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Application of open and closed-path lasers for improving the estimates of the agricultural emissions of methane and nitrous oxide

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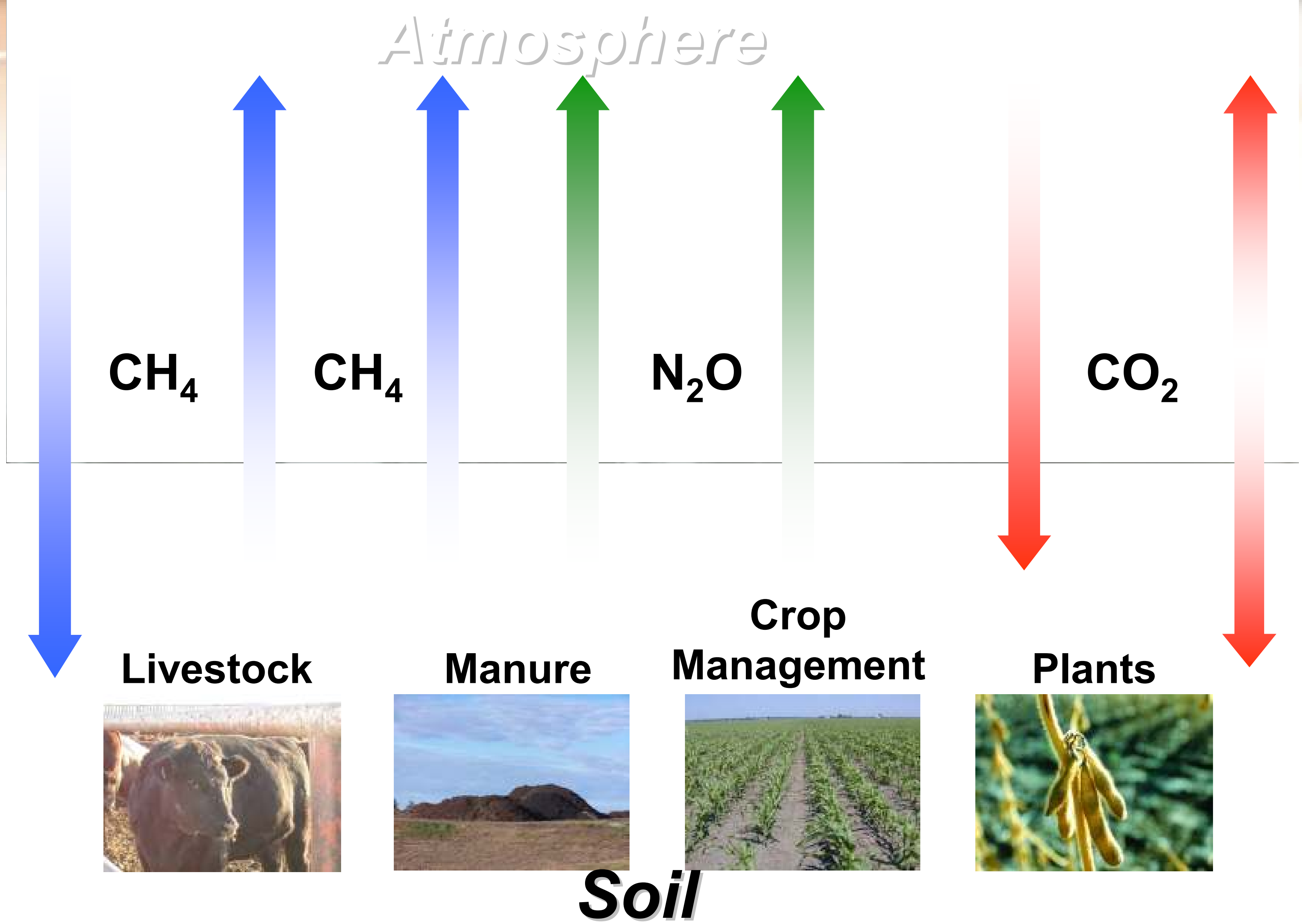
Outline

- Greenhouse gas emissions from agricultural sources
- A tool to calculate GHG emissions at the farm level
- Open-path lasers for the measurement of CH_4 and NH_3 emissions from agricultural sources
- Closed path lasers for the measurement of CH_4 and N_2O emissions (field and regional scales)
- Summary

Agricultural GHG Emissions



Global sources of anthropogenic greenhouse gas emissions: Methane and Nitrous Oxide

Methane emissions from the energy, waste and agriculture sectors amount to about 350 Tg CH_4 per year or 7350 Tg CO_2 eq. (1Tg = 1 million tonnes).

Nitrous oxide emissions from all sectors amount to 6.7-8.1 Tg N_2O-N per year or 2077-2511 Tg CO_2 eq.

Source: Denman et al. (2007)

Agriculture's contribution to global methane and nitrous oxide emissions

Agriculture is responsible for approximately 40-50% of global methane emissions.

Agriculture is responsible for approximately 50-70% of global nitrous oxide emissions.

Source: Denman et al. (2007)

Agricultural Sources of Methane

Enteric fermentation (digestion) by ruminant animals 86 Tg CH_4 per year

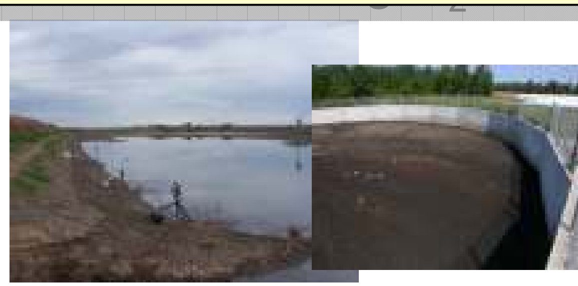
Management of animal manures 18 Tg CH_4 per year

Source: Denman et al. (2007)

Agricultural Sources of Nitrous Oxide

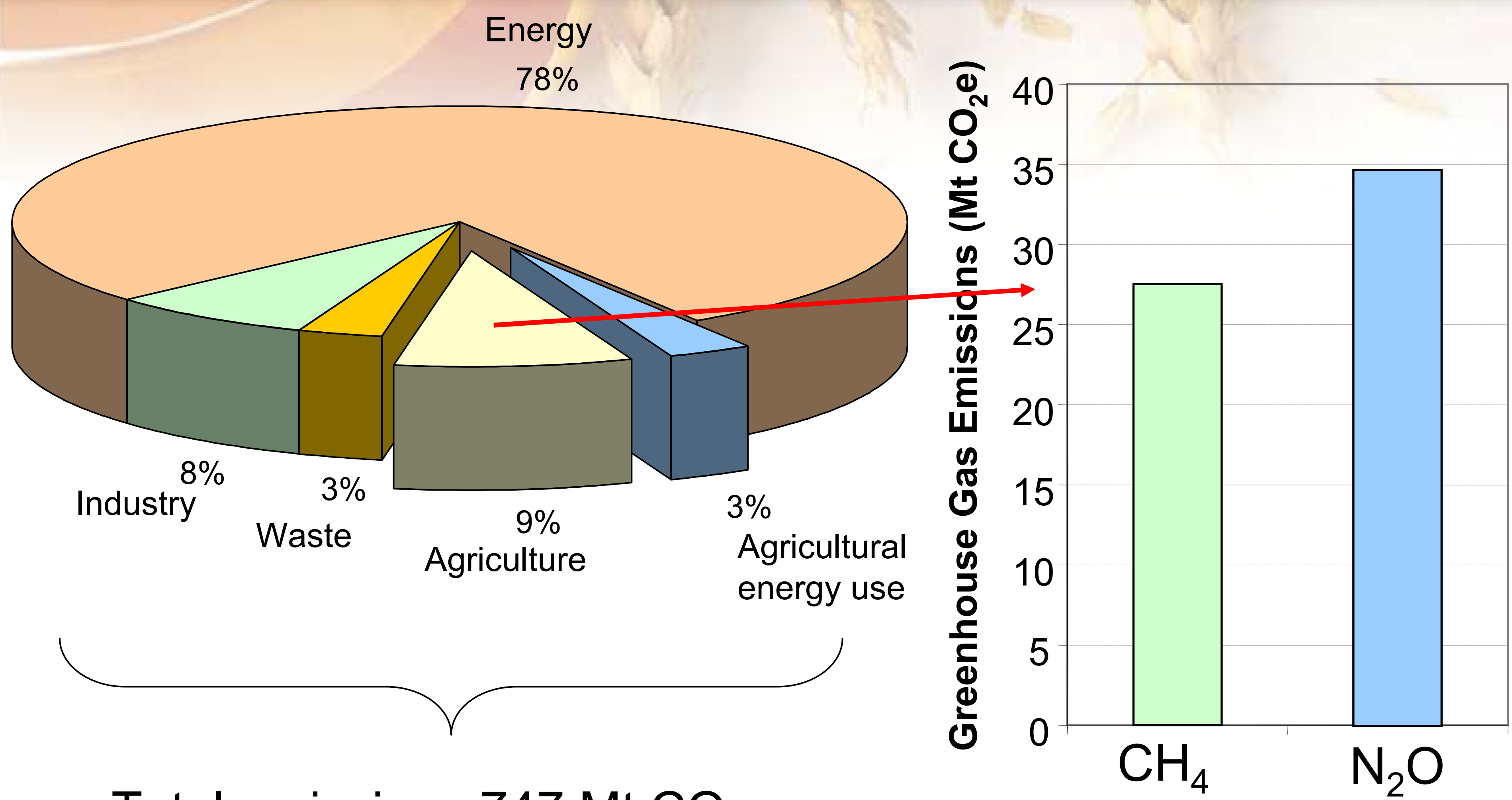
Agricultural soils – Direct and indirect emissions from application of synthetic/manure fertilizers, crop residue decomposition, waste deposition by grazing animals and cultivation of organic soils 4.7 Tg N_2O-N.

Manure Management – Direct emissions from manure storage 0.5 Tg N_2O-N.



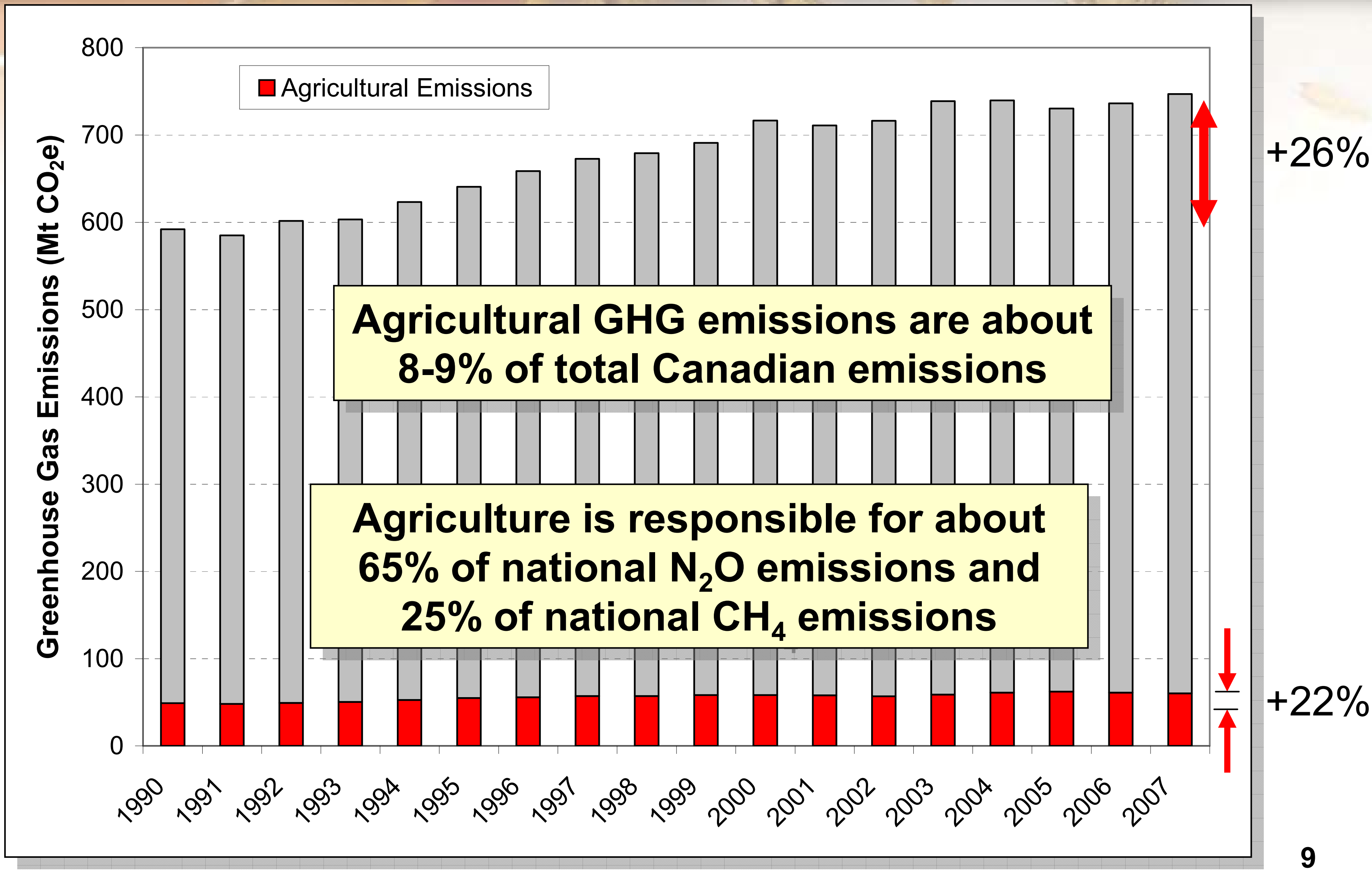
Source: US EPA (2006)

Greenhouse Gas Emissions by Sector in Canada – 2006



Total emissions 747 Mt CO_2e

Canada's Greenhouse Gas Emissions



Holos – A tool to calculate whole farm GHG emissions in Canada

Knowledge gained during the Model Farm program has been synthesized in a user friendly computer program, Holos, which estimates whole farm GHG emissions.

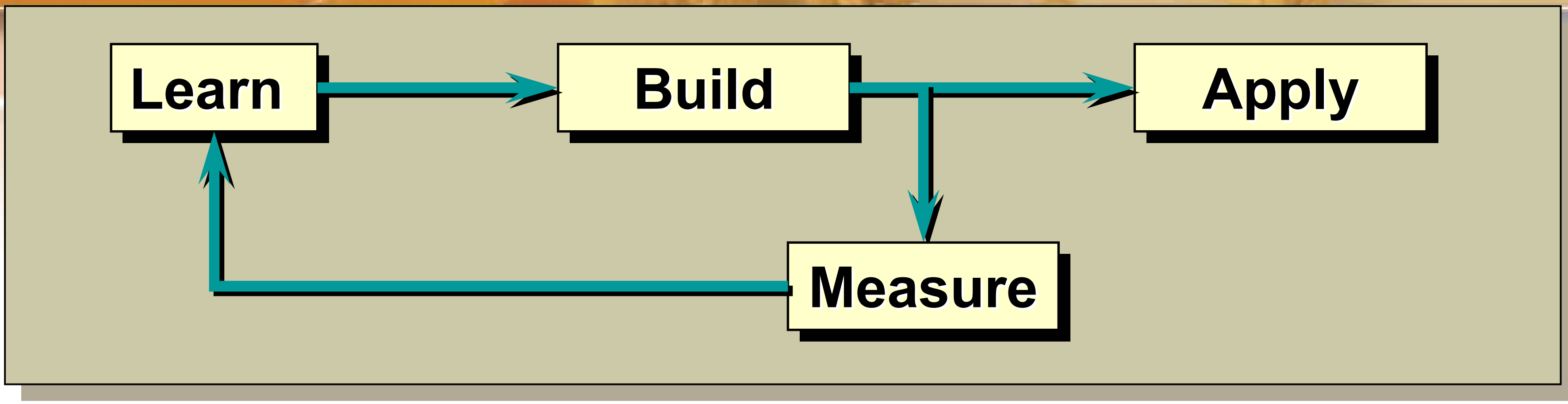
Holos – Greek, meaning whole or complete

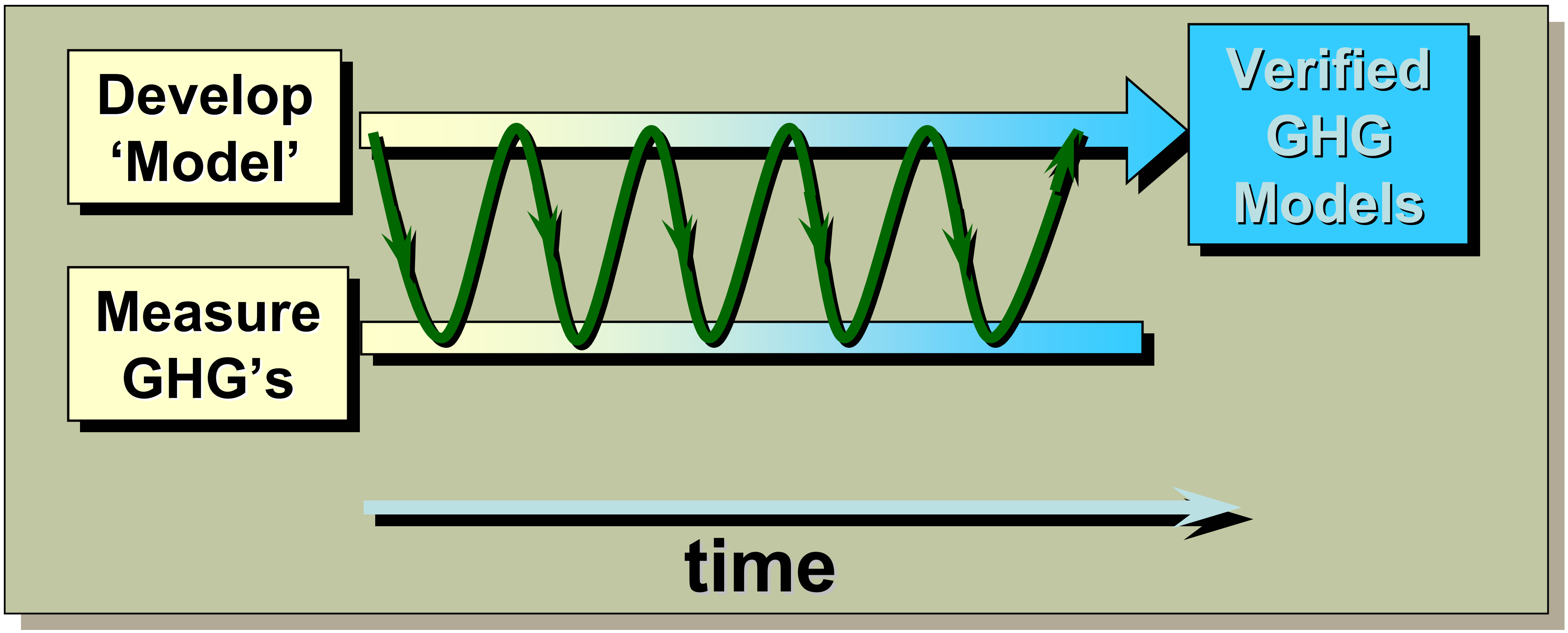
Holos

A tool to estimate and reduce GHGs from farms

Program available for download at: www4.agr.gc.ca. Follow the 'Science and Innovation' link

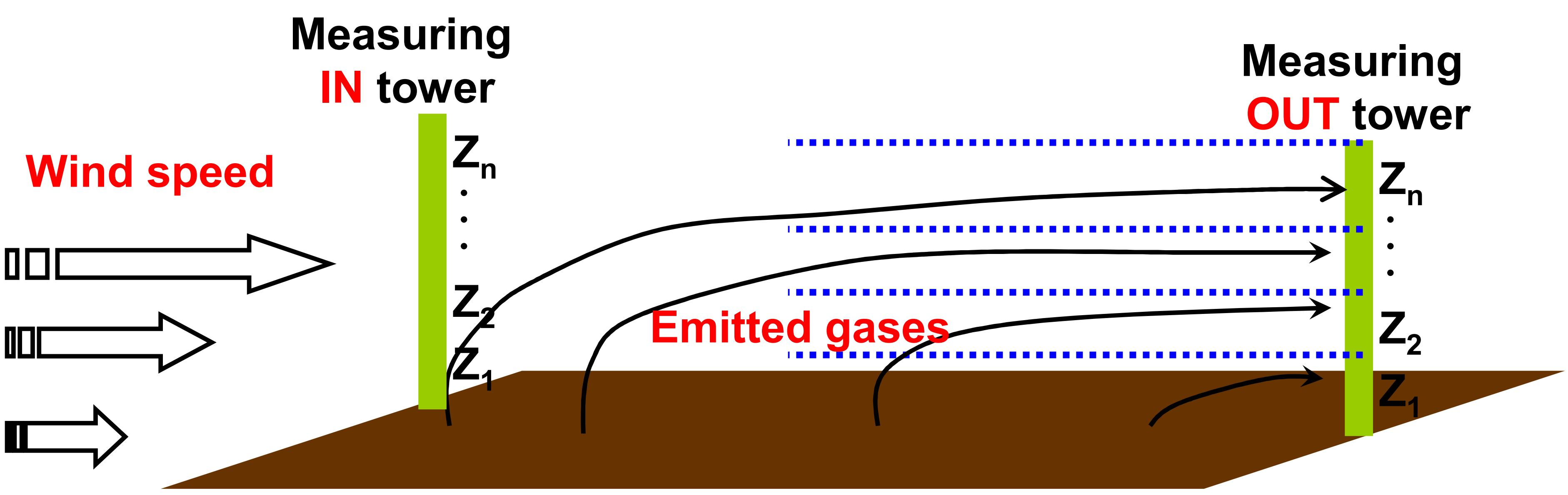
How do you build such a tool?





Micrometeorological Mass Balance (Integrated Horizontal Flux) method

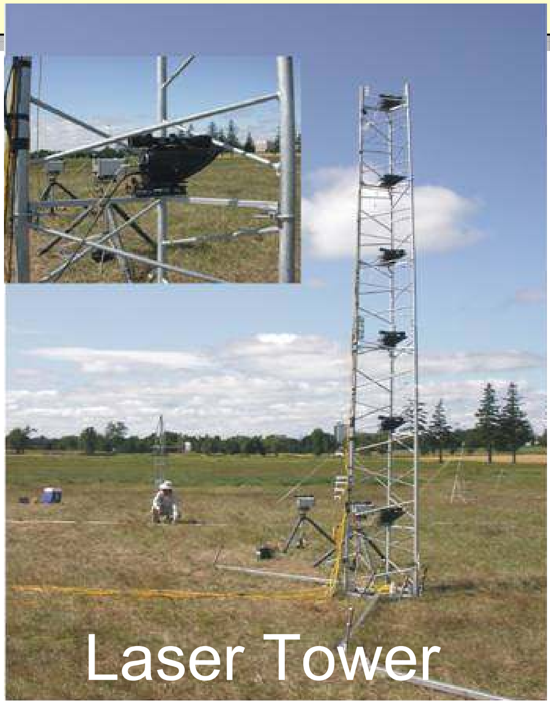
- Appropriate for heterogeneous and small areas (<0.2 ha)
- Difference in concentration between OUT and IN tower (ΔC)



Strong source with small area (eg. manure tank)

Mass Balance Technique – Modified Micrometeorological Mass Difference approach

- Simplified approach, does not require air sampling on all four sides, only upwind and downwind
- Width of laser line should be at least 6 times the width the of the source area
- Limited by wind direction, which should not be more than 45º to the laser lines



Testing the MMD technique with a synthetic tracer release

The MMD technique was tested using a synthetic tracer (CH_4) release to simulate on farm release by cattle.

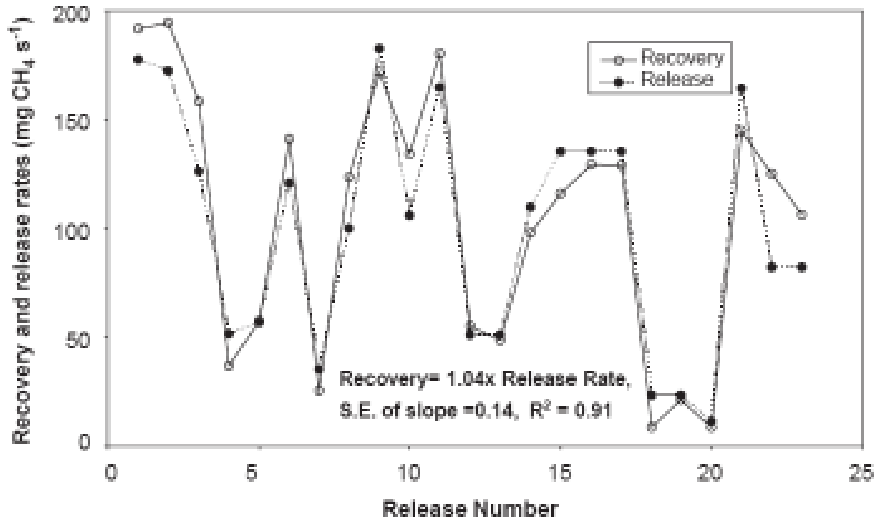


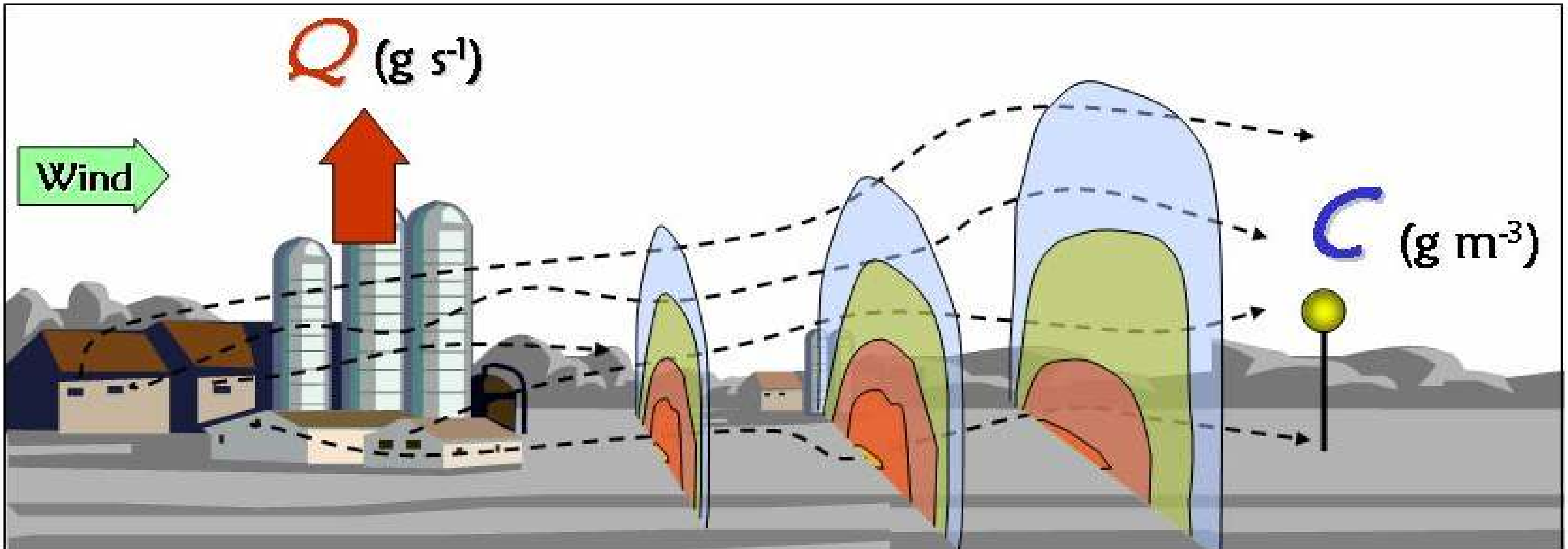
Fig. 5. Recovery and release rates in all acceptable releases. Recoveries are for the integrated instantaneous horizontal fluxes and an exclusion angle of 10°.

Methane recovery slightly exceeded methane release and was found that it could identify 10% changes in the rate of emission, provided the rate of emission was greater than about 40 mg CH_4 s^{-1}, equivalent to roughly 10 dairy cattle.

Source: Desjardins et al. (2004)

Micrometeorological tools: Inverse Dispersion Modeling

•Measuring emissions is about relating concentration observations (*C*) to emission rates (*Q*).
•Inverse-dispersion methods use atmospheric dispersion models to make the *C*-*Q* connection:
- •Measure downwind *C*
- •Model estimates *C*-*Q* relationship for given winds & source configuration
- •*Q* = Measured *C* * Model (*Q*/*C*)



•Gives substantial economy & flexibility -- ***especially with open-path sensors***
•bLS is a widely used variant of the inverse-dispersion method

Measurement Tools – Open path lasers

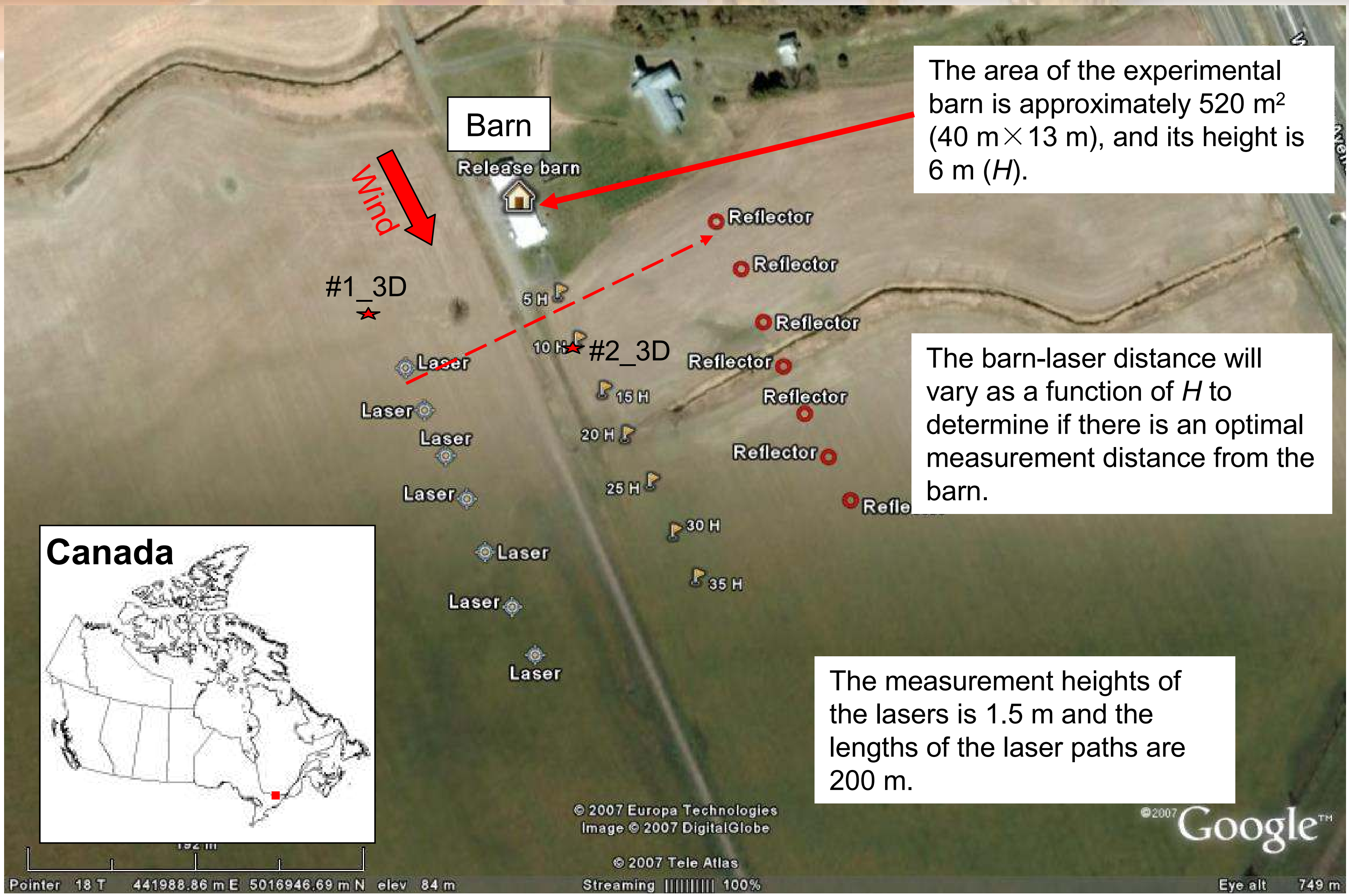
•Boreal Laser GasFinder or PKL Spectra-1 open path lasers for measurement of CH_4 and NH_3 emissions from agricultural sources (e.g. feedlots, barns, manure tanks, . . .)

•Lasers operate in the NIR (1,300 to 1,700 nm) with a spectral width of about 0.3 nm

•Approximate sensitivity for 100 m path length – CH_4: 0.02 ppm; NH_3: 0.1 ppm

•Path length of up to 1 km, depending on target gas

Estimating CH_4 emissions from synthetic barn release

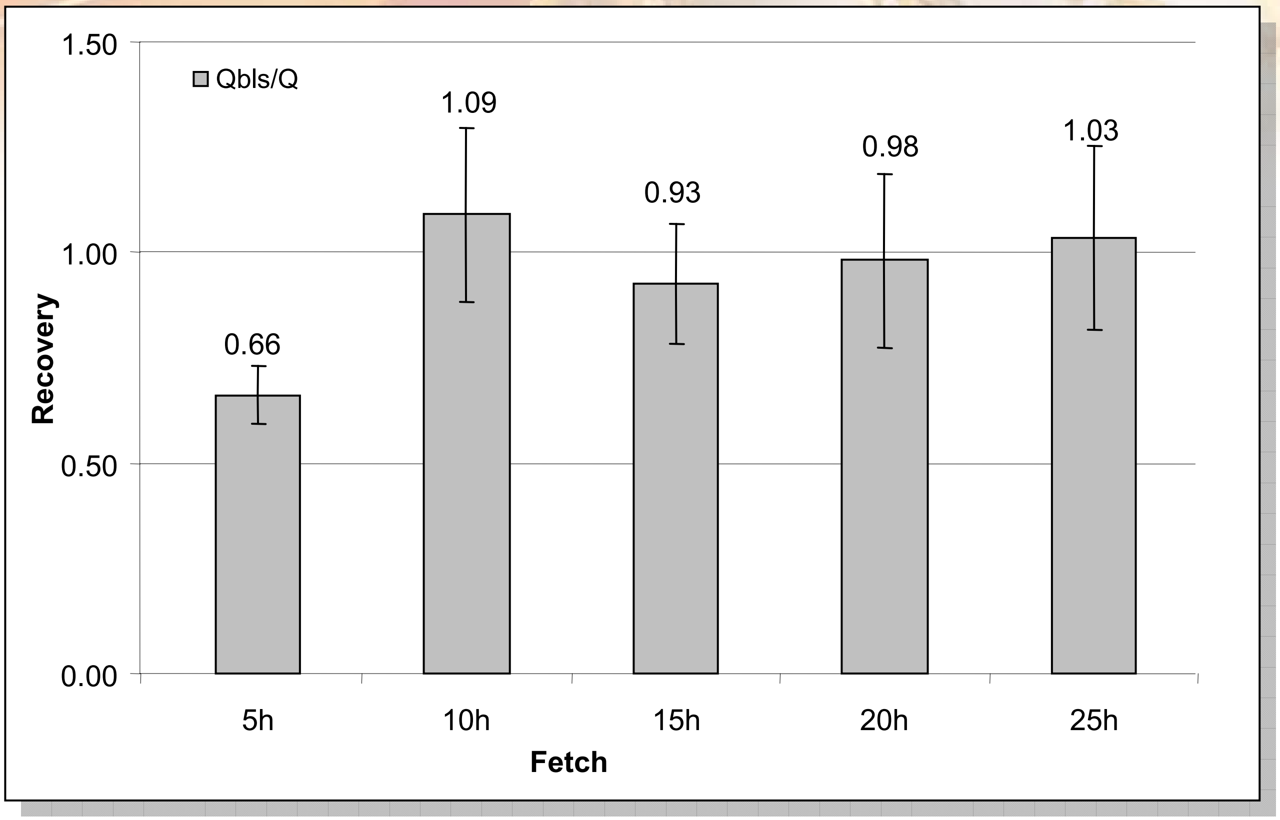


The area of the experimental barn is approximately 520 m^2 (40 m × 13 m), and its height is 6 m (*H*).

The barn-laser distance will vary as a function of *H* to determine if there is an optimal measurement distance from the barn.

The measurement heights of the lasers is 1.5 m and the lengths of the laser paths are 200 m.

Preliminary results of barn release in 2008

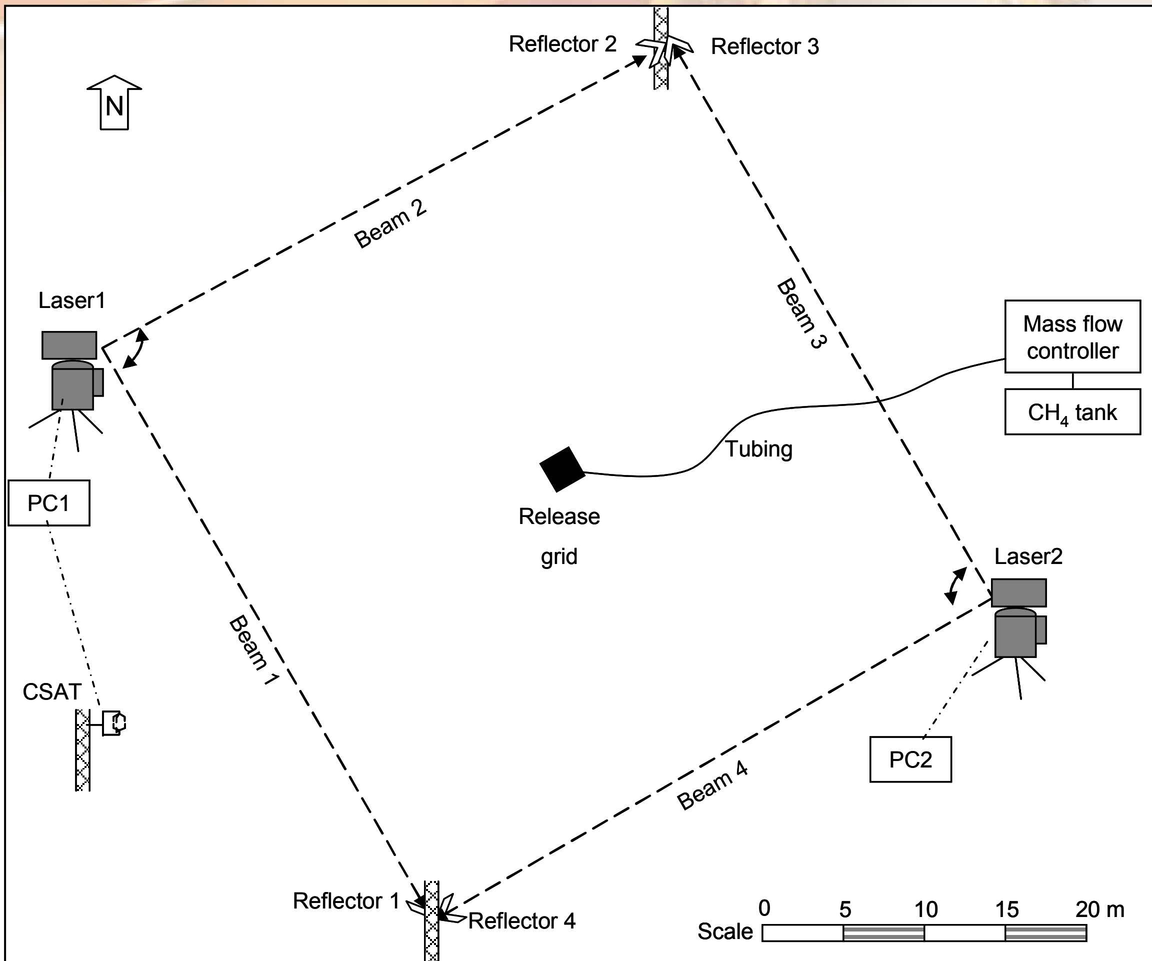


The flux rates from the barn were 60 L/min (140 dairy cows) and 80 L/min.

The criteria of the model for u_*, L and z_0 were met.

The barn height *h* was 6 m.

Continuous Measurement of Gas Emissions



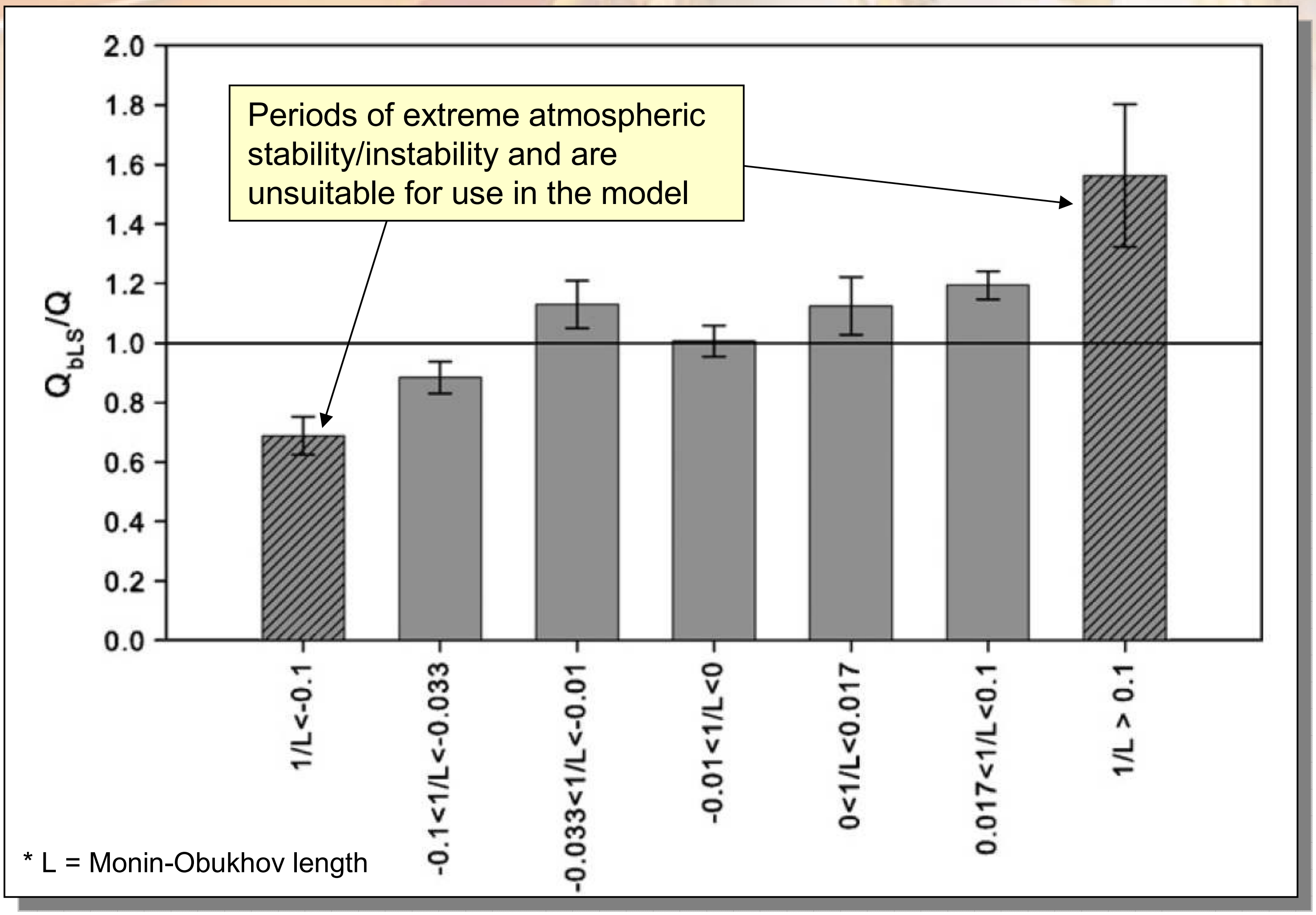
Set-up:

•2-lasers mounted on computer controlled pan-tilt aiming systems, each monitor two sides of a rectangular area

•Concentration can be monitored for all wind directions, making continuous measurements possible

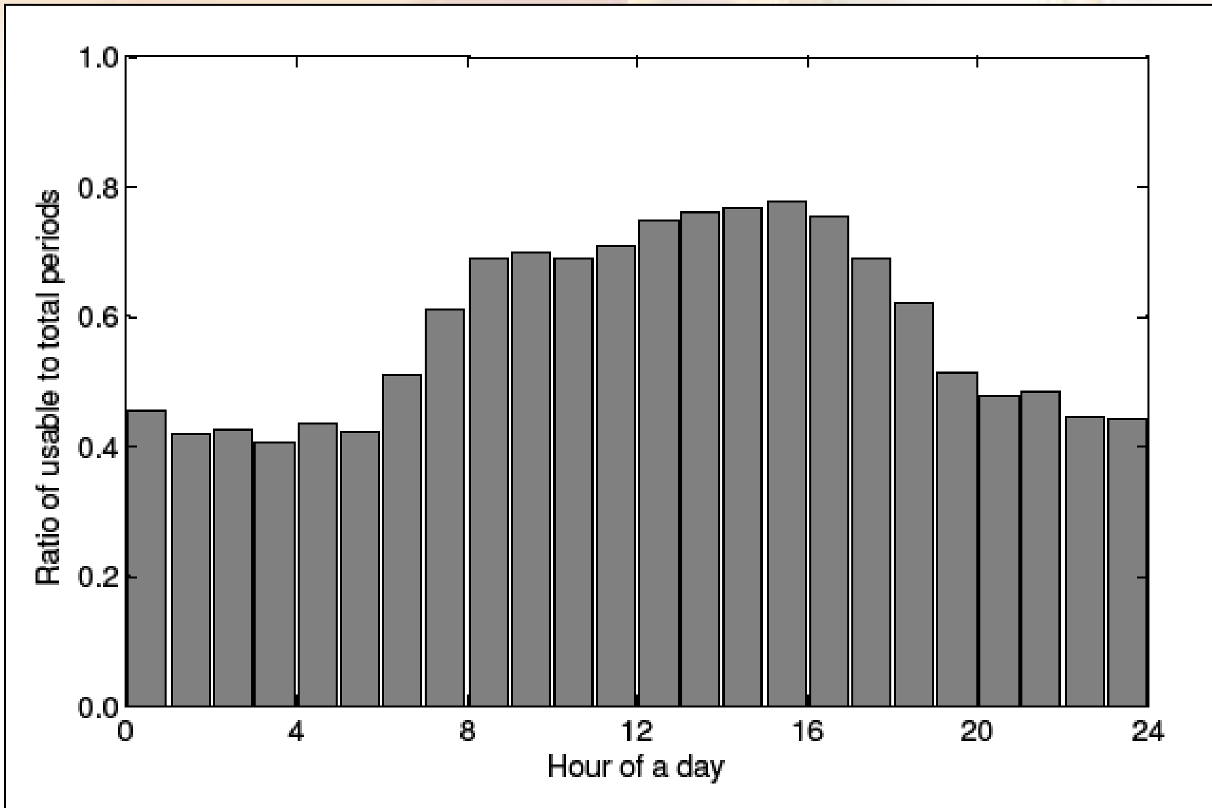
Source: Gao et al. (2009)

Influence of Atmospheric Stability on Gas Recovery Ratios



Source: Gao et al. (2009)

Estimating Diurnal Patterns of Emission for CH_4



Ratio of usable period to total periods in Ottawa, Canada

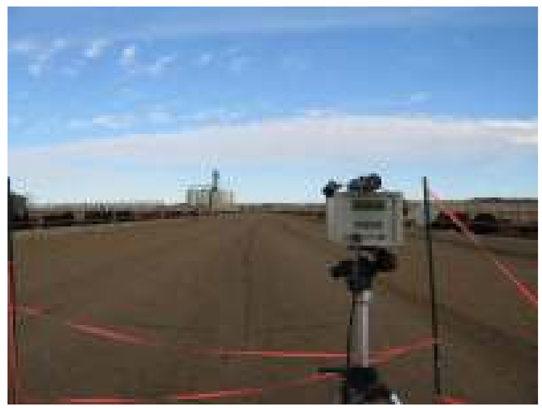
- Periods of low wind velocity or atmospheric stability mean that not all measurements will be acceptable
- This is more common at night
- Continuous measurement over a period of 6 days should yield sufficient data to generate the diurnal curve of emissions

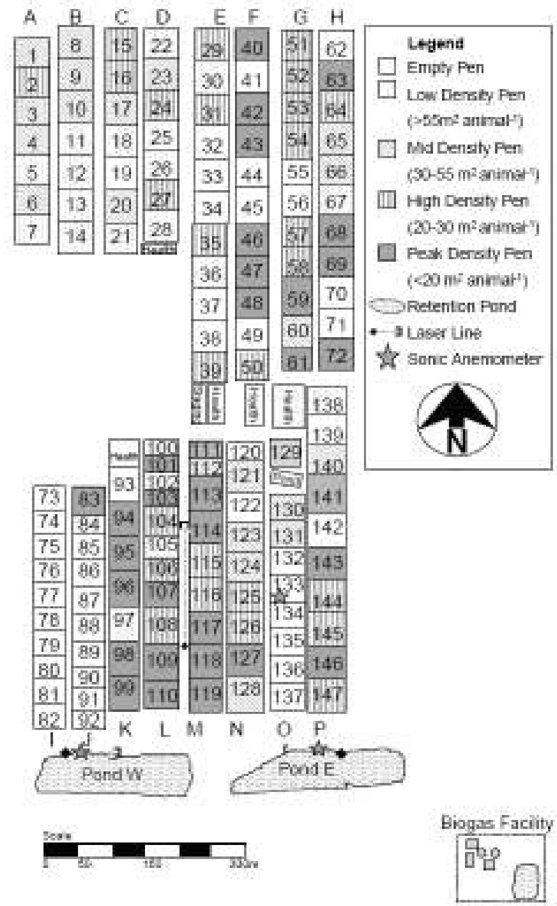
Source: Gao et al. (2009)

Estimating Methane and Ammonia Emissions from a Beef Feedlot

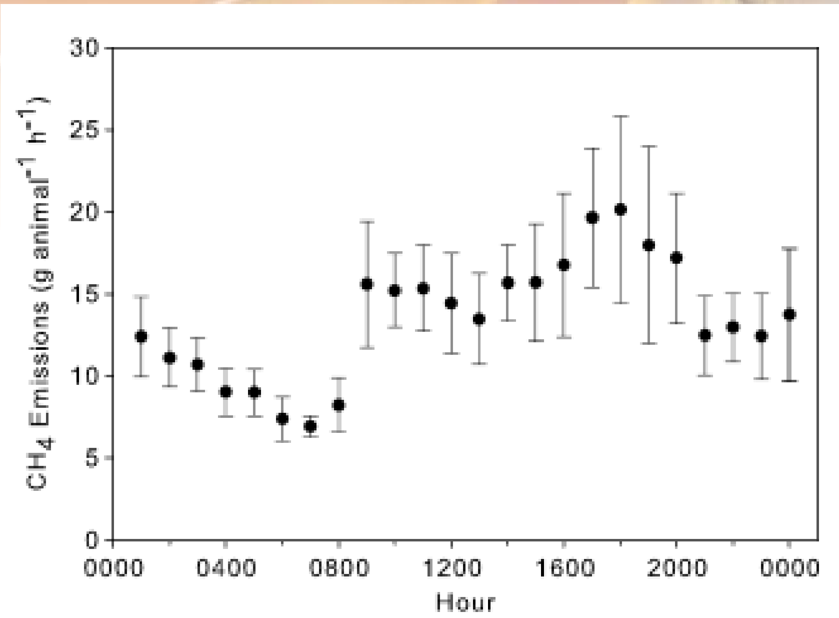
Set-up:

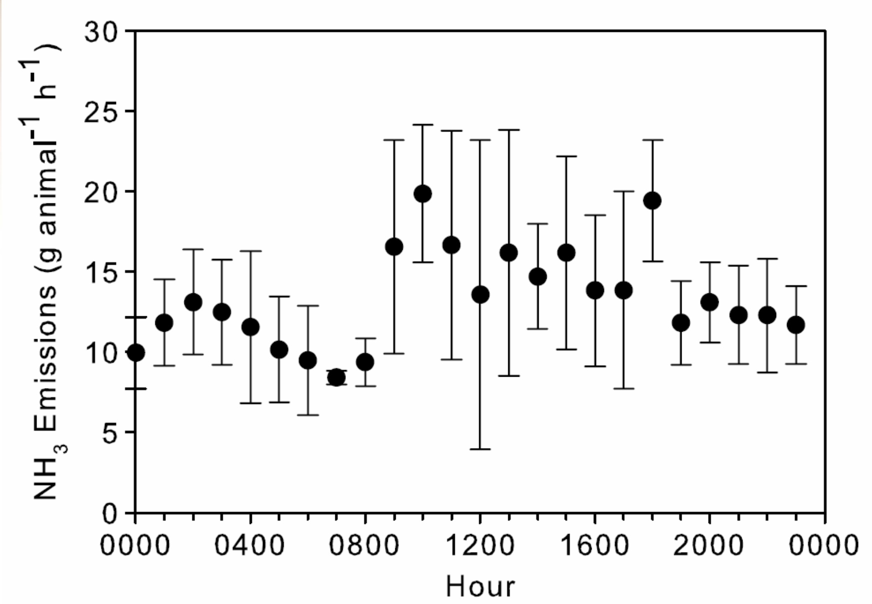
•Lasers and reflectors are established in the alley of a large (500m x 2,500m; 32,000 head capacity) beef feedlot





Estimating Methane and Ammonia Emissions from a Beef Feedlot

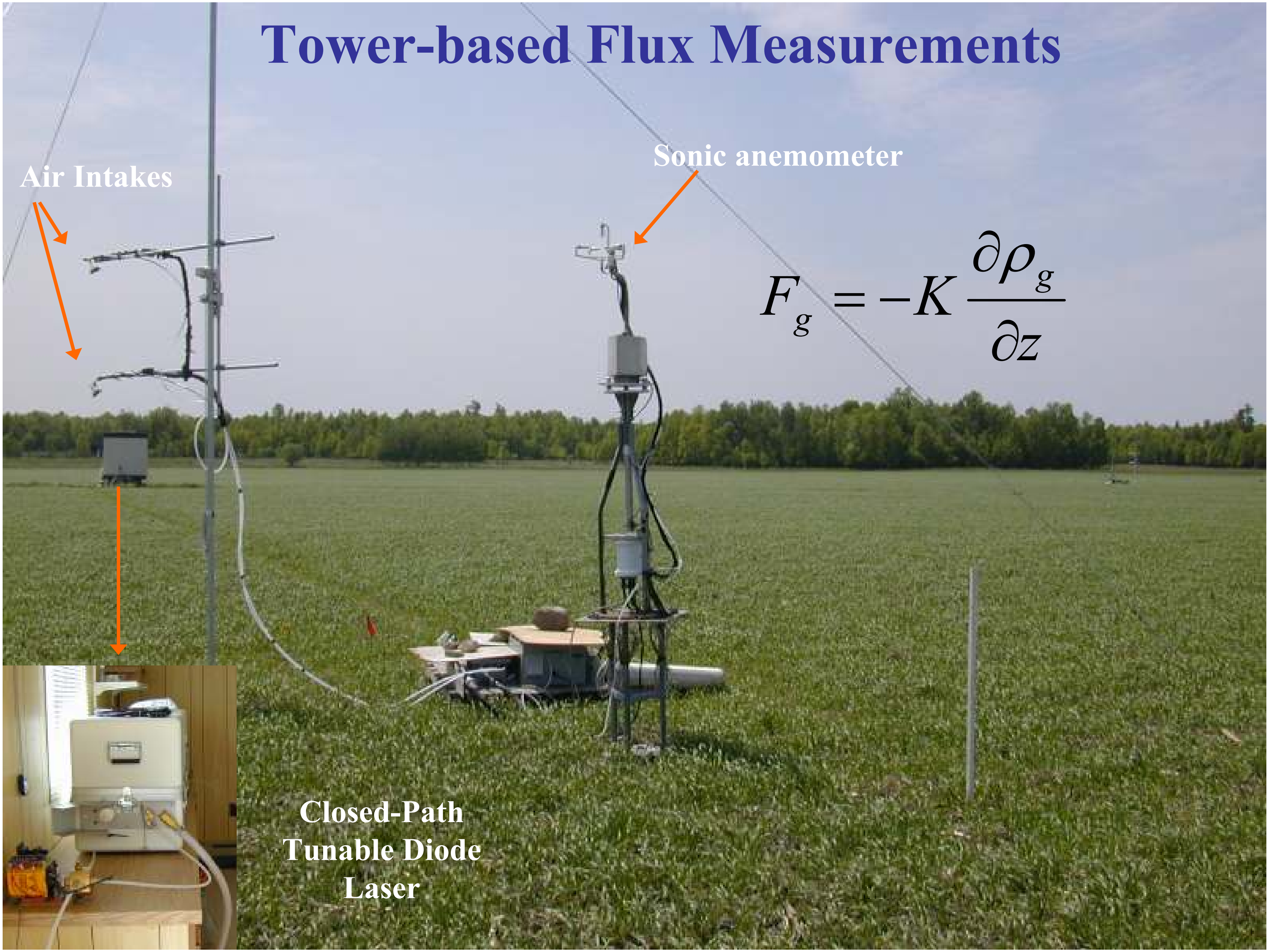




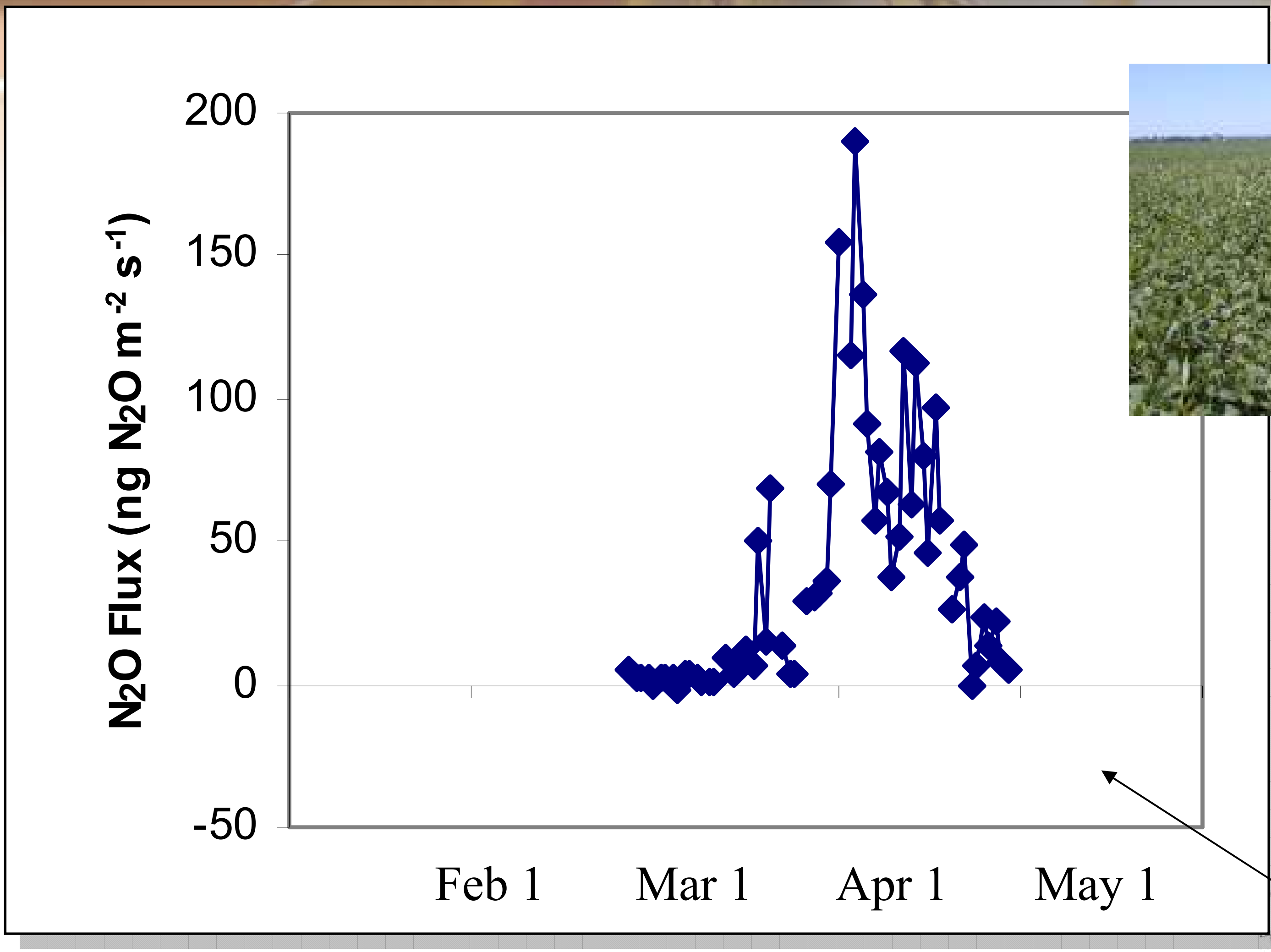
Methane emissions represent about 4% of Gross Energy Intake by cattle. IPCC default number is 3%

Ammonia emissions represent about 72% of nitrogen intake.

Source: van Haarlem et al. (2008)


Tower-based Flux Measurements
Air Intakes
Sonic anemometer
$F_g = -K \frac{\partial \rho_g}{\partial z}$
Closed-Path
Tunable Diode
Laser

Nitrous oxide emissions measured in 1996 over a soybean field in Ottawa Canada, using a tower-based system



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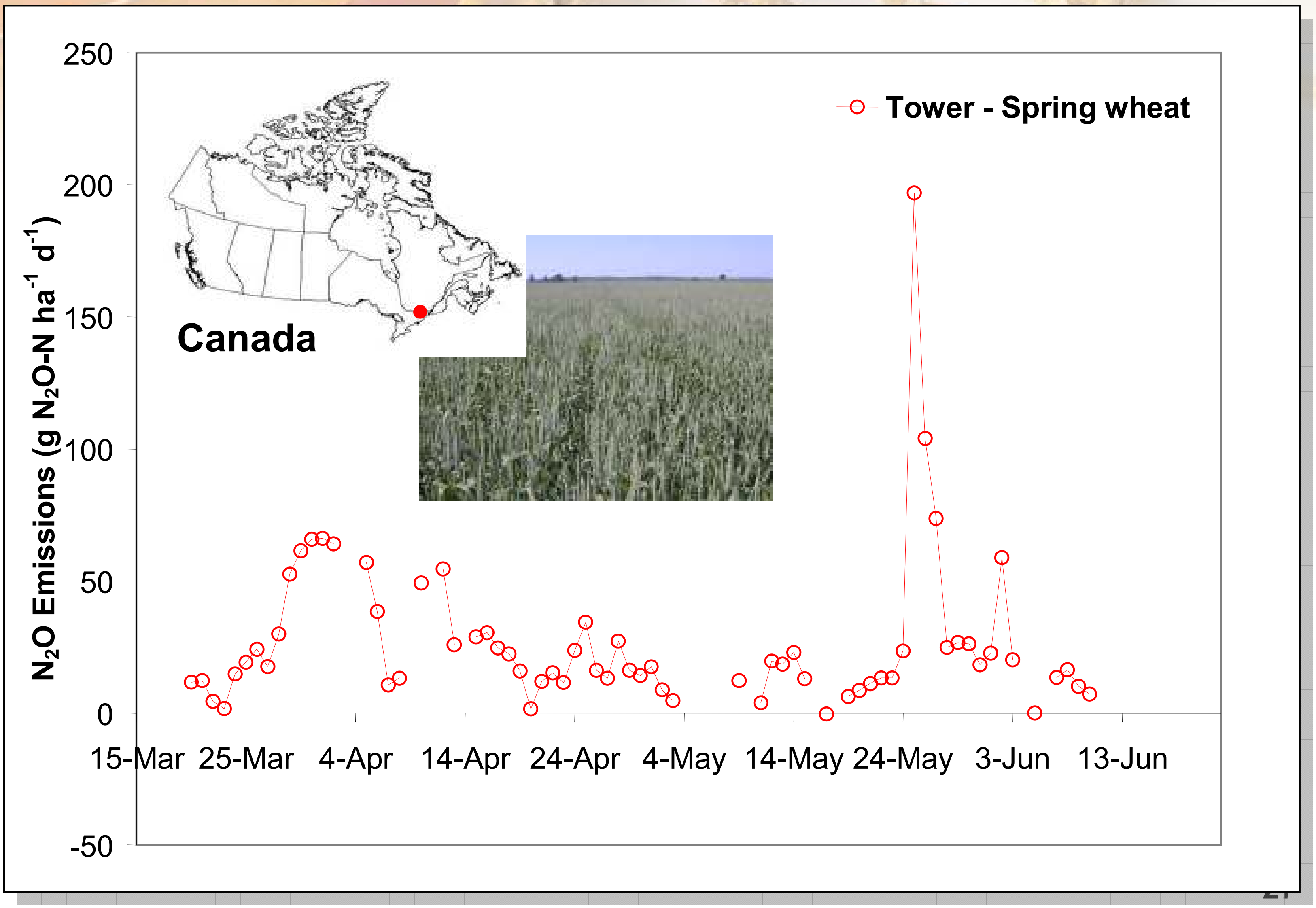
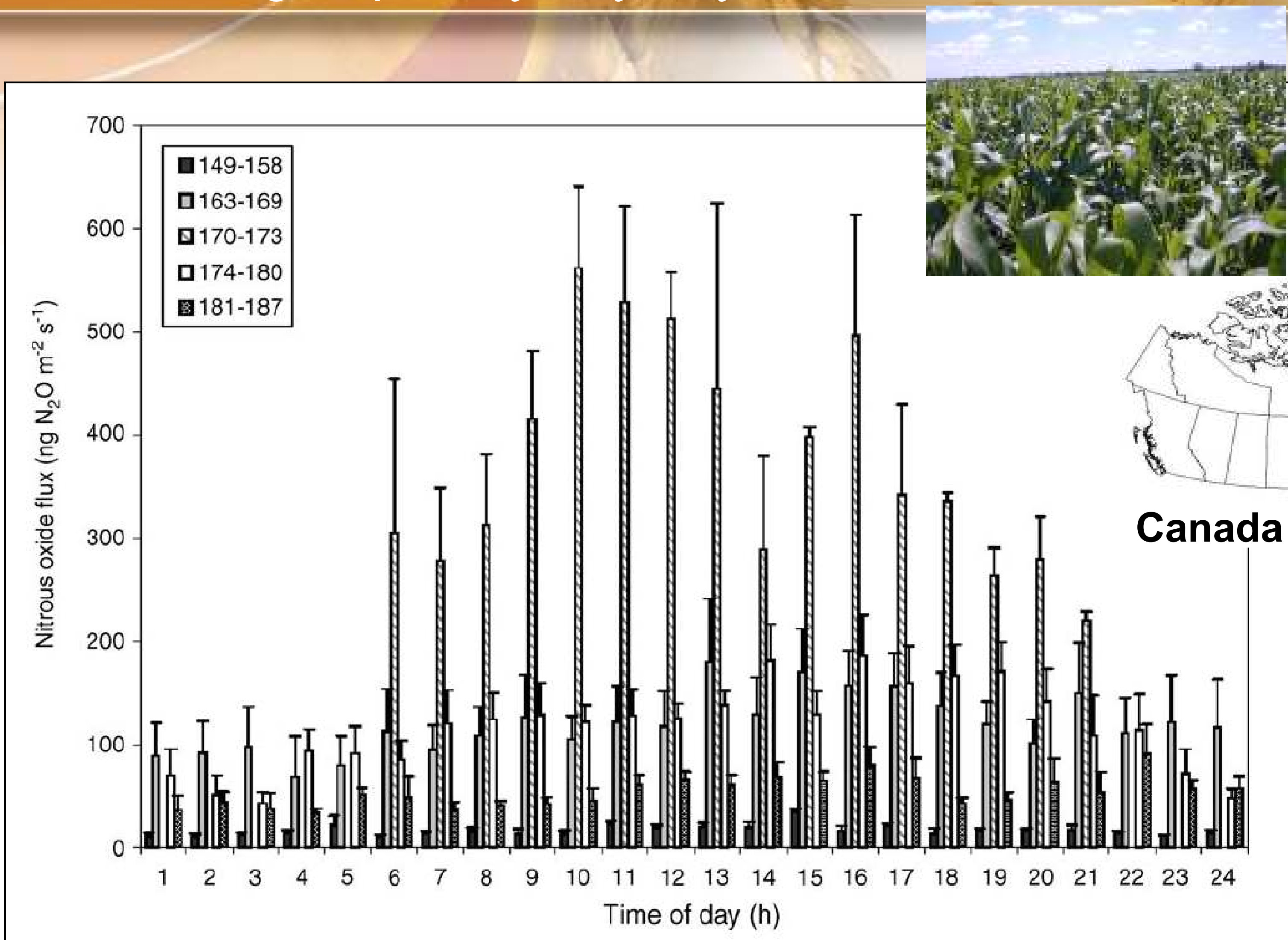
Tower based N_2O flux estimates over spring wheat, 2004



Source: Desjardins et al (2009)

Hourly binned estimates of N_2O flux above a fertilized corn field, grouped by day of year

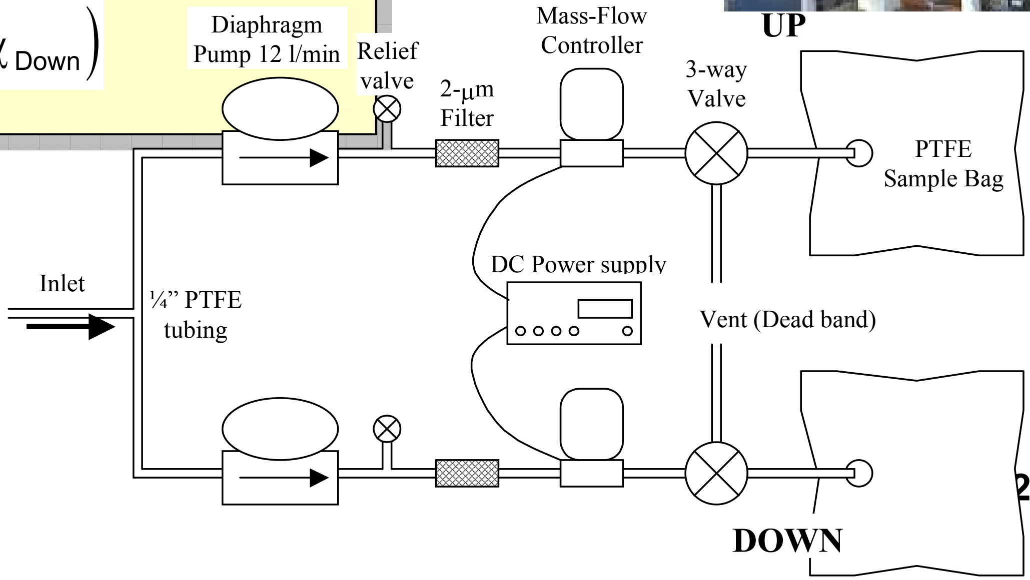


Source: Pattey et al. (2006)

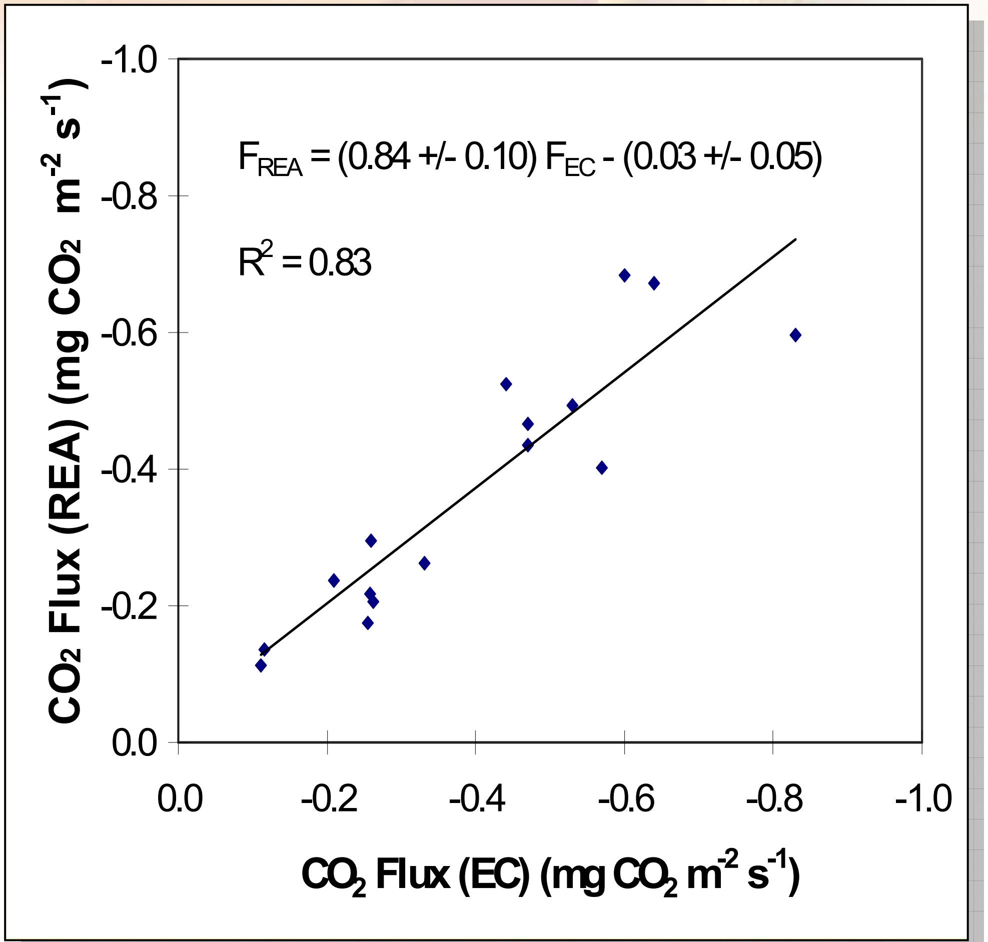
Relaxed Eddy Accumulation (REA) Technique

- Alternate to eddy covariance technique to measure fluxes of trace gases for situations where fast-response analyzers are unavailable
- Air samples from updrafts and downdrafts are collected in two separate reservoirs for later analysis
- In EA, sample flow rate is proportional to w; this requirement is 'relaxed' in REA (i.e., full flow into up or down reservoir depending on the direction of the vertical wind)

$$F_\chi = \overline{w'\chi'} = A\sigma_w\left(\chi_{Up} - \chi_{Down}\right)$$

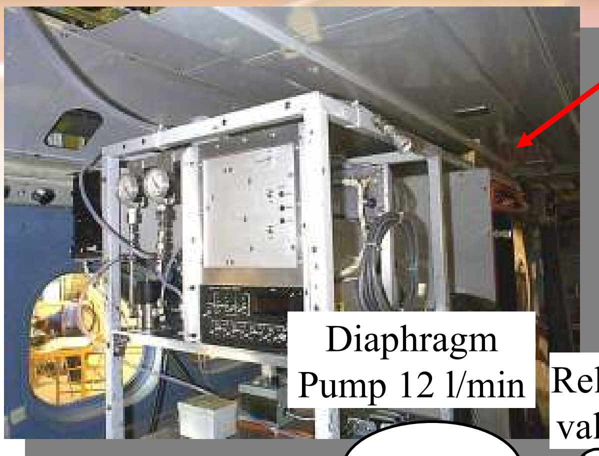


Comparison of EC and REA Flux Estimates of CO_2



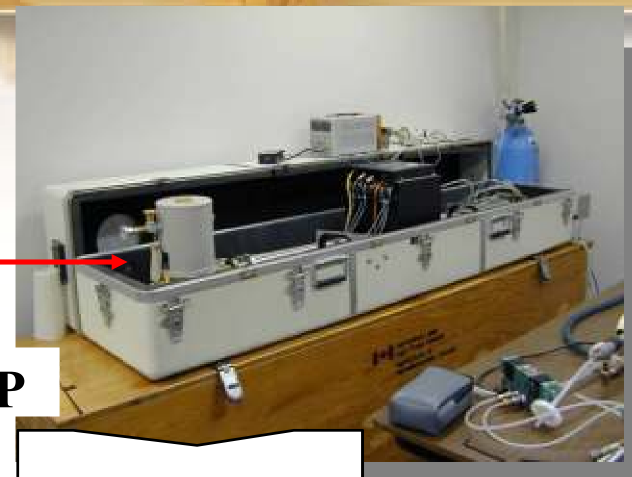
- Forest and agricultural fields
- Stainless steel canisters, with in-line magnesium percholate to remove water

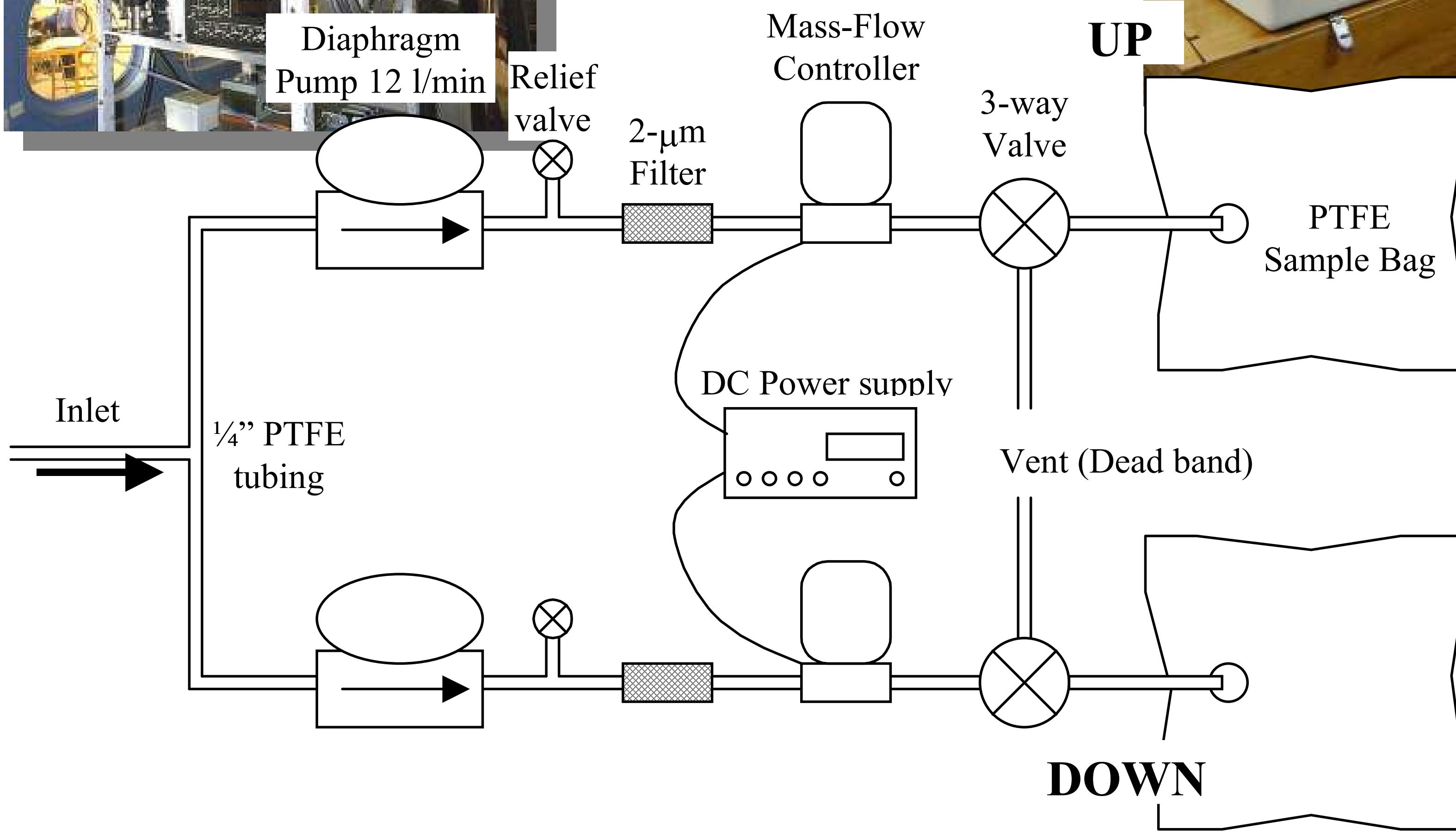
Relaxed eddy accumulation instrumentation



Aircraft REA system

Laboratory TDL Laser

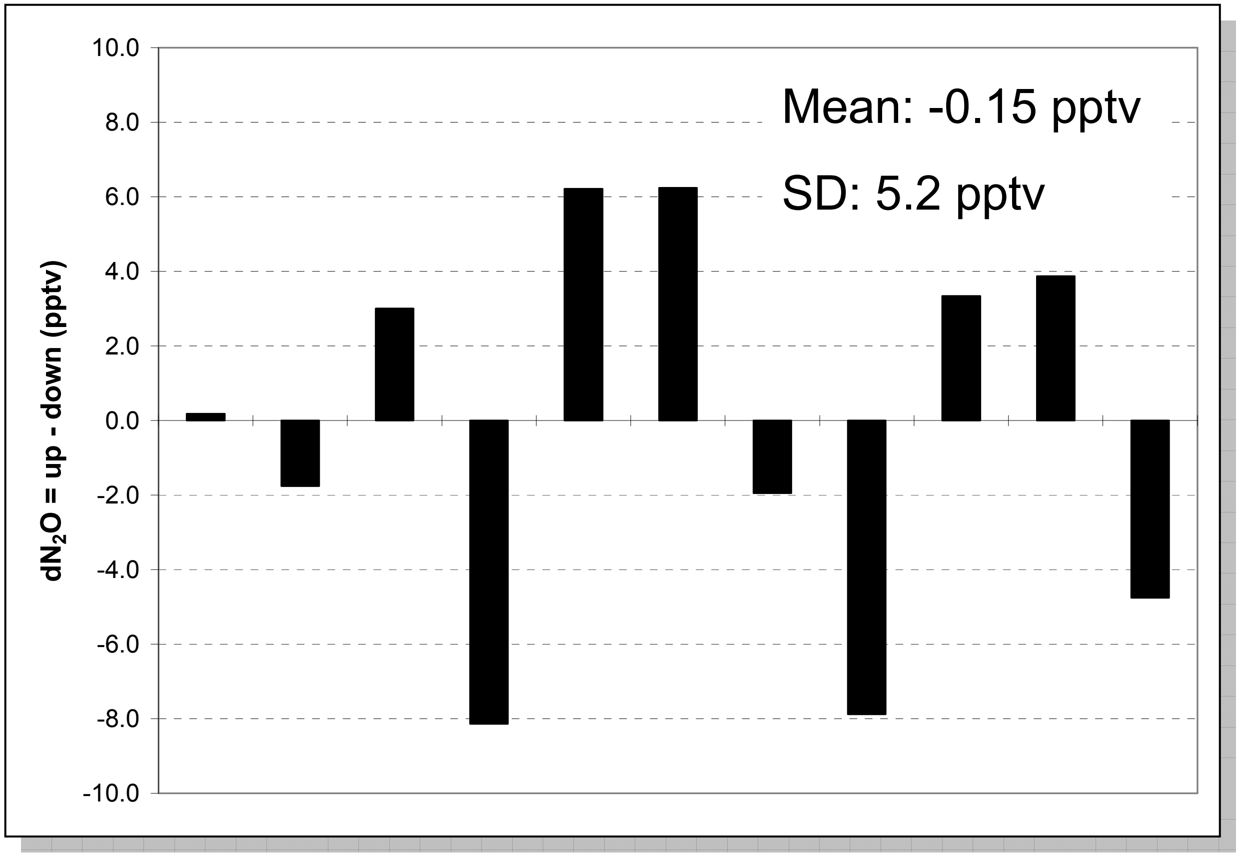




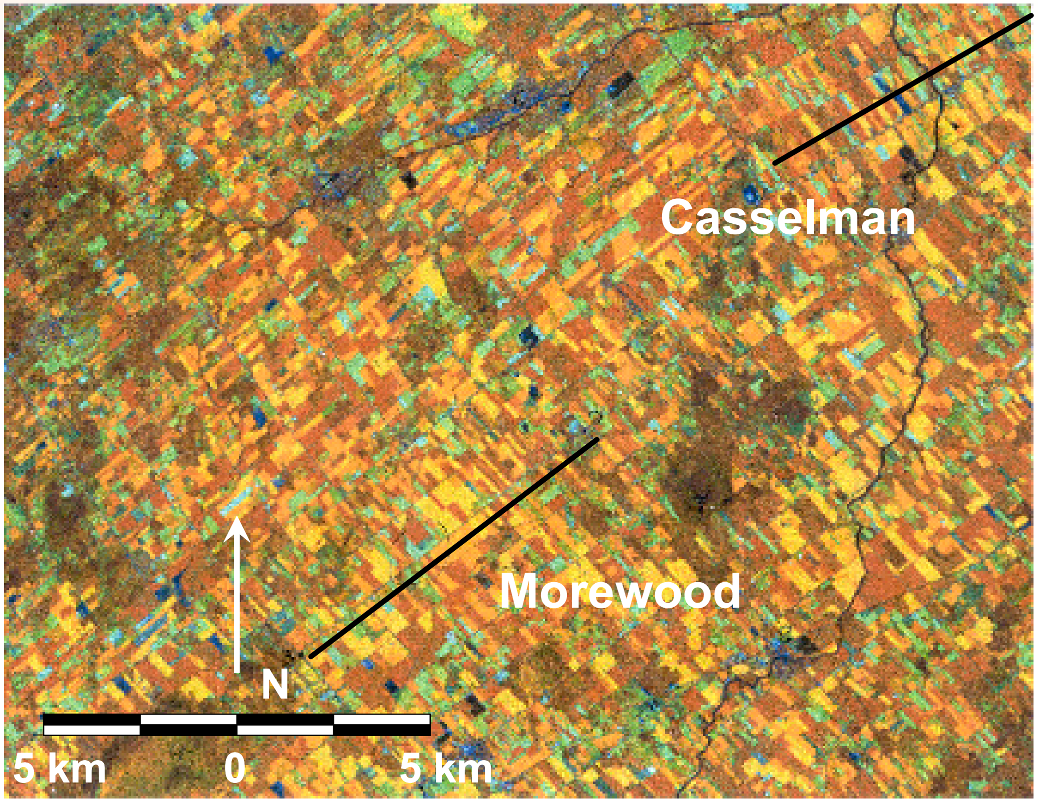
Resolution of the REA system for N_2O flux measurement

$$FN_2O = \rho_{N2O} \times 0.56 \times \sigma_w \times dN_2O$$

dN_2O (pptv)	$\sigma_w = 0.3\ m\ s^{-1}$	$\sigma_w = 0.9\ m\ s^{-1}$
5	1.6	2.8 g N_2O-N $ha^{-1}\ d^{-1}$



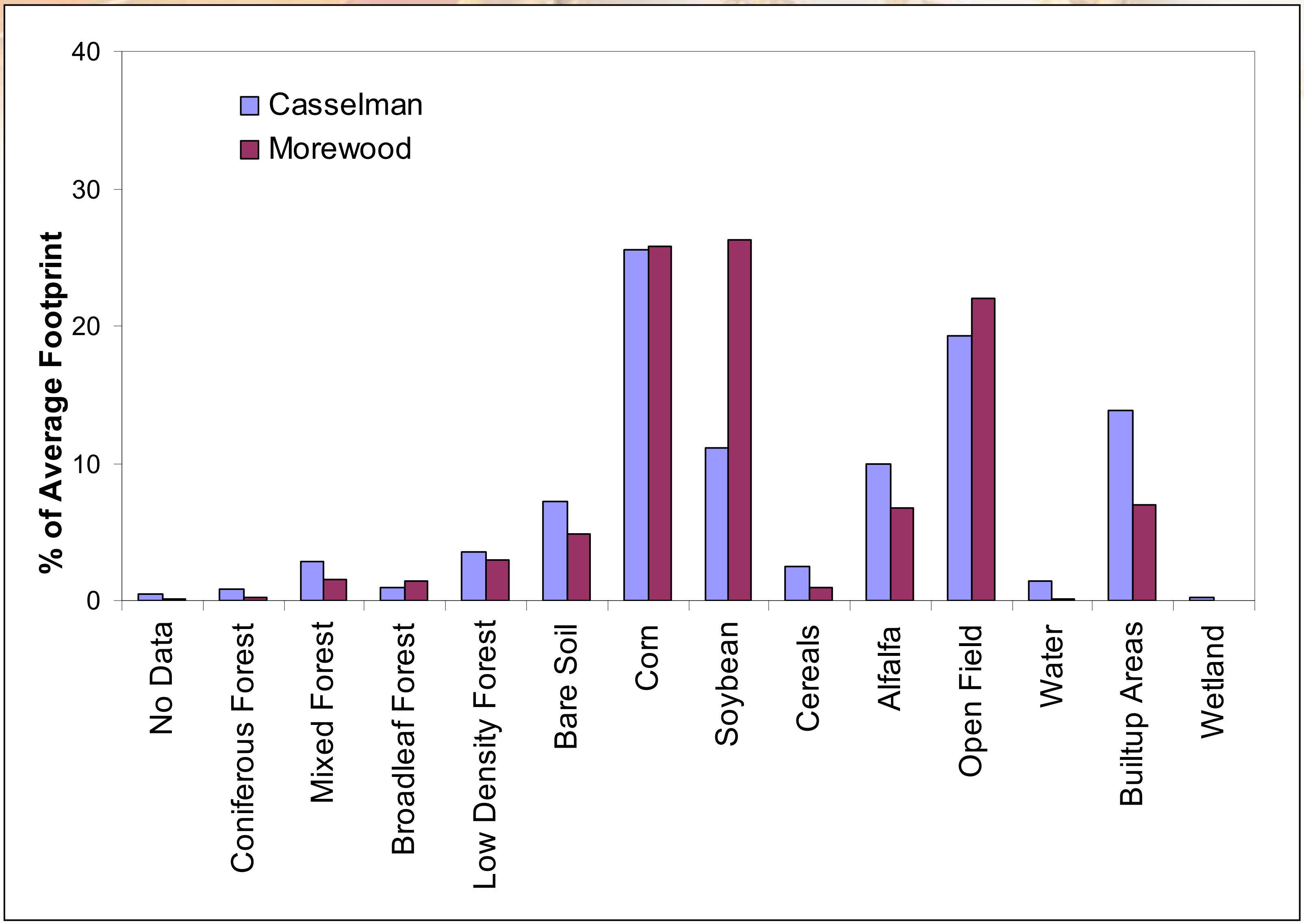
Crop types in the aircraft footprint



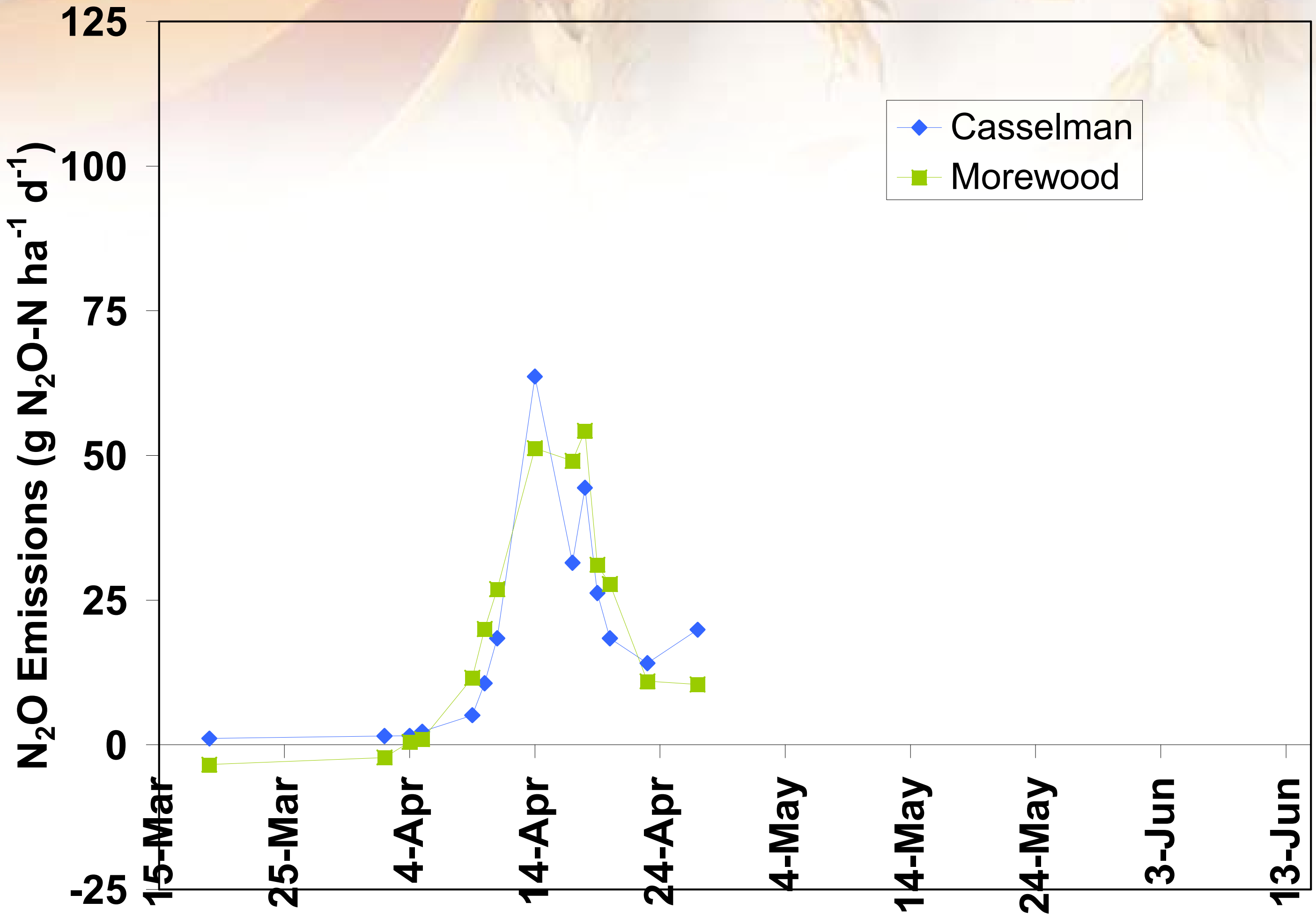
LEGEND

- cereals
- pasture/grass
- alfalfa
- forest
- soybean
- corn
- town

Land use information in 2001 within footprint of aircraft transects

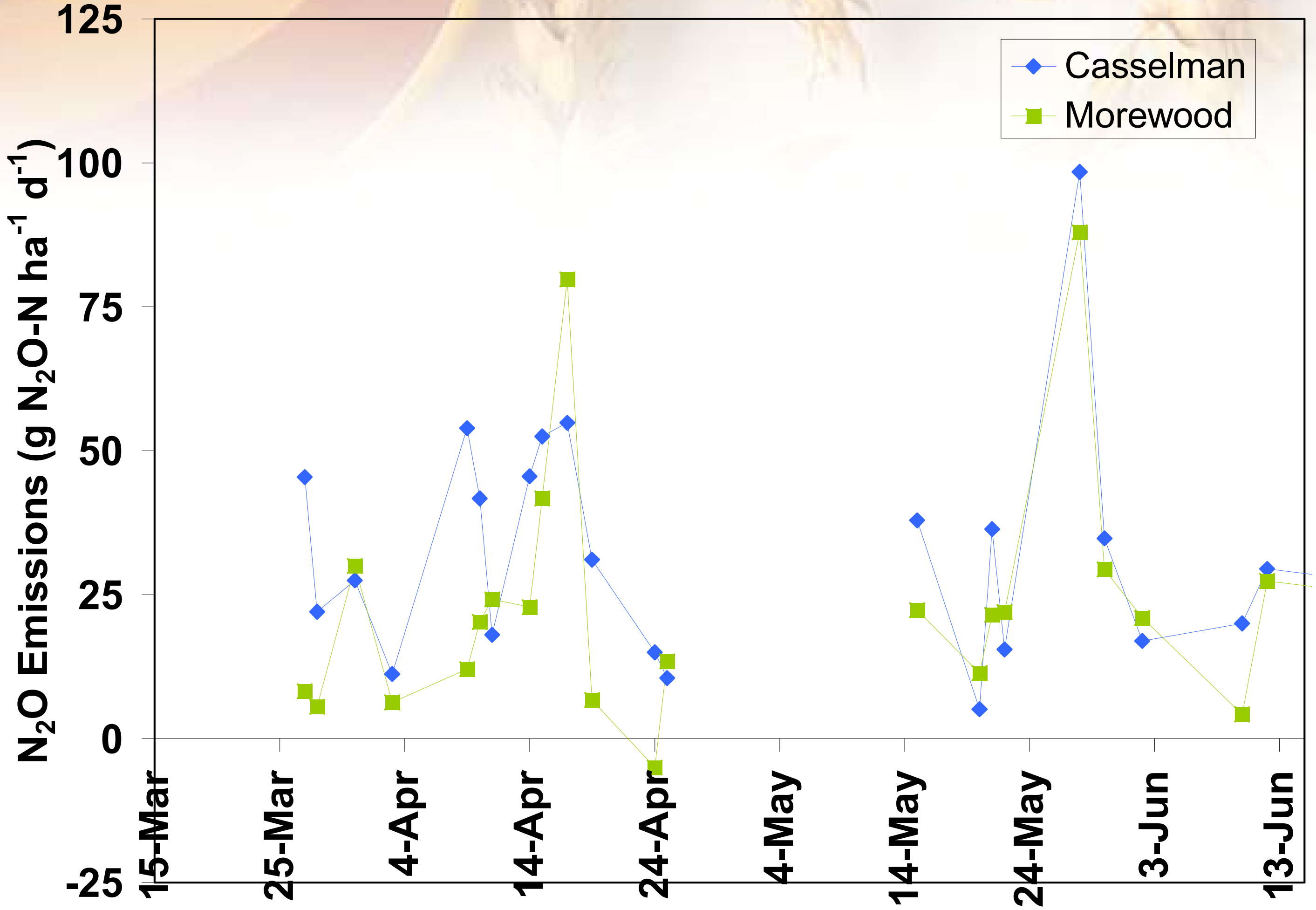


N_2O emissions during and right after snowmelt at the Eastern Canada study sites in 2001

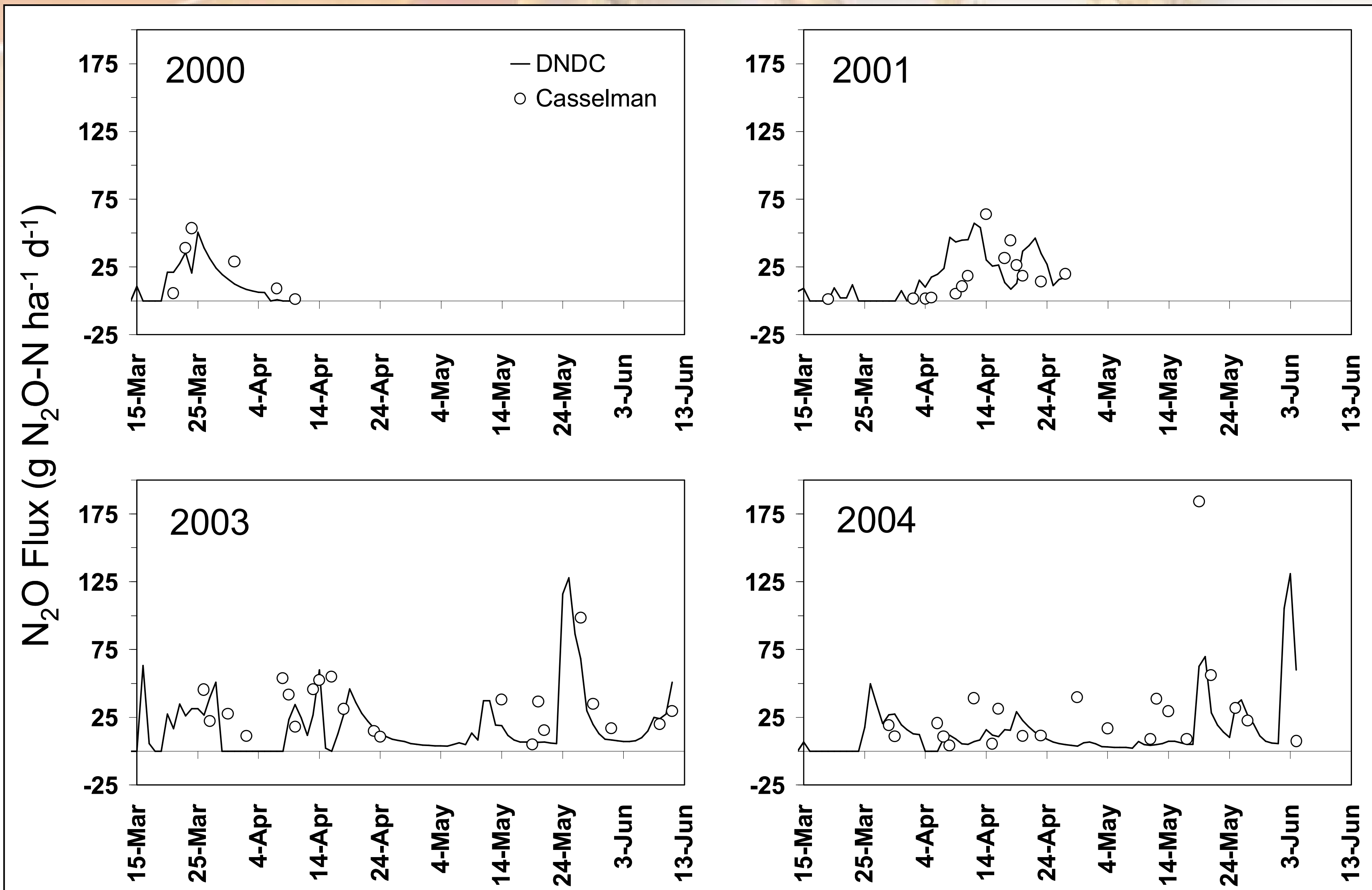


Each data point represents the average of 3 samples, collected during two consecutive 10 km flight legs (total flight distance for one data point is ≈ 20 km)

N_2O emissions right after snowmelt and after planting at the Eastern Canada study sites in 2003



Multi-year comparison of aircraft and modeled estimates of N_2O emissions



Multi-year comparison of N_2O emissions: Summary of results

Year	Measurement Period	Casselman*	Morewood*	DNDC[1]
		kg N_2O-N ha^{-1}		
	May 15 to Jun 12			
2004	Mar 29 to Jun 4	1.77	1.29	1.11

Modeled estimated of N_2O emissions are on average 23% less than the measured estimates of N_2O emissions.

However, modeled estimates only represent direct emissions, whereas using the IPCC methodology indirect emissions are about 20% of total emissions.

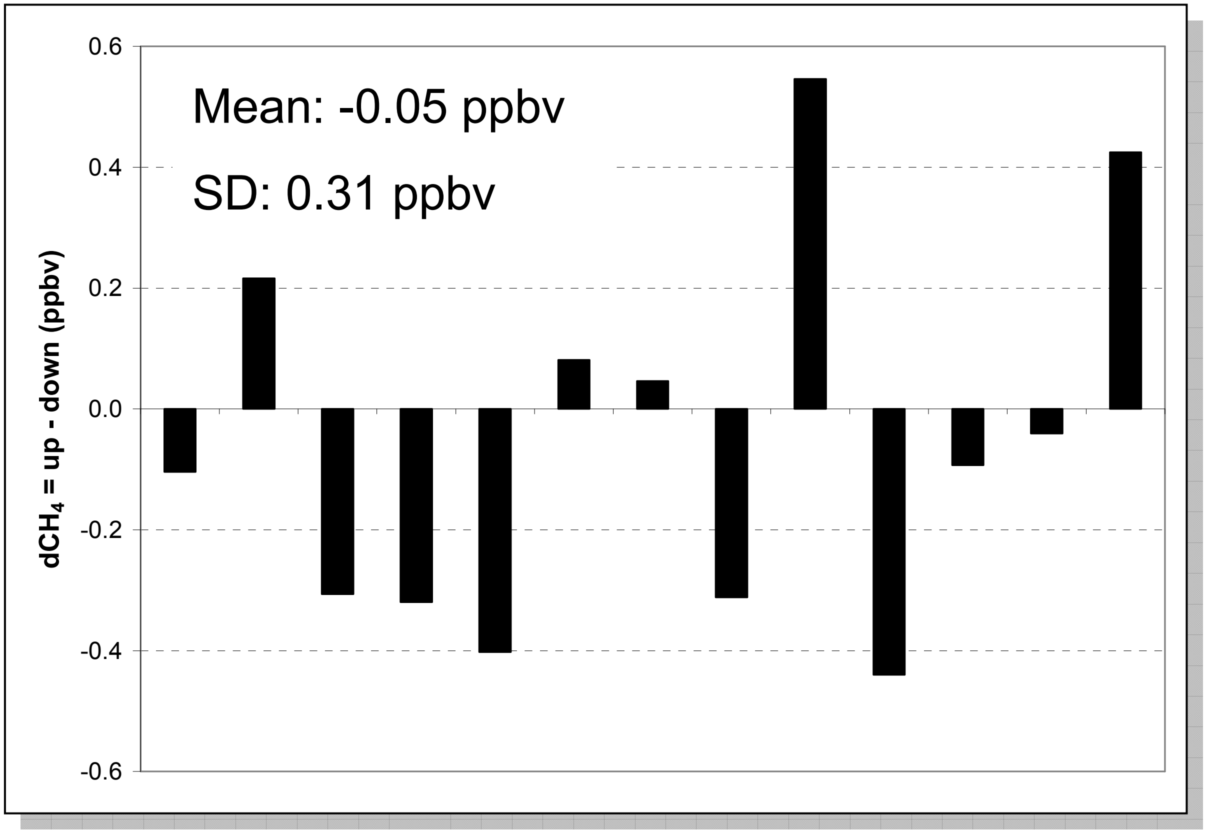
* Measured using the aircraft-based REA method

[1] Modeled by DNDC using the crop distribution for the Casselman flight track

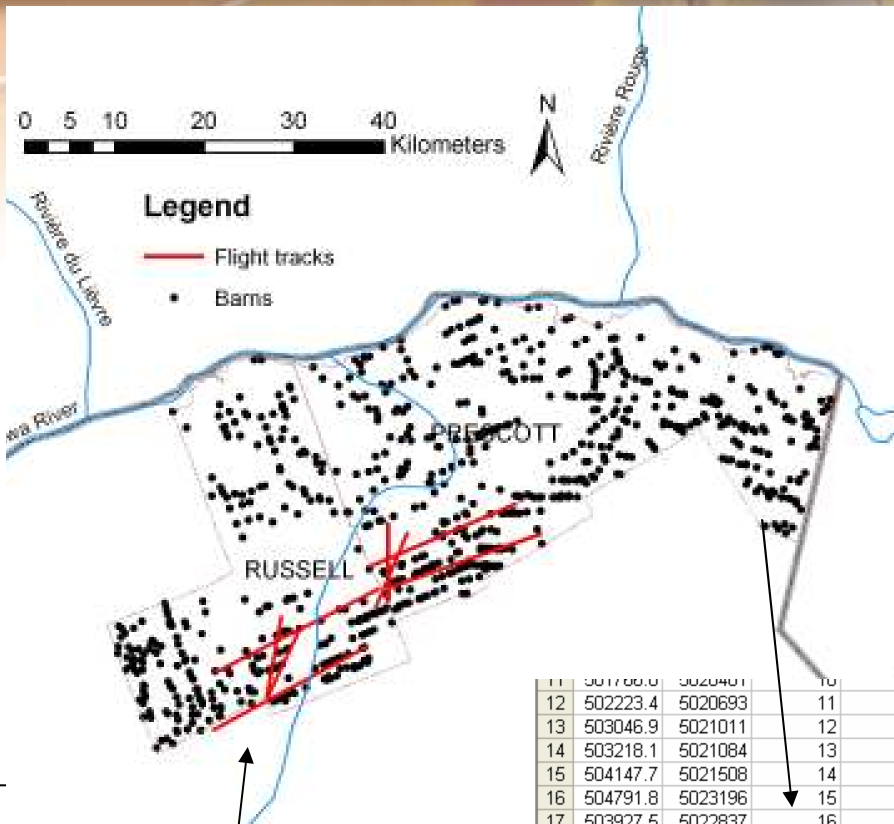
Resolution of the REA system for CH_4 flux measurement

$$FCH_4 = 0.56 \times \sigma_w \times dCH4$$

dCH4(ppbv)	$\sigma_w = 0.3\ m\ s^{-1}$	$\sigma_w = 0.9\ m\ s^{-1}$
0.3	1150	3650 kg $km^{-2}\ y^{-1}$



Estimating regional scale methane emissions

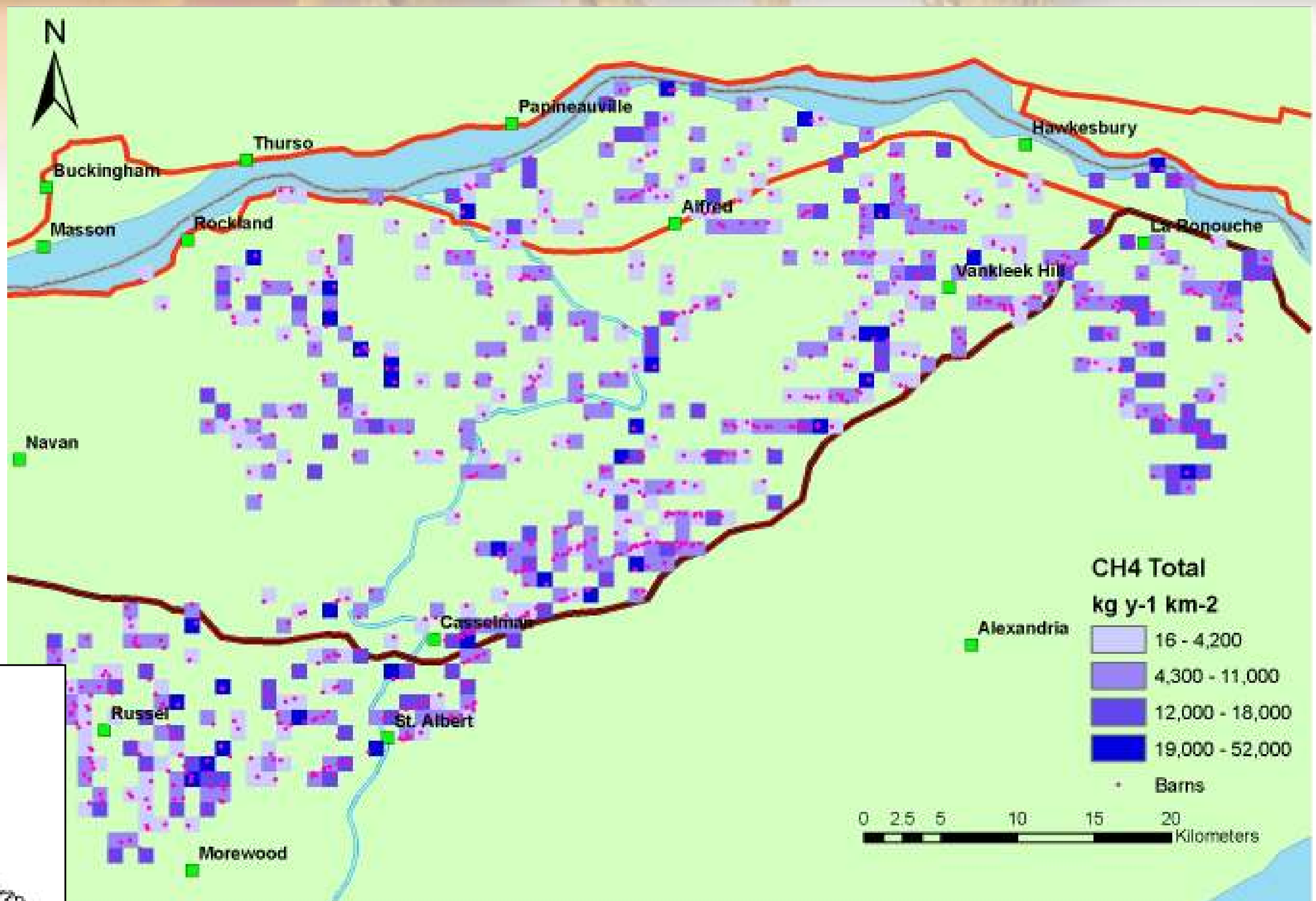


For each geo-referenced barn location, there is an estimate of animal type, population and manure management system

12	502223.4	5020693	11	74	74	11	Beef	1	20	solid	1	20
13	503046.9	5021011	12	75	75	13	Dairy	2	100	liquid	2	150
14	503218.1	5021084	13	76	76	14	Dairy	2	300	solid	1	450
15	504147.7	5021508	14	77	77	15	Dairy	2	60	liquid	2	90
16	504791.8	5023196	15	78	78	16	Dairy	2	50	liquid	2	75
17	503927.5	5022837	16	79	79	17	Dairy	2	20	solid	1	30
18	503210	5022552	17	80	80	18	Dairy	2	25	solid	1	37.5
19	500396.9	5021386	18	81	81	19	Dairy	2	80	liquid	2	120
20	499076	5021378	19	82	82	20	Dairy	2	30	liquid	2	45
21	498766.2	5022209	20	83	83	21	Beef	1	35	solid	1	35
22	498415.6	5022185	21	84	84	22	Dairy	2	40	liquid	2	60
23	499010.8	5022487	22	85	85	23	Dairy	2	60	liquid	2	90
24	499108.7	5022323	23	86	86	24	Beef	1	30	solid	1	30
25	499549	5022527	24	87	87	25	Dairy	2	90	liquid	2	135
26	500878	5023016	25	88	88	26	Dairy	2	30	s/l	3	45
27	501090	5023294	26	89	89	27	Beef	1	20	solid	1	20
28	501448.8	5023									2	90
29	501726	5023									1	90
30	501962.5	5023									1	120
31	502443.5	5023									1	37.5

Geo-referenced database from which to estimate methane emissions

Estimated Agricultural CH_4 Emissions



Regional CH_4 Emissions, 2003 and 2004

Date	CM	MW	CM	MW
	Aircraft REA Estimate		Barn Estimate within flux footprint *)	
	$kg\ CH_4\ km^{-2}\ yr^{-1}$		$kg\ CH_4\ km^{-2}\ yr^{-1}$	
Sept. 3, 2003	10400	7100	18665	12540
Sept. 18, 2003	9200	18200	13130	8366
Jul. 21, 2004	24800	19200	16641	12159
Oct. 8, 2004	11700	13100	16247	10679
Avg.	14025	14400	16171	10936

*) Results calculated using the backward Lagrangian stochastic model of Kljun et al. (2002)

Summary

- Several examples were presented of laser based techniques to measure CH_4 and N_2O emissions from agroecosystems
- These techniques allow measurements for scales ranging from point sources to regions
- First example of verification of GHG inventory at a regional scale using the relax eddy accumulation technique- The measurements show that N_2O and CH_4 emission estimates in the Canadian GHG inventory appear to be realistic
- There is a need to improve upon the accuracy of the methane concentration measurements. There is also a need to obtain more regional flux measurements to better capture the diurnal and annual cycles

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