Ammonia emissions from western livestock waste lagoons

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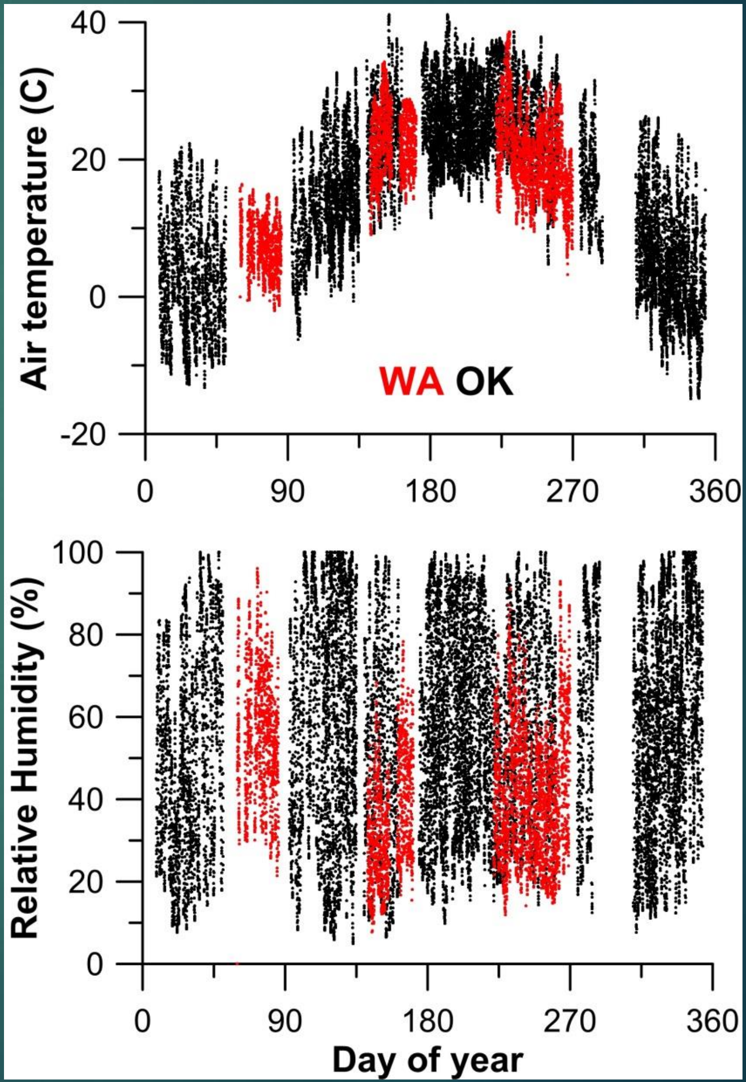
Introduction- Western Livestock

- The dry hot western US climates have high evaporation rates, potential concentration of solutes and solids, and can result in more common manure storage surface crusting.
- Emissions measurements are needed specifically in these environments to understand their influence on the livestock operation emissions



Introduction- Dairy farm

- Dairies in the dry western US typically free stall systems with exercise areas.
- Measurements of NH_3 emissions were made over two years at one of two manure storage basins of a
- Manure handling
  - Basin filled, dried, then the solids removed by front-end loader to drying pad
  - Liquid is removed in basin by skimming and stored in lagoon downslope

Introduction- Dairy farm

- 5600 cow dairy (1200 dry, 4400 milking)

Area- west basin (ha)	1.5
Area- east basin (ha)	1.3

Climate

Monthly temperatures: 7° to 23°C
Mean wind speed: 2.3 and 5.5 m/s
Dry during study- no liquid removals

Manure handling cycle- Dairy farm

- Manure flushed from barns and milking parlor 4 times/d
- Basin filling over 280 d
  - Crust formation on infilling basin occurred within 60 d of start of filling
- Basin drying over 60 d
- Basin manure removal over 30 d

BASINS	
Loading rate (kg total solids m^{-2} d^{-1})	9000
Estimated N loading (kg d^{-1})	1910

Introduction- Hog farms

- Hog operations
  - Sow breed to wean:

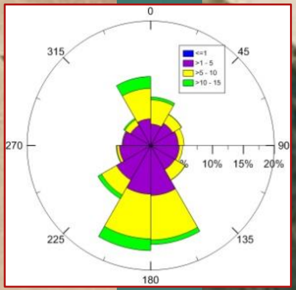
    sows have16 week gestation times

    piglets take 2-3 weeks to wean
  - Finisher: pigs grown 16 weeks to market

- Climate
  - Monthly temperatures: 1° to 27°C
  - Mean wind speed: 4.3 and 4.8 m/s
  - Dry during study- no liquid removals

Introduction- Hog farms

Breed to wean farm has 2784 sows (464 AU)	Finisher farm has 2742 hogs (1279 AU)



LAGOON	Breed to wean	Finisher
Area (ha)	2.1	2.2

Manure handling cycle- Hog farms

Breed- Wean

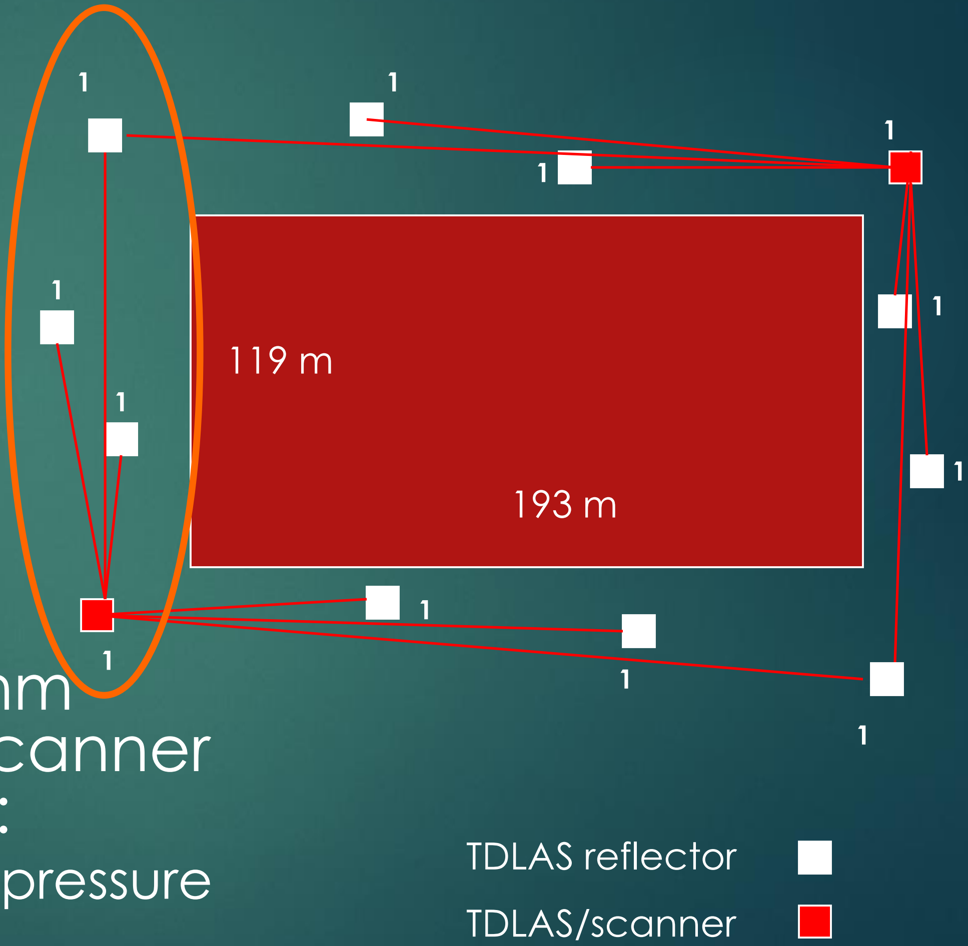
- Manure flushed from gestation barns weekly
- Manure flushed from farrowing barn every 2 ½ weeks

Finishing

- Manure flushed from barns 3 x week

LAGOONS	Breed to wean	Finisher
Loading rate (kg volatile solids m^{-2} d^{-1})	236	323
Estimated N loading (kg d^{-1})	108	262

NH_3 Measurements



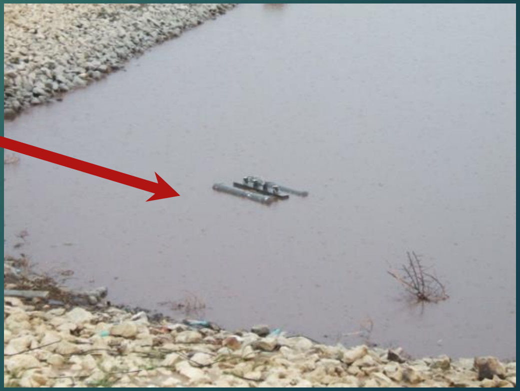
GasFinder2 at 1541.2 nm
Directed Perception scanner
Unattended scanning:
All retro-reflectors heated, pressure vented

Other Measurements

- Atmospheric properties
  - 3D turbulence (16Hz)
  - Air temperature, humidity, barometric pressure, surface wetness, solar radiation

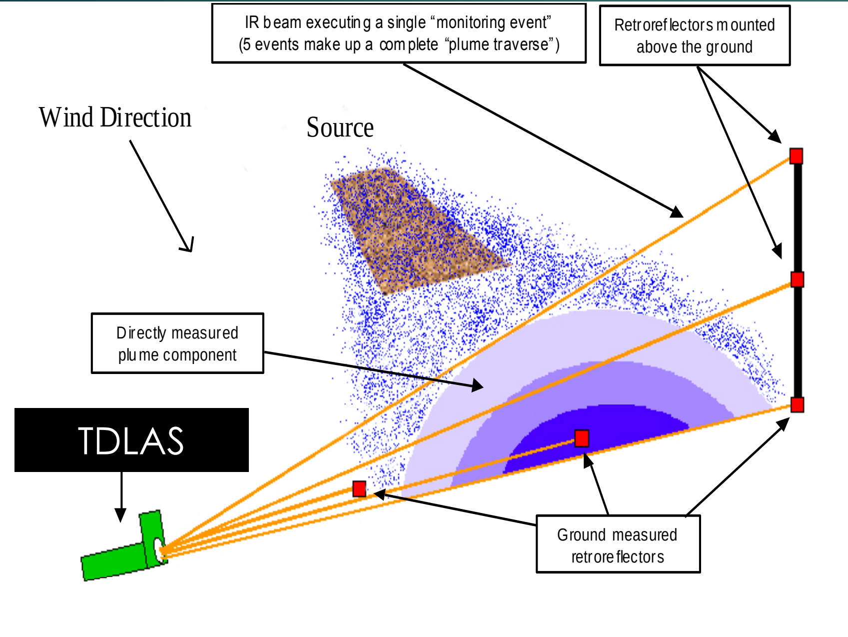
- Lagoon properties

  temperature, pH, redox potential (hog only)



- Collected operation and production records from producer

Emissions: RPM



Measurements:

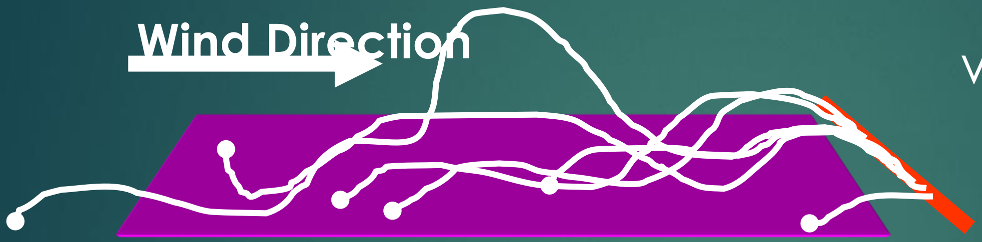
Each lagoon side has 5 OP, (3 at 1m, 1 at ~7m and 1 at ~15 m)

3 wind speed heights for profile

Valid RPM measurement:

- If all four sides (upwind and downwind) valid, horizontal mass balance
- If 2 downwind sides and 1 upwind OP valid, background determined by upwind OP

Emissions: bLS (WindTrax)



within 10m of source edge

NH_3 measured on m=12 optical paths; 12 PICs (1 m)

C_{bkgr} calculated by model

$$a_i = \frac{(PIC_i / path_i - C_{bkgr})}{[C_{sim} / Q_{sim}]}$$

with C_{bkgr} *and Q solved from:*

$$Q = \left(PIC_i / path_i - C_{bkgr}\right) / a_i$$

$$Q = \left(PIC_m / path_m - C_{bkgr}\right) / a_m$$

Emissions: bLS (WindTrax)

Emissions valid when

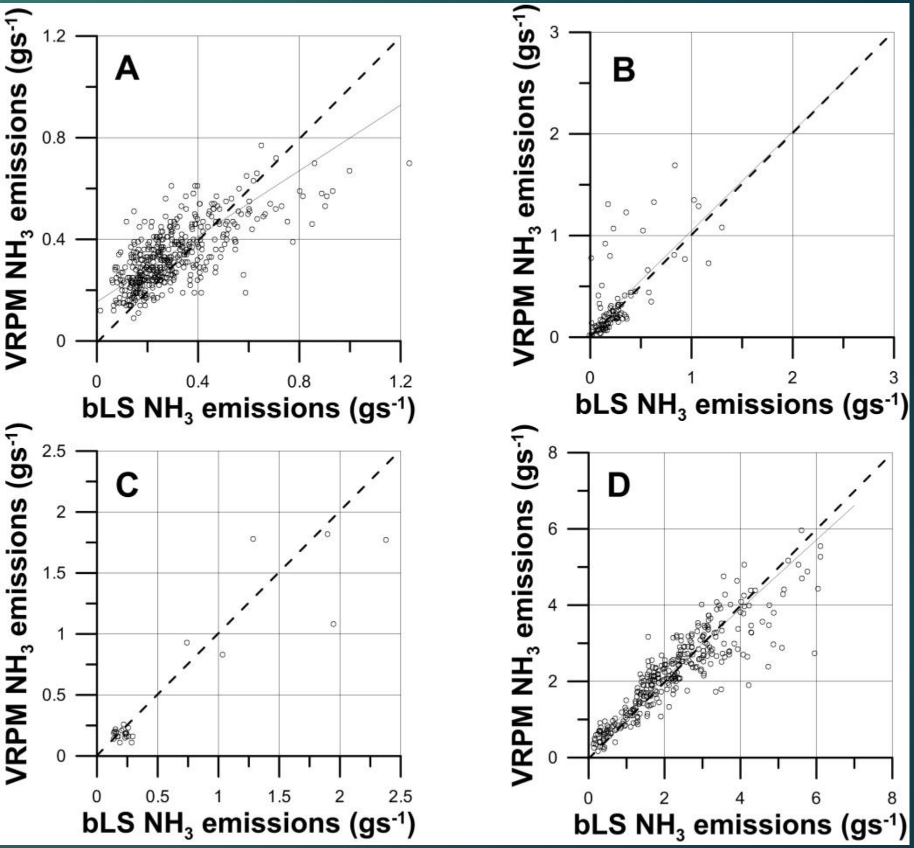
- $u_* > 0.15$ m/s
- $|L| > 2$ m
- $\sigma_\theta < 30°$
- angle of attack of a valid downwind PIC<60°
- $C_{bkgr} < 10$ ppb
- touchdown fraction>0.05

Emission error estimated at +/- 30% with +/-15% error due to representativeness of turbulence measurements

Emissions comparisons: RPM and bLS

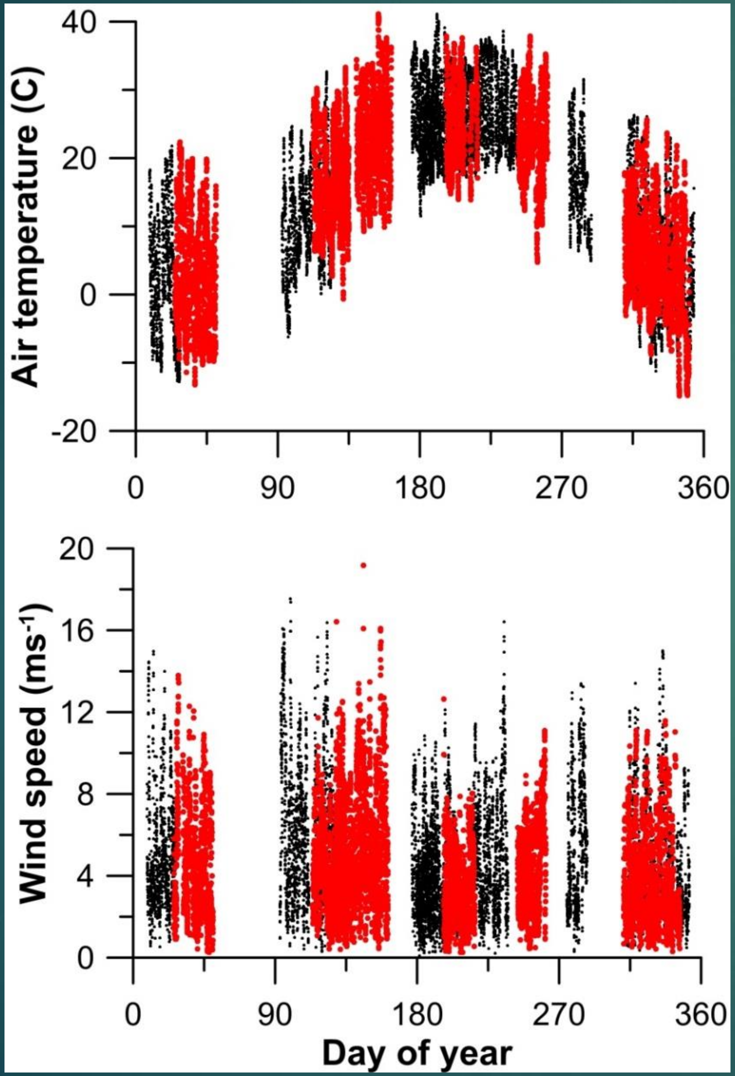
Comparisons of NH3 emissions determined by RPM and bLS at lagoons across USA

- Mean bias (RPM-bLS) across 8 farms: -0.04 gs^{-1} (-5%)



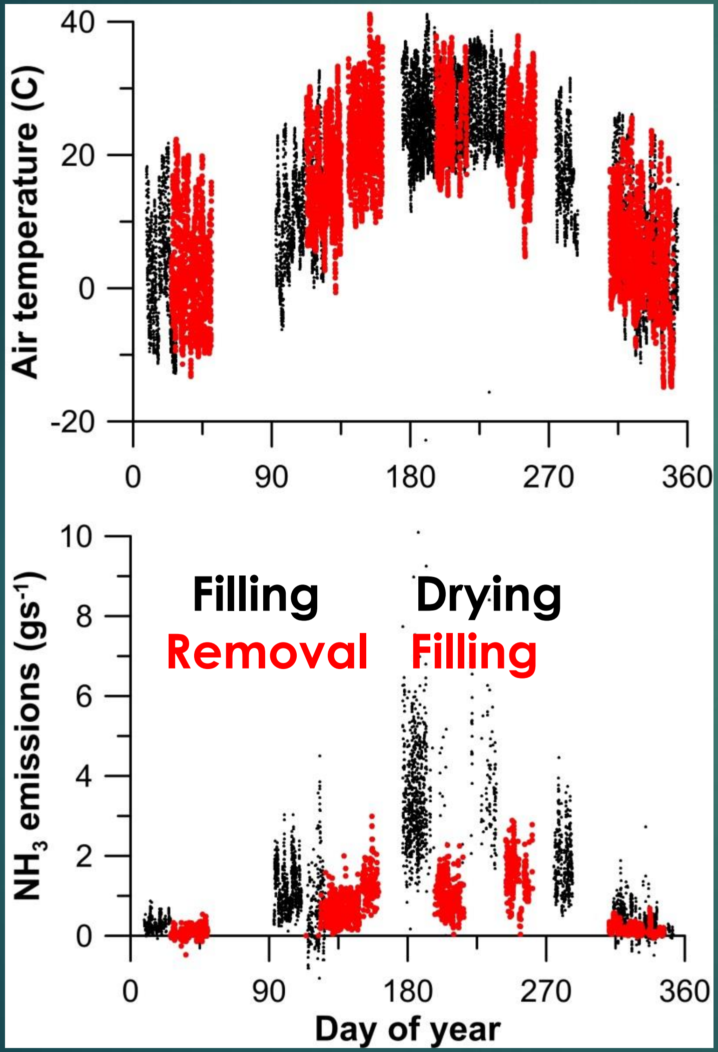
(Grant and Boehm, 2012)

OK climate- Hog farms



- Weather conditions similar at the two farms
- Wind speeds high all year
  - Lower maximums in summer than winter
- Temperature ranges greater in winter than summer

Hog lagoon emissions



- Breed to wean: 4526 meas.
- Finisher: 4367 meas.
- Highly variable daily variations vary through year
- Related to temperatures
- Greater from breed to wean than finisher Hog farm, but
  - Finisher manure loading > Breed to wean
- **Determine daily emission over year**

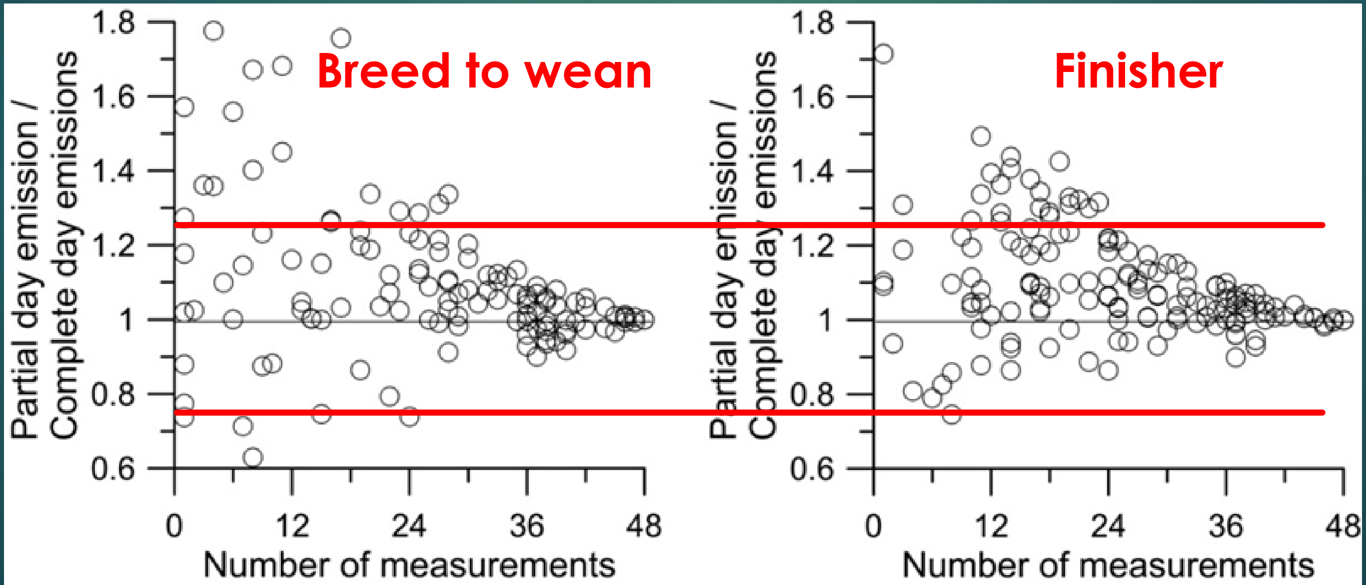
Hog farm conditions

	Breed to wean Mean C_{bkg}	Finisher Mean C_{bkg}
Month	NH_3 ($\mu L\ L^{-1}$)	NH_3 ($\mu L\ L^{-1}$)
Jan,Feb	-0.012	0.028
Apr	0.000	0.034
May	0.057	0.054
June	0.147	0.029
Juky	0.054	0.145
Aug	0.086	0.226
Sept	0.111	
Oct		0.040
Nov, Dec	0.071	0.006

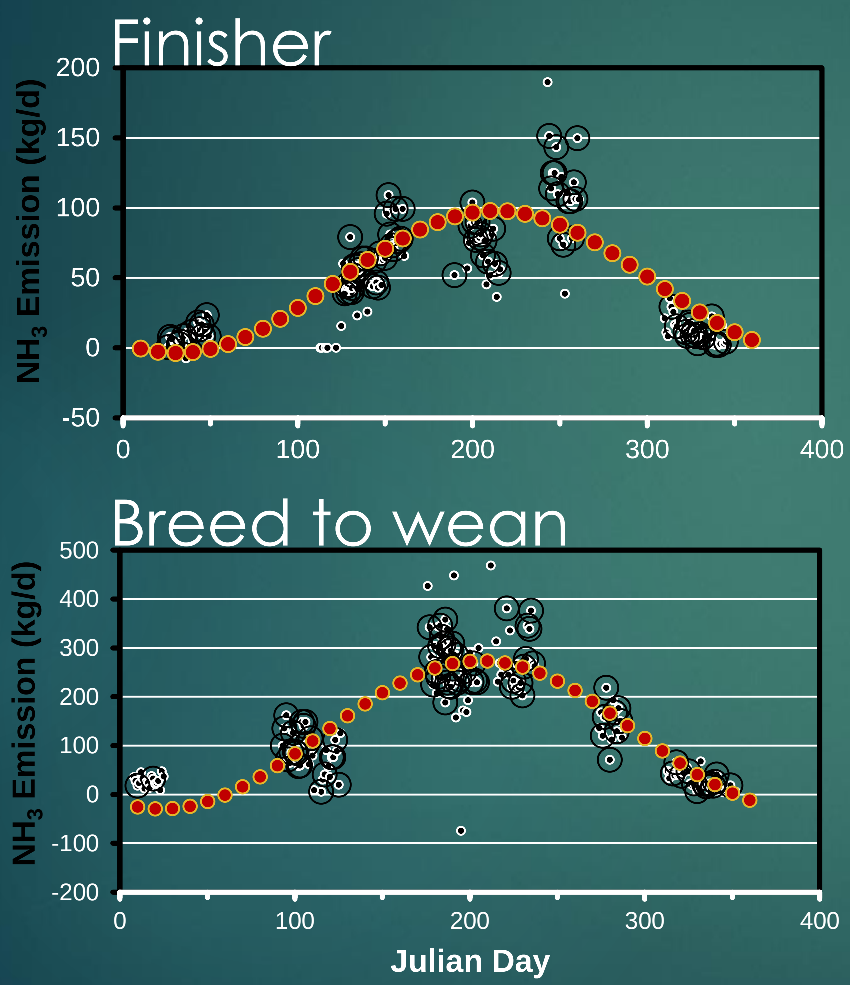
- Background concentrations were significant due to proximity to barns and surrounding farms

Daily emissions of representative day

- Detailed analysis of emissions characteristics at OK hog farms showed measurements of >50% of day gave a daily emissions estimate error of less than 25%



Annual pattern: daily emissions



(Grant et al. 2013)

- Breed to wean > finisher farm
- Pattern correlated with temperature
  - Winter emissions low due to ice and cold

Large circles indicate representative day

Annual emissions

Mean emission	Breed/ wean	Finisher
Kg d^{-1}	144	56
g m^{-2} d^{-1}	6.8	1.2

Summer emissions

Mean emission	Breed/ wean	Finisher
Kg d^{-1}	274	83
g m^{-2} d^{-1}	13	3.7

Summer emissions twice that of annual emissions (assuming +/-30% error)

(Grant et al. 2013)

Annual emissions

Mean emission	Breed/ wean	Finisher
Kg d^{-1}	144	56
g d^{-1} hd^{-1}	52	19

Summer emissions

Mean emission	Breed/ wean	Finisher
Kg d^{-1}	274	83
g d^{-1} hd^{-1}	98	30

Feed input est. 131 gNH_3 $d^{-1}hd^{-1}$:
Approx. 40% (Breed to wean) and 15% (Finisher) of N lost as NH_3 from lagoons.

High emissions in summer must incl. much stored from spring.

(Grant et al. 2013)

Annual emissions: hog farms

Mean emission	Breed/ wean	Finisher
$g\ m^{-2}\ d^{-1}$	6.8	1.2
$mg\ kg\ VS^{-1}$	29	4
$g\ d^{-1} AU^{-1}$	110	120

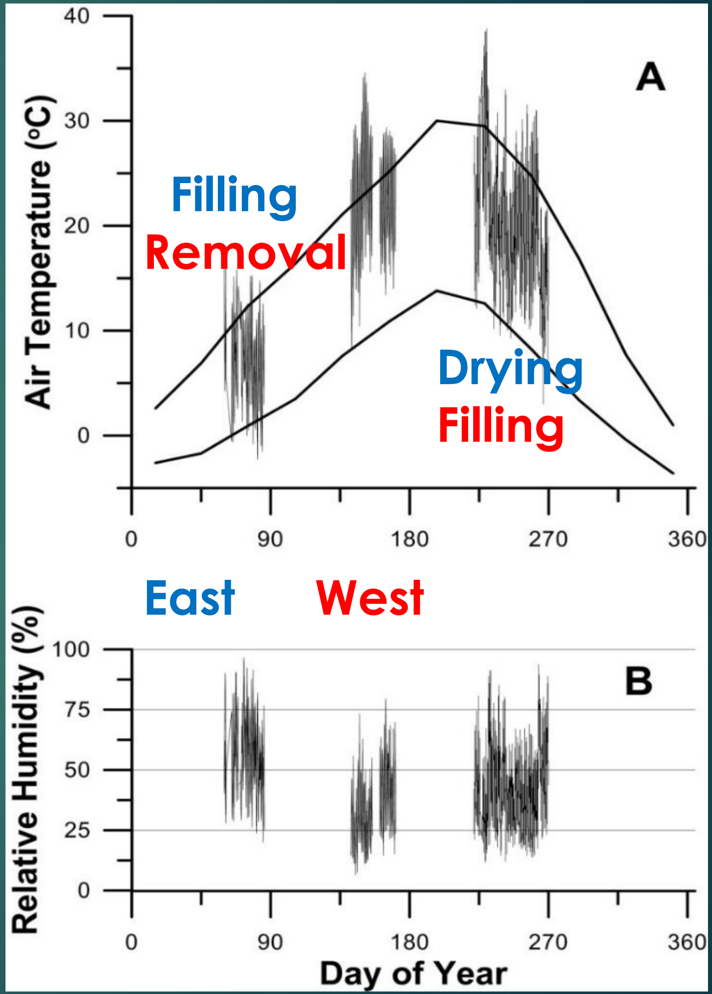
Emissions best correlated with AU

not VS loading as commonly used in IPCC estimates

(Grant et al. 2013)

WA climate: Dairy farm

- Measurement periods distributed over year
  - Manure phase x temperatures
- Measurement periods were representative of climate
  - Dry climate: H_2O evaporation increases basin[NH_3]

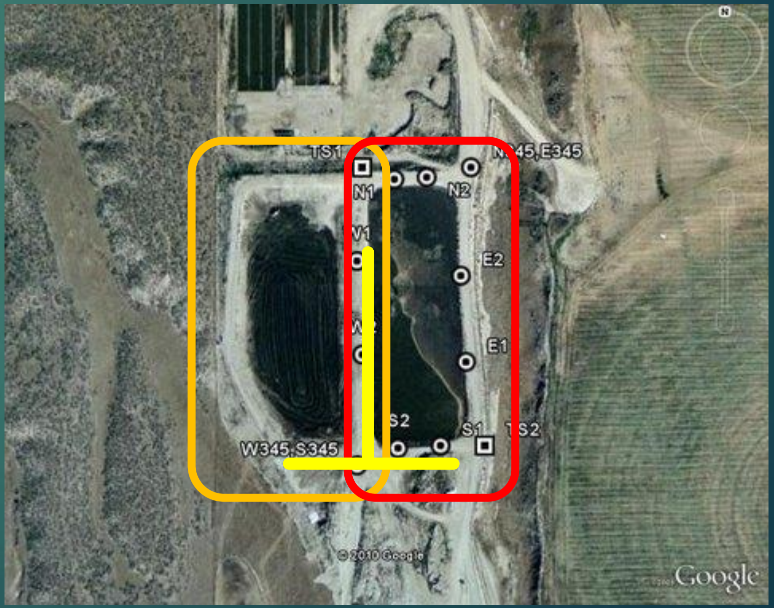


(Grant and Boehm, 2015)

Dairy farm conditions

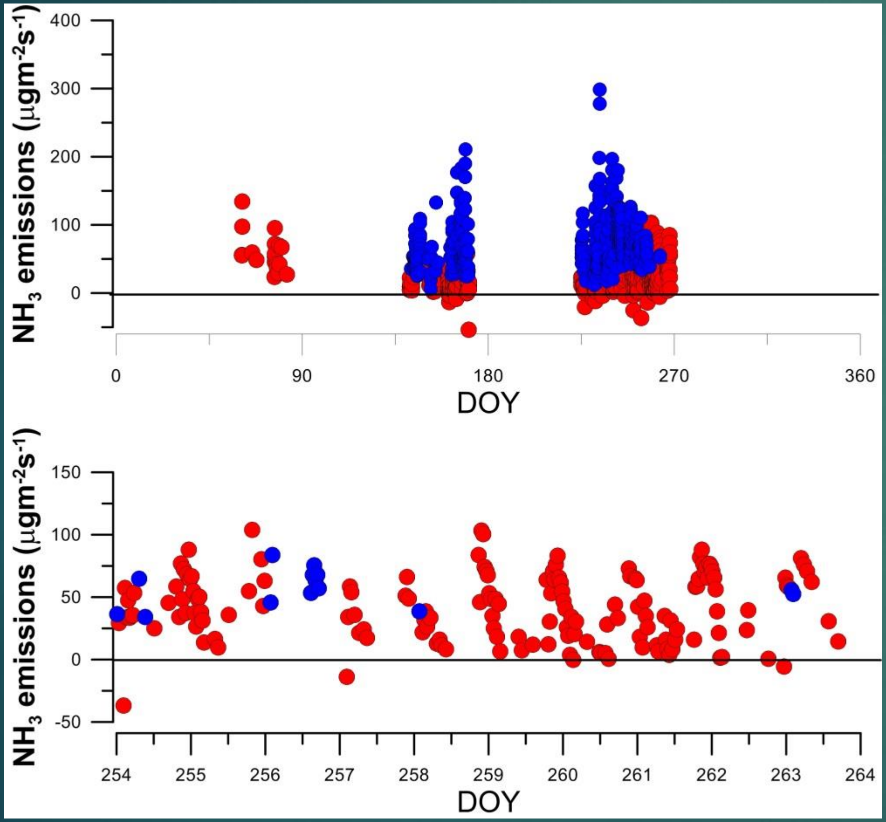
Month	Mean background concentration	Mean flux across east basin upwind side
	NH_3 (μL L^{-1})	NH_3 (gs^{-1})
Feb-Mar	0.037	0.014
May	0.149	0.279
Aug	0.142	0.436
Sept	0.156	0.229

Background concentrations were significant due to wide range of activities surrounding the measured basin



Background concentrations and VRPM influx to west basin not measured

Dairy basin emissions



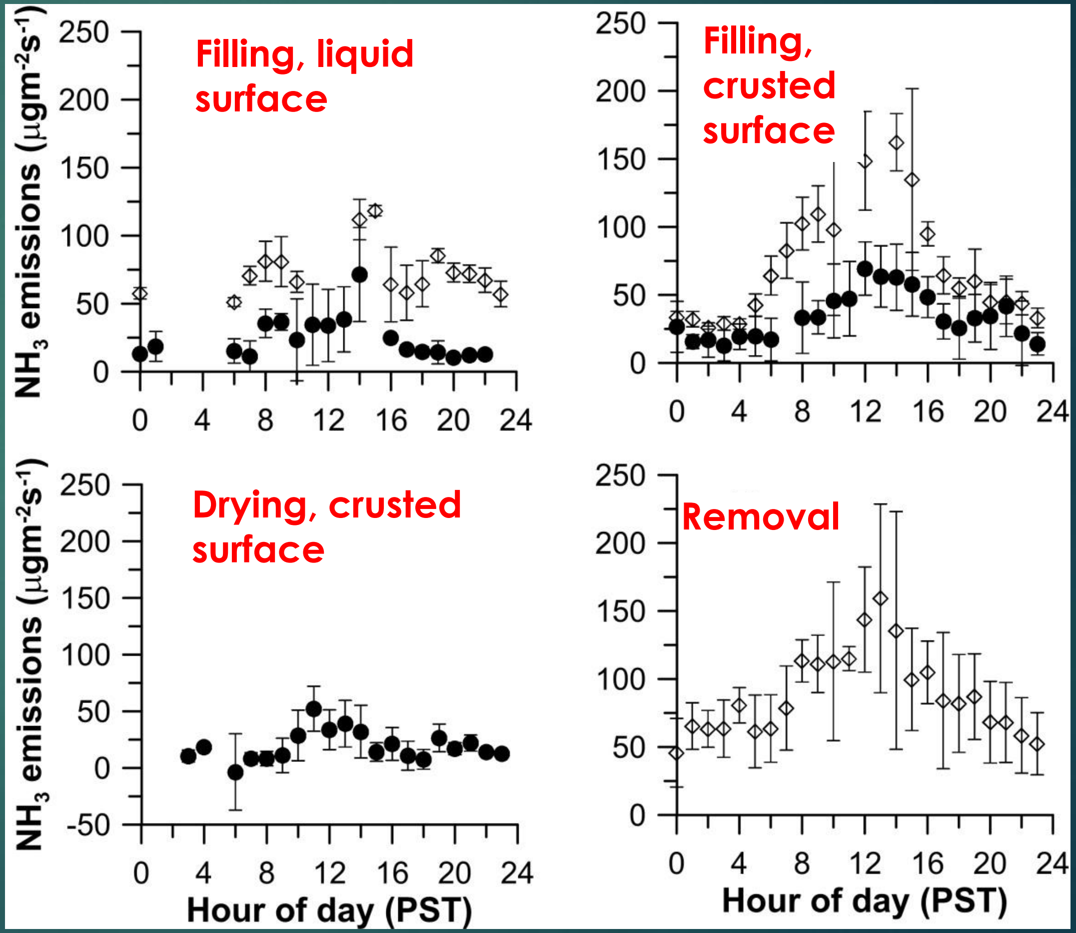
- East Basin: 522 meas.
- West Basin: 386 meas.
- East and west basin emissions similar
- Tendency for greater emissions variation over a day than over the year
- No valid representative days of emission (>75% measured)
- **Determine emissions of average day by phase of handing**

Diurnal variation at dairy

- Diurnal variation during filling and removal
- Negligible variation during drying with surface crust

Emissions from east (open circle) and west (closed diamond) basins.

Bars represent one standard deviation.



(Grant and Boehm, 2015)

Dairy NH_3 emissions during manure treatment phases

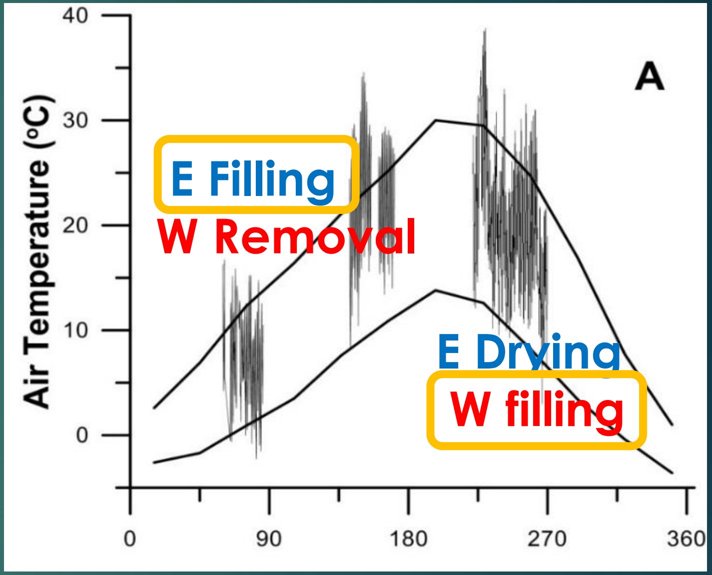
	bLS		VRPM		
Lagoon Conditions	N	Mean (SD) gs^{-1}	N	Mean (SD) gs^{-1}	
Liquid Fill (E basin)	19	0.66 (0.21)			
Liquid Fill (W basin)			64	0.69 (0.20)*	
Crusting Fill (E basin)	188	0.50 (0.27)	235	0.28 (0.20)	=
Crusting Fill (W basin)			126	0.69 (0.31)*	
Drying (E basin)	17	0.22 (0.15)	121	0.11 (0.14)	=
Removal (W basin)			196	0.70 (0.45)*	

* Assuming upwind flux of 0.24 gs^{-1} +/- 0.17 gs^{-1}

(Grant and Boehm, 2015)

Dairy NH_3 emissions during manure treatment phases

Lagoon Conditions	Best Estimate
	Mean (+/- SD)
	Kg d^{-1}
Liquid Fill (east basin)	59 (24)
Liquid fill (west basin)	90 (27)
Crusting Fill (east basin)	35 (29)
Crusting fill (west basin)	86 (50)
Drying (east basin)	34 (28)
Removal (west basin)	89 (42)



(Grant and Boehm, 2015)

Note differences in west and east basin emissions

Dairy NH_3 emissions during manure treatment phases

	Best Estimate	
Lagoon Conditions	Mean (+/- SD)	
	Kg d^{-1}	g $d^{-1}m^{-2}$
Liquid Fill (east basin)	59 (24)	4.5
Liquid fill (west basin)	90 (27)	6.0
Crusting Fill (east basin)	35 (29)	2.3
Crusting fill (west basin)	86 (50)	5.7
Drying (east basin)	34 (28)	2.6
Removal (west basin)	89 (42)	5.9

Note similarity in west and east basin area-based emissions during filling

except

(Grant and Boehm, 2015)

Dairy NH_3 emissions during manure treatment phases

	Best Estimate	
Lagoon Conditions	Mean (+/- SD)	
	Kg d^{-1}	g $d^{-1}m^{-2}$
Liquid Fill (east basin)	59 (24)	4.5
Liquid fill (west basin)	90 (27)	6.0
Crusting Fill (east basin)	35 (29)	2.3
Crusting fill (west basin)	86 (50)	5.7
Drying (east basin)	34 (28)	2.6
Removal (west basin)	89 (42)	5.9

Note similarity in west basin emissions in all phases

Unknown error in upwind flux estimation

(Grant and Boehm, 2015)

Dairy NH_3 emissions during manure treatment phases

	Best Estimate	
Lagoon Conditions	Mean (+/- SD)	
	Kg d^{-1}	g $d^{-1}m^{-2}$
Liquid Fill (east basin)	59 (24)	4.5
Liquid fill (west basin)	90 (27)	6.0
Crusting Fill (east basin)	35 (29)	2.3
Crusting fill (west basin)	86 (50)	5.7
Drying (east basin)	34 (28)	2.6
Removal (west basin)	89 (42)	5.9

Note similarity in east basin area-based emissions crusting to drying

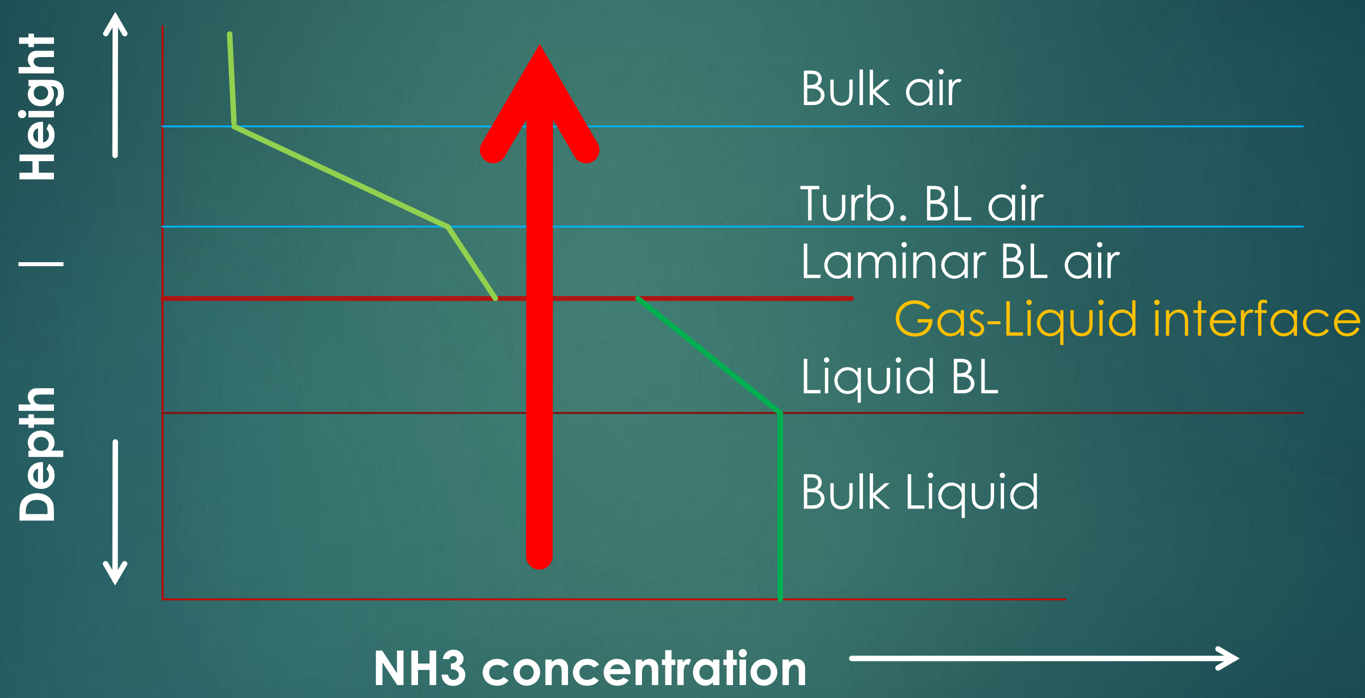
(Grant and Boehm, 2015)

NH_3 emissions during storage basin manure treatment phases (270 d cycle)

Lagoon Conditions	(Grant and Boehm, 2015)		
	g $d^{-1}hd^{-1}$	g $d^{-1}AU^{-1}$	g $d^{-1}AU^{-1}ha^{-1}$
Fill	17.4	9.1	6.0
Drying	7.2	4.9	3.2
Removal	18.8	12.8	8.5

NH_3 emissions from basin (as N) represents 23% (+/-9%) of manure N loading over fill time

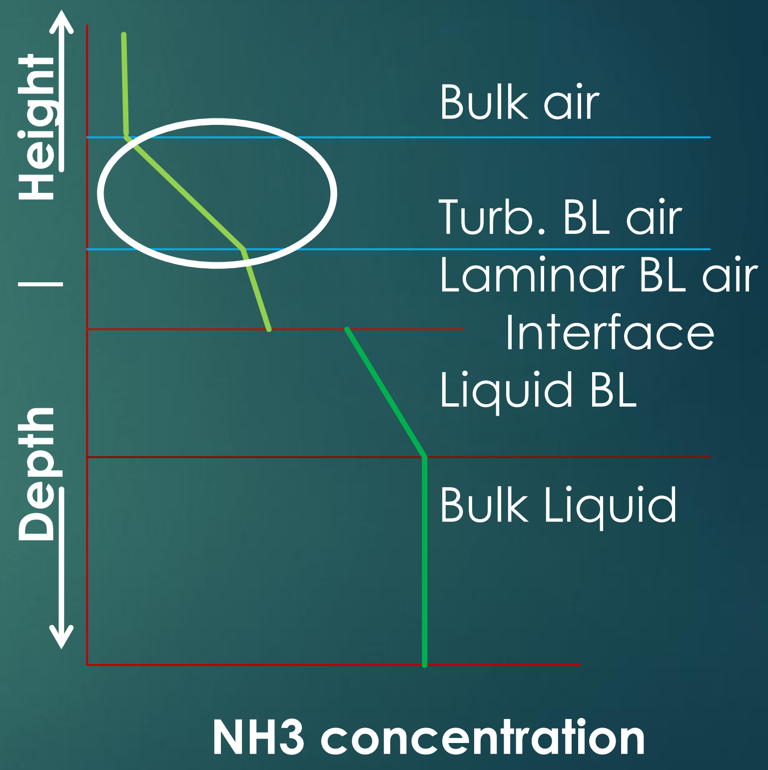
Modeling NH_3 emissions: Two film diffusion theory



Emission depends on
- NH_3 solubility properties
- lagoon properties
- Air flow/transport properties

Wind influence

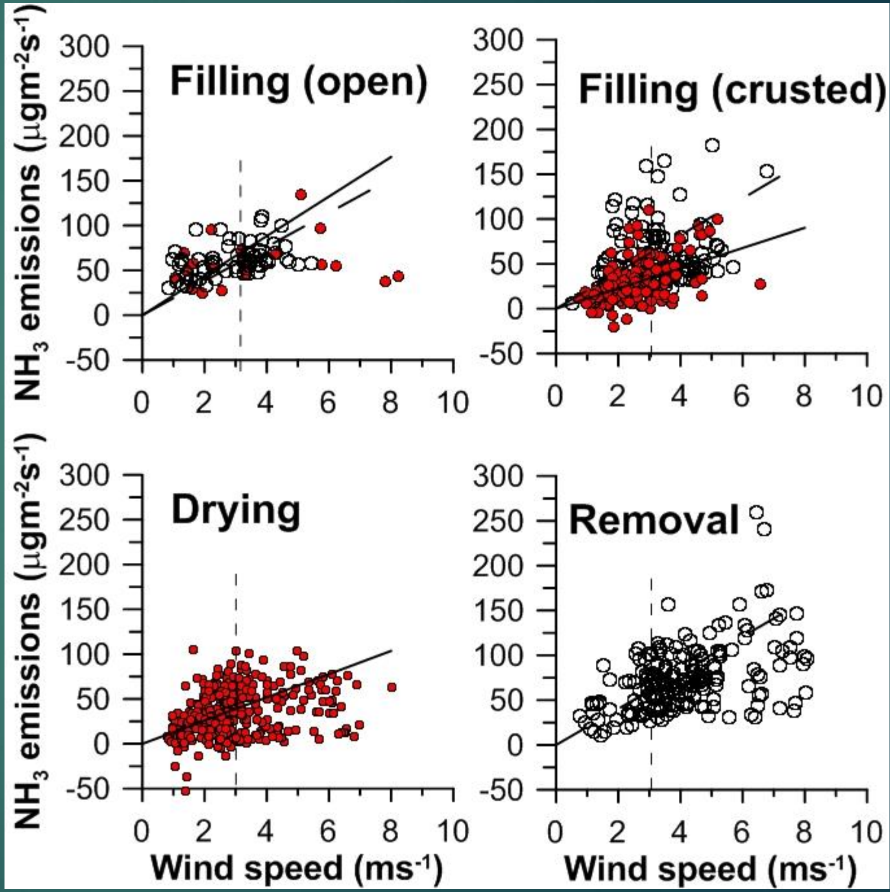
- **Wind-induced turbulence removes NH3 from laminar layer of air above lagoon/basin**



Wind influence: Dairy farm

Wind speed correlated with NH_3 emissions as two-film theory

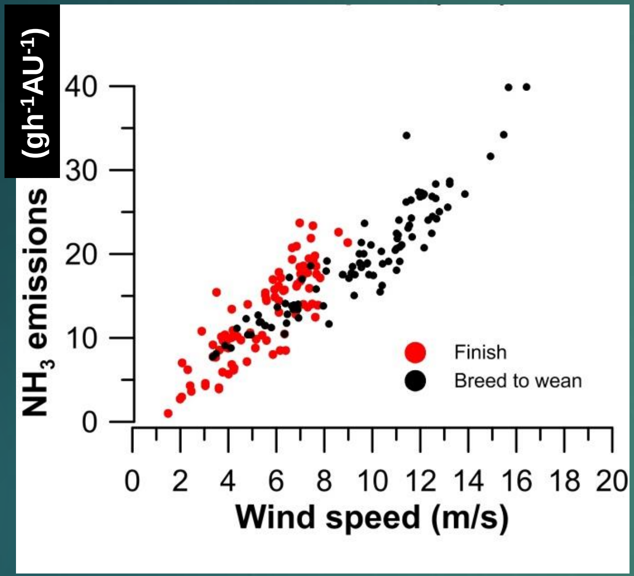
Linear (R^2)	East	West
Filling, liquid	0.88	0.71
Filling, crust	0.68	0.75
Drying	0.70	
Removal		0.85

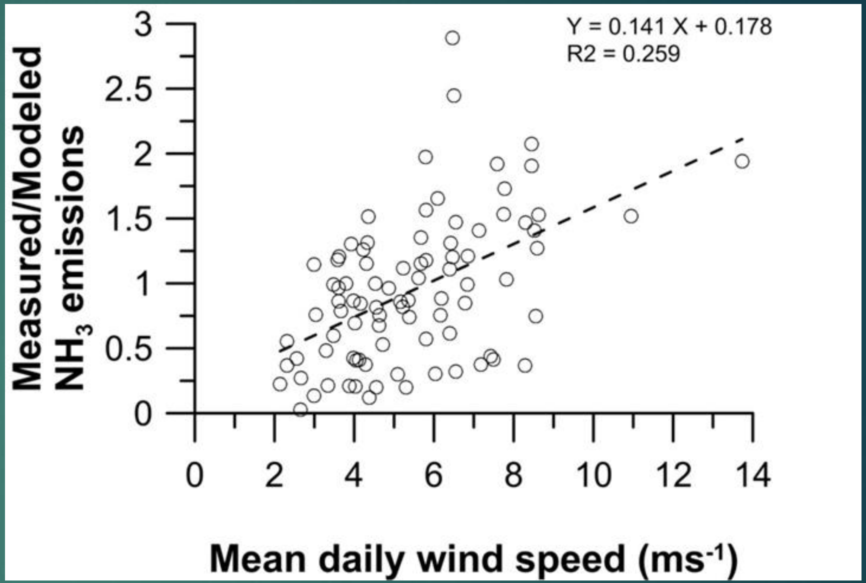


$$\overline{E_{phase}} = \alpha \overline{U}$$

(Grant and Boehm, 2015)

Wind influence: Hog farms



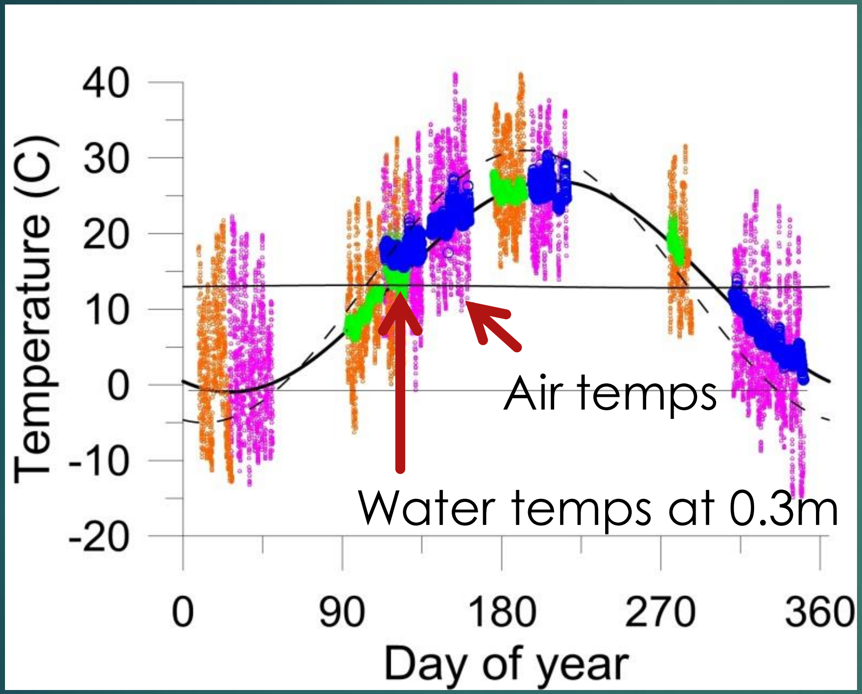


- Good correlation between wind speed and emissions exists for various days
- Variation in correlation of wind speed and temperature (stability) confuses the ‘typical daily emissions’’

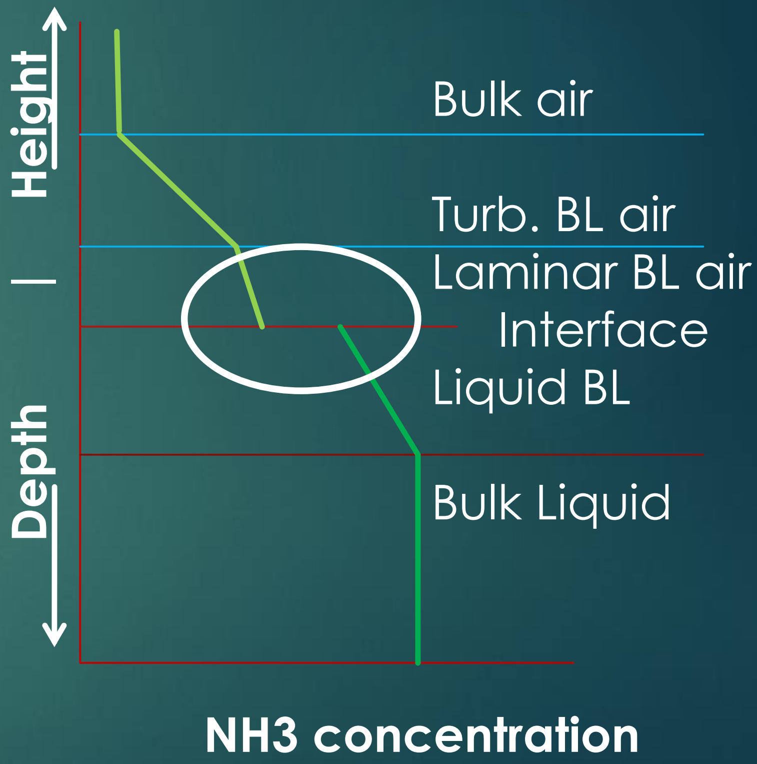
(Grant et al. 2013)

Temperature Influence

Solubility of NH_3 : Van't Hoff equation: $e^{-B\left(\frac{1}{T_{air}}-\frac{1}{298}\right)}$



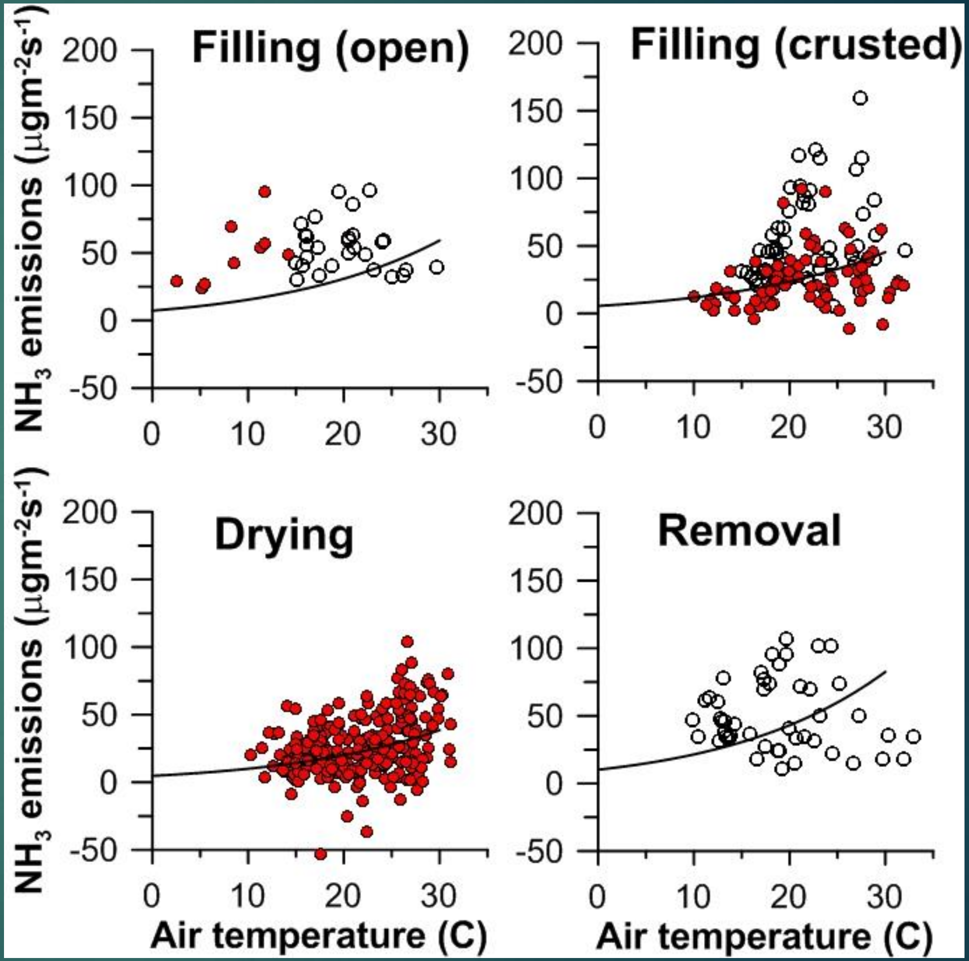
Proxy temperature overstates variability



Temperature influence: dairy farm

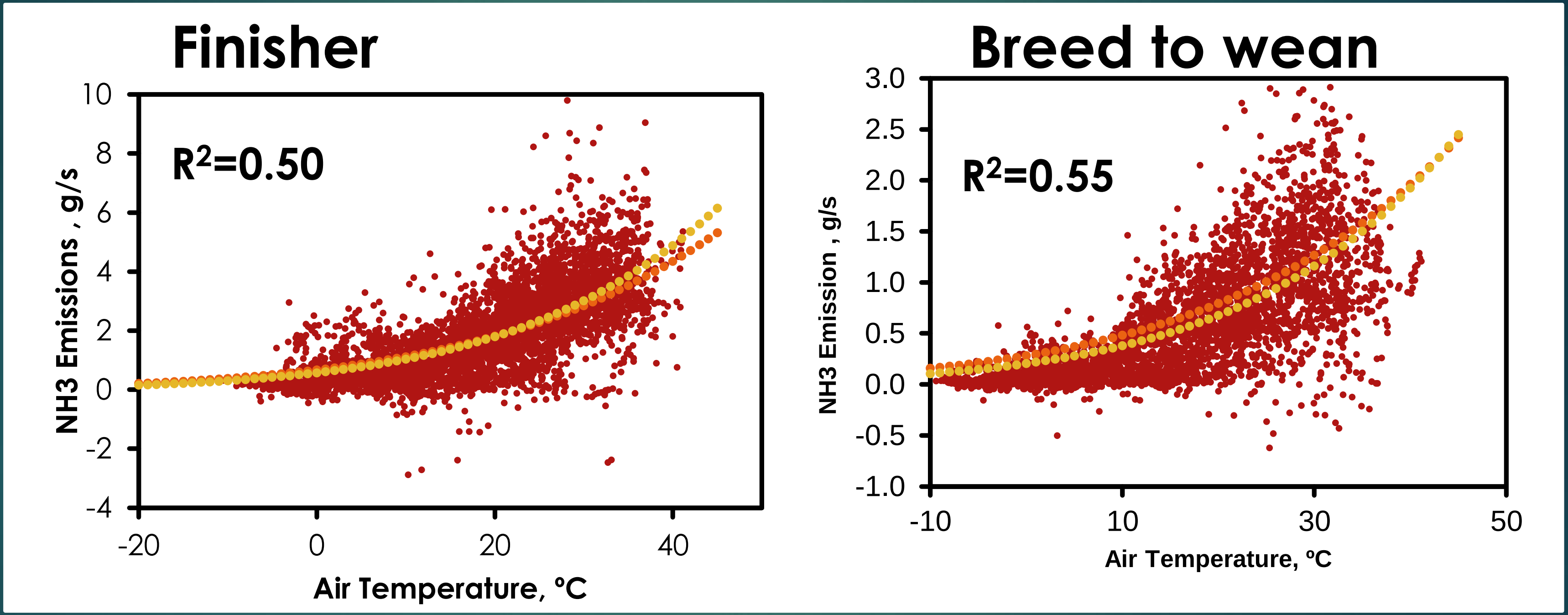
Emissions normalized by basin area under low wind (winds<3 ms^{-1})

- Temperature influence during filling and drying



Proxy temperature overstates variability

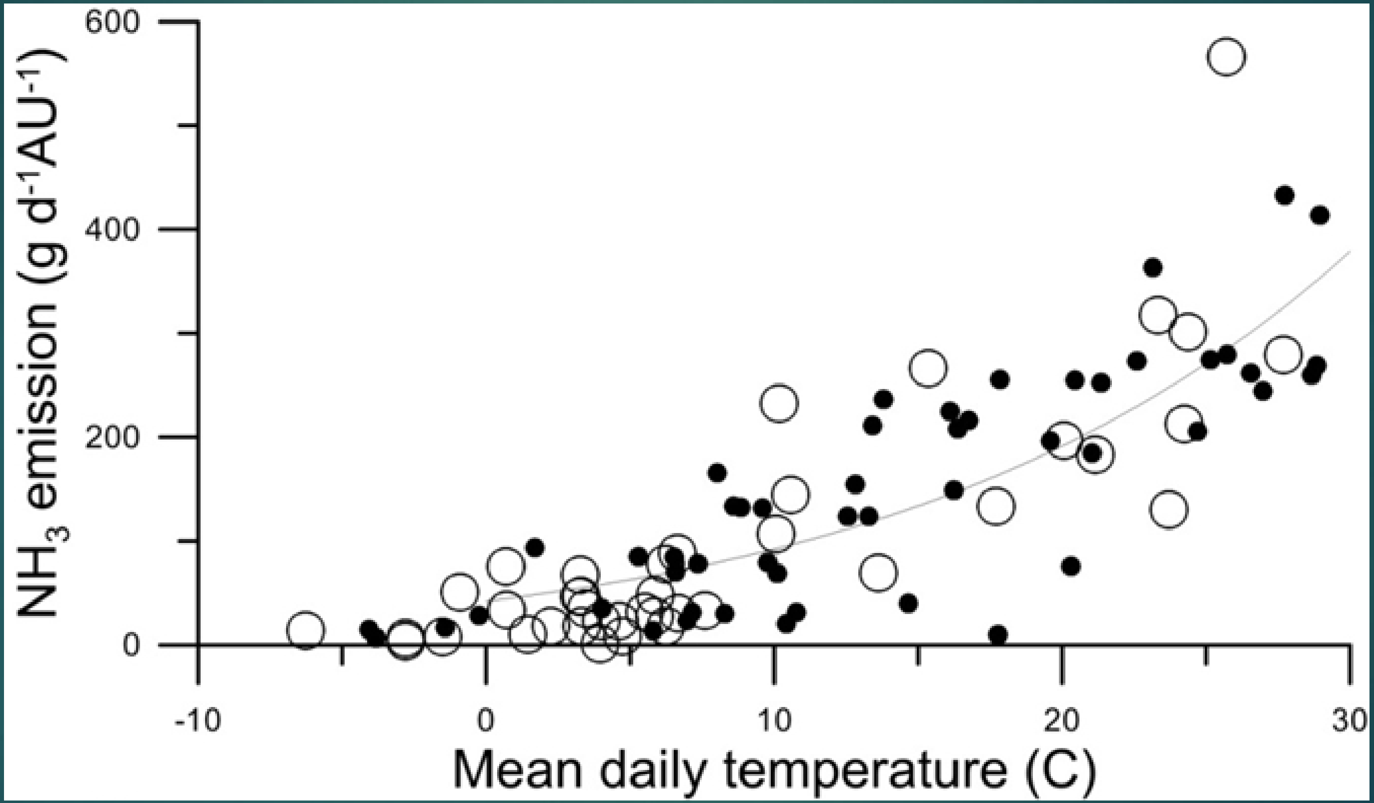
Temperature influence: hog farms



Proxy temperature overstates variability

(Grant et al. 2013)

Daily Temperature influence: hog farms



(Grant et al. 2013)

Summary: Hog and Dairy NH_3 emissions

- Emissions from two different types of hog operations were similar when normalized on AU
  - can be modeled primarily using temperature (Grant et al., 2013)

- Emissions of dairy basin vary over phases
  - greatest during removal and least during drying
  - can be modeled primarily using wind speed

  (Grant and Boehm, 2015)

Conclusions: Hog and Dairy NH_3 emissions

- Emissions cannot be estimated from current daily intake or manure production (large storage) (Grant et al., 2013).
- Emissions in the dry west are climate (temperature and wind) dependent (Grant et al., 2013 , Grant and Boehm, 2015)
- For farms with phases to manure handling, consideration of all phases and possibly the timing during the year is needed to assess annual emissions (Grant and Boehm, 2015)

References

- Grant, R.H.; M.T. Boehm and A.J. Lawrence. 2013. ***Agric. Forest Meteorol***. 180: 236-248
- Grant, R.H.; M.T. Boehm; A.J. Lawrence and A.J. Heber. 2013. ***Agric. Forest Meteorol***. 180: 203-210
- Grant, R.H.; M,T. Boehm. 2015. ***J. Environ. Qual***. 44:127-136

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