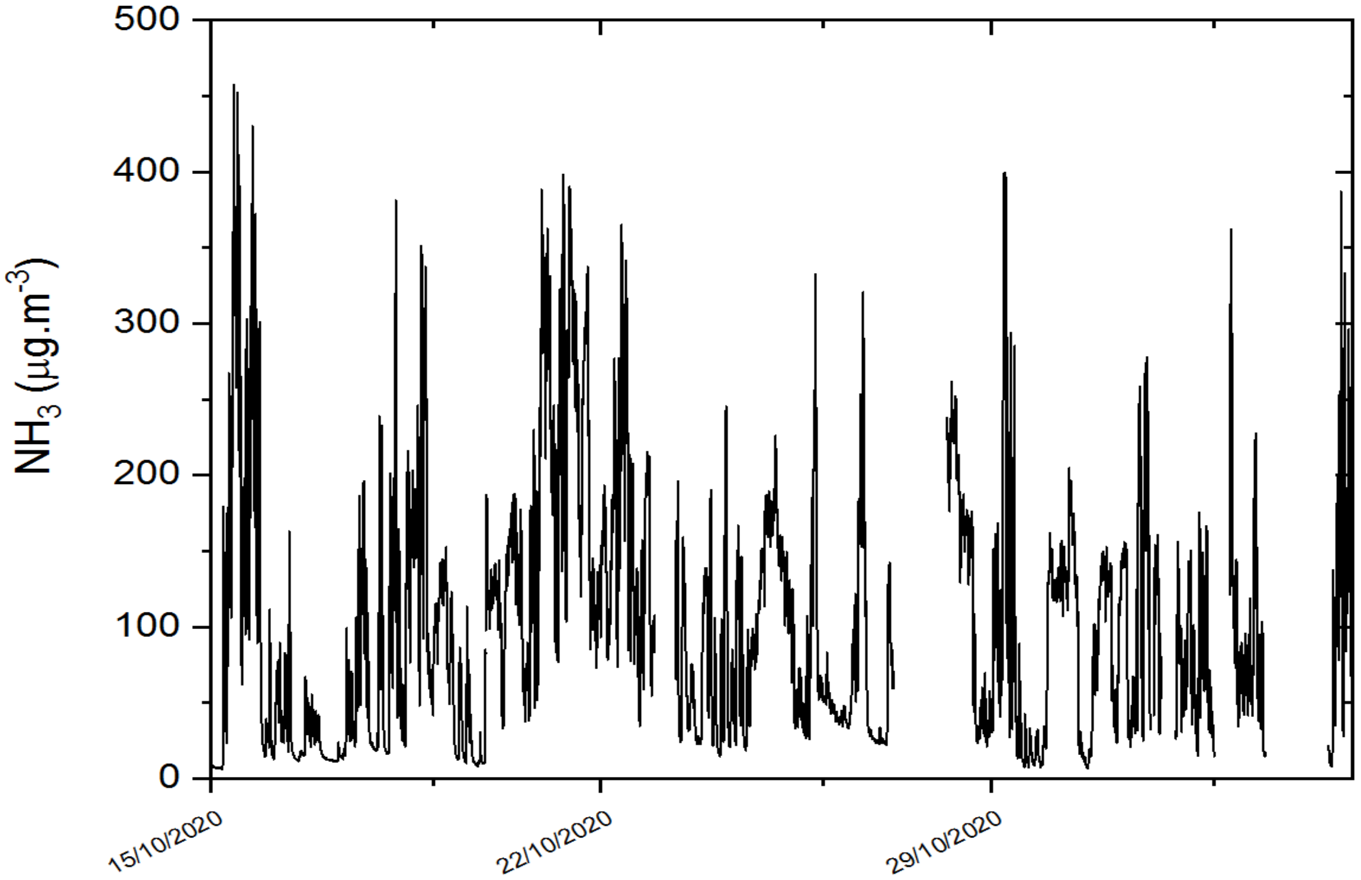
Site 1 AiRRmonia NH_3



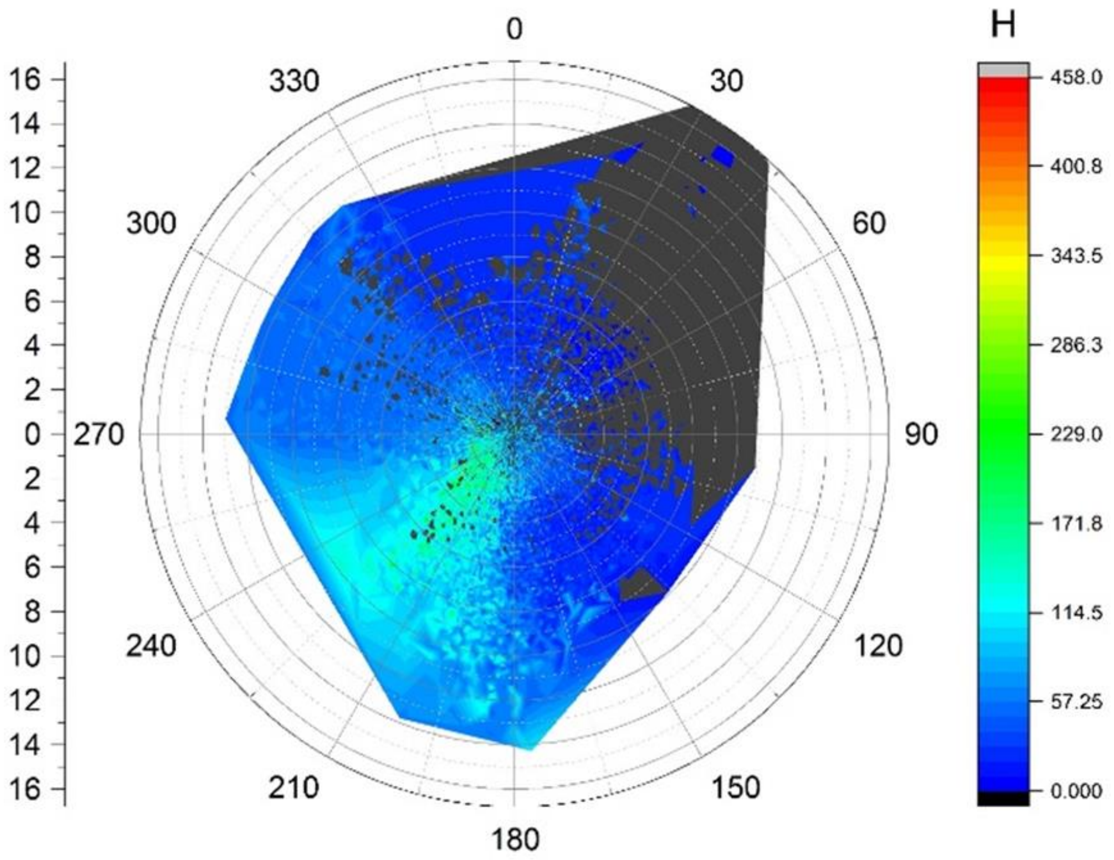
30° sector from shed (205° – 235°)
Mean = 120 µg NH_3 m^{-3}

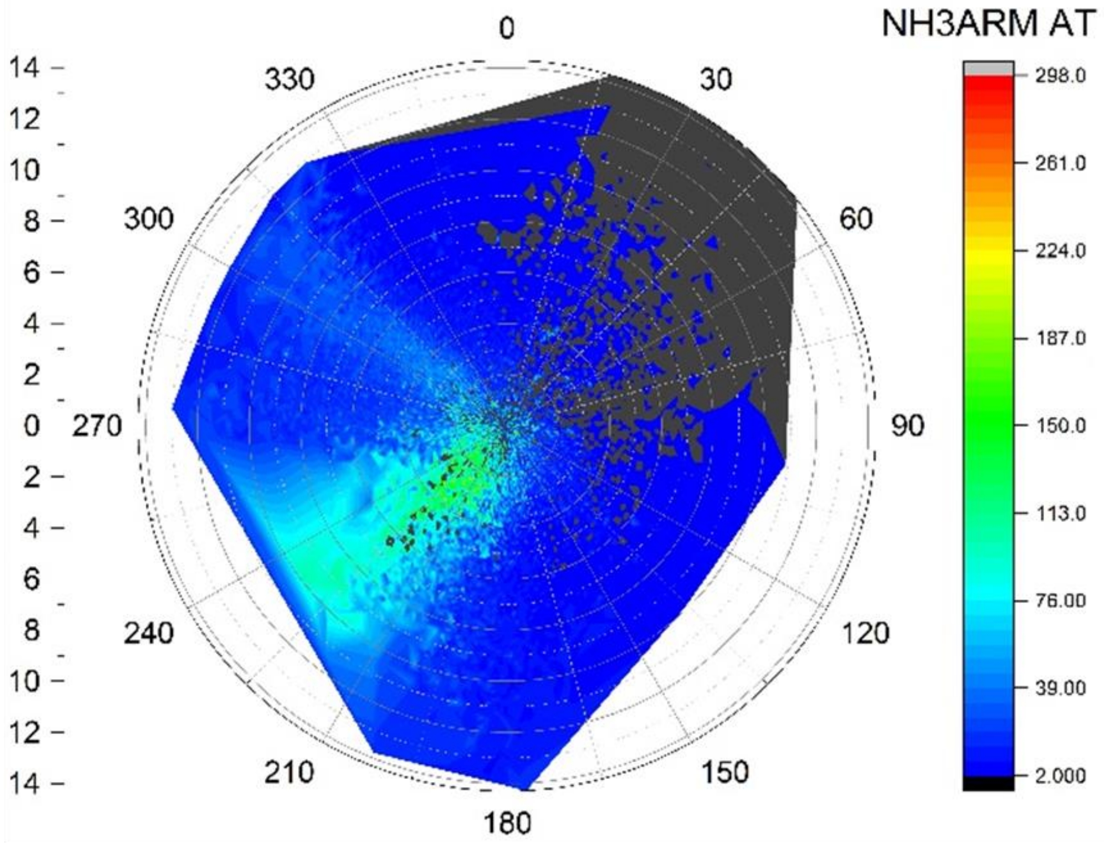
Wind rose and ammonia (AiRRmonia data) polar plots

- Site 1 weather station at site 1 before trees (height = 2 m),

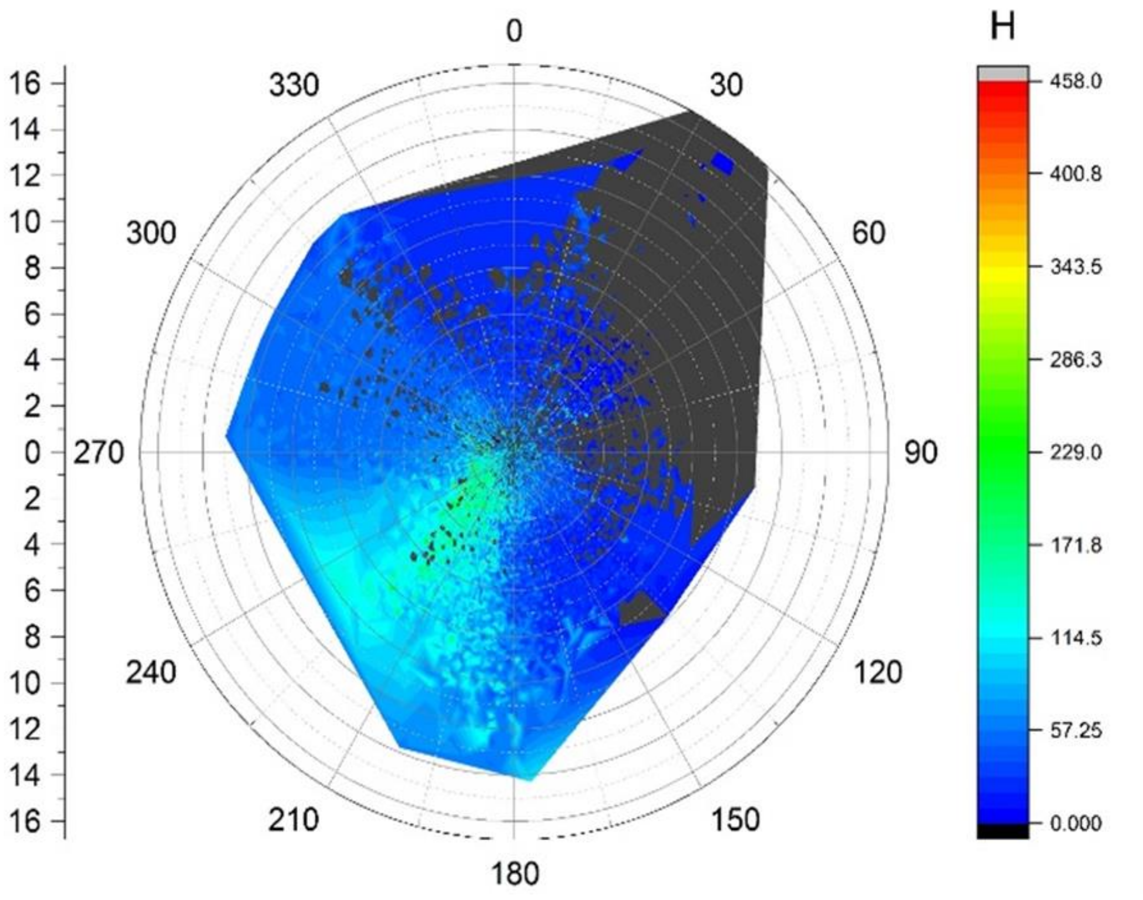


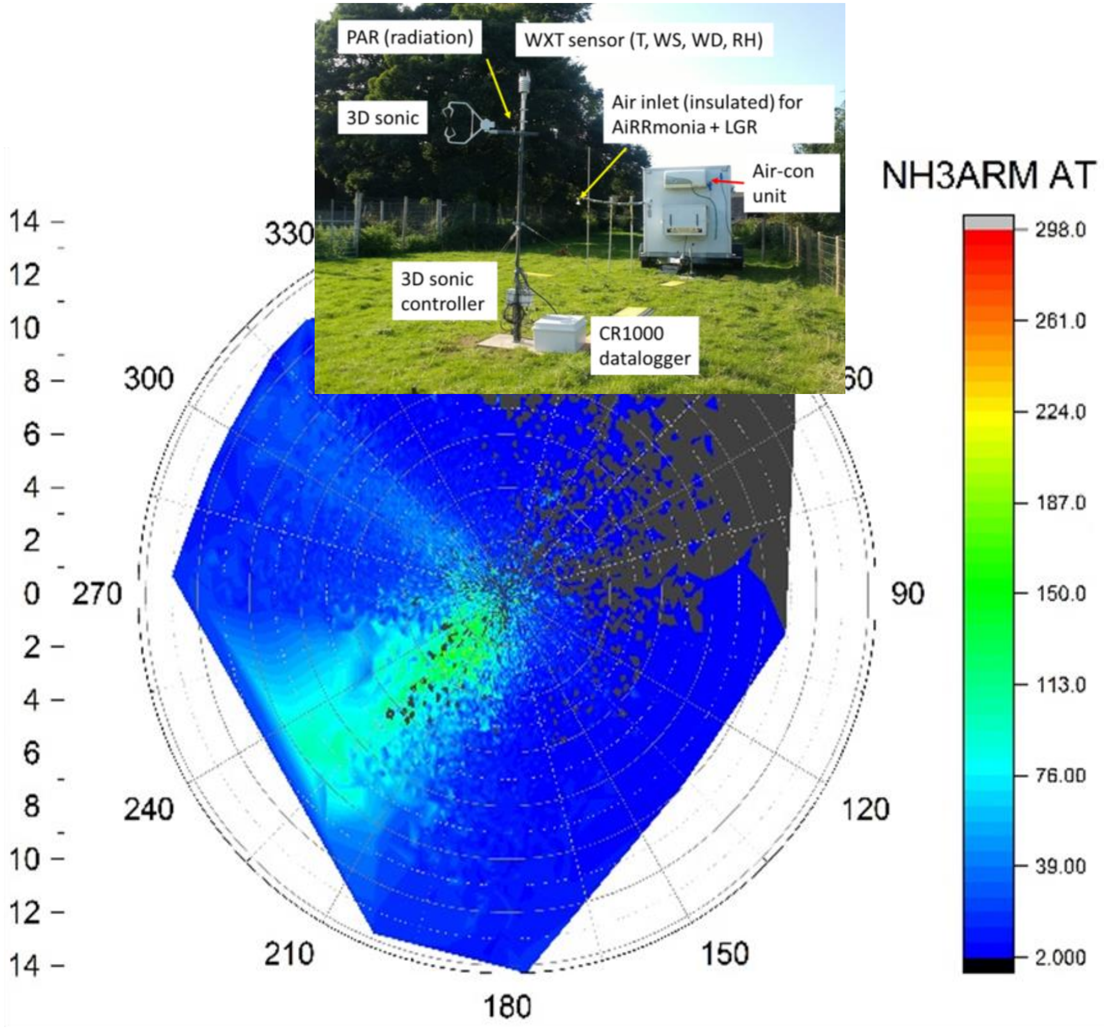
Ammonia concentration rose before and after trees





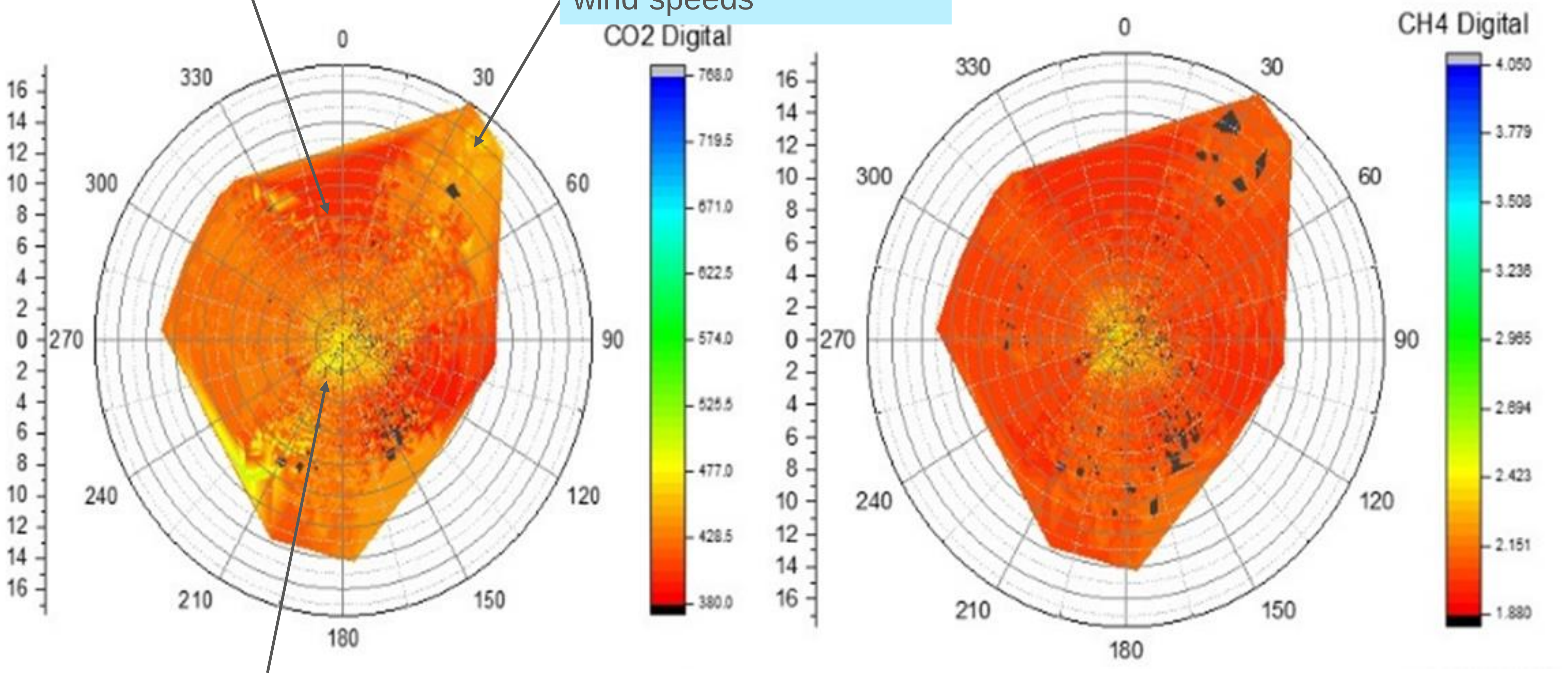
Ammonia concentration rose before and after trees





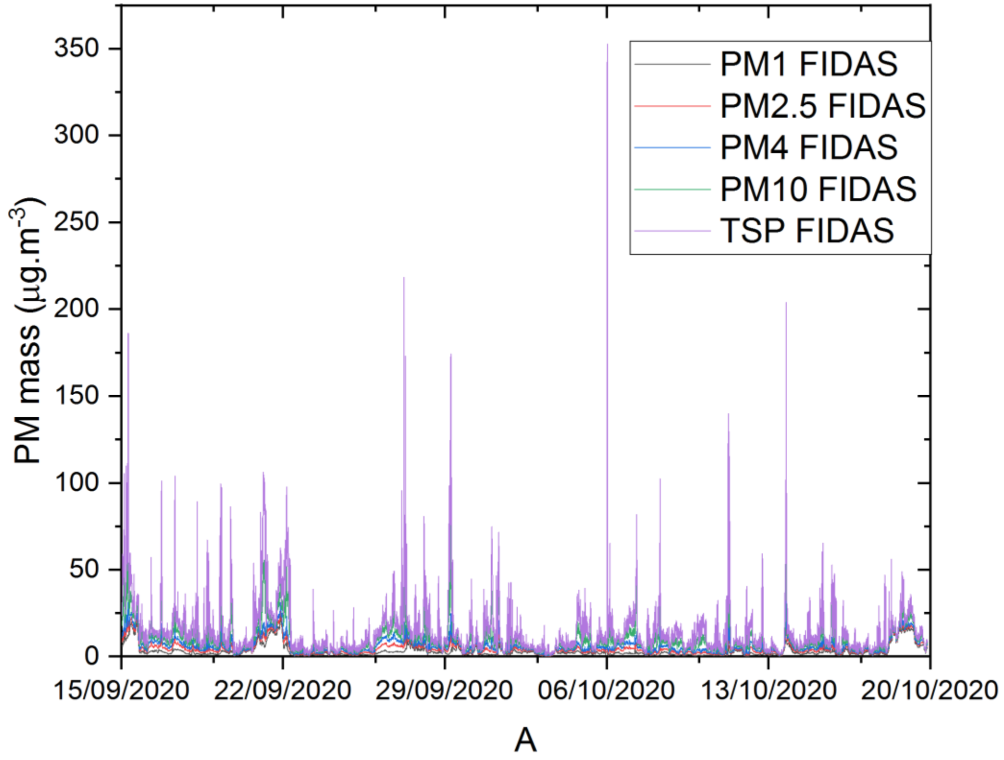
Background concentrations

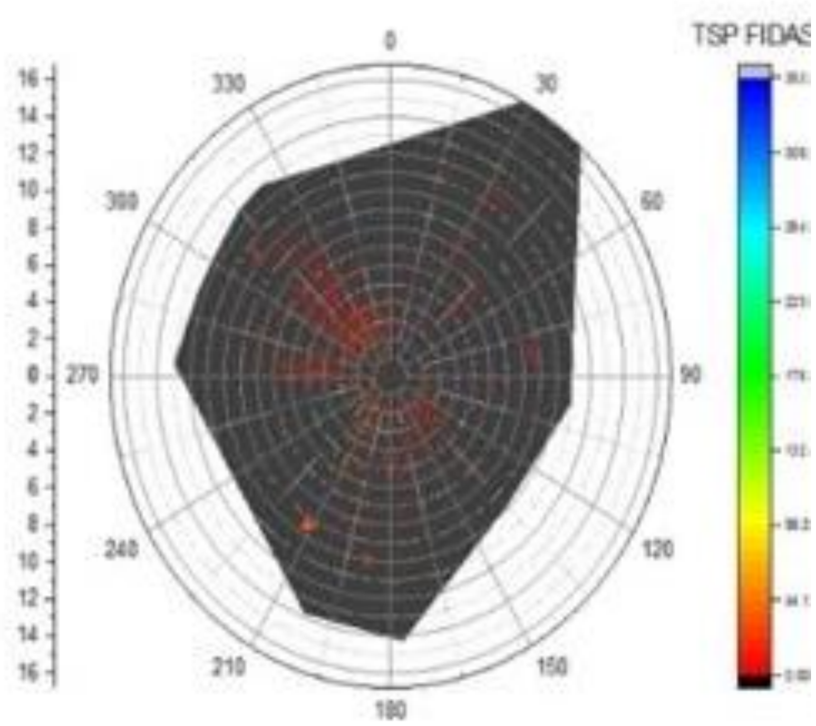
Source on other side of valley, only see at high wind speeds



Poultry 3 shed plume

Particulate matter





- Sources of total suspended particulate (TSP) matter did not come from Poultry 3.
- Sources primarily between 270-330º

Paired data example

NH_3, CO_2 and CH_4 decrease across tree belt.

This is expected as you are diluting the plume from the housing into the atmosphere

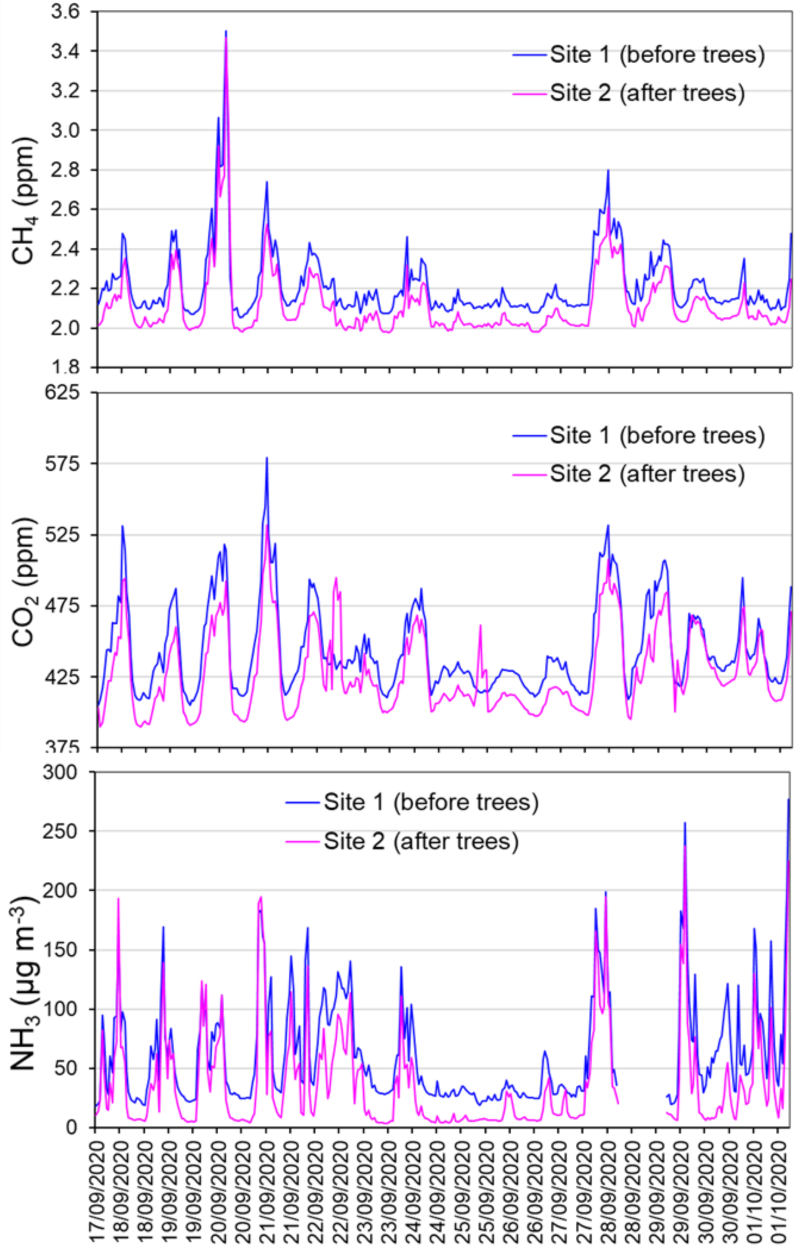
Note, regional background concentrations are:

$CO_2 \approx 398$ ppm
$CH_4 \approx 1.99$ ppm
$NH_3 \approx 0.003$ ppm (i.e. 3 ppb)

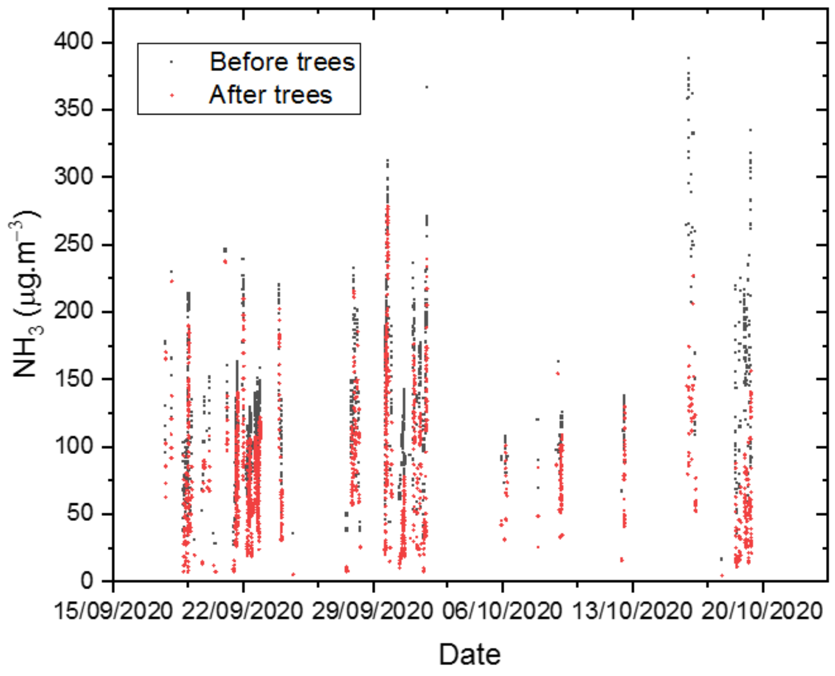
Therefore to understand the effect of the trees on the concentrations, the fractional loss from the local enhancement needs to be calculated carefully:

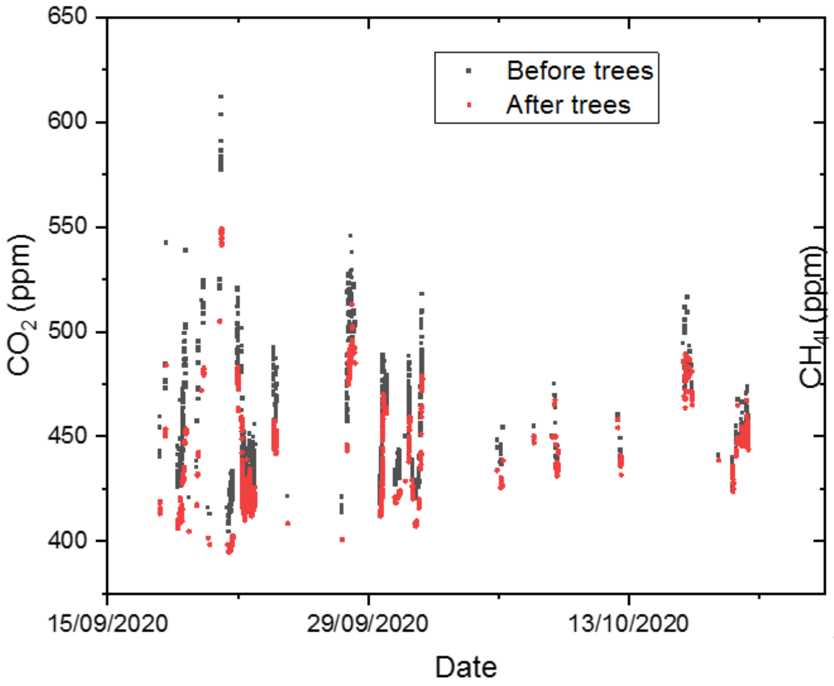
1. Select data from wind direction of interest (200-250° selected)
2. Select data where there is a wind (>2m.s^{-1} selected)
3. Data present from all the relevant instruments

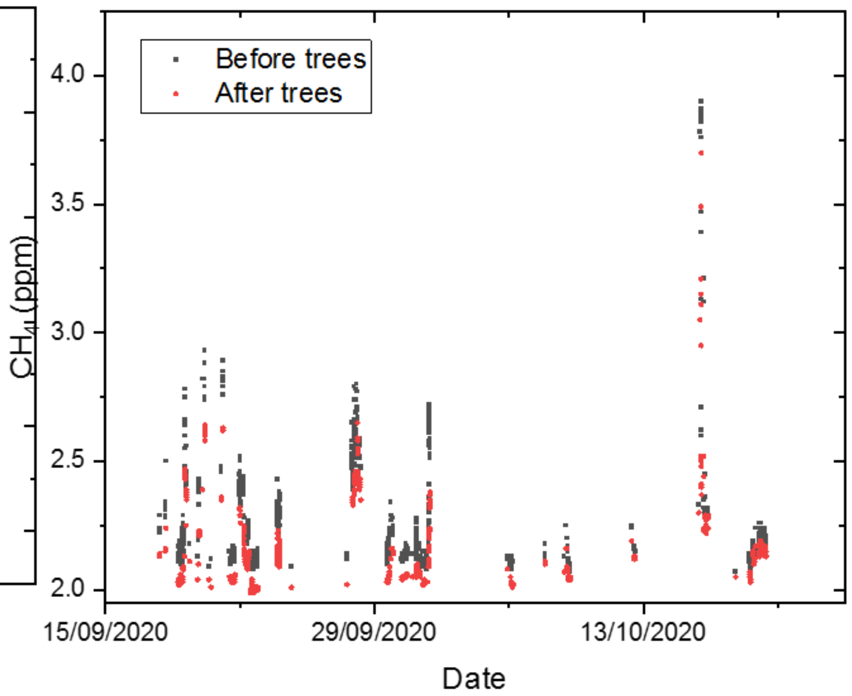
1969 data points out of ~80000



Remaining data!







Descriptive Statistics (before background subtraction)

	N total	Mean	Standard Deviation	SE of mean	Minimum	Median	Maximum
NH3 ARM BT	1969	133.0	52.4	1.2	16.2	123.1	387.8
NH3ARM AT	1969	84.6	47.9	1.1	4.4	79.4	277.9
CO2 BT	1969	447.204	25.724	0.57972	404.54	437.45	612.1
CO2 AT	1969	430.264	24.382	0.54948	394.69	421.64	549.1

Summary of findings

- NH_3 concentration reduction across trees: 38±20%
- Estimate from CO_2 tracer ratio method is that of the 38% concentration reduction, ~ 6.8% of that reduction was due to recapture by the vegetation, remainder due to dispersion and atmospheric dilution. This compares with the modelled value of 1.6%
- **It is noted that this calculation has high uncertainty due to short dataset**
- Results with high variability and hence uncertainty
- However dataset is available in combination with meteorology for future high resolution measurement-model comparison.
- MSc student due to start in March will take datasets for a detailed study. I.e. specific days and weather events (e.g. rain stripping and re-emission has a big effect)

Mixed model of measurement techniques

Research platform farm testing tools: Reference high resolution measurement and modelling

New/innovative farm intervention but standard methods: passive samplers and model validation

Application as part of farm plan: modelling to check plan

Future Strategies

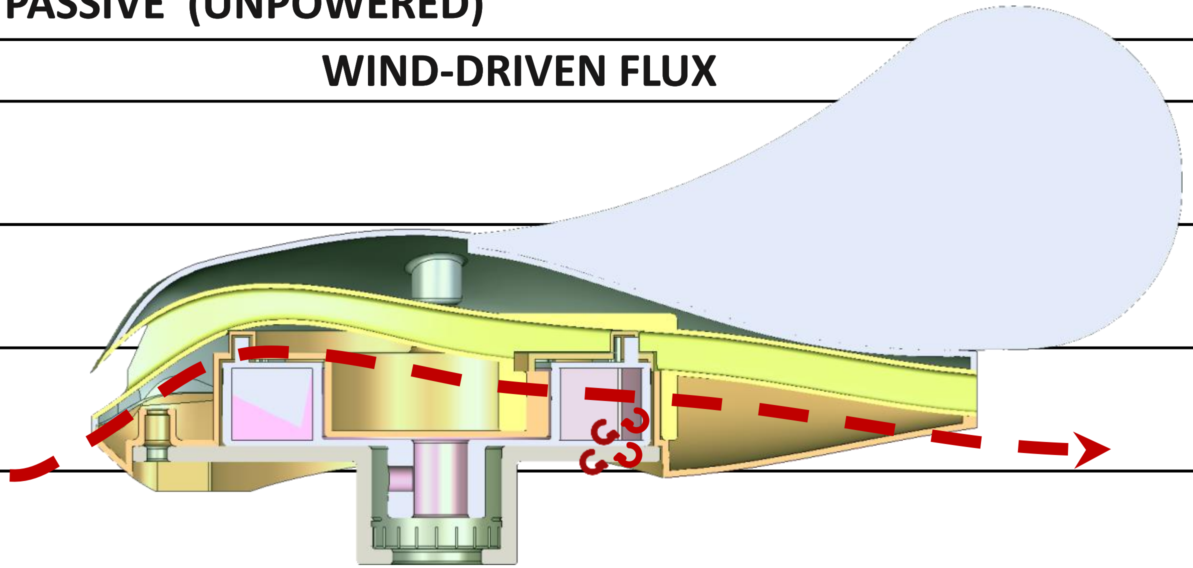
- Accurate and high-resolution measurements are key to inform policy
- Though instrumentation high cost to purchase, operational costs are not much more that "low cost-low resolution" samplers
- Once traceable and reproducible measurement protocols in place then information from measurements, whatever method is valuable to the farmer, the policy maker and the scientist
- Accuracy using traceable standards required **for all data** with associated uncertainties
- Dispersion AND recapture data required for fundamental validation and development of farmtreetoair tool so that users can have confidence in underpinning model parameters and processes.
- Sufficiently accurate concentration data needed to ground truth application of farmtreetoair where required for policymakers. Once operational protocols for more ammonia monitors available, high resolution data at 3 points would be gold standard.
- Where high resolution not available, sufficient numbers of off-line samplers to statistically test the policy intervention against models is needed
- If greenhouse gas emission footprint needed (for other purposes) the carbon dioxide, methane and N_2O should be co-measured

Using Directional Passive Air Samplers (DPAS) to measure poultry NH_3 signals & reduction by trees

Roger Timmis
(roger.timmis@environment-agency.gov.uk)
Environment Agency

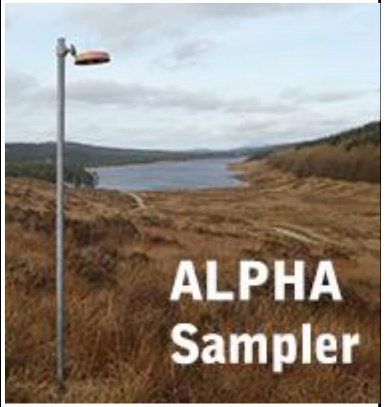
Passive ammonia monitor types and capabilities

CAPABILITY	PASSIVE (UNPOWERED)	
	DIFFUSION	WIND-DRIVEN FLUX
Small, cheap, easy to deploy	√	√
Needs no power	√	√
Cumulative NH_3	√	√
Resolves directions	×	√
Usable for farms & ecosystems	√	√



Through-flow Principle

Examples:



ALPHA

DPAS

Directional Passive Air Sampler (DPAS) with Mini ANnular Denuders (MANDEs) in 30º Channels

Figure 1. DPAS showing inlet to airway and vane that turns it to face upwind. The inlet is ~1.3 m above ground.

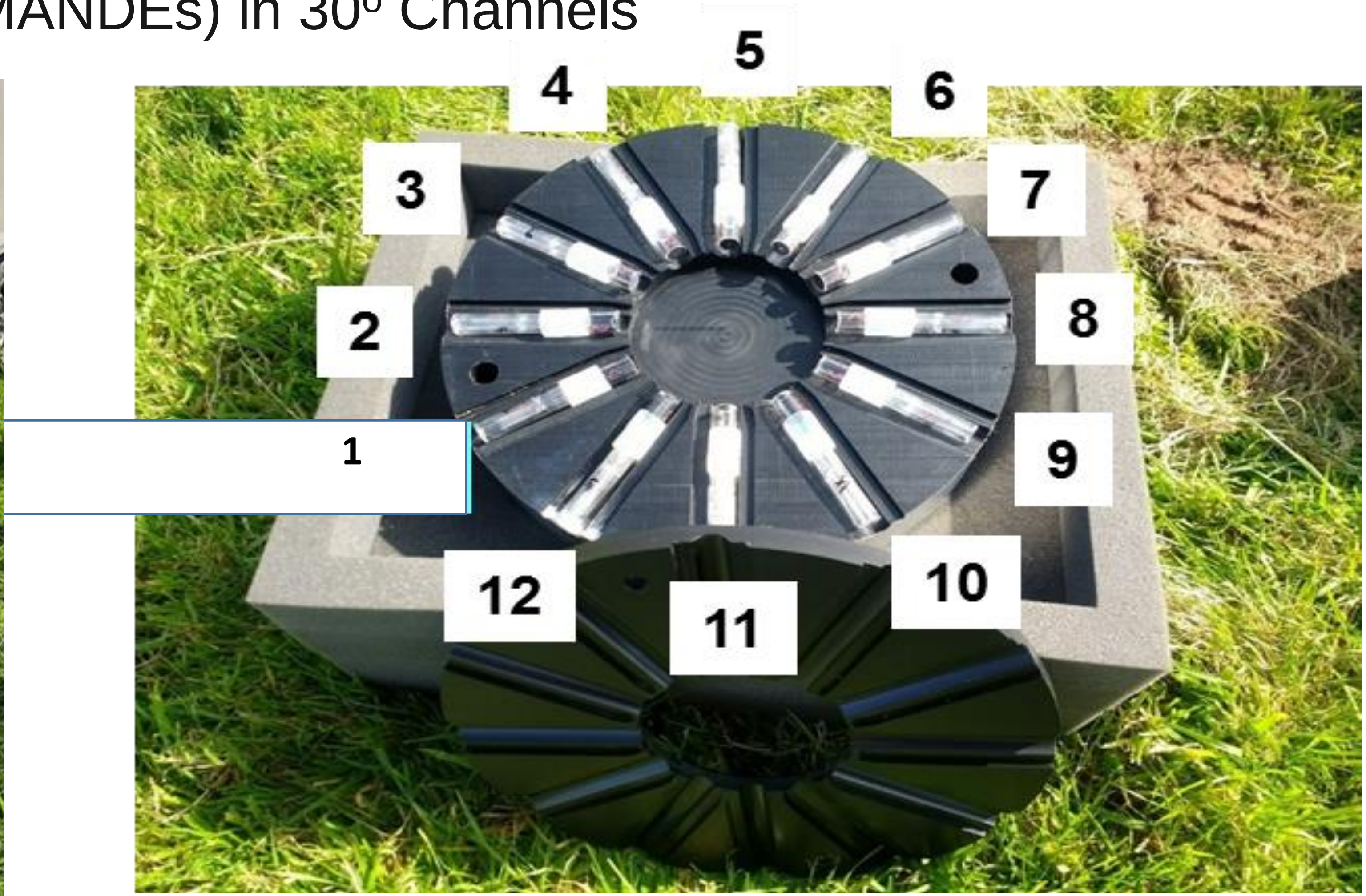


Figure 2. Internal carousel after removal from inside DPAS, with cover (front, bottom) removed to show 12 x 30º sectors with directional channels containing MANDEs

Questions for DPAS-MANDE monitoring of poultry NH_3

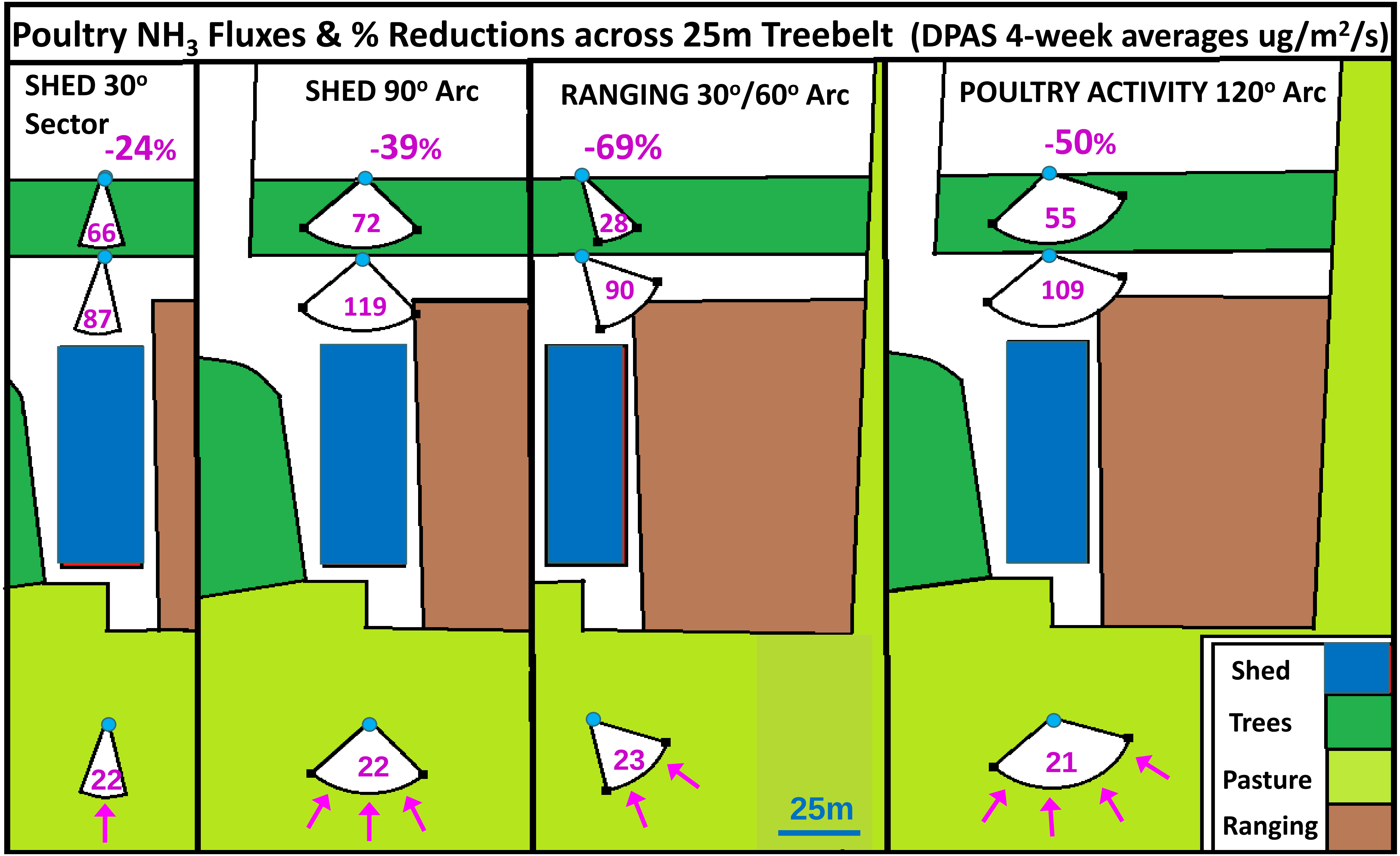
- Are NH_3 levels from poultry activities reduced downwind of trees?
- How much of reduction is due to
  (a) basic plume dispersion with distance?
  (b) extra tree-induced turbulent mixing and tree-surface deposition?
- Are NH_3 reductions different for different types of poultry source?
- Do tree-belts reduce well-mixed "background" NH_3 from pasture?
- How far away can we detect a poultry farm NH_3 signal?
- Is Numerical Weather Prediction adequate for data interpretation?

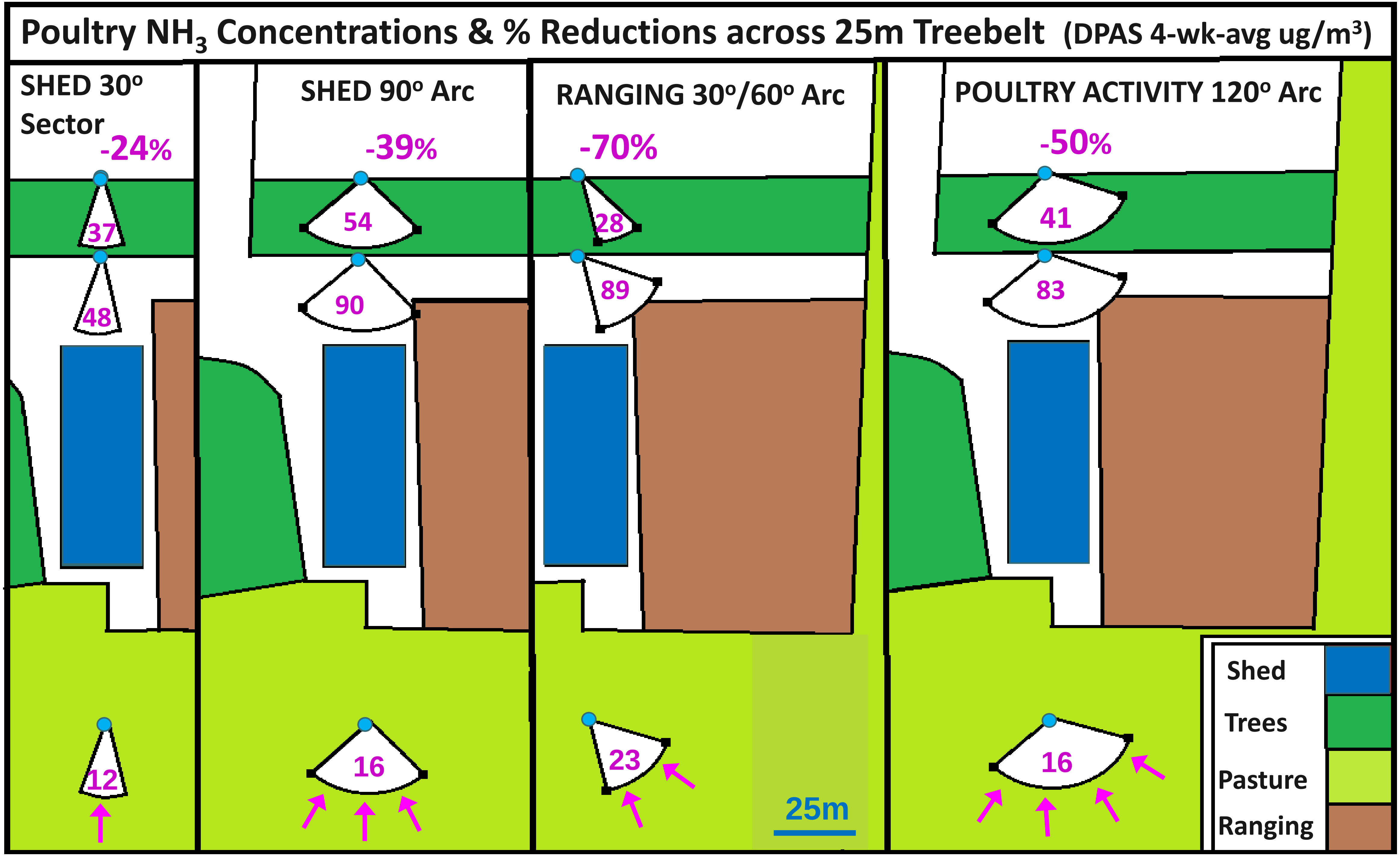
SW & NE poultry farms for DPAS monitoring showing:

- Sheds
- Nos. birds
- Tree belts
- Other farm buildings
- DPASs
- ALPHAs
- Surrounding pasture

Intensive (NE) Farm showing:

- Sheds/flocks
- Trees
- 6k flock with:
  - 25m tree belt
  - ranging area
- DPASs 1-3:
  1 - upwind
  2 - before trees
  3 - after trees


Poultry NH_3 Fluxes & % Reductions across 25m Treebelt (DPAS 4-week averages ug/m²/s)
SHED 30° Sector
-24%
66
87
22
SHED 90° Arc
-39%
72
119
22
RANGING 30°/60° Arc
-69%
28
90
23
25m
POULTRY ACTIVITY 120° Arc
-50%
55
109
21
Shed
Trees
Pasture
Ranging

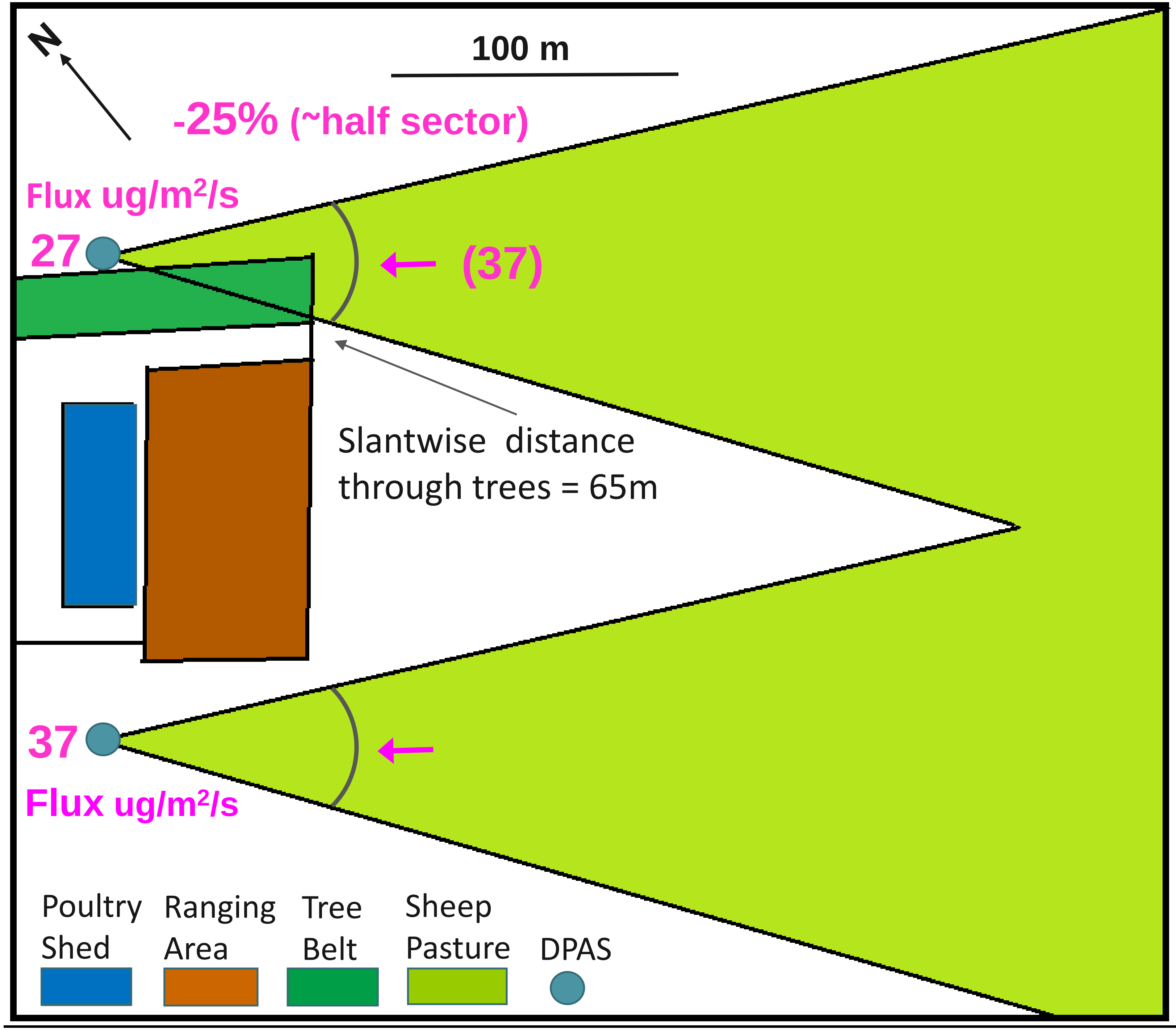


Poultry NH_3 Concentrations & % Reductions across 25m Treebelt (DPAS 4-wk-avg ug/m^3)
SHED 30º Sector
-24%
37
48
12
SHED 90º Arc
-39%
54
90
16
RANGING 30º/60º Arc
-70%
28
89
23
25m
POULTRY ACTIVITY 120º Arc
-50%
41
83
16
Shed
Trees
Pasture
Ranging

Ammonia Fluxes at NE Poultry Farm from adjacent 30° Sectors containing

- Pasture only (bottom)
- Pasture + Part of Tree Belt (top)

(6-week-averages of DPAS samples)



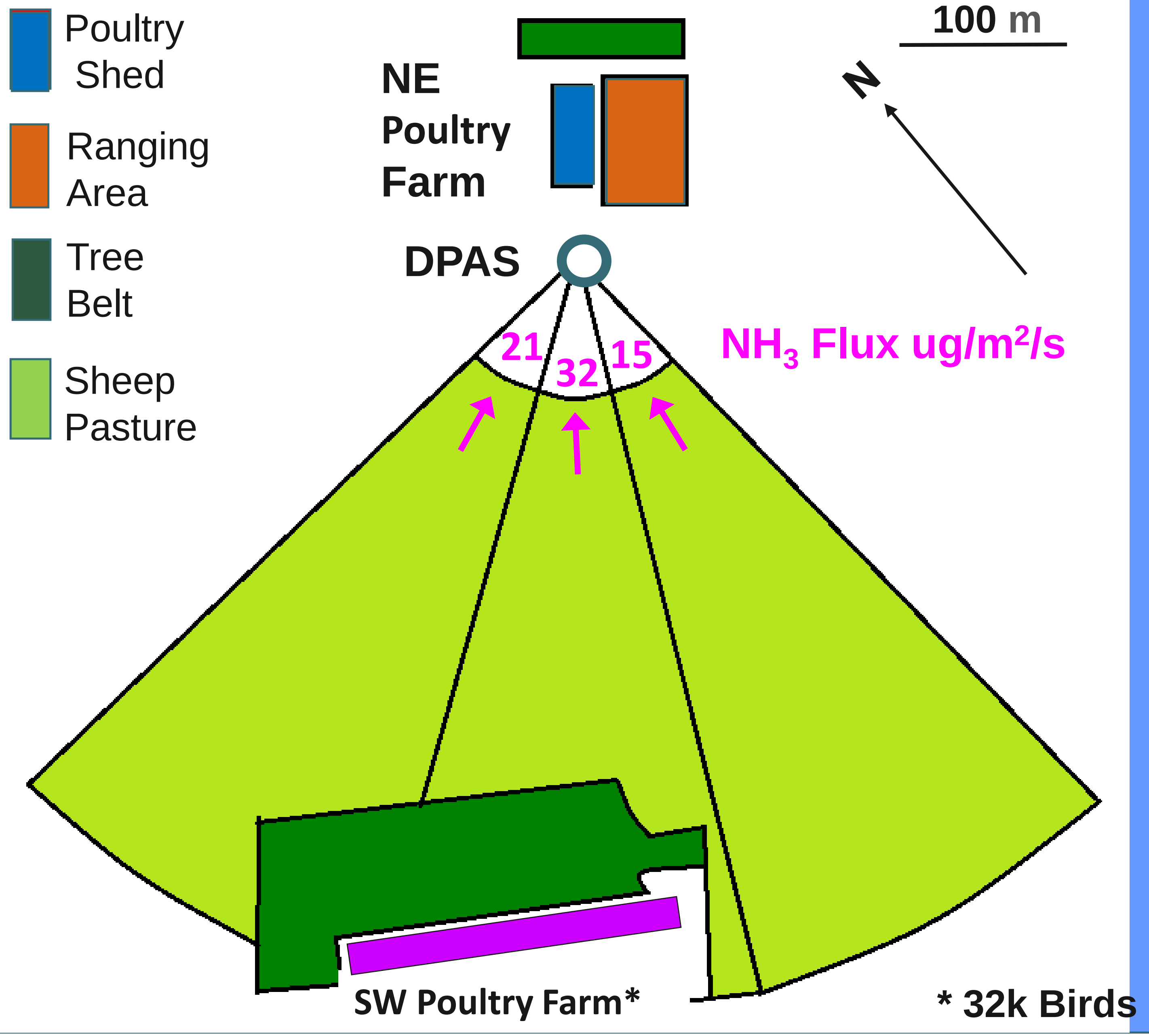
DPAS: % Reductions in fluxes & concentrations by trees (4 or 6-week averages): summary for different transects, emission heights, distances, + normalised to 25m

Transect			% Reduction in Flux		% Reduction in Concn.	
Description	Height of NH_3 emission	Distance through trees	Un-normalised for distance	Normalised to 25m	Un-normalised for distance	Normalised to 25m
Shed 30º Sector	3m (eaves)	25m	-24%	-24% *	-24%	-24% *
Shed 90º Arc	0-3m (variable)	27m	-39%	-36% *	-39%	-36% *
Overall 120º Arc	0-3m (variable)	31m	-50%	-40% *	-50%	-40% *
Ranging 30º/60º Arc	0m (ground)	28m	-69%	-62% *	-70%	-63% *
Background 30º Sector	n/a (well-mixed)	65m	-50%	-19% #	-56%	-22% #

* Reduction due to interception by 25m of trees and plume dispersion over 25m

Reduction due to interception by 25m of trees only.

Ammonia Fluxes at NE Poultry farm from 30° Sector containing SW Poultry Farm and adjoining 30° sectors (4-week-averages of DPAS data)



DPAS NH_3 Concentrations & Fluxes: Comparison of Reductions by Trees using: (a) On-site meteorology (UKCEH) and (b) Numerical Weather Prediction (NWP)

Transect	Source of Wind data	Duration		Wind Speed	Concentration ug/m^3				Flux ug/m^2/s			
		Periods	hours	m/s	Up-wind	Before Trees	After Trees	% Reduction	Up-wind	Before Trees	After Trees	% Reduction
Shed 30°	UKCEH	3 + 4	121.1	1.78	12.2	48.4	36.8	**-24%**	21.8	86.8	66.1	**-24%**
	NWP	3 + 4	82.6	1.47	21.7	86.4	65.7	**-24%**	32.0	127.3	96.9	**-24%**
Ranging Area 30°/60°	UKCEH	1 + 3	97.8	1.01	22.7	88.6	27.7	**-70%**	23.0	89.6	28.0	**-69%**
	NWP	3 + 4	105.7	1.24	11.8	94.4	34.2	**-64%**	14.7	117.2	42.4	**-64%**

Reductions similar for on-site & NWP (but NWP height/speed lowered from 10m)

Reduction of ammonia by trees: DPAS Summary and Questions

- Non-directional (ALPHA) and directional (DPAS) passive monitors both show NH_3 reductions
- Non-directional ALPHA data can be hard to interpret due to other sources & variable winds
- Directional DPAS data easier to interpret; but needed screening for low-wind-speed issue
- Reductions by 25m trees: Shed: -25% (eaves/overfly); Ranging -60% (ground); Overall -40%
- Reduction of well-mixed background by 25m of trees: -19%; =>benefit of hedges (Shrops.)
- 32k poultry shed with tree belt resolved by DPAS from ~0.5km away; => landscape surveys
- NWP Met. data can be used instead of on-site monitoring, if adjusted for height/roughness
- Can we use DPAS and NWP for other agricultural fugitive emissions, e.g. N_2O, CH_4?
- Use inverse modelling to infer source strength from downwind minus upwind DPAS NH_3?

ART Cumbria field experiment

Summary and Conclusions

Christine Braban (chri2@ceh.ac.uk)
UKCEH

Project Objectives

- Targeted approach to monitoring, gathering evidence
- Impact monitoring
- Simple tool for agencies
- Introduce evidence towards improving confidence in tools
- Guidance on best methodological approach to farm assessment

What are we aiming to achieve?

Training	• EA to develop protocol for instrument calibration for these types of deployments; test EA cylinder
Dataset curation	• Cleaned and checked dataset made available for study and measurement-model comparison • Data review and lessons learned
Interpretation of concentration patterns	• Can methane and/or CO_2 be used for understanding interaction of NH_3 with trees? Which is better? • How useful is it for source apportionment checks cf other methods
Advice for future ELMS measurements	• What is the cost-benefit of deploying high resolution measurements compared to the passive approach • Which additional measurements would provide a low cost addition that would also significantly improve evidence value

Project Summary: methodological approaches

ALPHA® 2-weekly measurements
Ideal for transects, spatial surveys and model prediction validation
12 x monthly measurements will provide annual mean concentrations – compare with Critical Levels of NH_3, and with models (e.g. SCAIL)
Follows BSI/CEN standard methodology

Intensive measurements
Source apportionment
Estimate emissions
Model validation
Model process checks

DPAS directional NH3
Screening

Notes:
emission fluxes and surface fluxes of ammonia were not measured but would be highly valuable approaches
Many other methods for ammonia measurement are available, however there are no NH_3 measurement standards for automatic analysers yet

Project Summary: methodological approaches

Tree structure and chemistry
health of tree belts
nitrogen pathways
Carbon sequestration

Lichen
local pollution status
local ecology

Nitrogen in vegetation and soil
nitrogen pathways
Pollution swapping
Ecosystem change

Summary – Concentration difference across treebelt?

	average % NH_3 concentration difference across treebelt				
Farm / **Method**	**Poultry 1**	**Dairy 1**	**Poultry 2**	**Poultry 4**	**Poultry 3**
ALPHA measurements	97%	73%	58%	56%	42%
SCAIL (modelled as if no treebelt)	83%‡	66%	46%	78%	29%*‡
High resolution measurement NH_3					45%**
DPAS					40%**

*‡ SCAIL modelling at these farms did not align well with the nearest sampling point to source. The model was around x10 less than the measurements (discussed in main text); * modelled over 3 measurement periods;** Sept-Oct only*

2. Increased mixing of the air increases plume dispersion

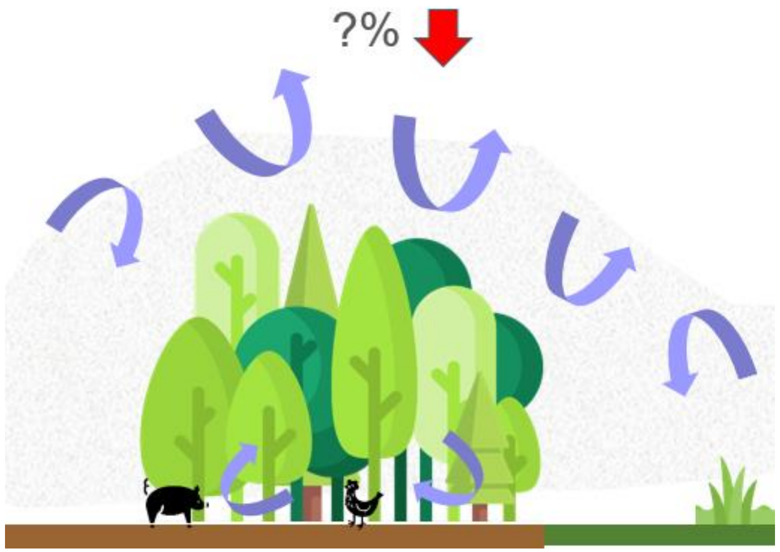
?%

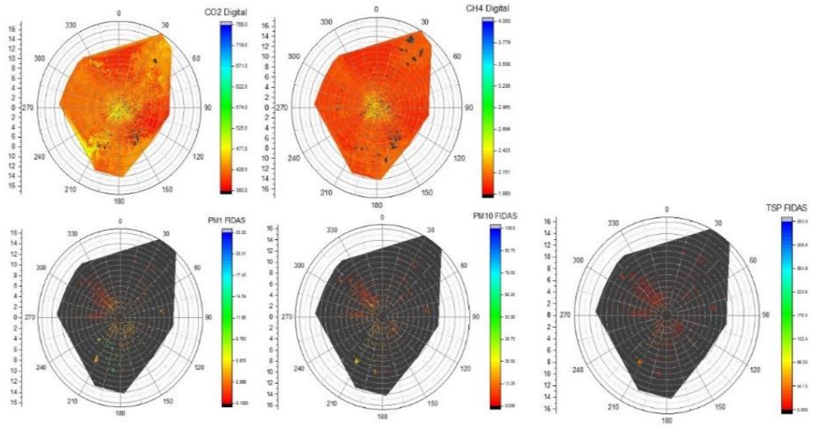
Enhancing local recapture and dispersion = reducing NH_3 concentrations & deposition to sensitive habitats

Intensive Campaign at Poultry 3 – Recapture by canopy?

	% recapture of Ammonia (NH_3) by Treebelt					
Recapture calculation method	**Poultry 1** Treebelt Depth 100 m	**Poultry 2** Treebelt 30 m	**Poultry 3** Treebelt 25 m	**Poultry 4** Treebelt 65 m	**Dairy 1** Treebelt 330 m	**Dairy 2** Treebelt 170 m
MODDAS-OPenFoam*	1.0 (roof fans) 1.6 (side ventilated)	1.3	1.7	0.1	80.6	4.2
High resolution measurement CO_2 tracer			6.6			
High resolution measurement CH_4 tracer			0.3			

1. Recapture of NH_3 by the canopy





https://www.farmtreestoair.ceh.ac.uk/ART

Acknowledgement

We would like to thank all the farms for permission to carry out the field measurements at their sites, and for their assistance and very helpful input into the project.

2-weekly ammonia measurements

- Can concentration measurements give a quantitative measure of ammonia reduction by tree shelterbelts?

Modelling

- Question: How can we improve uncertainty, especially through improved LAI by age of treebelt & by species?

Tree measurements

- How above ground N compares to belowground N capture, storage and cycling by different trees and soils?
- What is the influence of N on carbon capture above and belowground?
- What is the influence of N input on soil biodiversity, nitrogen leaching and soil GHG?

Intensive measurements

- Experimental design, reference methods, best practice?

Directional passive ammonia measurements

- Can we use DPAS and NWP for other agricultural fugitive emissions, e.g. N_2O, CH_4?
- Use inverse modelling to infer source strength from downwind minus upwind DPAS NH_3?