Agriculture and Agri-Food Canada
Agriculture et Agroalimentaire Canada

Measuring and Modeling Greenhouse Gas Emissions from Agroecosystems

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Beijing, China

Canada

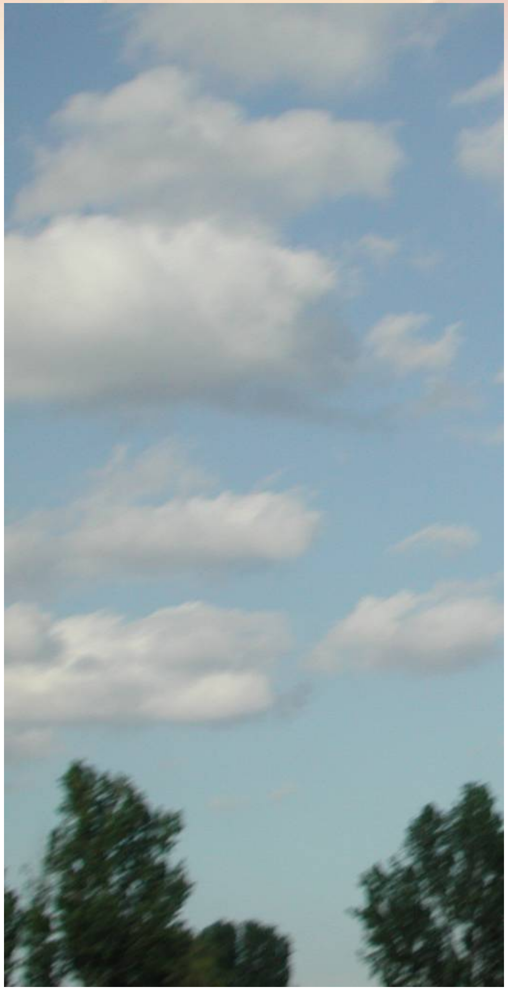
Outline

- Greenhouse gas emissions from agroecosystems
- Flux meauring techniques
  - Carbon dioxide
  - Methane
  - Nitrous oxide

.Modeling techniques

  - Carbon dioxide exchange
  - Methane emissions
  - Nitrous oxide emissions
- Progress towards a more sustainable agriculture

Atmospheric gases



Our dry atmosphere is made up of a mixture of gases, consisting of:

- 78.1% N_2;Nitrogen
- 20.9% O_2; Oxygen
- 0.9% Ar; Argon
- 0.1% all other gases including the greenhouse gases CO_2 (carbon dioxide), CH_4 (methane), N_2O (nitrous oxide) and O_3 (ozone)

On a wet basis, our atmosphere contains ≈ 1-4% H_2O

Atmospheric greenhouse gases (GHGs)

Atmospheric GHGs, including H_2O, CO_2, CH_4, N_2O and O_3 trap longwave radiation and maintain our climate at a temperature that can support life.

In recent years, human activities have led to an accumulation of GHGs in the atmosphere (mainly CO_2, CH_4 and N_2O), resulting in an increased temperature on Earth through increased trapping of longwave radiation.

This is known as the enhanced greenhouse effect.

Recent trends in atmospheric greenhouse gas concentrations

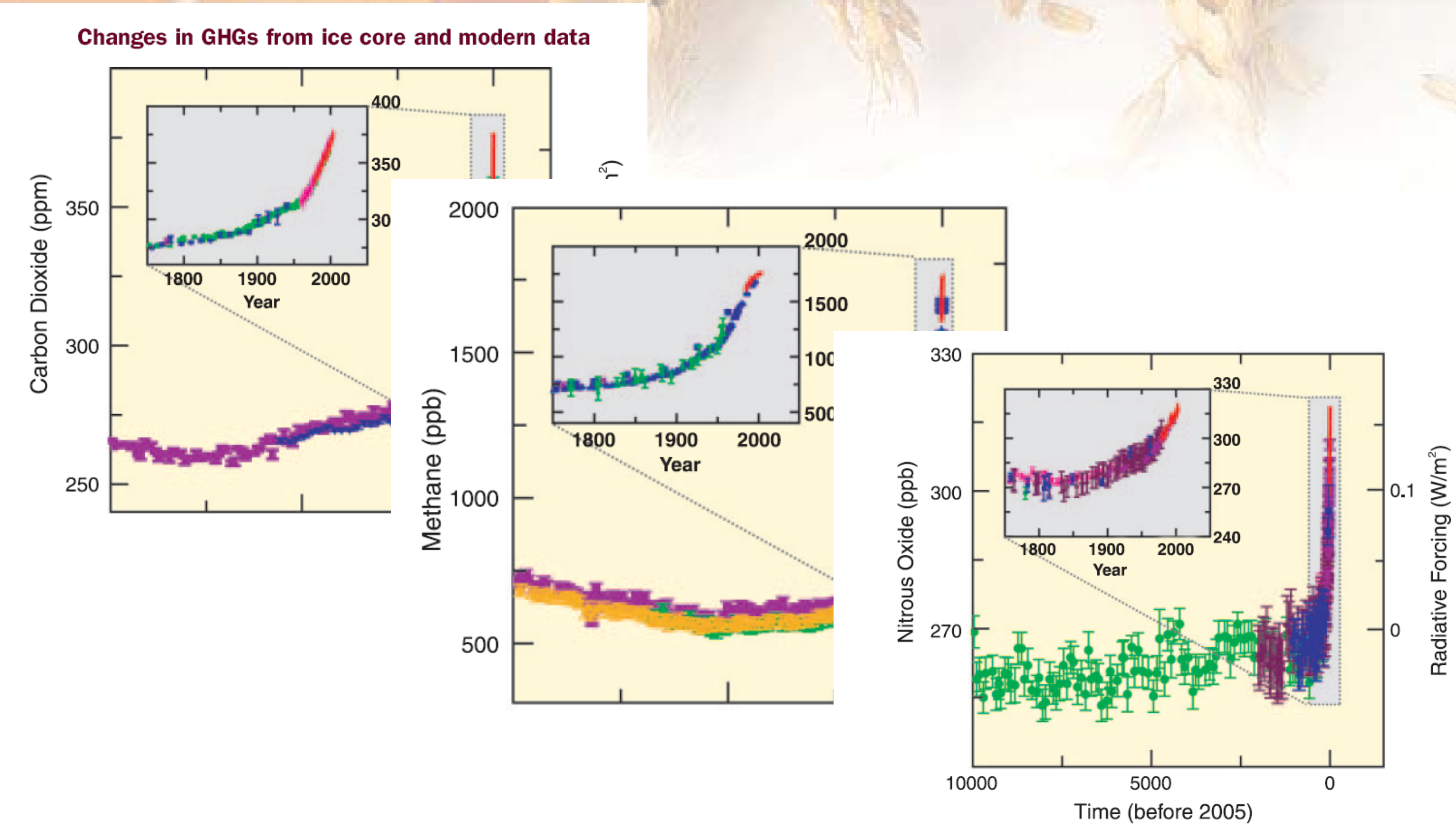
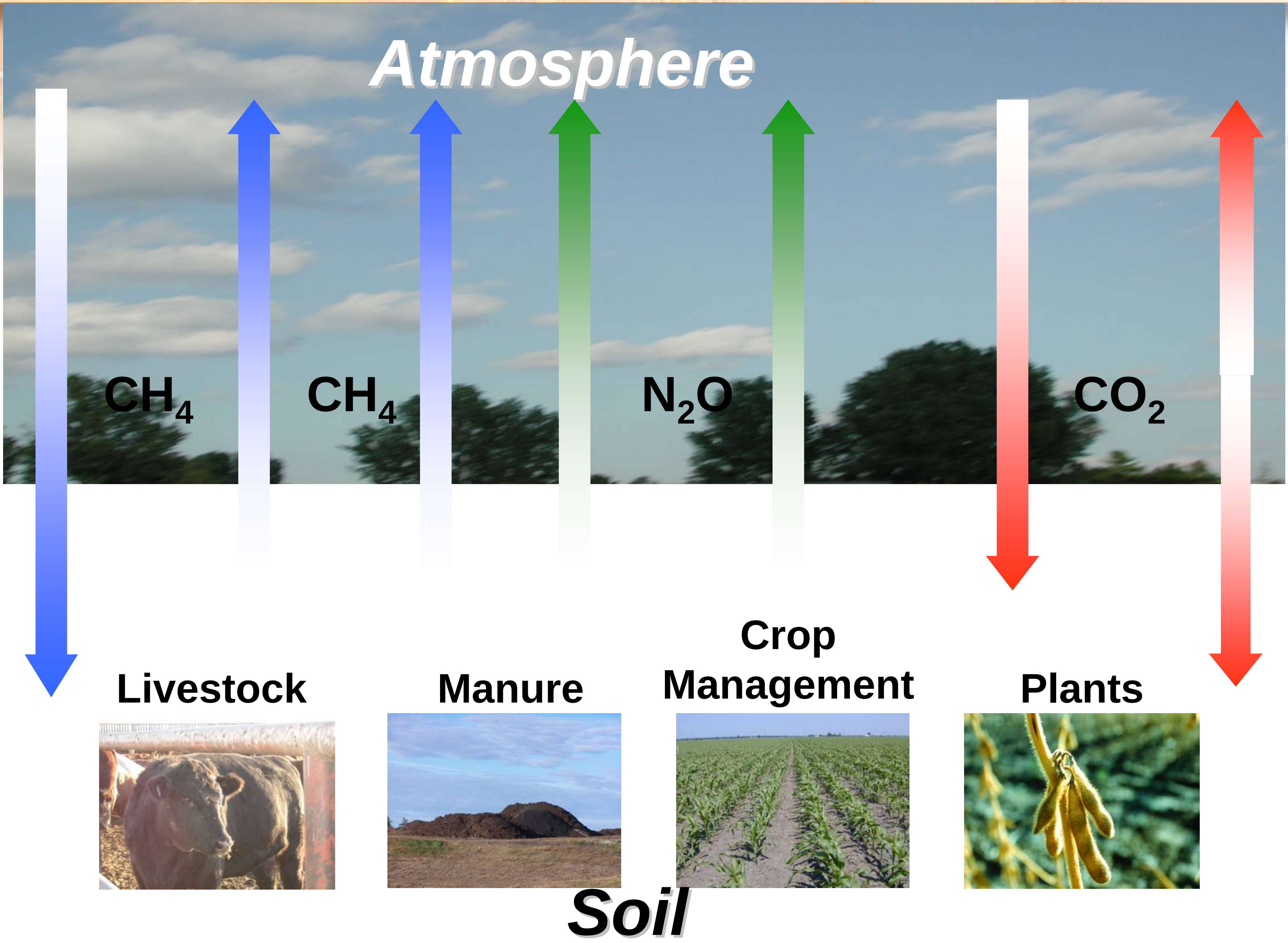


Figure 2.3. *Atmospheric concentrations of CO_2, CH_4 and N_2O over the last 10,000 years (large panels) and since 1750 (inset panels). Measurements are shown from ice cores (symbols with different colours for different studies) and atmospheric samples (red lines). The corresponding radiative forcings relative to 1750 are shown on the right hand axes of the large panels. {WGI Figure SPM.1}*

Source: IPCC (2007)

Agricultural GHG Emissions



Atmosphere

CH_4

CH_4

N_2O

CO_2

Livestock

Manure

Crop Management

Plants

Soil

Global Warming Potential (GWP_{100})

- Greenhouse gases are not equal in their ability to trap radiation and on a mass basis over a 100 year time horizon, are indexed relative to CO_2
- CH_4 is 21 times more powerful than CO_2
- N_2O is 310 times more powerful than CO_2
- Using the global warming potential (GWP) of each gas, GHG emissions are often expressed as CO_2e, or ‘carbon dioxide equivalents’

$$\boxed{CO_2e = CO_2 \times 1 + CH_4 \times 21 + N_2O \times 310}$$

SAR (1996)

$$\boxed{CO_2e = CO_2 \times 1 + CH_4 \times 25 + N_2O \times 298}$$

AR4 (2007)

Global sources of anthropogenic greenhouse gas emissions: Carbon Dioxide

Carbon Dioxide emissions from fossil fuel combustion and cement amount to 7.2 Pg C as CO_2 per year (1Pg = 1 billion tonnes).

Carbon Dioxide emissions from land use change (e.g. deforestation) amount to 1.6 Pg C as CO_2 per year

Source: Denman et al. (2007)

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 (1Tg = 1 million tonnes).

Nitrous oxide emissions from all sectors amount to 6.7-8.1 Tg N_2O-N per year

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

China: 8.9 Tg Ch_4 per year

Rice cultivation 60 Tg CH_4 per year

China: 6.0 Tg CH_4 per year

Management of animal manures 18 Tg CH_4 per year

China: 3.8 Tg CH_4 per year

Source: Denman et al. (2007); FAO (2006); Huang et al. (2006)

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.

China: 1.2 Tg N_2O-N

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

China: 0.15 Tg N_2O-N

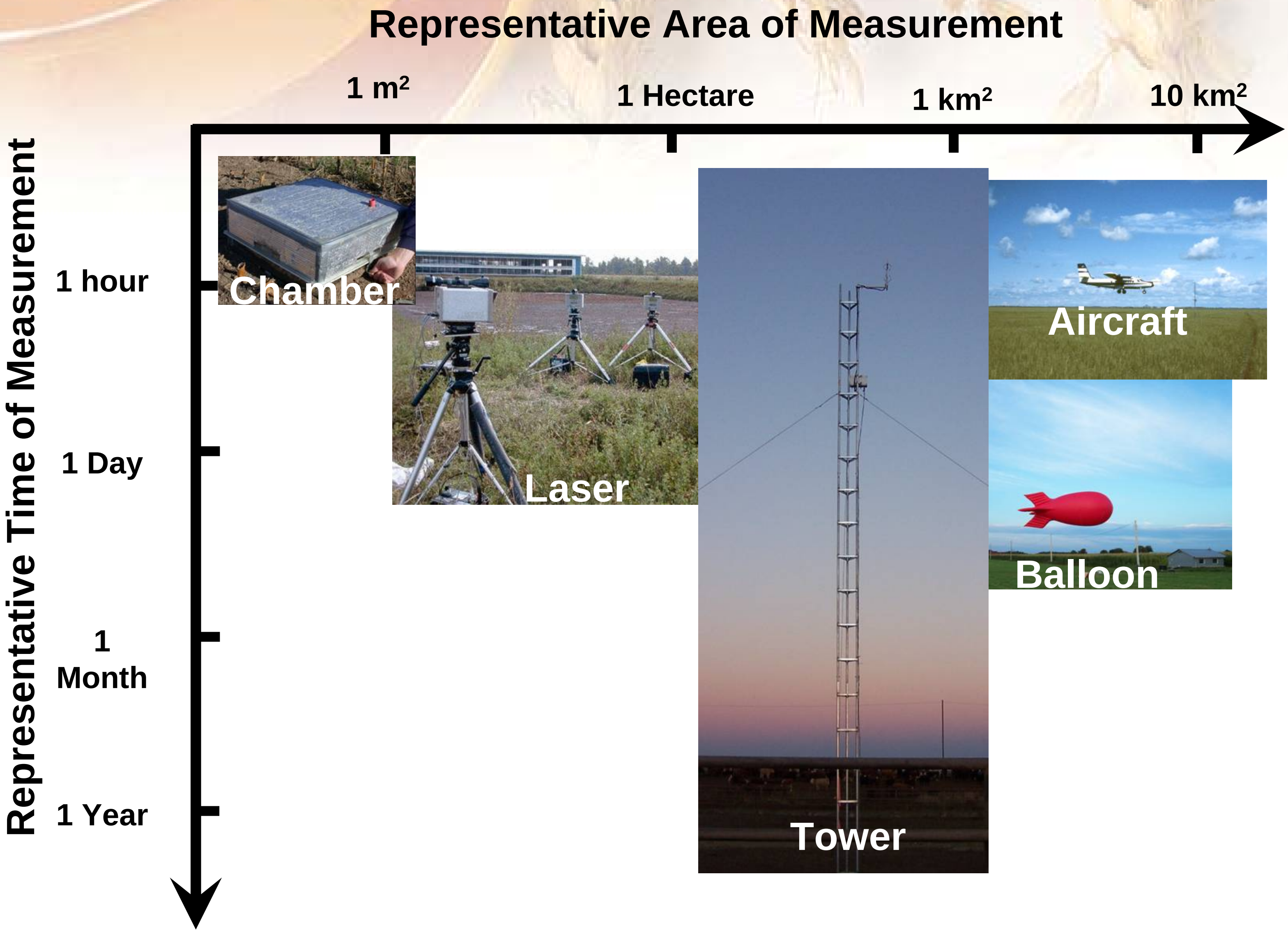
Source: US EPA (2006)

Agricultural greenhouse gas emissions

	Methane Emissions	**Nitrous oxide Emissions**
 Global	120-180 Tg CH_4	1.7-4.8 Tg N_2O-N
 China	18 Tg CH_4	0.5 Tg N_2O-N

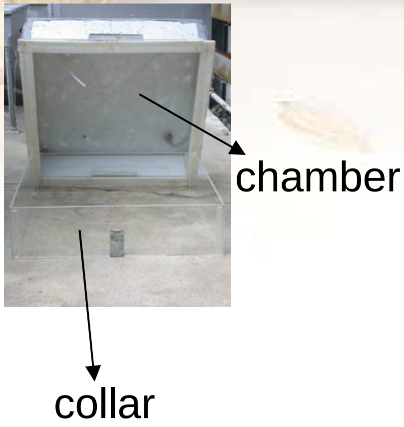
Source: Denman et al. (2007); People’s Republic of China (1994)

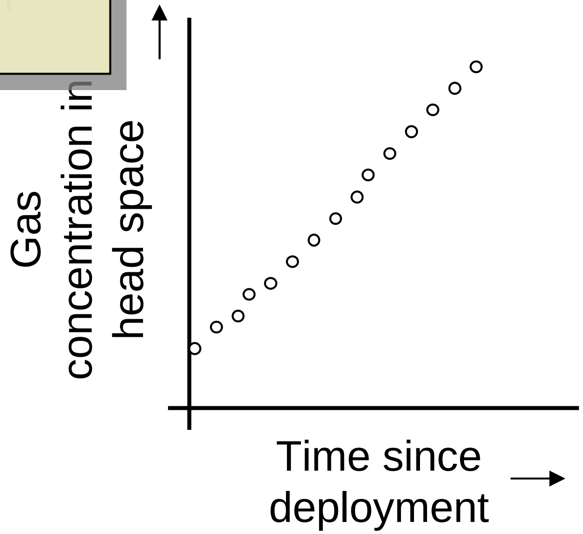
Space and Time Scale of Measurement Techniques



Non-Flow Through Non-Steady State (NFT-NSS) chambers: principles of operation

- Insert collar into soil, affix chamber to collar
- Gas accumulates in head space, no replacement of air
- Gas concentration in the chamber rises continually
- Sample periodically, typically at intervals of a few minutes and for periods of 15-30 minutes
- Gas samples returned to the lab and analyzed with e.g. gas chromatography
- Most common type of chamber because large concentration change is possible, mechanically simple, no need for power and no need for gas analysis on-line





Non-Flow Through Non-Steady State (NFT-NSS) chambers: Closed Chambers

Flux calculation:

$$F_g = \left(\frac{V}{A}\right) \times \left(\frac{dC}{dt}\right)$$

F_g = flux density of gas

V = volume of head space

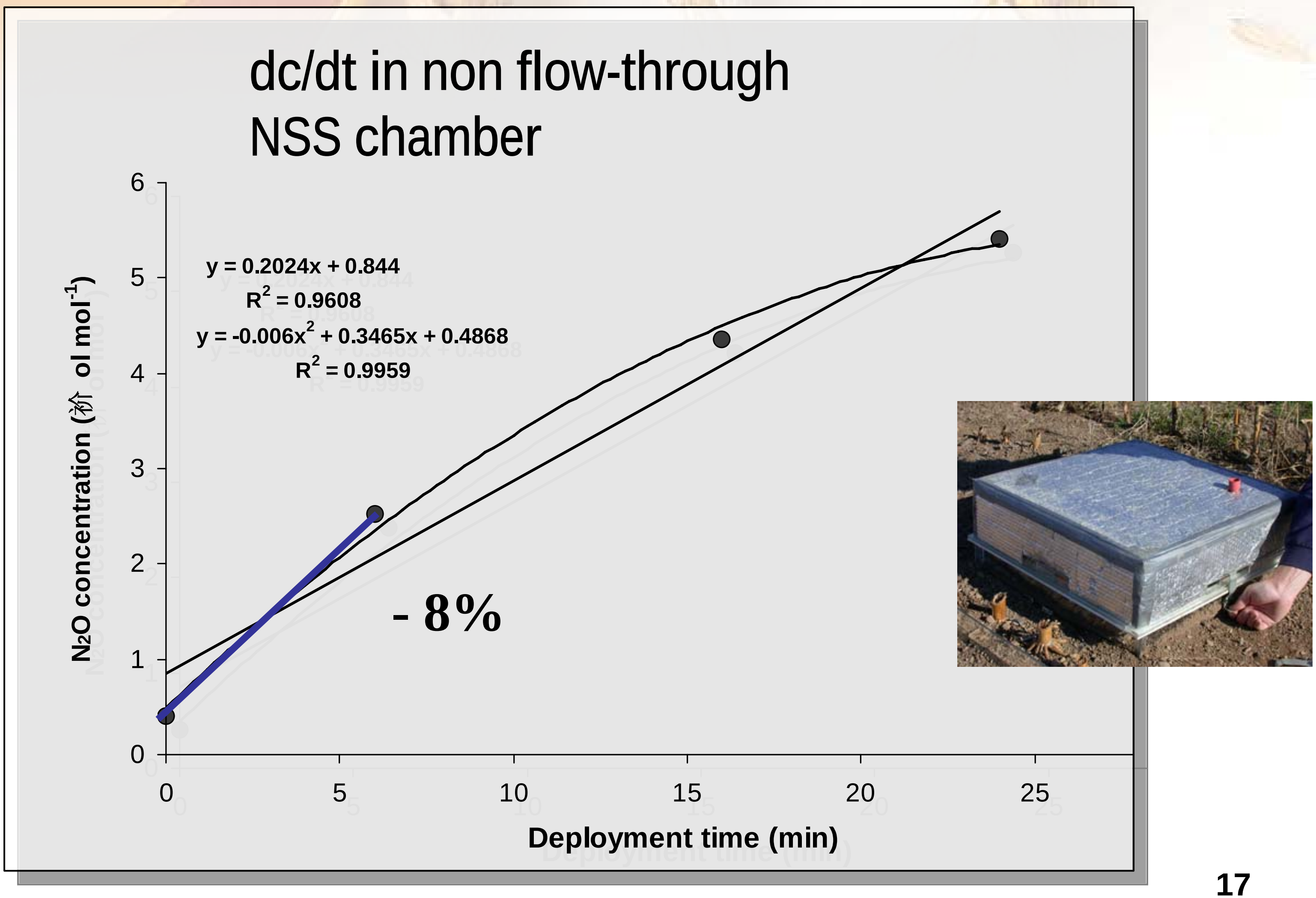
A = area of land enclosed

C = gas concentration in head space

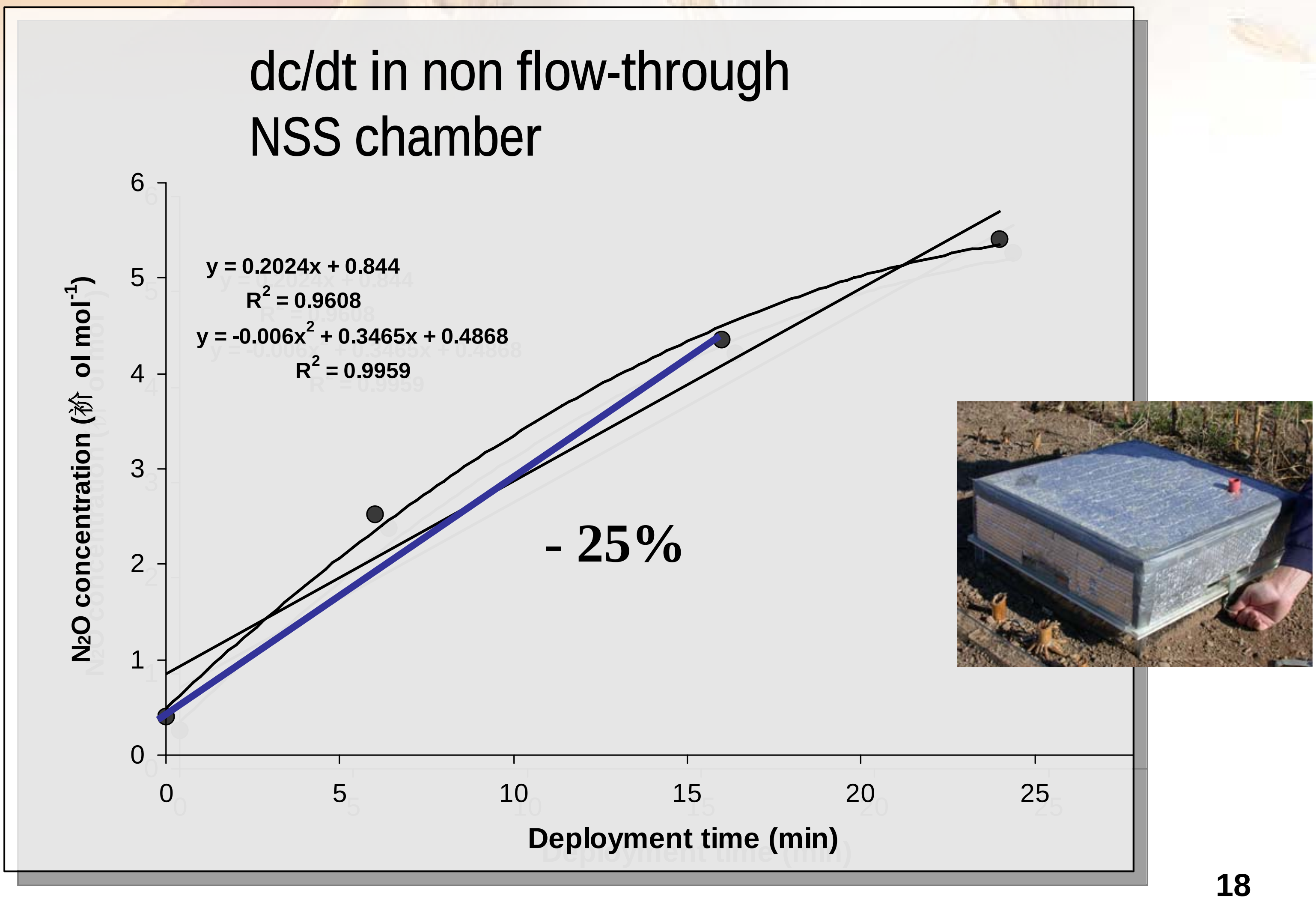
t = time

Because the head space is small and confined, the resolution for these measurements are much higher than using any other technique.

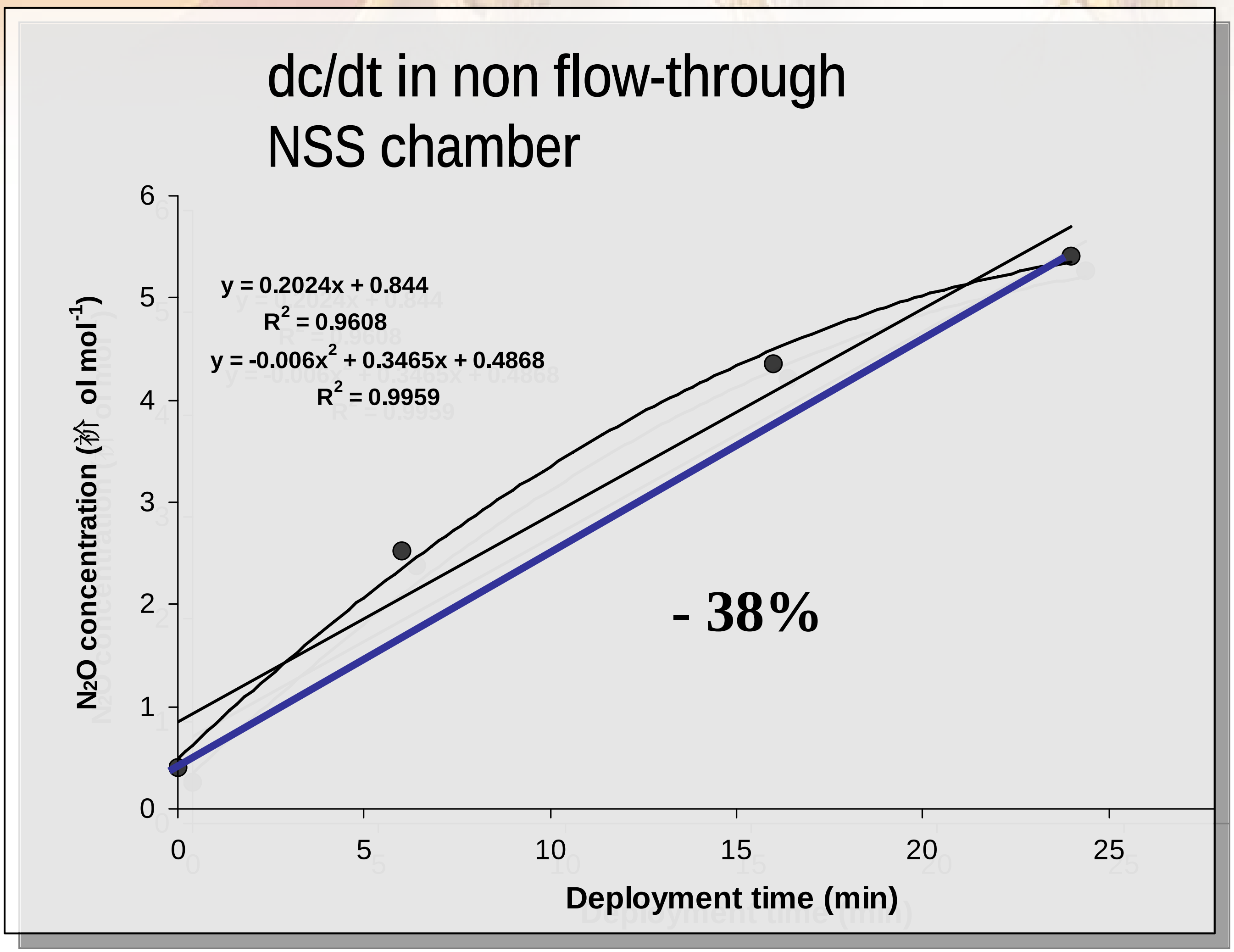
Concentration Change Over Time in Closed Chambers



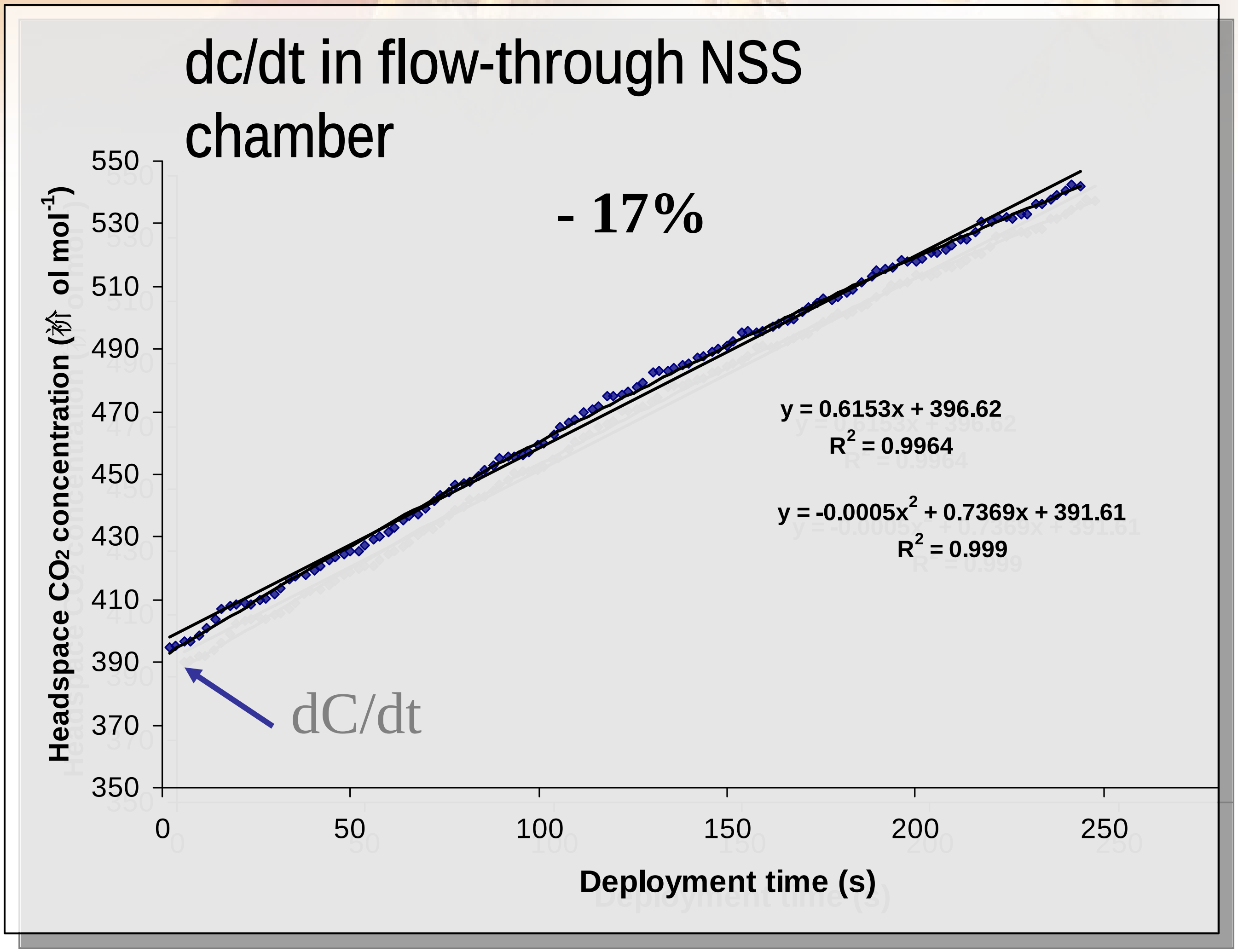
Concentration Change Over Time in Closed Chambers



Concentration Change Over Time in Closed Chambers



Concentration Change Over Time in Open Chambers



Criteria for reliable soil flux measurements

Rochette and Eriksen-Hamel (2007) evaluated the quality of soil N_2O emissions that have been collected using closed chambers and has suggested the confidence level in 50% of recent (2005-2007) N_2O flux measurements is low or very low owing to poor methodologies or incomplete reporting. They proposed the following series of requirements to ensure a minimum standard and confidence in chamber measurements:

1. Use insulated and vented base and chamber design
2. Avoid chamber heights lower than 10 cm
3. Have a minimum collar insertion depth of 5 cm
4. Avoid plastic syringes for sample storage
5. Take a minimum of 3 samples, including 1 at time t=0
6. Test non-linearity of changes in headspace gas concentration

Mass Balance Technique – Micrometeorological Mass Difference approach

Flux from within the enclosed source area can be calculated as the difference between the total gas fluxes across the upwind and downwind boundaries of the space, as follows:

$$F_{MMD} = \int_0^z \int_0^x \overline{u_z}\left(\overline{\rho}_{g4.z} - \overline{\rho}_{g2.z}\right) + \overline{v_z}\left(\overline{\rho}_{g3.z} - \overline{\rho}_{g1.z}\right) dxdz$$

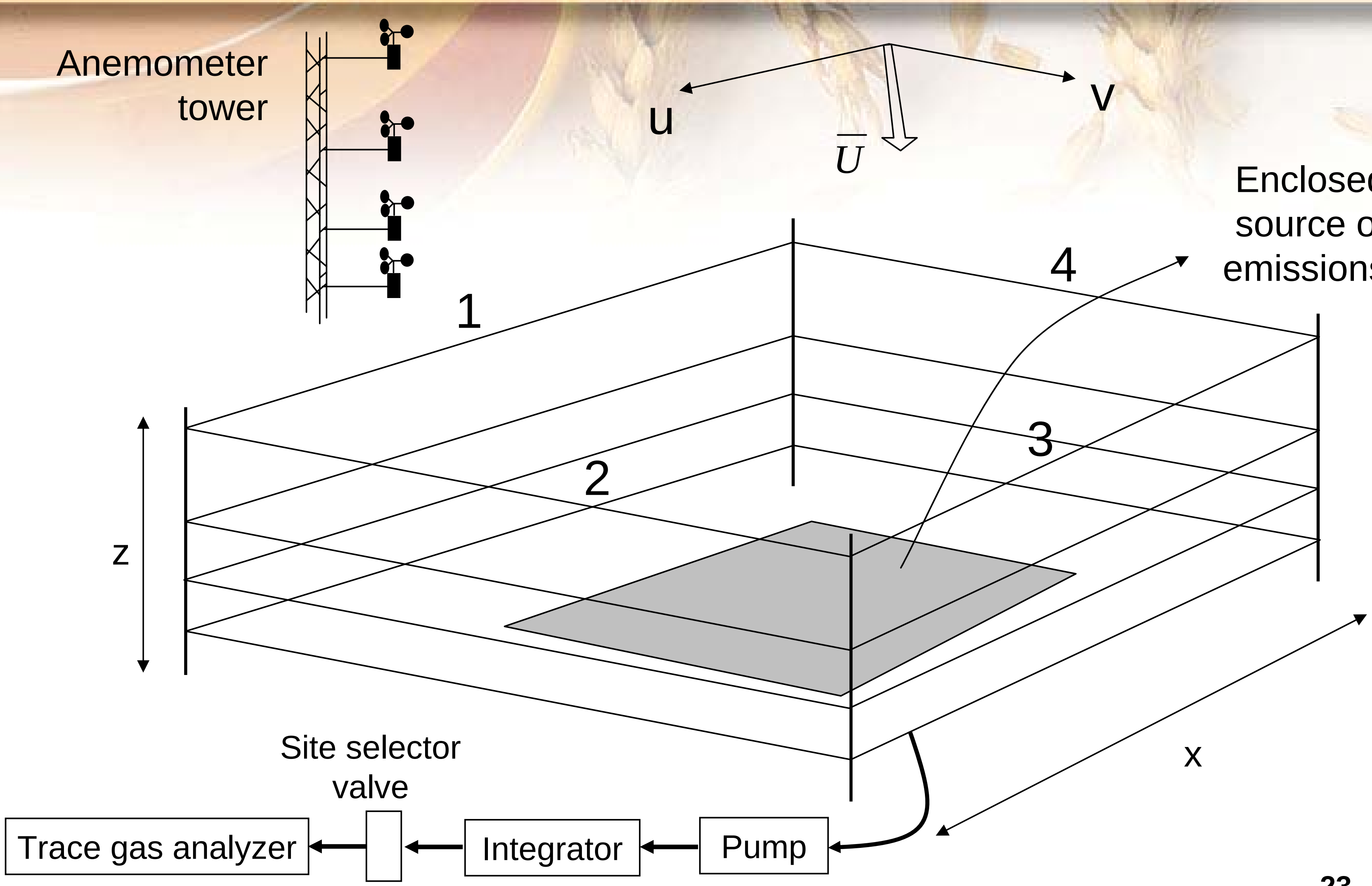
Where,

$\overline{\rho}$ = the gas concentration across each boundary

$\overline{u}, \overline{v}$ = wind vectors perpendicular to the boundary

However, the MMD technique is limited by the fact that it can only be applied at a scale of perhaps 10’s of meters, it computationally demanding and it requires a significant amount of set up.

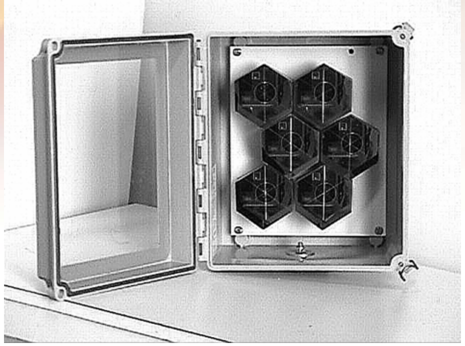
Mass Balance Technique – Micrometeorological Mass Difference approach



Instrumentation

Open-path lasers and retroreflector

Boreal GasFinder



PKL Spectra-1

- Gas detector (NH_3, CO_2, CH_4 and H_2S) for area sources
- On board calibration cell and datalogger
- Narrow wavelength minimizes interference with CO_2 and H_2O
- Path length up to 1000 m (depends on target gas)
- Detection limit for CH_4 of 2.0 ppm-m
- e.g. Boreal Laser GasFinder, PKL Spectra-1

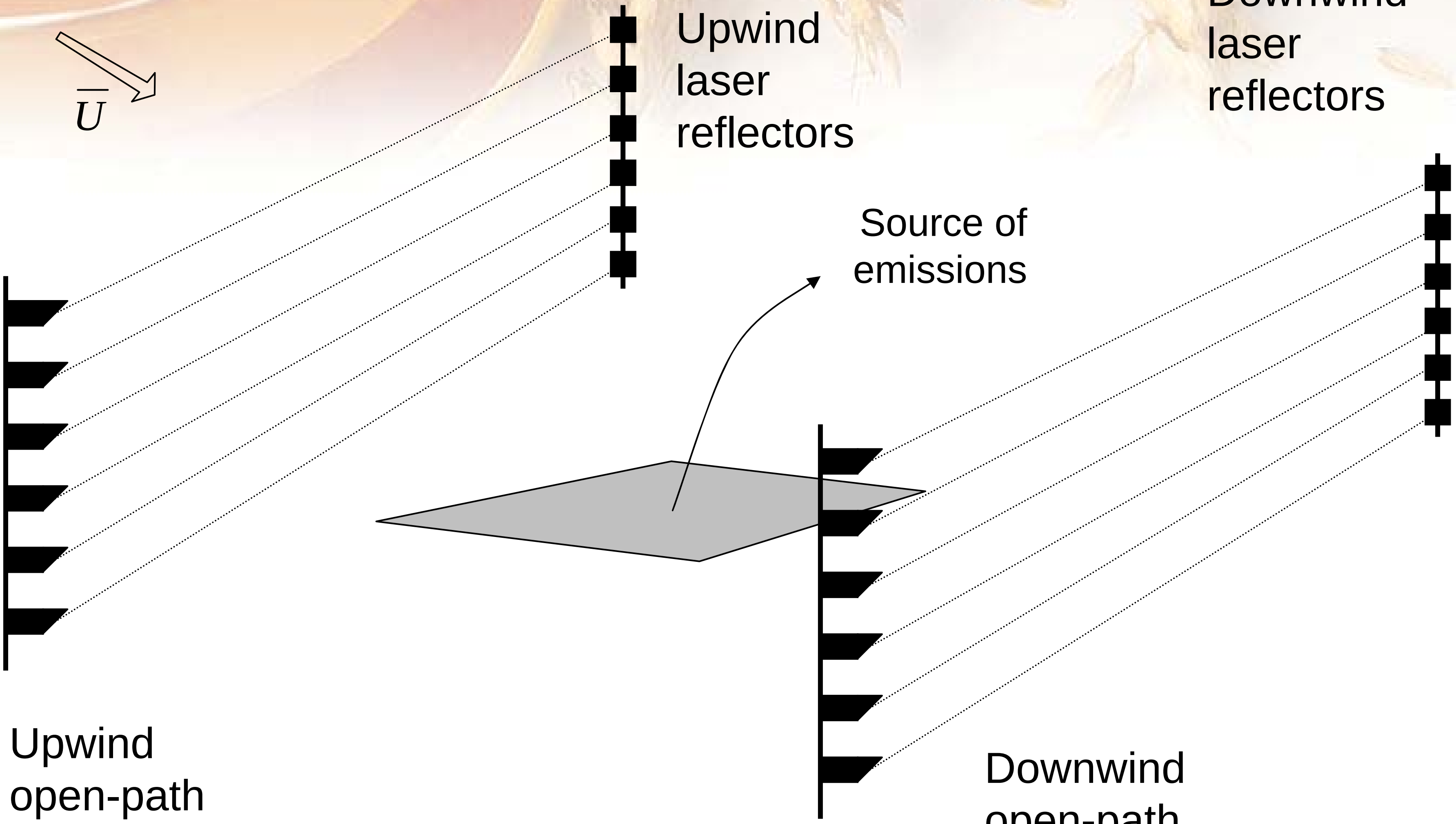
Mass Balance Technique – Modified Micrometeorological Mass Difference approach

- 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

Laser Tower

Reflector Tower

Mass Balance Technique – Modified Micrometeorological Mass Difference approach



$\overline{U}$

Upwind
laser
reflectors

Downwind
laser
reflectors

Source of
emissions

Upwind
open-path
lasers

Downwind
open-path
lasers

Mass Balance Technique: Integrated horizontal flux method

If a laser based measurement technique is used, such that the width of the laser line is much greater than the width of the plume of gas being measured and that the wind speed at any given height for all points along the laser line is uniform, then

$$F_g = X \int_0^Z \overline{U_n \left(\rho_{g_{z,d}} - \rho_{g_{z,b}} \right)} dz$$

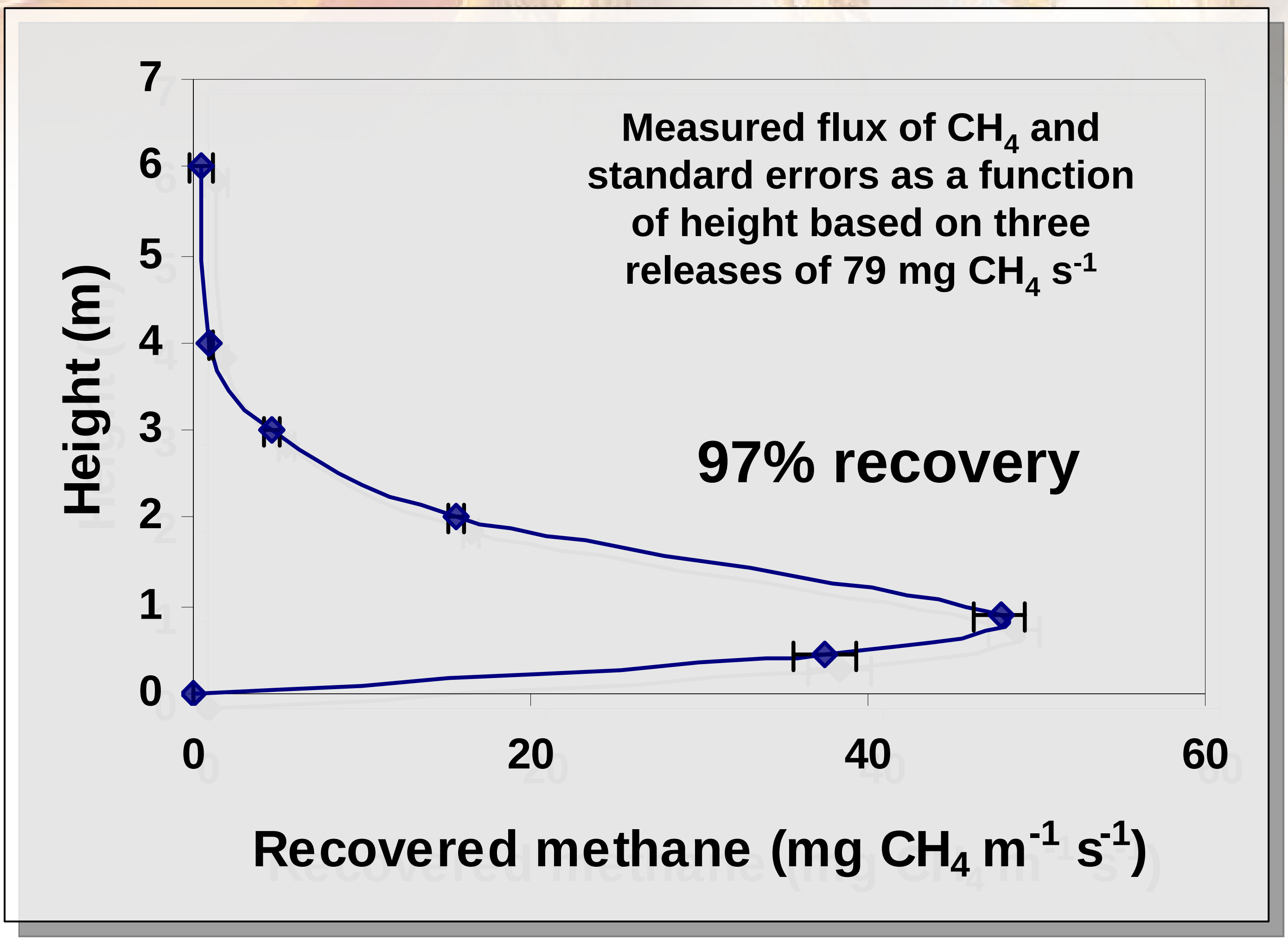
Where,

X = the length of the laser path

U_n = the wind speed normal to the boundaries

ρ_g = the scalar concentration and the subscripts *d* and *b* denote the downwind and background, respectively

Recovery from Synthetic Gas Release



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.

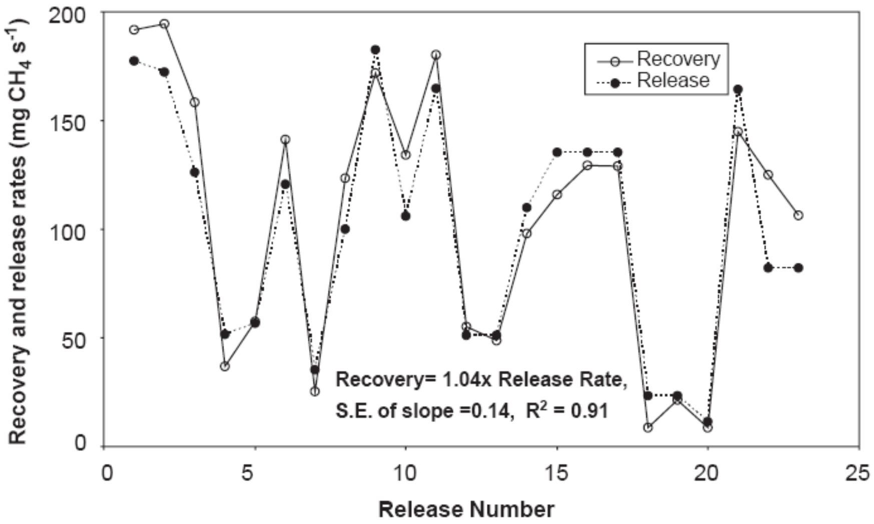
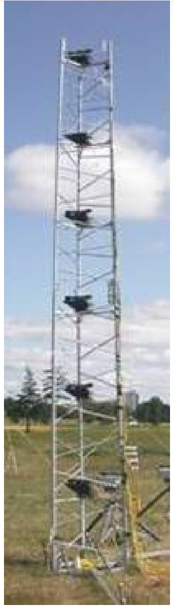


Fig. 5. Recovery and release rates in all acceptable releases. Recoveries are for the integrated instantaneous horizontal fluxes and an exclusion angle of 10°.

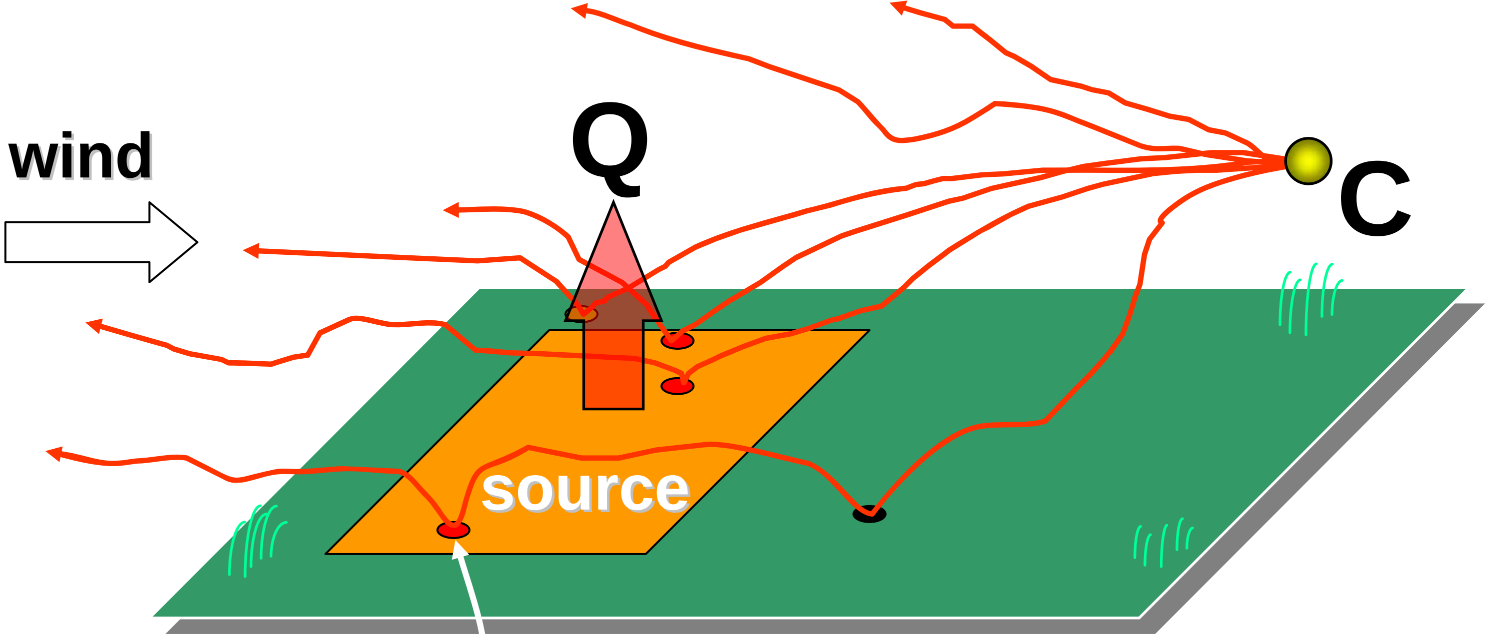


Methane recovery slightly exceeded methane release and was found that it could identify 10% changes in the rate of emission, provided the rate of emission was greater than about 40 mg CH_4 s^{-1}, equivalent to roughly 10 dairy cattle.

Source: Desjardins et al. (2004)

Micrometeorological tools: bLS modelling

- Calculate trajectories *upwind* from *C*, using e.g. the Windtrax model*
- Efficient & simple to find the rate of emission, *Q* from an area source
- *C*-*Q* relationship given by "touchdowns"

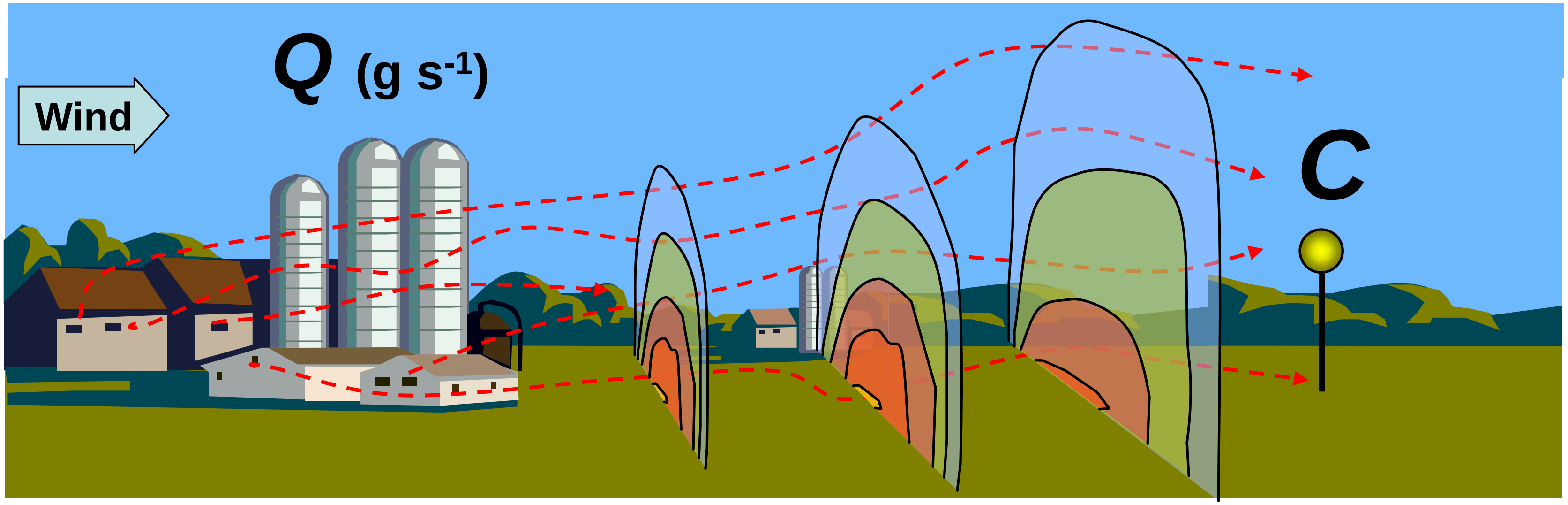


Trajectories affected by average wind and turbulence, i.e., different touchdown pattern during day (unstable) and night (stable).

*See: http://www.thunderbeachscientific.com/windtrax.html for more details

Inverse Dispersion Modeling

- Dispersion model relates concentration *C* to emission rate *Q* (“*C-Q relationship*”) for prevailing winds
- Measure *C* then infers *Q*



Advantages

+ simple measurements
+ total emissions
+ no operation disruption
+ remote measurement

Open path lasers and the backwards Lagrangian Stochastic modelling technique to estimate CH_4 emissions

Advantages:

- Non-invasive measurement technique
- Simple measurement set-up (one open path laser, one sonic anemometer)
- Effective for a range of emission sources (e.g. manure tank, beef feedlot, whole farm)

Open path lasers and the backwards Lagrangian Stochastic modelling technique to estimate CH_4 emissions

Disadvantages:

- Ineffective during light wind conditions and periods of extreme stability
- Obstructions to wind flow must be accounted for by placing the lasers downwind about 10-20 times the height of the wind obstruction
- Open path lasers are not available for all gas species of interest (e.g. N_2O) therefore this technique cannot be used for such gases

Micrometeorological tools: bLS modeling

In practice, C is measured along a line with open path lasers

Wind speed and direction is measured using a sonic anemometer and friction velocity, u*, surface roughness, z_0 and Obukhov stability length, L are calculated, from which the vertical touchdown velocity, w_0 can be estimated.

Using a line measurement:

$$Q_{bLS} = \frac{(C_L - C_b)}{(C_L / Q)_{sim}} \longrightarrow (C_L / Q)_{sim} = \frac{1}{P}\sum_{i=1}^{P}\left(\frac{1}{N}\sum\left|\frac{2}{w_0}\right|\right)$$

where,

Q_{bLS} = Estimated emission rate

Q = Uniform but unknown emission rate

C_L = Line concentration

C_b = Background concentration

P = Point Concentrations evenly spaced along the path

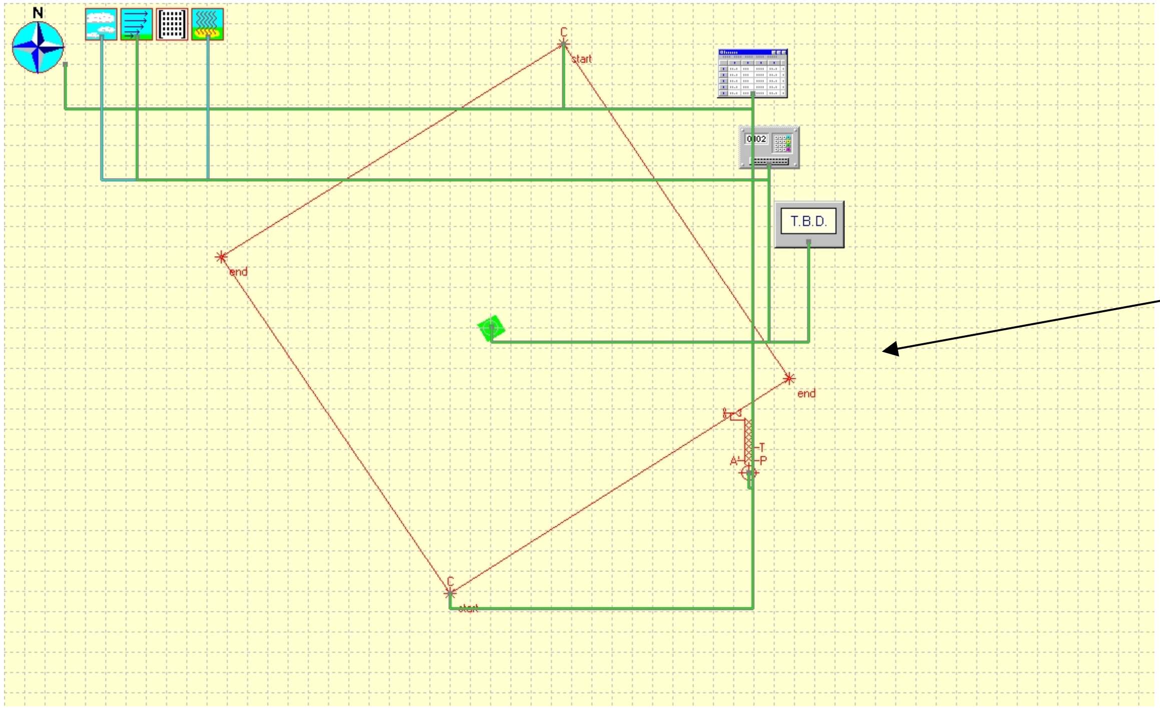
N = Total number of particles released at each point

w_o = Vertical touchdown velocities

** The inner summation refers only to touchdowns within the source*

bLS Modeling Software: WindTrax

- WindTrax is a software tool for simulating short-range atmospheric dispersion
- Operates in backward and forward Lagrangian Stochastic modes to estimate the concentration and downwind concentration for ground level sources
- Operates with point or line averaged concentrations

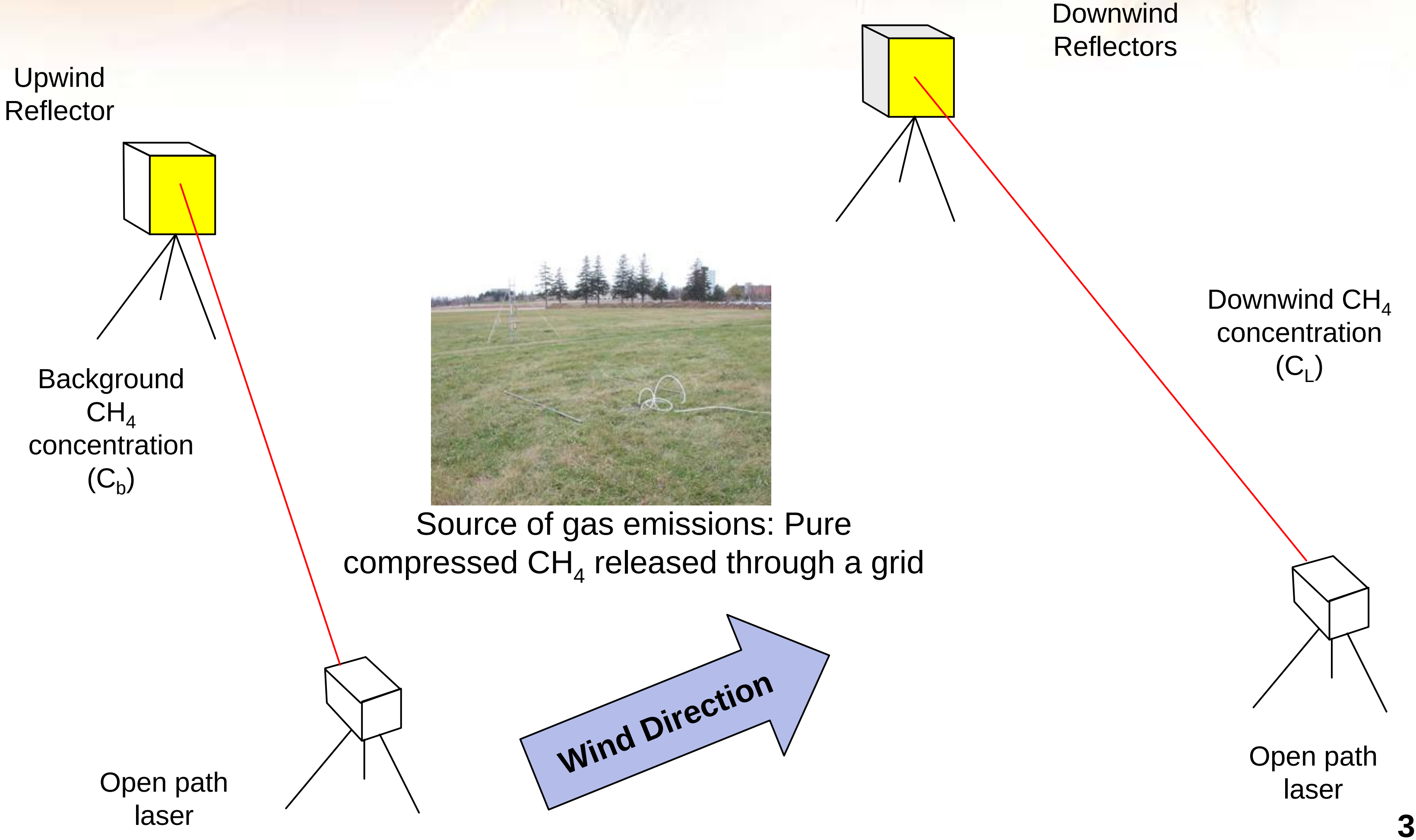


Graphical display to enter instrument and emissions source locations.

WindTrax can be downloaded from:
http://www.thunderbeachscientific.com/windtrax.html

Experimental setup for pure CH_4 release to test the bLS technique

Estimate CH_4 concentration in air using open path lasers



Downwind Reflectors

Upwind Reflector

Downwind CH_4 concentration (C_L)

Background CH_4 concentration (C_b)

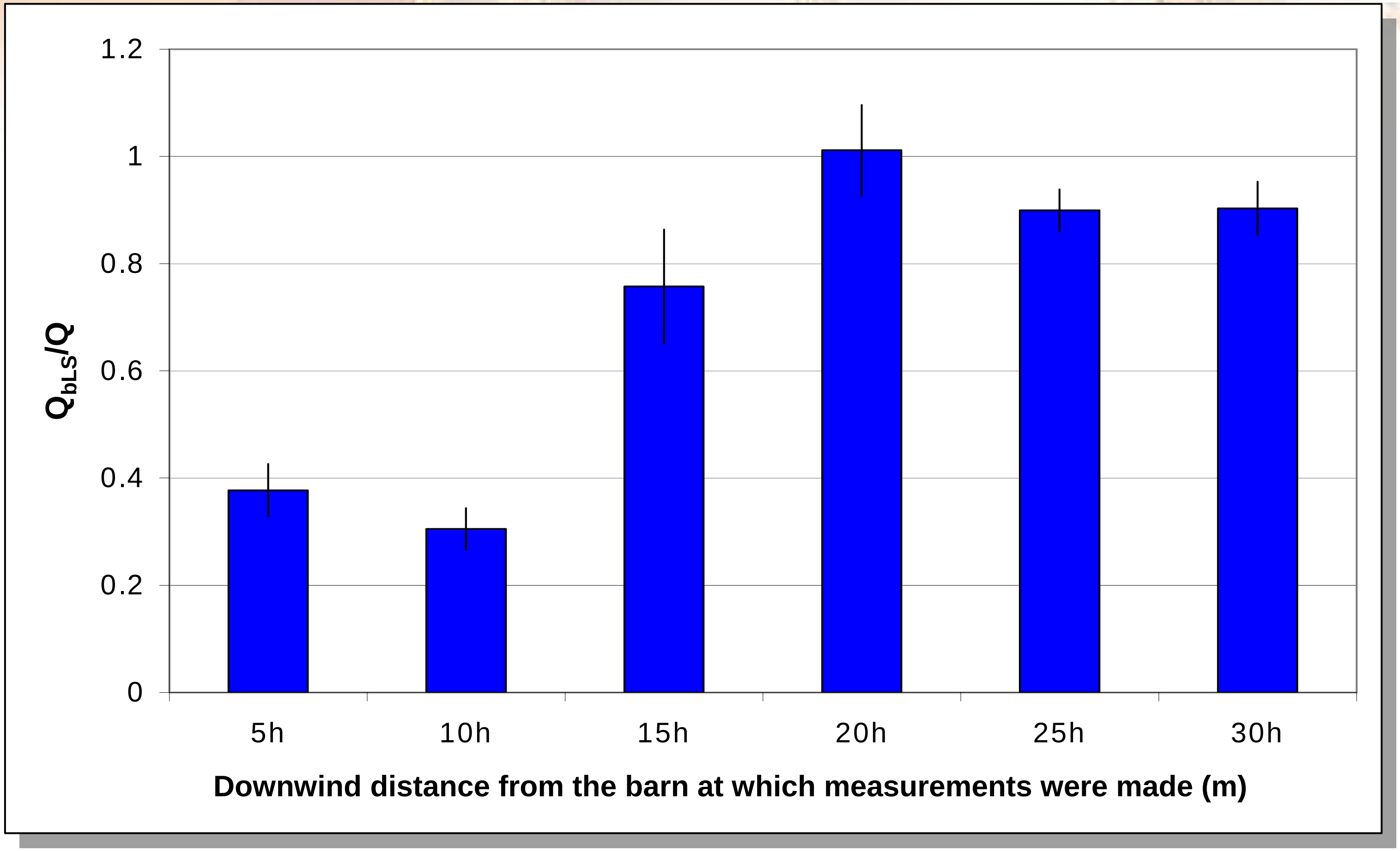
Source of gas emissions: Pure compressed CH_4 released through a grid

Wind Direction

Open path laser

Open path laser

Testing the bLS technique under complex conditions: Methane release in a barn



h = 6m

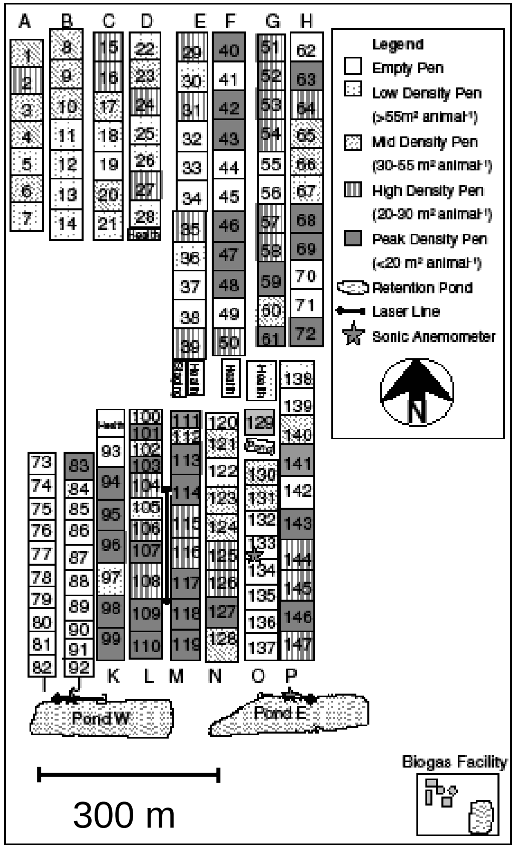
Gao et al. 2006. Evaluating the backward Lagrangian Stochastic (bLS) technique for estimating methane emissions from a barn. In preparation.

Measuring methane emissions from beef feedlot

Canada

Study site:

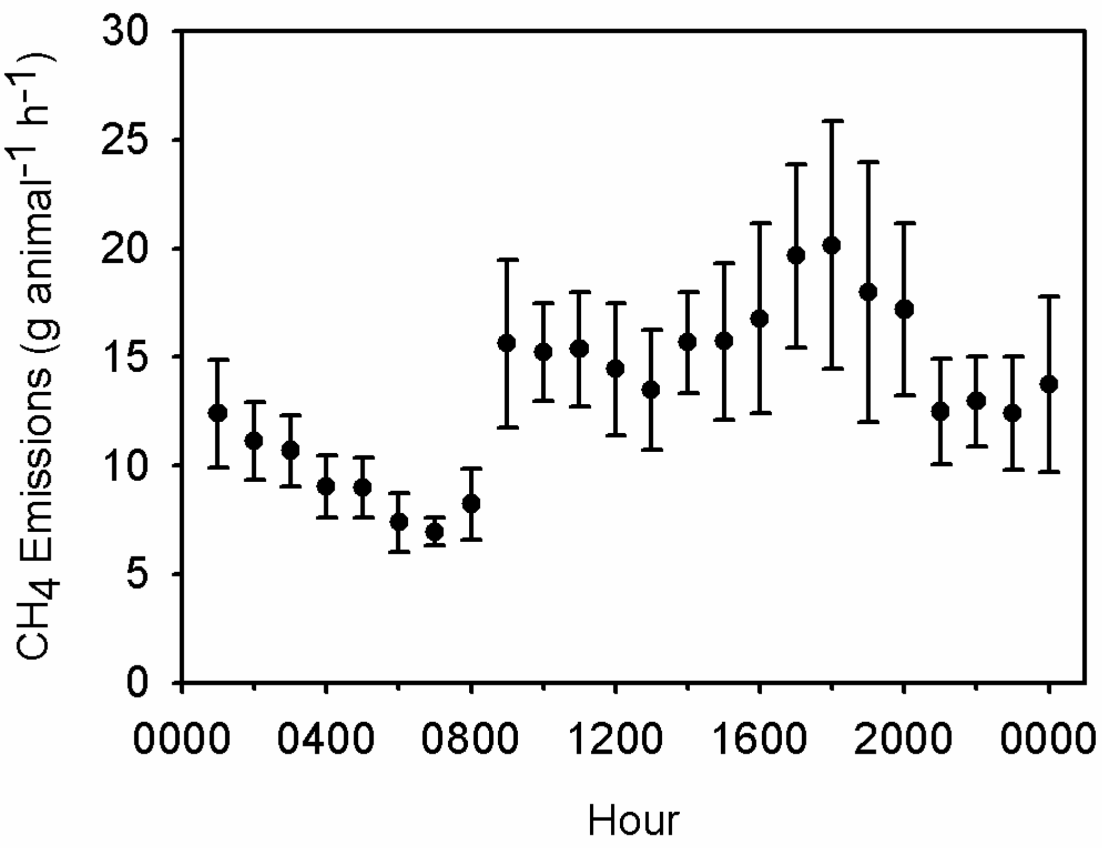
- Near to Vegreville, Canada
- Beef feedlot: 17,000 head



Source: Van Haarlem et al. (2008)

backwards Lagrangian Stochastic modelling: CH_4 emissions from whole farm feedlots

Diurnal Cycle in CH_4 emissions, corresponding with feeding times



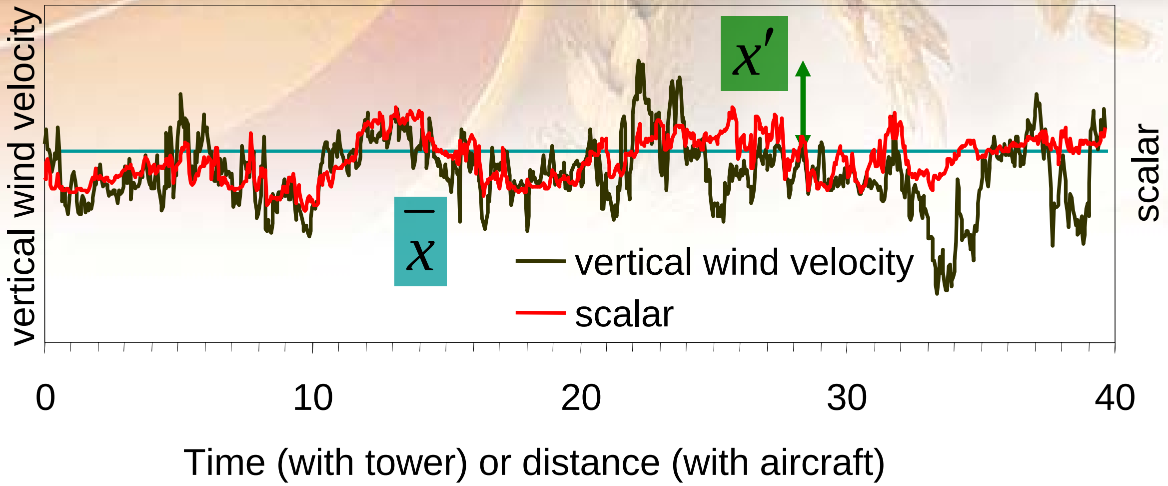
Average daily emission rate: 320 g CH_4 animal^{-1} d^{-1}

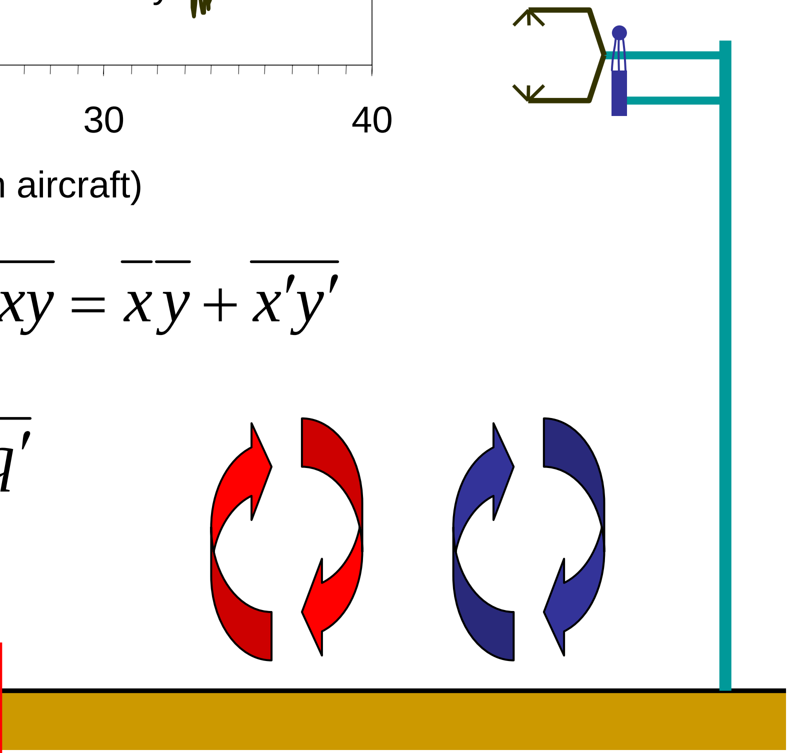
The CH_4 emission factor estimated using the IPCC methodology is approximately 240 g CH_4 animal^{-1} d^{-1}

$$EF_{CH4} = GEI \times Y_m$$

Source: Van Haarlem et al. (2008)

The Eddy Covariance Method





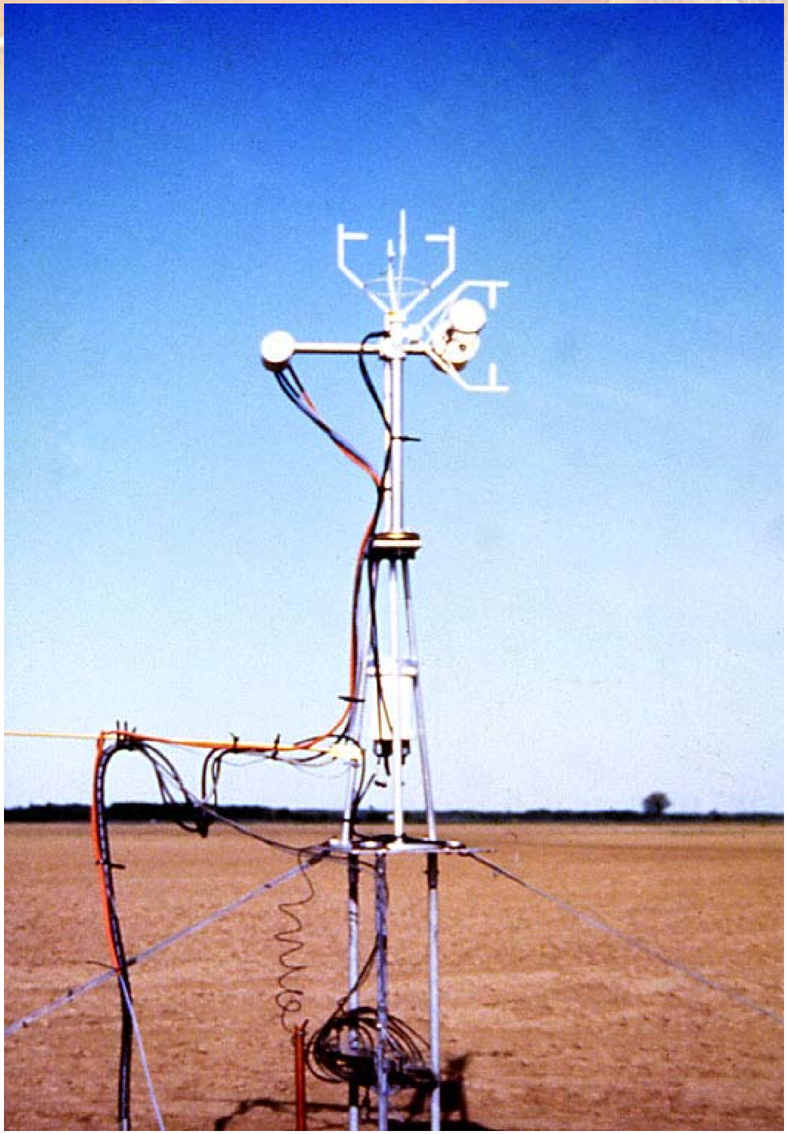
Reynolds: $x = \overline{x} + x', \quad \overline{x'} = 0, \quad \overline{xy} = \overline{x}\,\overline{y} + \overline{x'y'}$

Flux: $F = \overline{wq} = \cancel{\overline{w}\,\overline{q}} + \overline{w'q'}$

$$\boxed{\overline{w} = 0}$$

assuming stationarity and horizontal homogeneity!

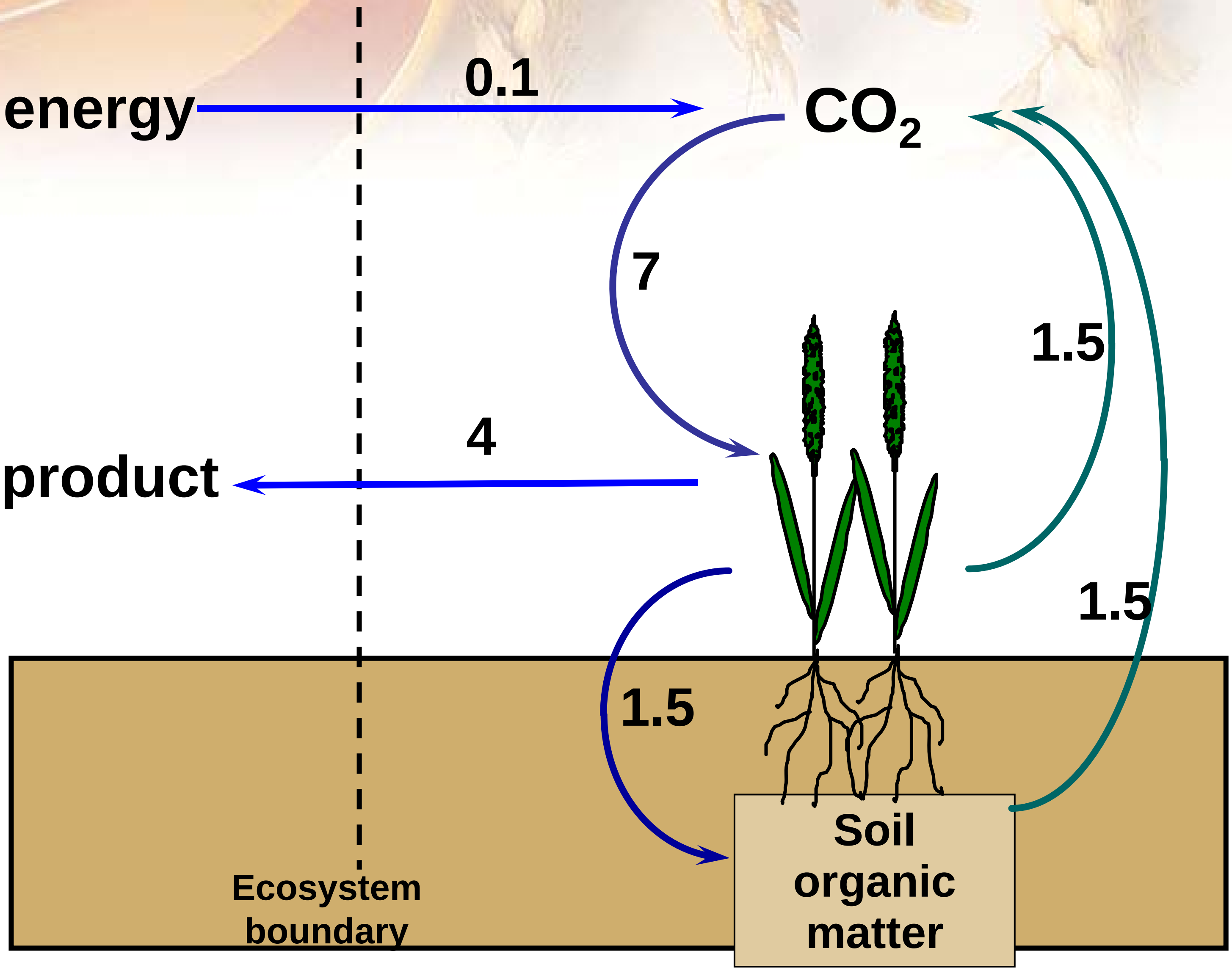
Measuring Changes in Soil Organic Carbon



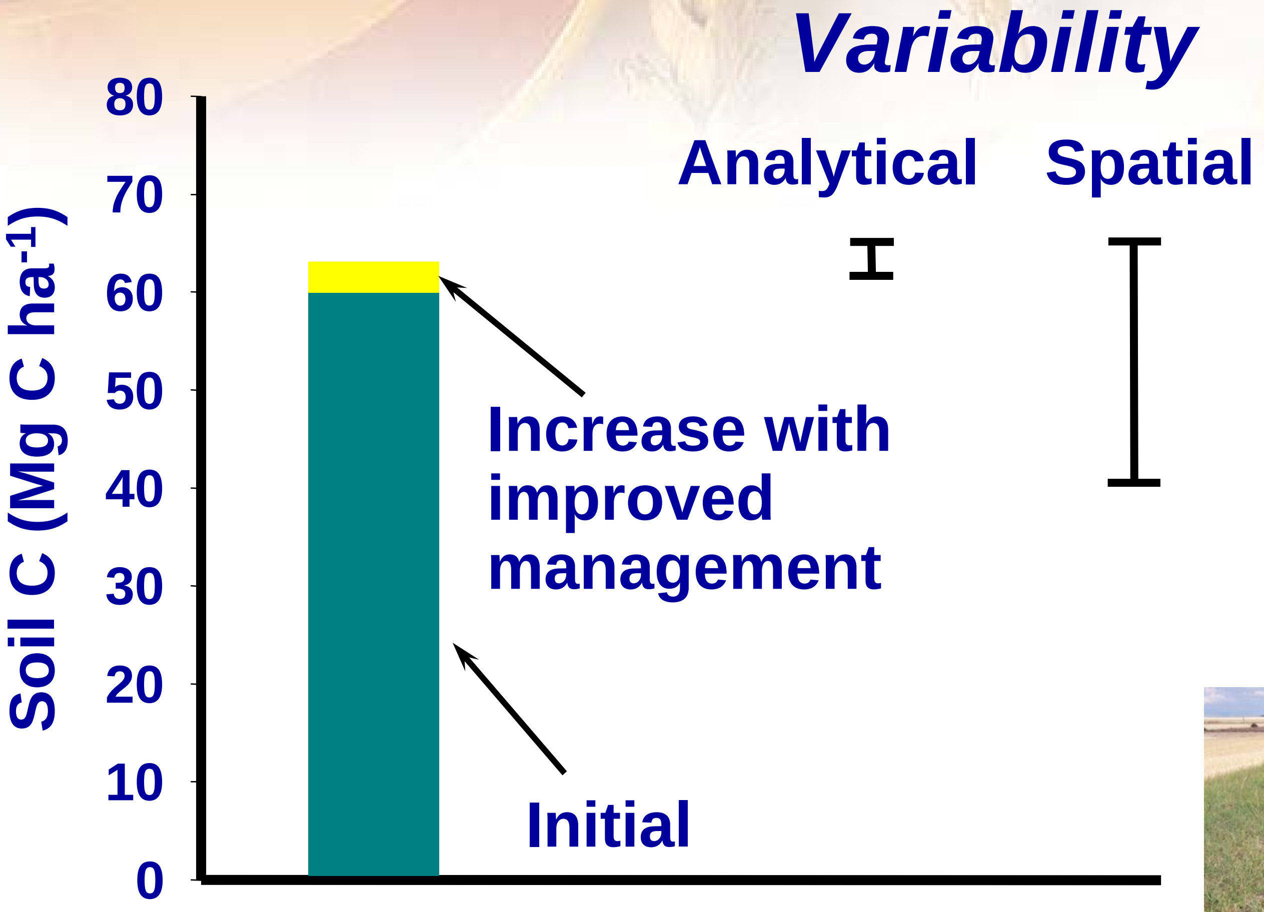
CO_2 - flux data have the potential to provide high resolution measurements of changes in C sequestration on the scale of hectares.

e.g. ChinaFlux;
Carbo Europe;
AmeriFlux;
Fluxnet - Canada

The carbon cycle in agroecosystems



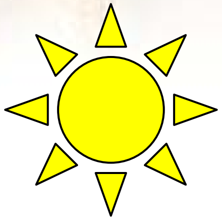
Measurement of Soil C Gain



Flux Underestimation

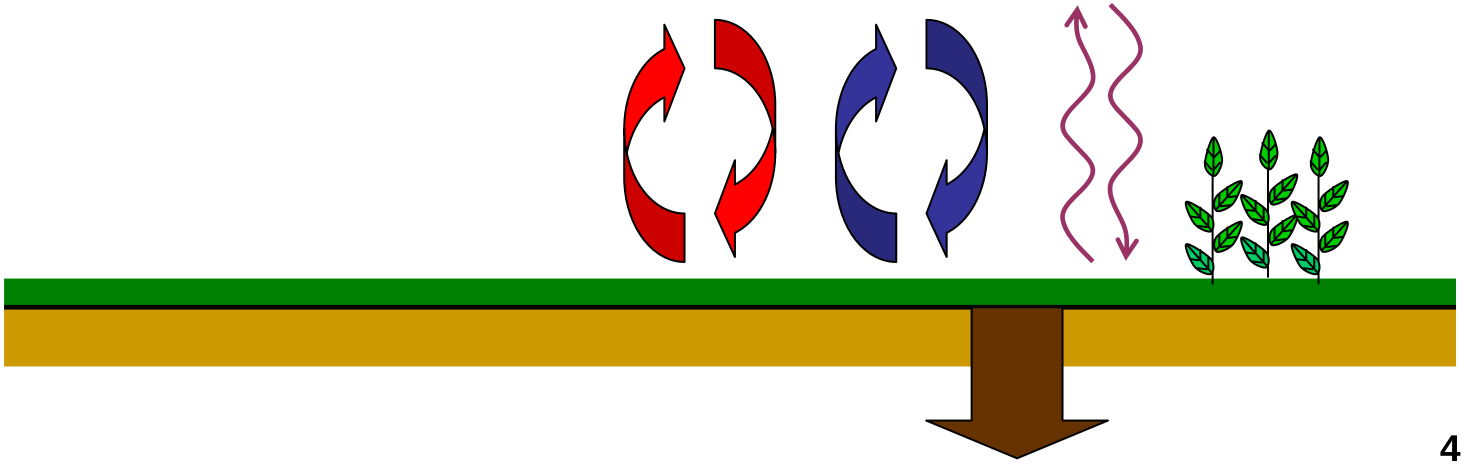
From the basic energy balance equation,

$Q_n - Q_G - \Delta Q_S = Q_E + Q_H$



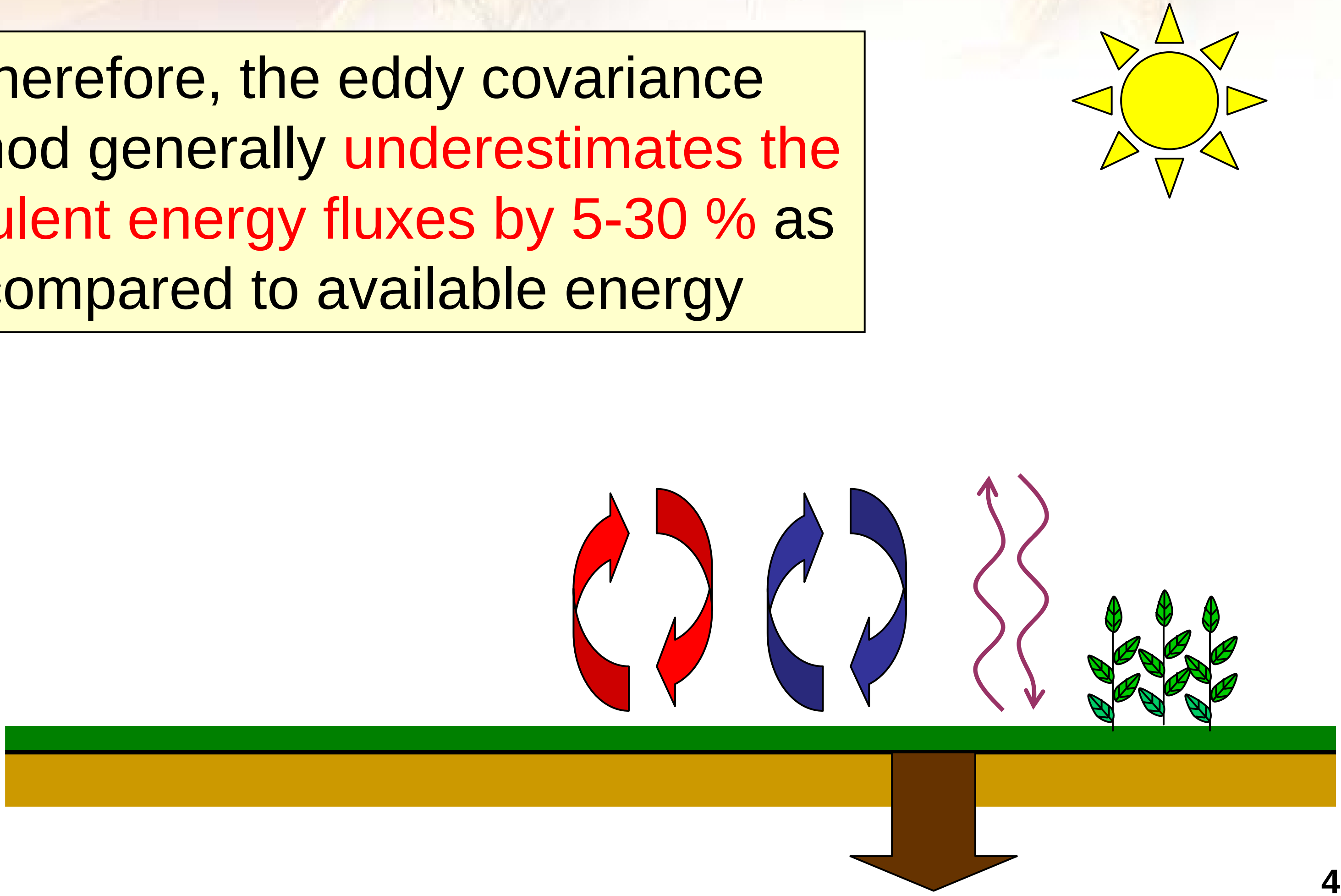
However, experimentally it has generally been found that

$Q_n - Q_G - \Delta Q_S > Q_E + Q_H$

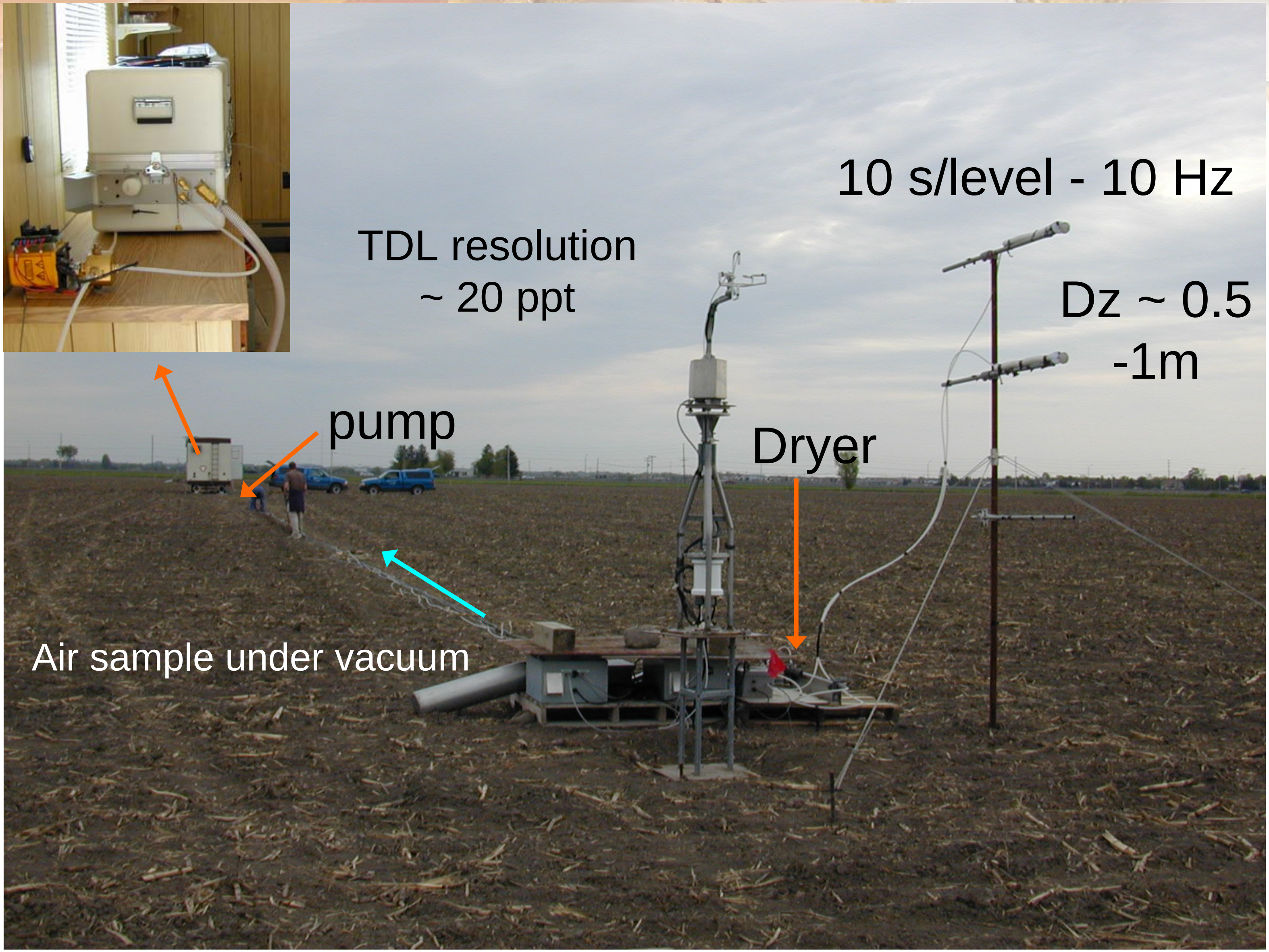


Flux Underestimation – A persistent Problem

Therefore, the eddy covariance method generally underestimates the turbulent energy fluxes by 5-30 % as compared to available energy



Tower-based N_2O Flux



10 s/level - 10 Hz

TDL resolution
~ 20 ppt

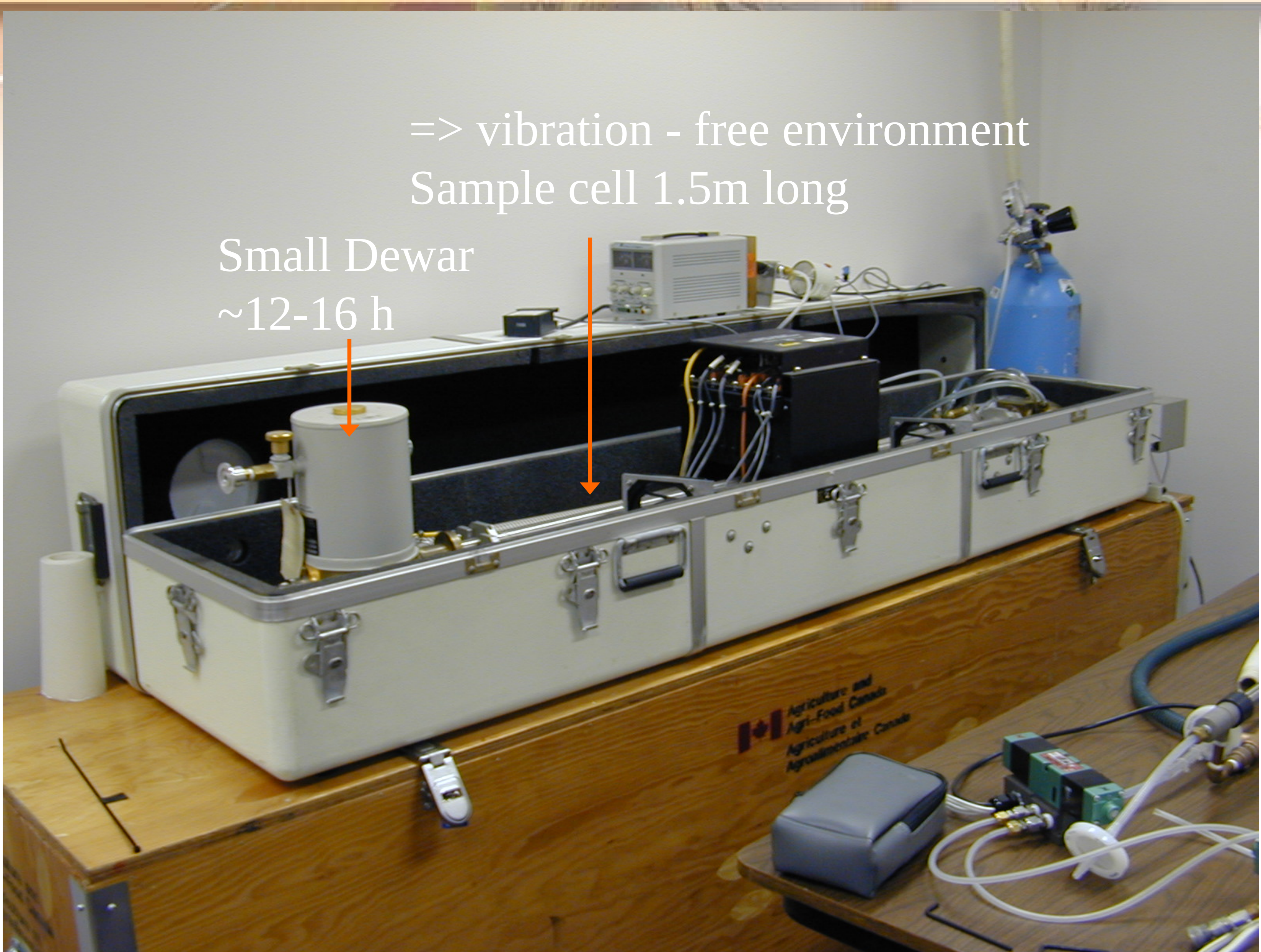
Dz ~ 0.5
-1m

pump

Dryer

Air sample under vacuum

Tunable Diode Laser



=> vibration - free environment

Sample cell 1.5m long

Small Dewar

~12-16 h

The aerodynamic method, stable and unstable conditions

The aerodynamic method can be extended to stable and unstable atmospheric conditions as follows:

$$F_g = \frac{k^2\left(\overline{u_2} - \overline{u_1}\right)\left(\overline{C_2} - \overline{C_1}\right)}{\left[\ln\left(\frac{z_2}{z_1}\right) - \left[\psi_1(z_2) - \psi_1(z_1)\right]\right]\left[\ln\left(\frac{z_2}{z_1}\right) - \left[\psi_2(z_2) - \psi_2(z_1)\right]\right]}$$

where, ψ_1 and ψ_2 are corrections for stability. In stable conditions,

$$\psi_1 = \psi_2 = -5\frac{z}{L}$$

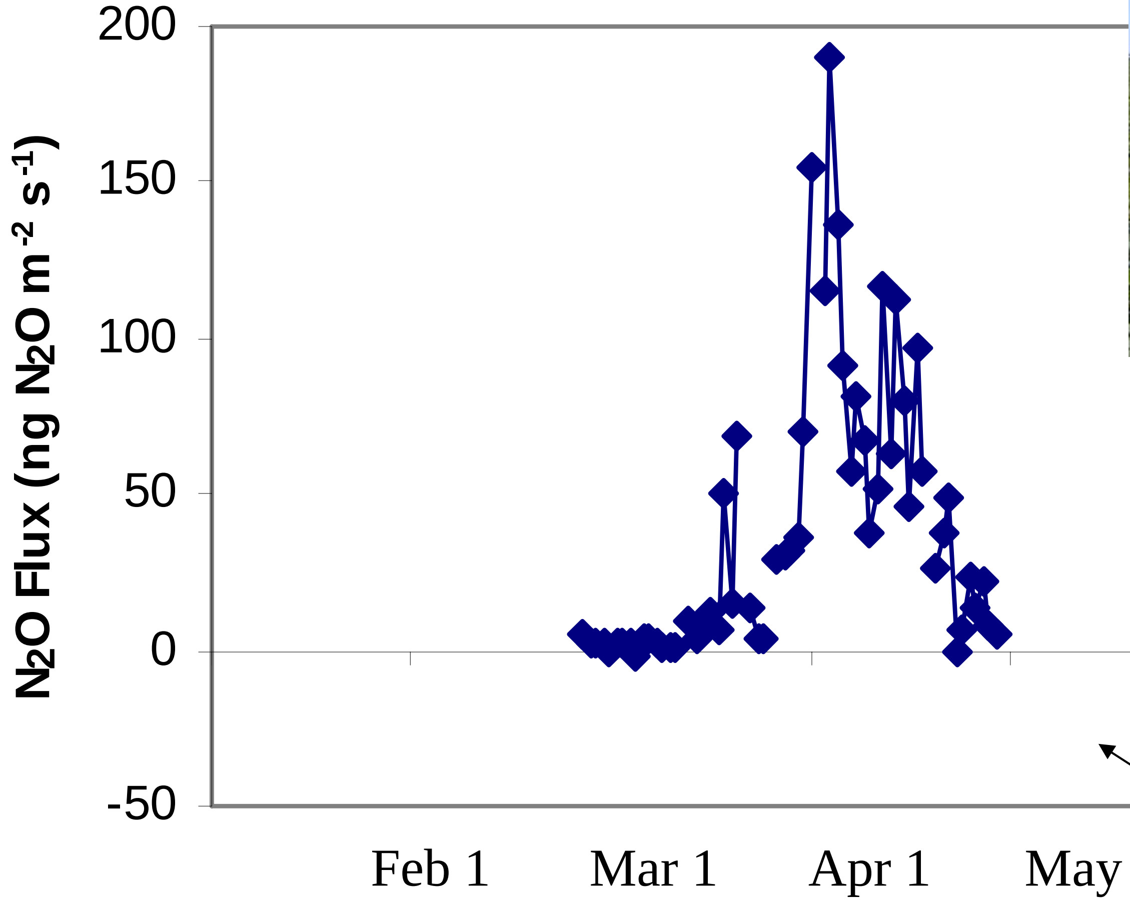
In unstable conditions,

$$\psi_1 = 2\ln\left[\frac{(1+x)}{2}\right] + \ln\left[\frac{(1+x^2)}{2}\right] - 2\tan^{-1}x + \frac{\pi}{2}$$ and $$\psi_2 = 2\ln\left[\frac{(1+x^2)}{2}\right]$$

Where,

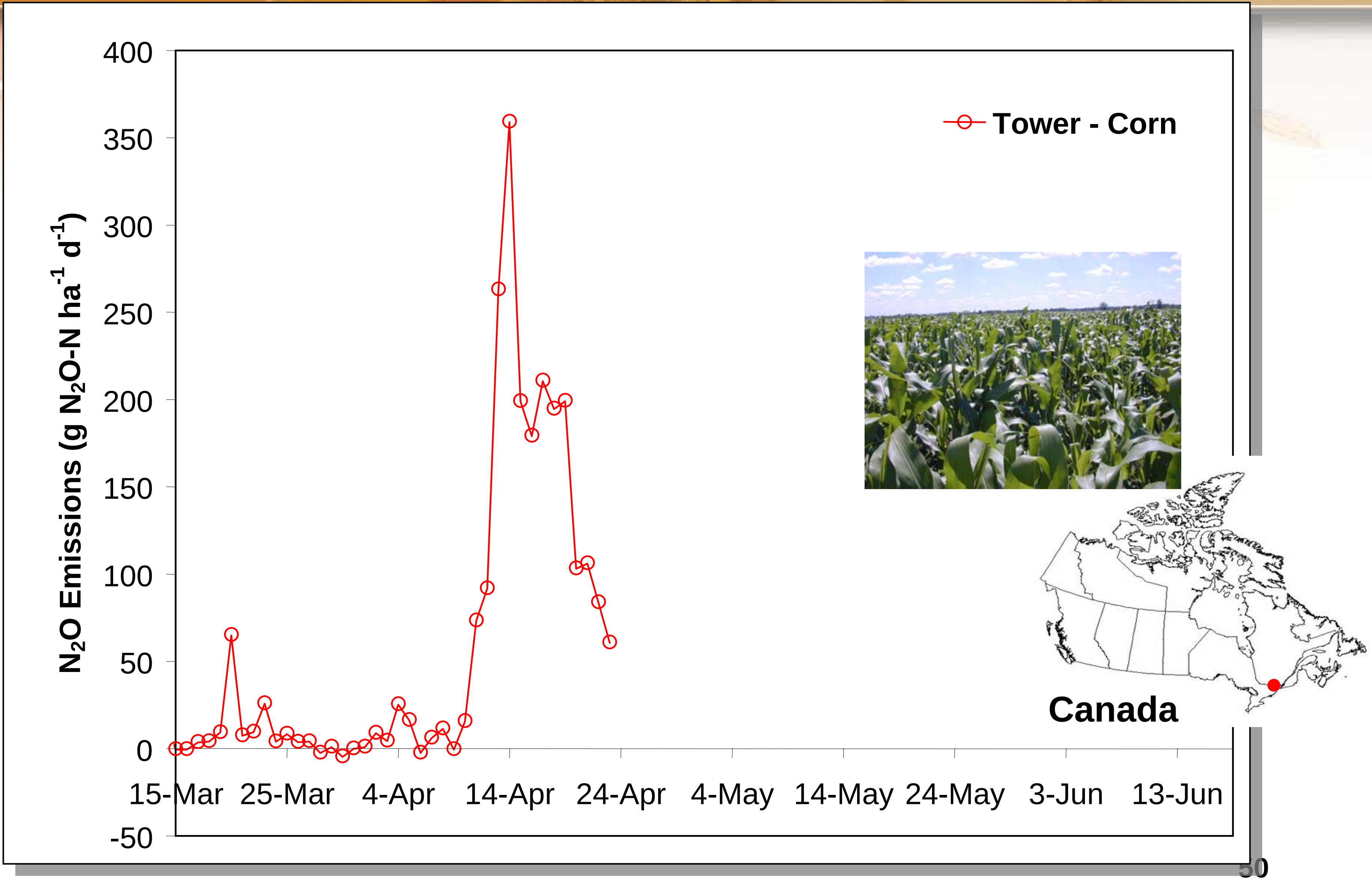
$$x = \left(1 - 16\frac{z}{L}\right)^{\frac{1}{4}}$$

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



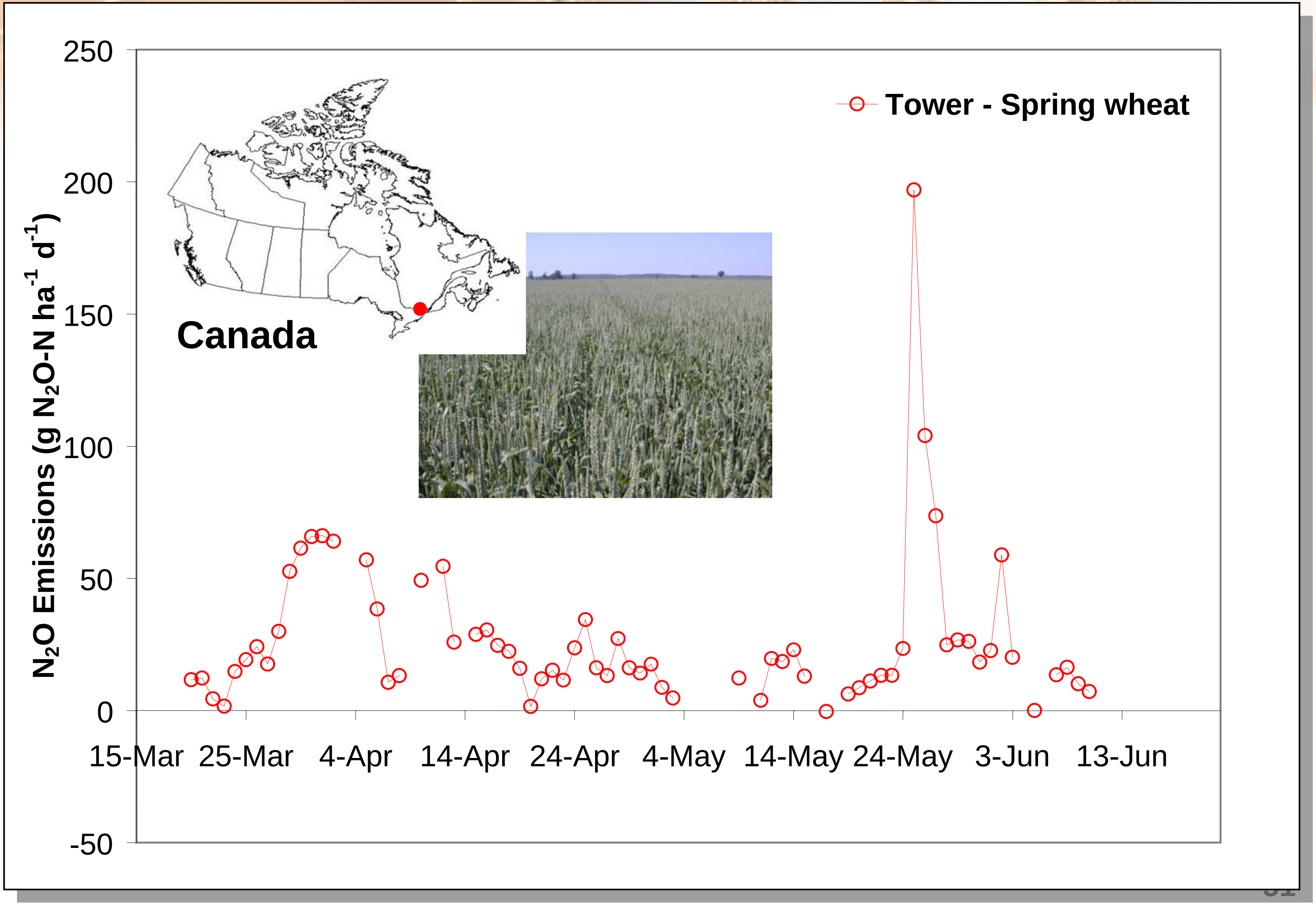
Canada

Tower based N_2O flux estimates over corn, 2001



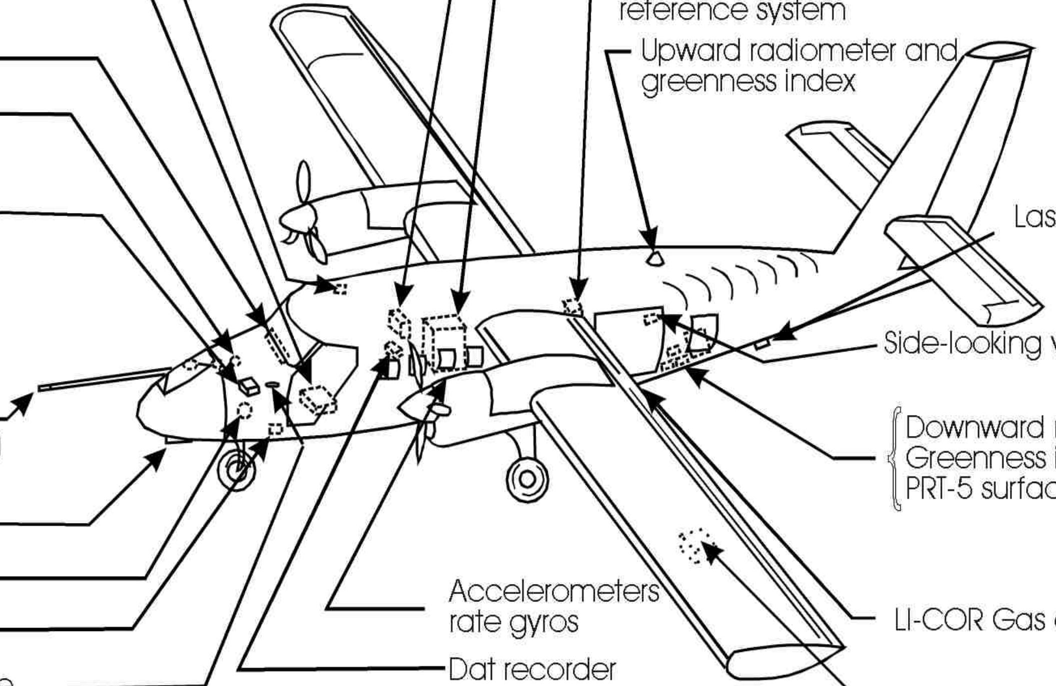
Source: Desjardins et al (2009)

Tower based N_2O flux estimates over spring wheat, 2004



Source: Desjardins et al (2009)

Aircraft Instrumentation for Regional Flux Measurement



Global positioning system antenna

Console, keyboard & navigation system controls

Data display

Dew point sensor

Nose LI-COR CO2/H2O analyser

Rosemount 858 (α, β, airspeed, altitude)

Video camera

Attitude gyro

Radio altimeter

Rosemount Temperature Probes (2 port, 1 starboard)

ozone analyzers (Teco and LOZ3)

Computer system

Litton 90 inertial reference system

Upward radiometer and greenness index

Laser altimeter

Side-looking video camera

Downward radiometer
Greenness index
PRT-5 surface temperature

LI-COR Gas analyzer (CO2/H2O)

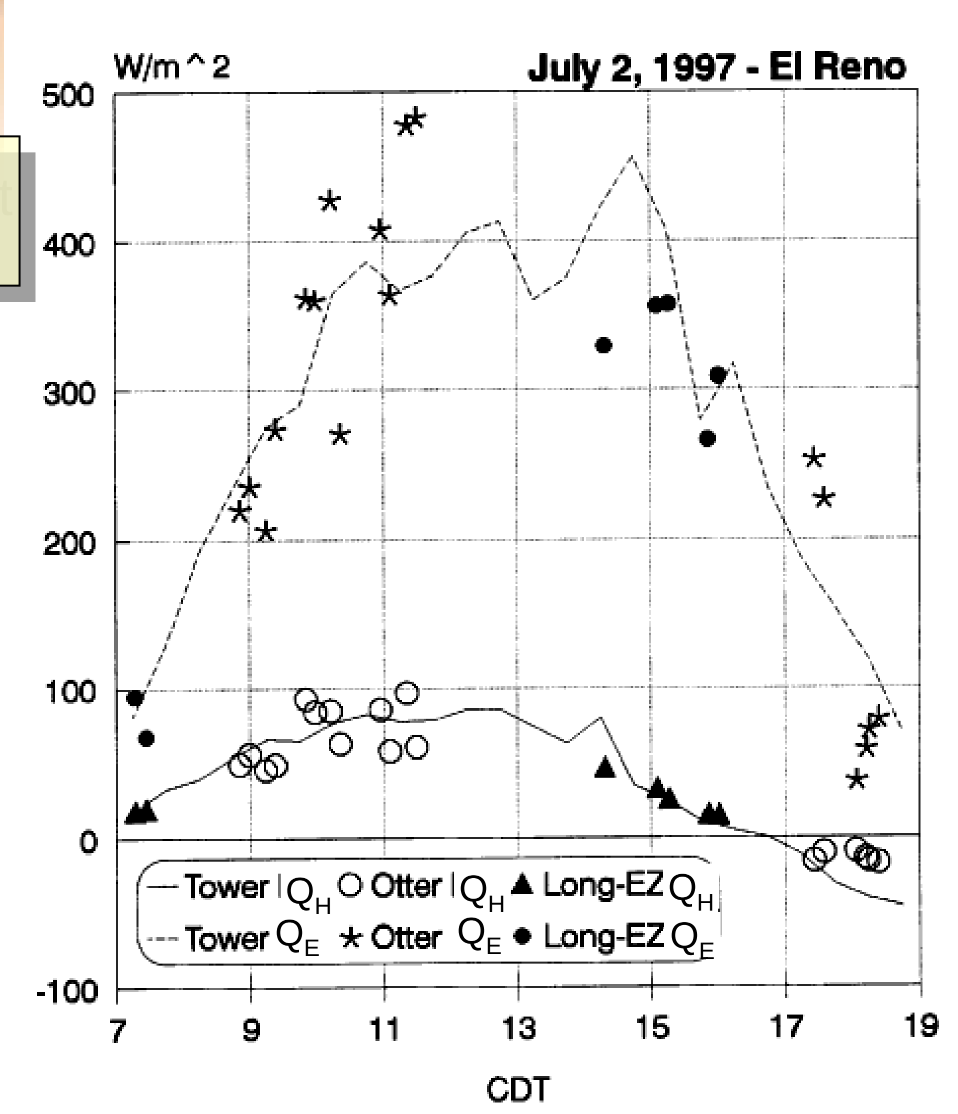
Satellite simulator

Accelerometers rate gyros

Dat recorder

Comparing Tower and Aircraft Flux Measurements

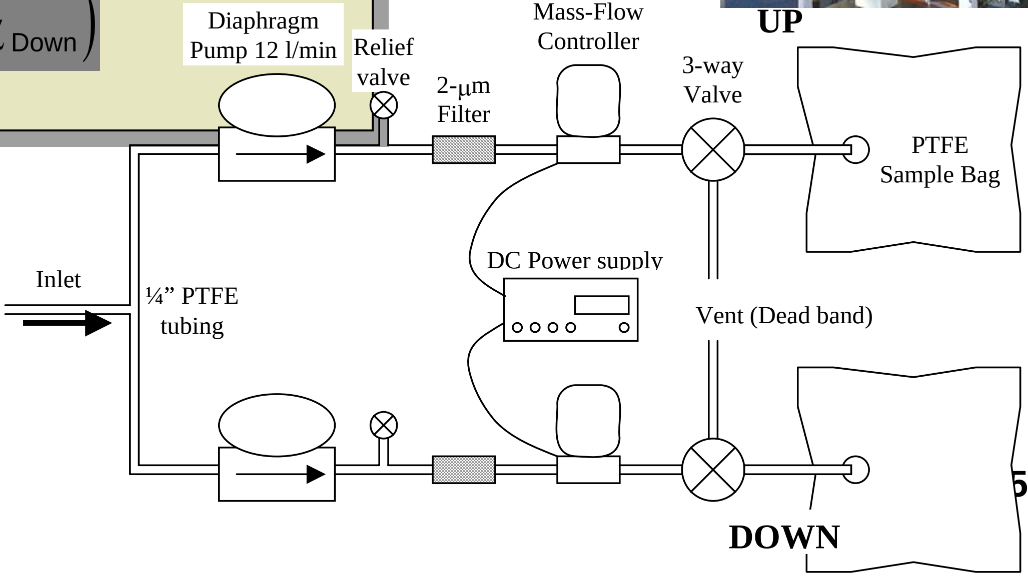
SGP project
1997



Relaxed Eddy Accumulation (REA)

- Alternate to eddy covariance technique to measure fluxes of trace gases for which there are no fast-response analyzers
- 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)

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



Relaxed eddy accumulation technique

- Easier to apply than eddy accumulation
- Fast-response anemometer measures *w* and controls a simple valving system
- Air is sampled at a constant rate and diverted into ‘up’ and ‘down’ bins depending on the direction of *w*

$$F_g = r\sigma_w\sigma_C$$

$$F_g = b\sigma_w\left(\overline{C_{up}} - \overline{C_{dn}}\right)$$

Where,

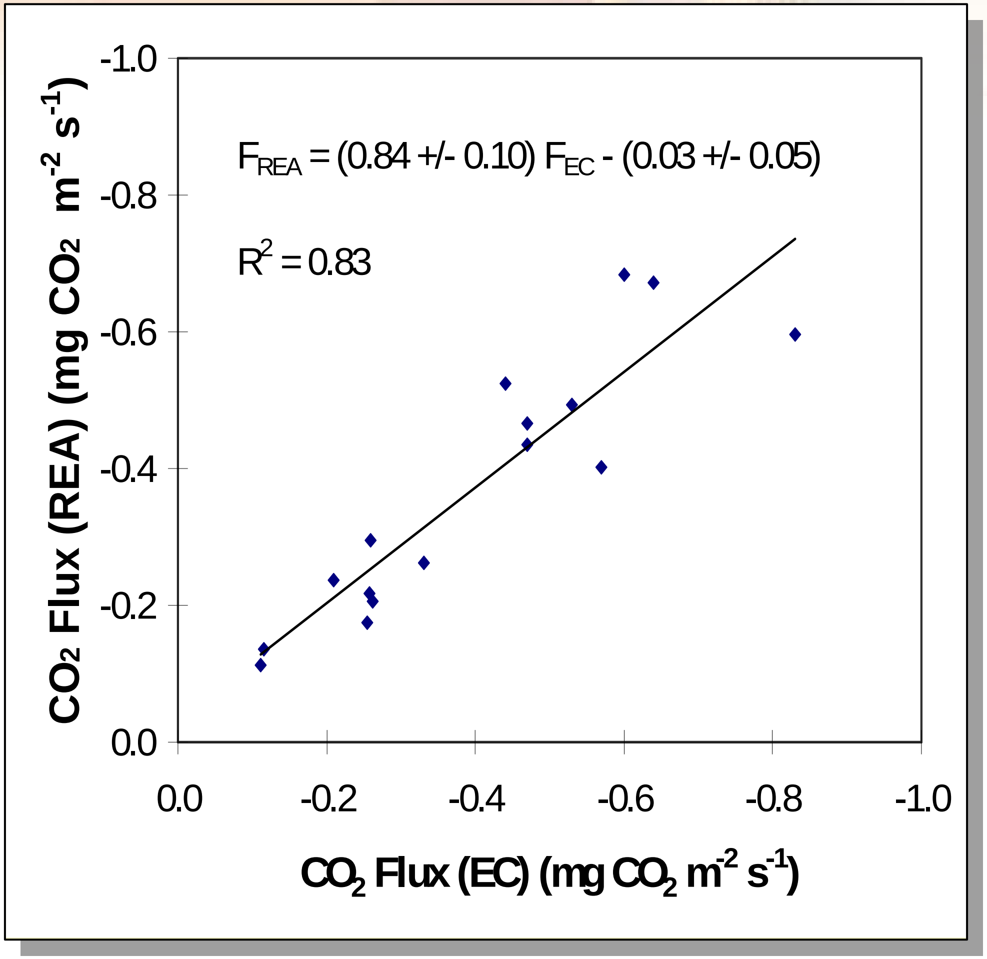
b = empirical coefficient that varies with the dead band

σ_w and σ_C = standard deviation of vertical velocity (*w) and concentration* (*C)*

r = correlation coefficient between *w* and *C*

Theory and experiments have suggested that *b* is constant and independent of stability, ≈ 0.6.

Comparison of EC and REA Flux Estimates of CO_2

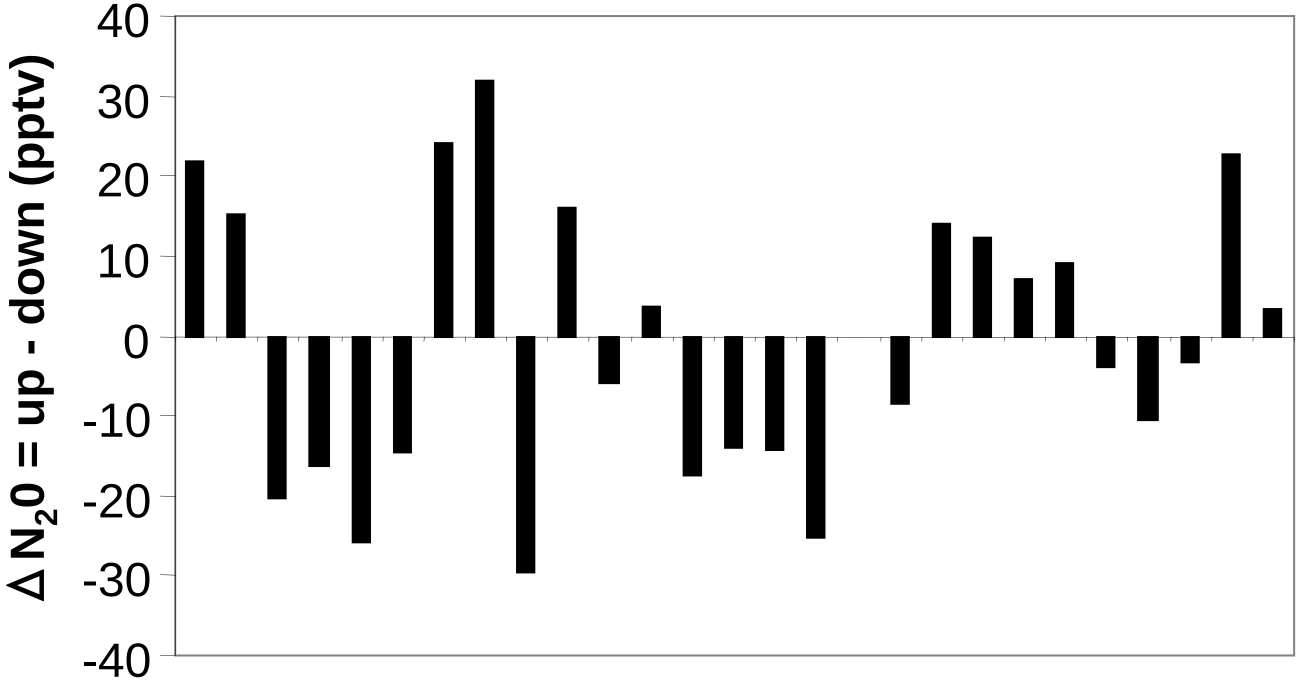


- Forest and agricultural fields
- Stainless steel canisters, with in-line magnesium percholate to remove water

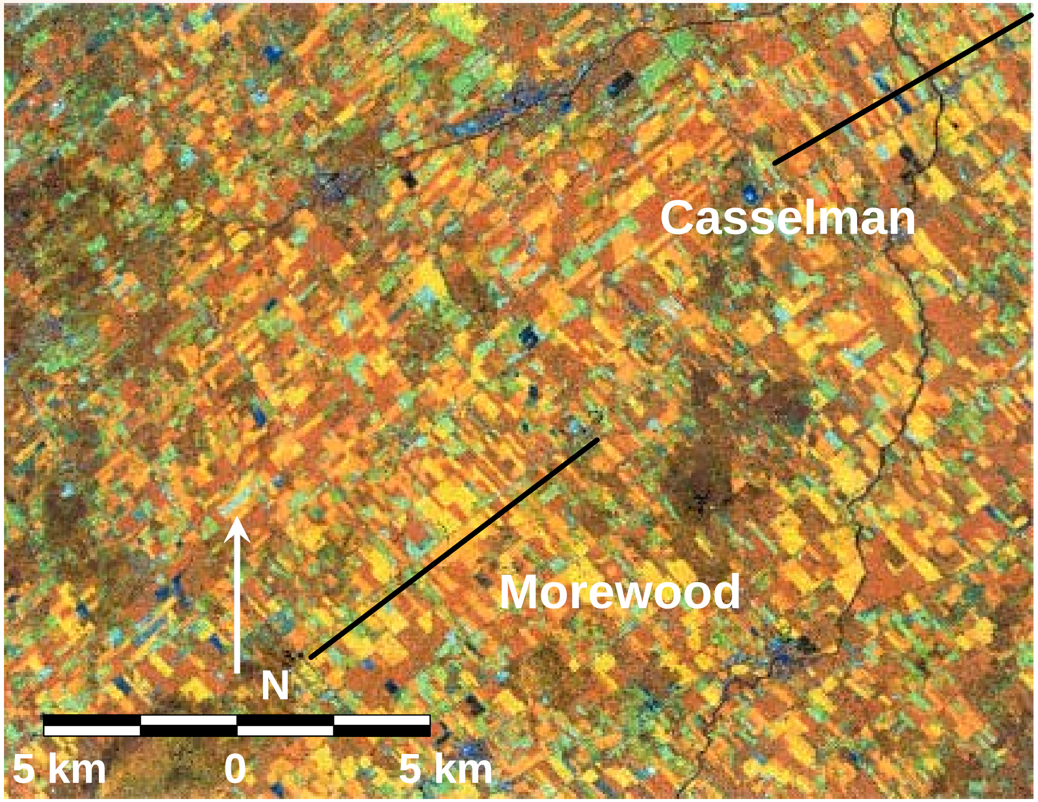
Resolution of the REA system for N_2O flux measurement

$$FN_2O = \rho_{N2O} \times 0.56 \times \sigma_w \times \Delta N_2O$$

ΔN_2O (pptv)	$\sigma_w = 0.3$ m s^{-1}	$\sigma_w = 0.9$ m s^{-1}
10	1.6	5.5 g N_2O-N ha^{-1} d^{-1}



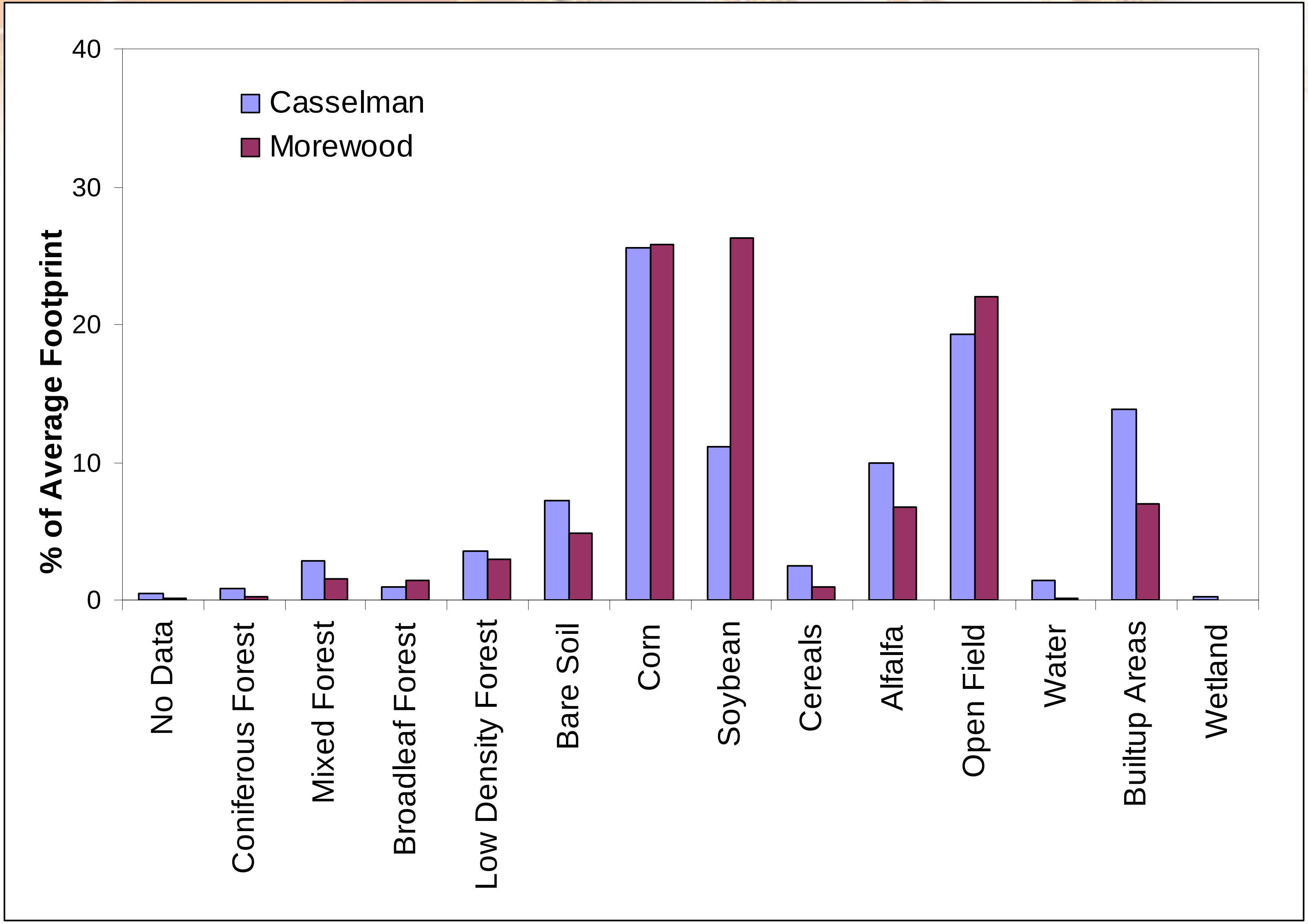
Crop types in the aircraft footprint



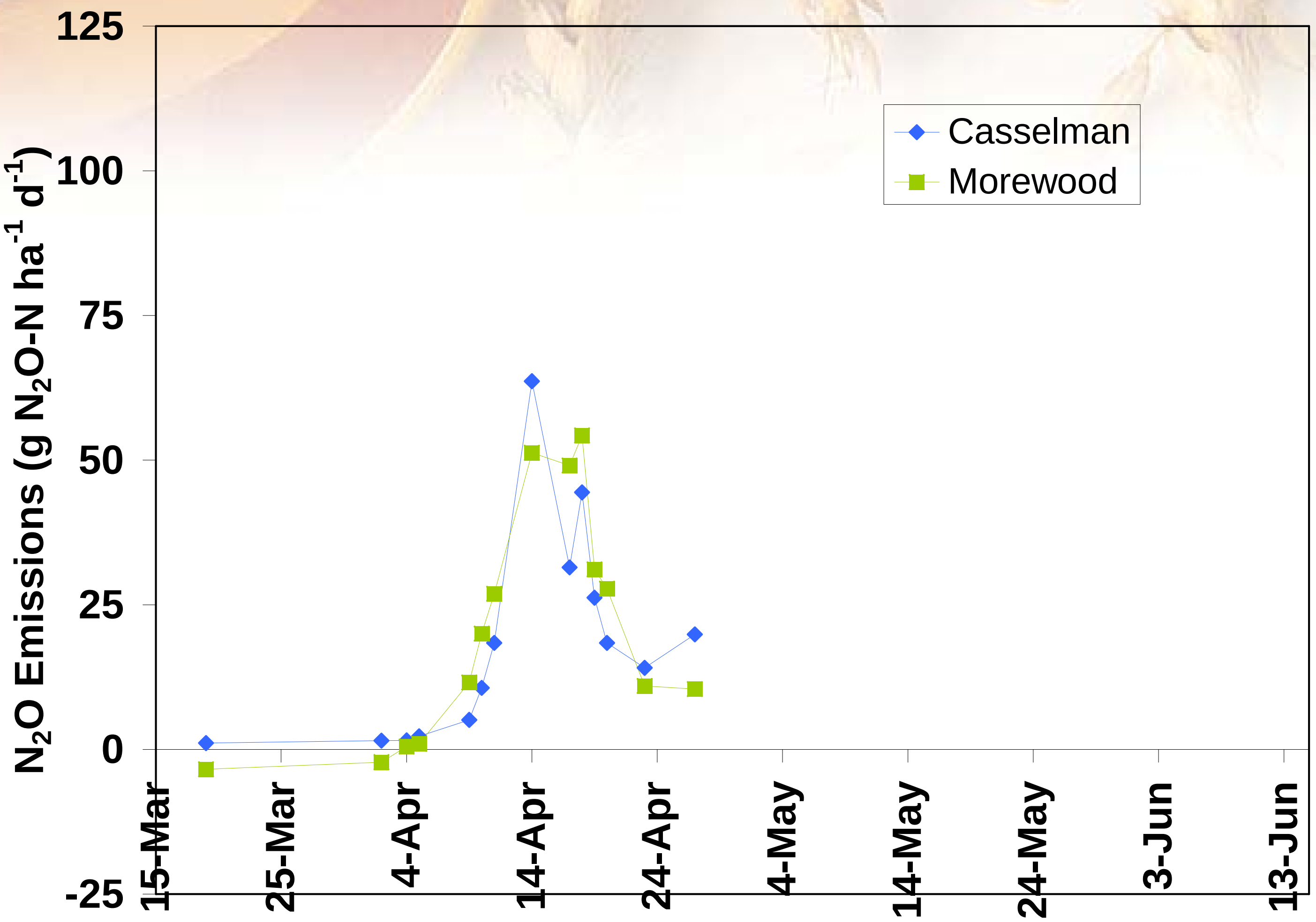
LEGEND

- 🟦 cereals
- ⬜ pasture/grass
- 🟩 alfalfa
- 🟫 forest
- 🟨 soy
- 🟧 corn
- 🟦 town

Land use information in 2001 within footprint of aircraft transects



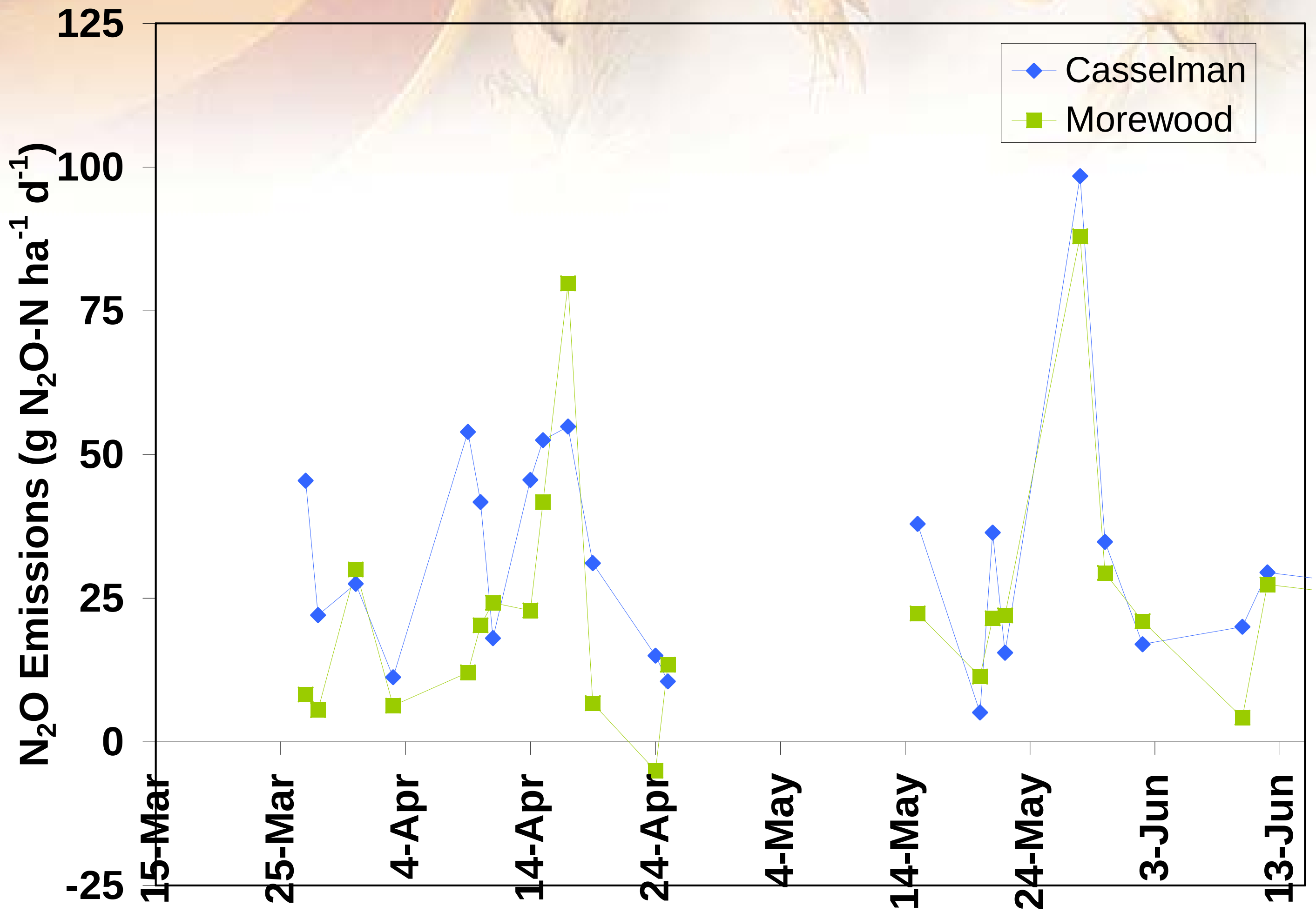
N_2O emissions during and right after snowmelt at the Eastern Canada study sites in 2001



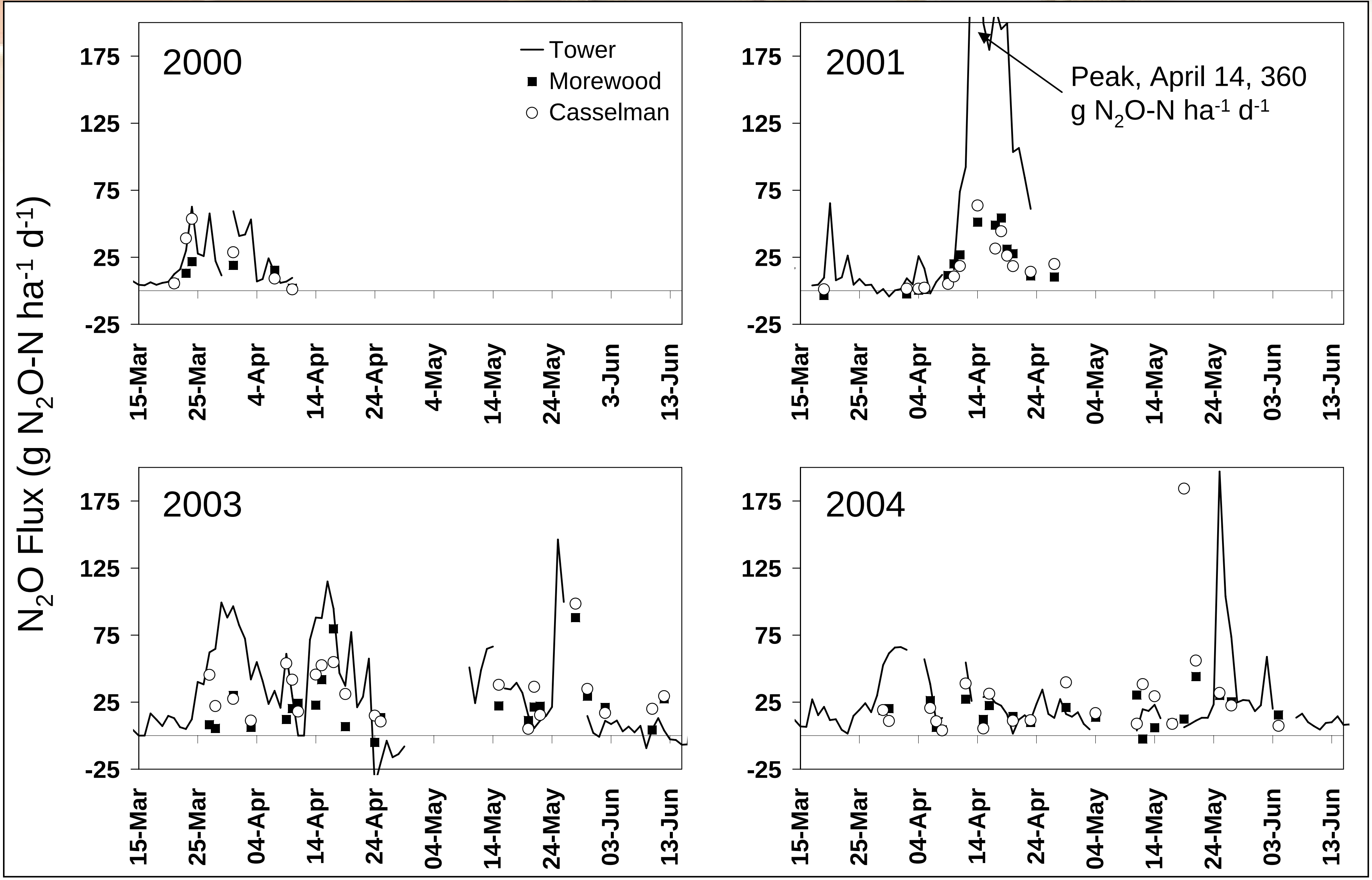
Each data point represents the average of 3 samples, collected during two consecutive 10 km flight legs (total flight distance for one data point is ≈ 20 km)

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)

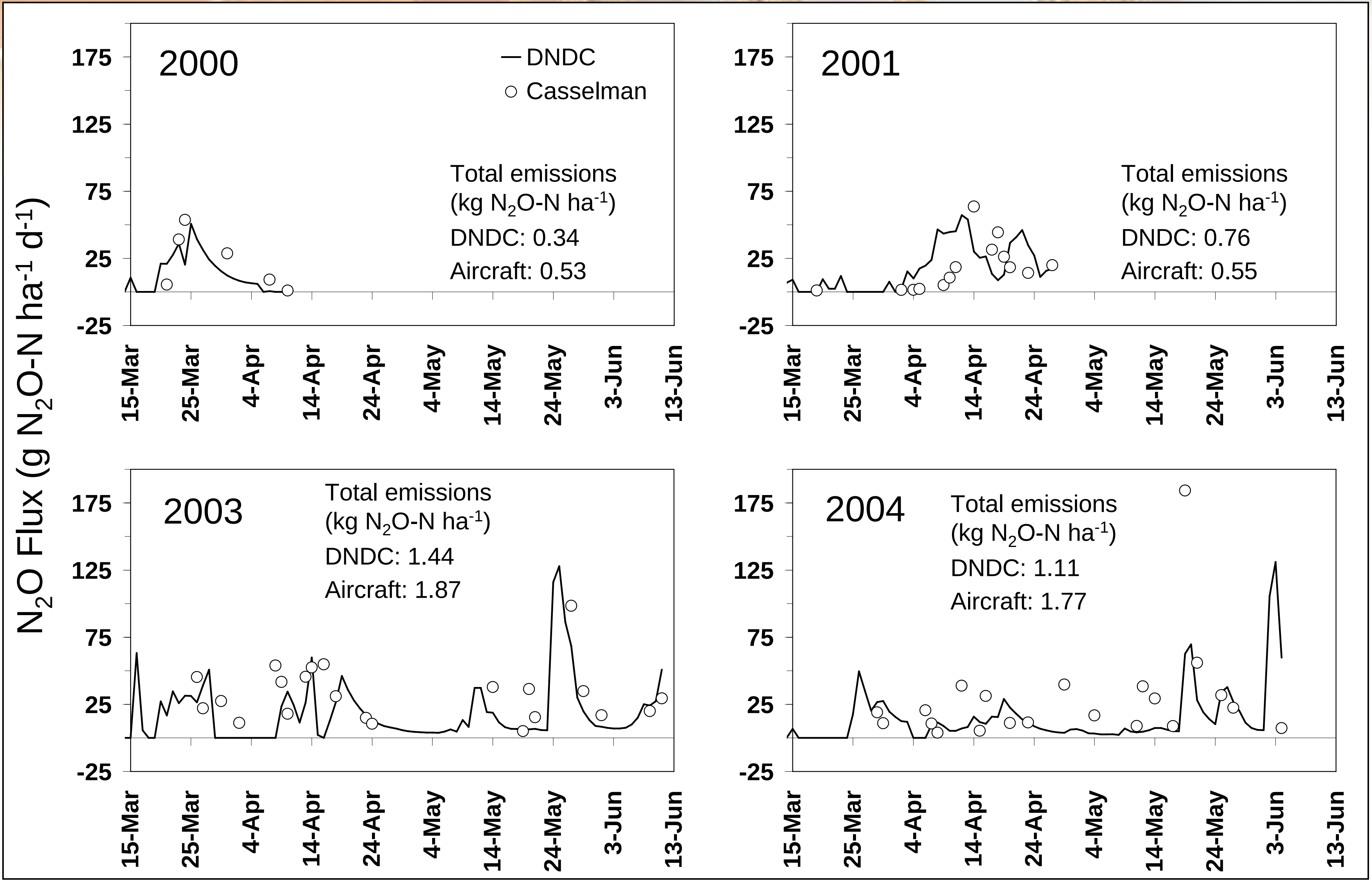
N$_2$O emissions right after snowmelt and after planting at the Eastern Canada study sites in 2003



Multi-year comparison of aircraft and tower based estimates of N_2O emissions



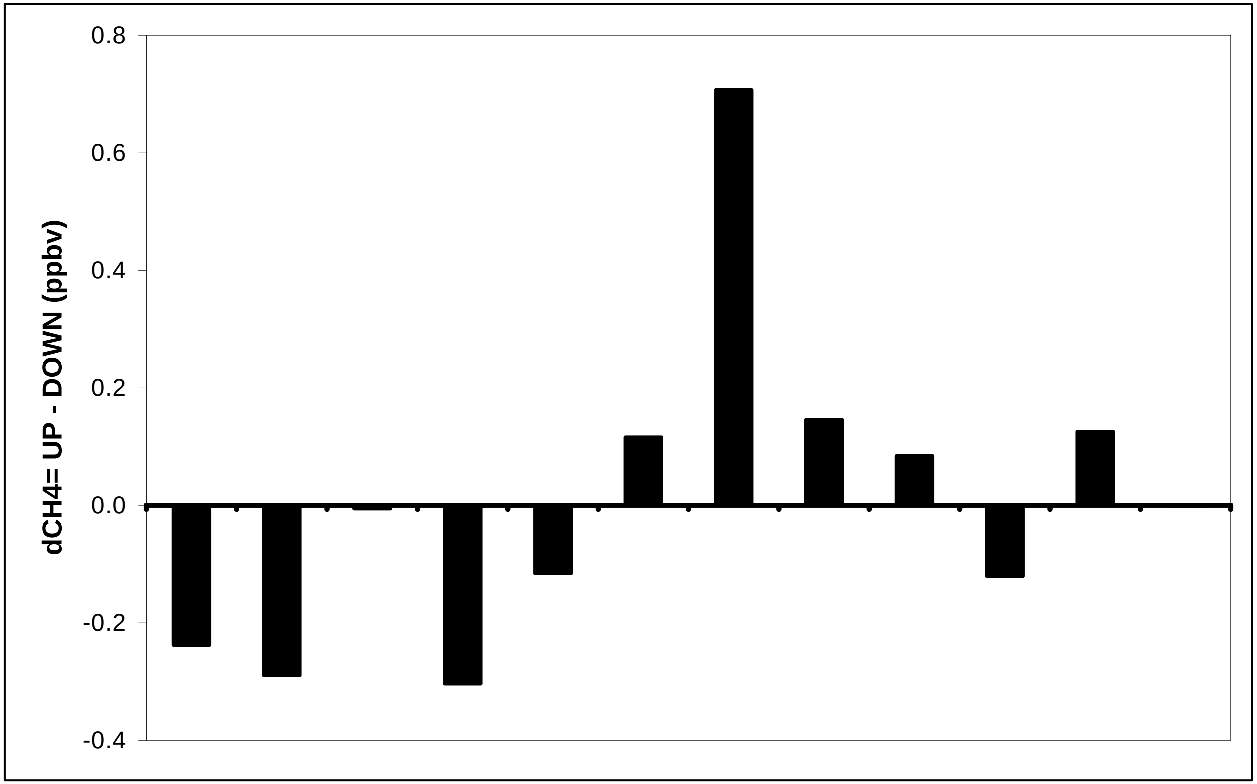
Multi-year comparison of aircraft and model estimates of N_2O emissions



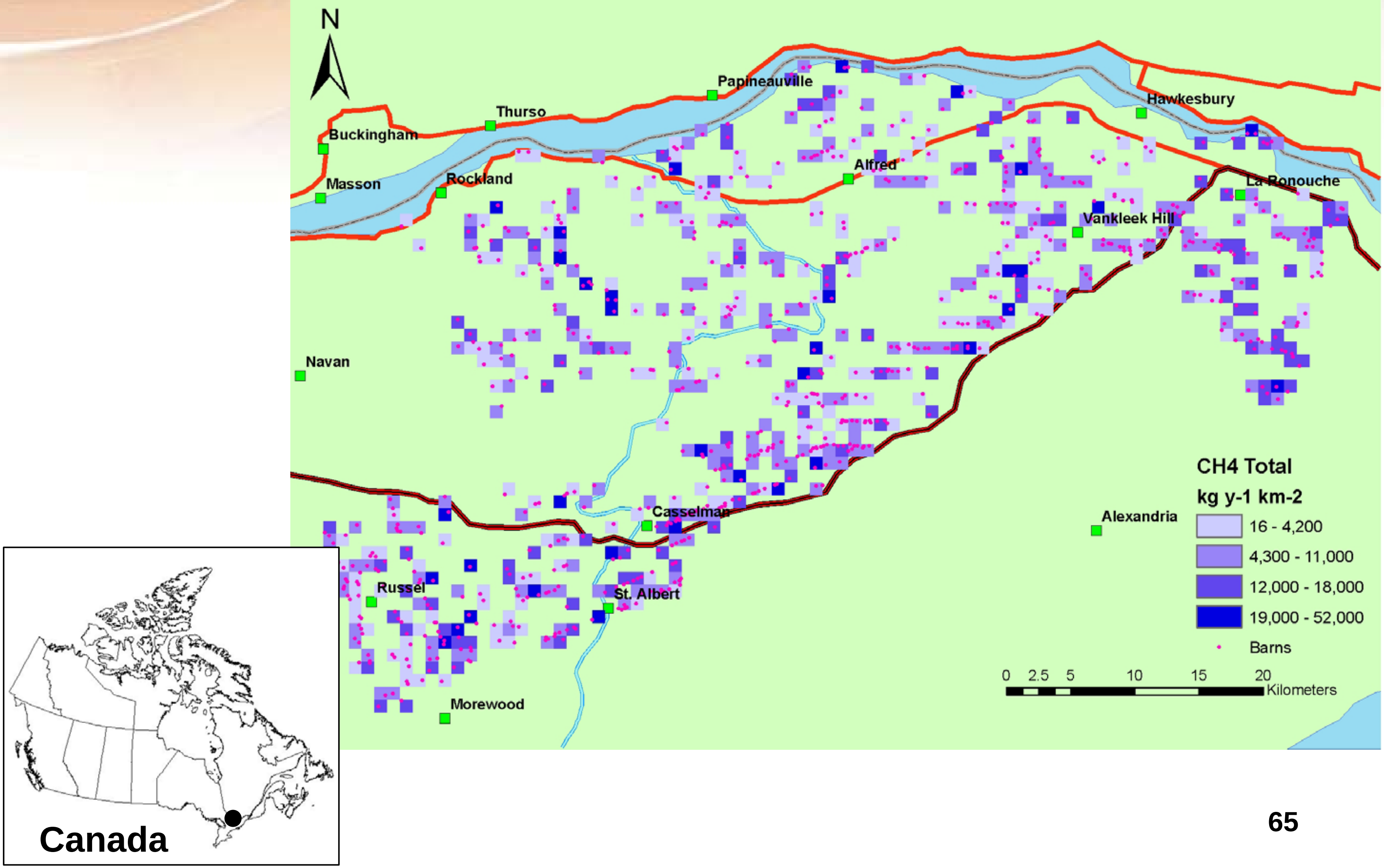
Resolution of the REA system for CH_4 flux measurement

$$FCH_4 = 0.56 \times \sigma_w \times \Delta CH4$$

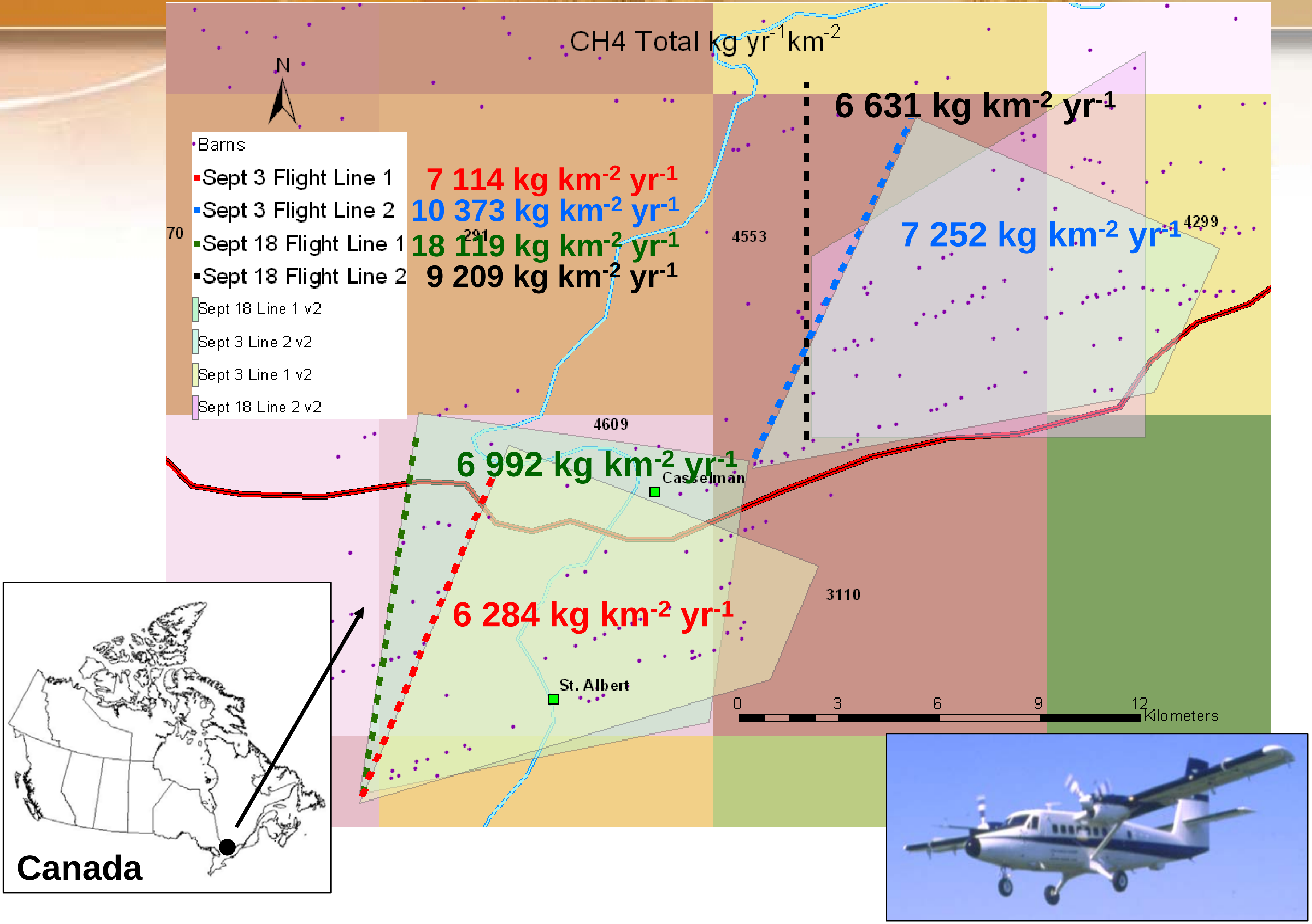
ΔCH4(ppbv)	$\sigma_w = 0.3\ m\ s^{-1}$	$\sigma_w = 0.9\ m\ s^{-1}$
0.2	2	6 mg m^{-2} d^{-1}
0.2	700	2100 kg km^{-2} y^{-1}



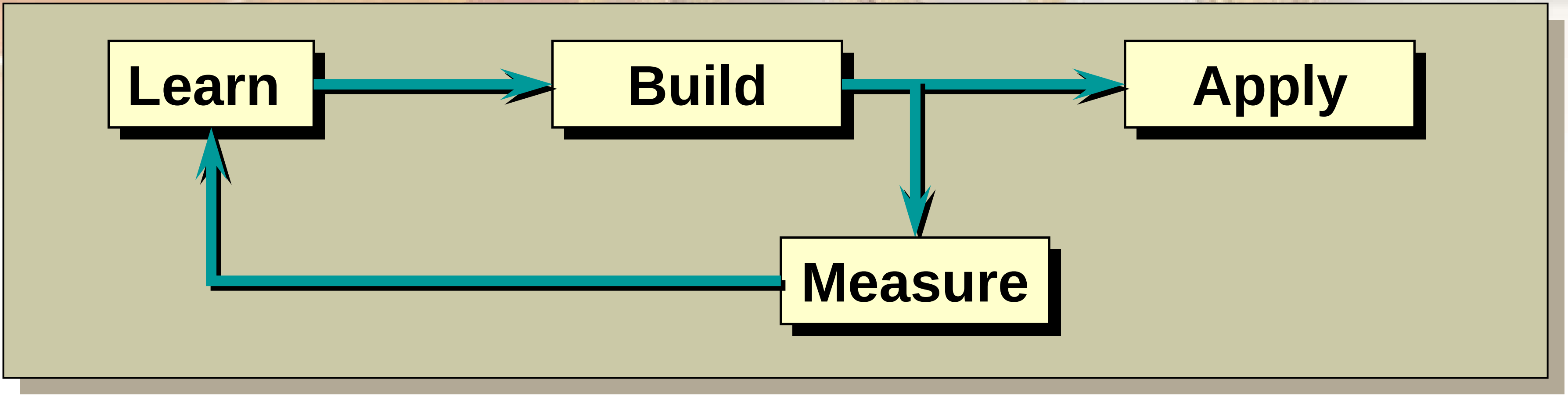
Estimated Agricultural CH_4 Emissions



Regional CH_4 Emissions, Sept. 3 and 18, 2003



Process of Model Development

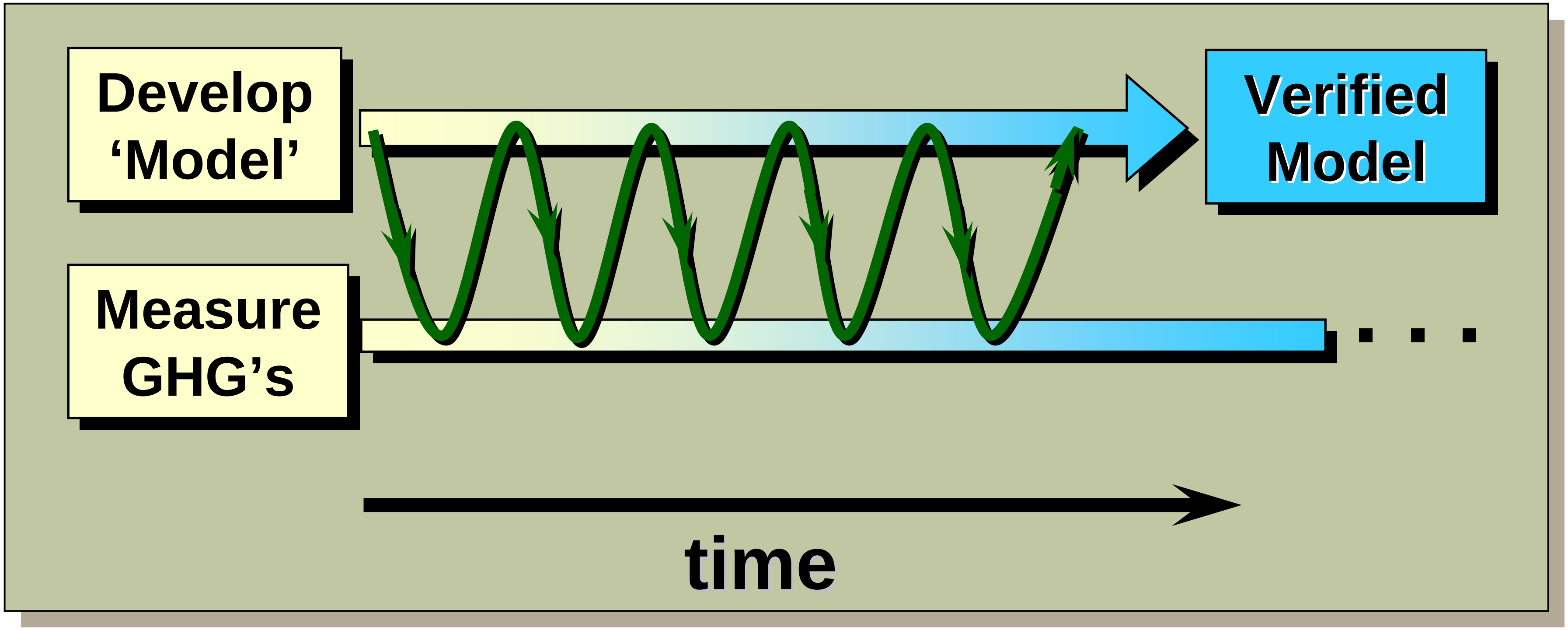


Learn

Build

Apply

Measure



Develop 'Model'

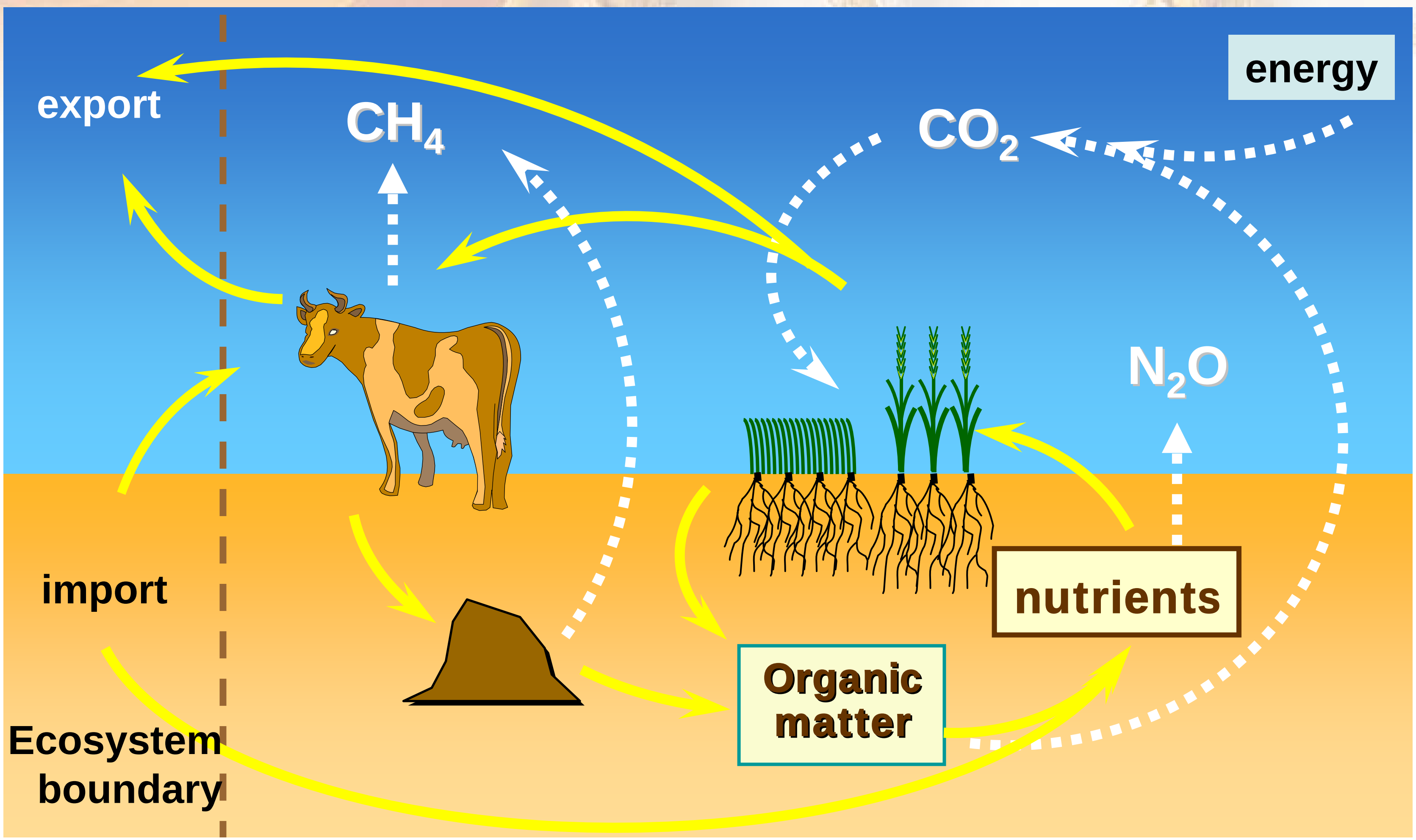
Verified Model

Measure GHG's

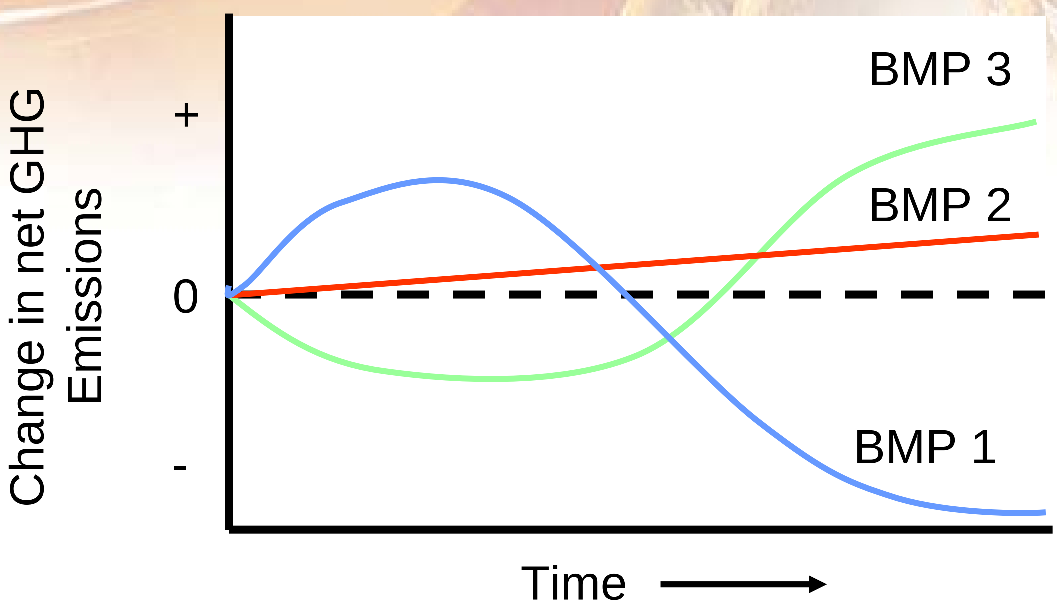
. . .

time

Nutrient and energy cycles in agricultural ecosystems



Influence of time on net GHG emissions



The relative benefit of adopting any one beneficial management practice (BMP) may change over time

Other factors may change over time that can affect GHG emissions. For example:

- Temperature
- Atmospheric CO_2
- Crop types
- Technology
- Economics
- Land use
- Government policy
- Population
- Social value of farms

Interactions between management decisions and GHG emissions

Management decision

Implications

Effect on GHG emissions

Residue return to

Decreased CO

What is the cumulative effect of this management decision on net greenhouse gas emissions?

Grow leguminous forage crops

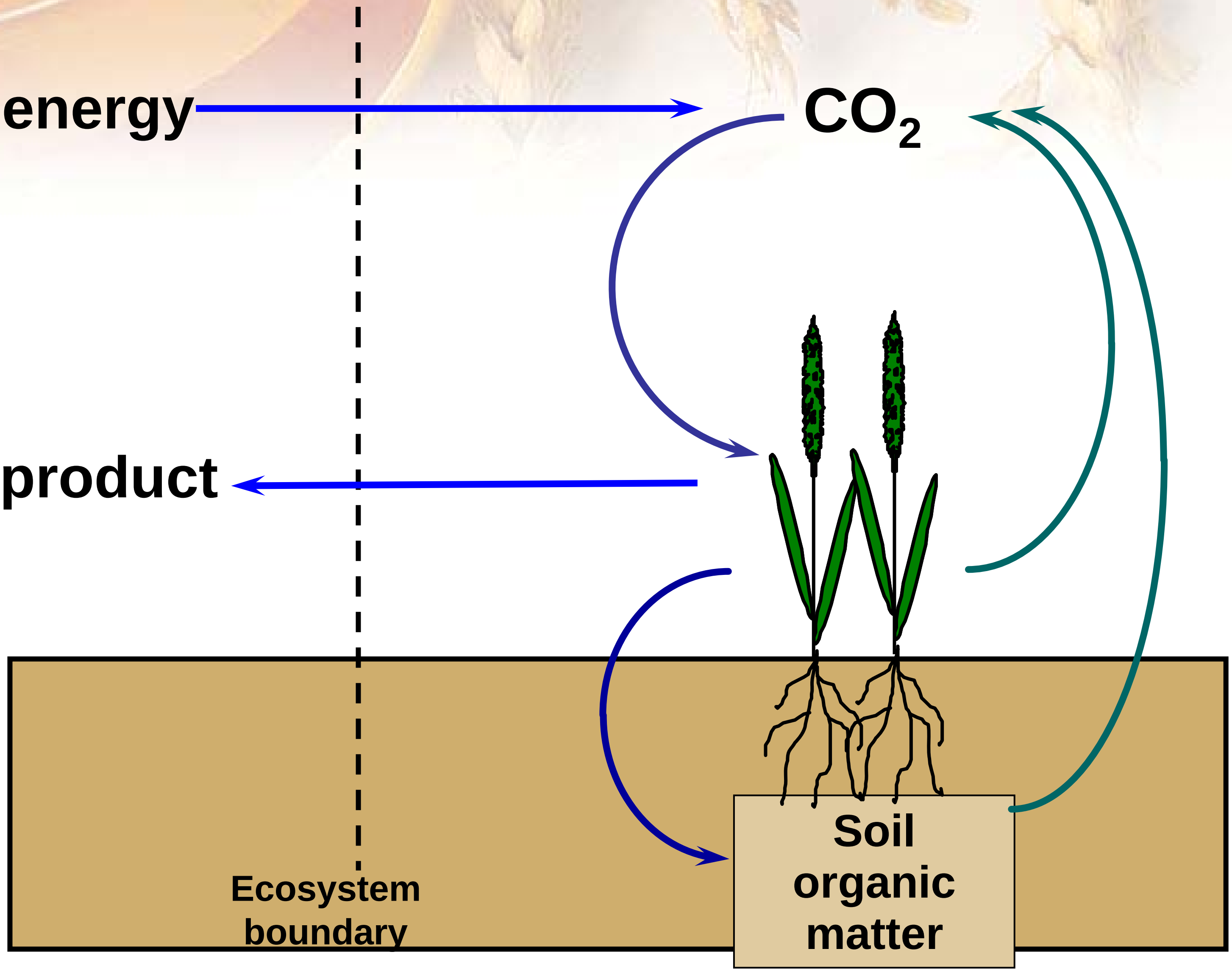
Forages fed to cattle → Increased CH_4

Models are necessary to answer these types of questions

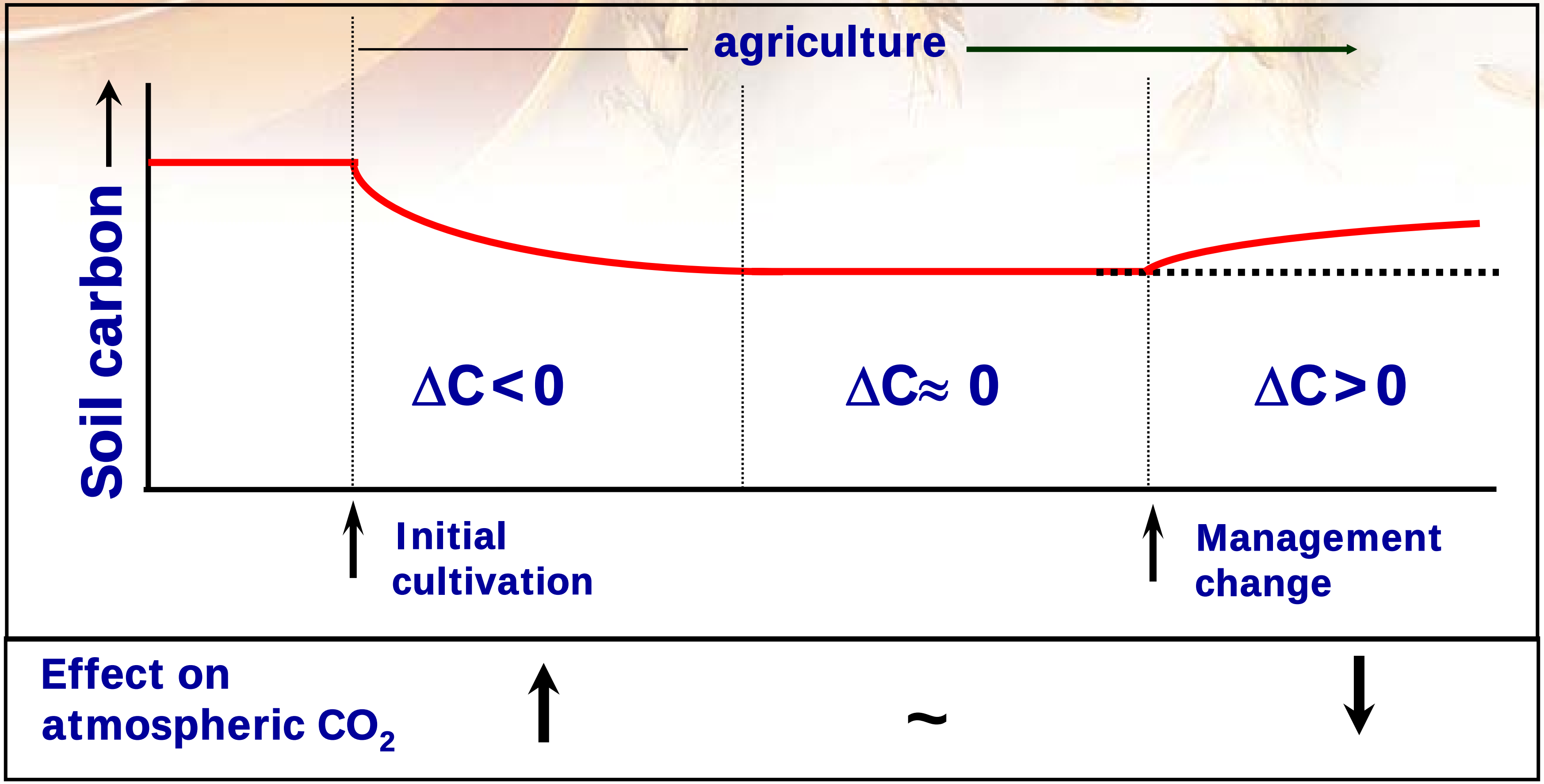
Increased manure production → Increased CH_4 and N_2O

Decreased synthetic fertilizer → Decreased N_2O and CO_2

The carbon cycle in agroecosystems



Management-Induced Carbon Change on Agricultural Land



agriculture

Soil carbon

$\Delta C < 0$

$\Delta C \approx 0$

$\Delta C > 0$

Initial cultivation

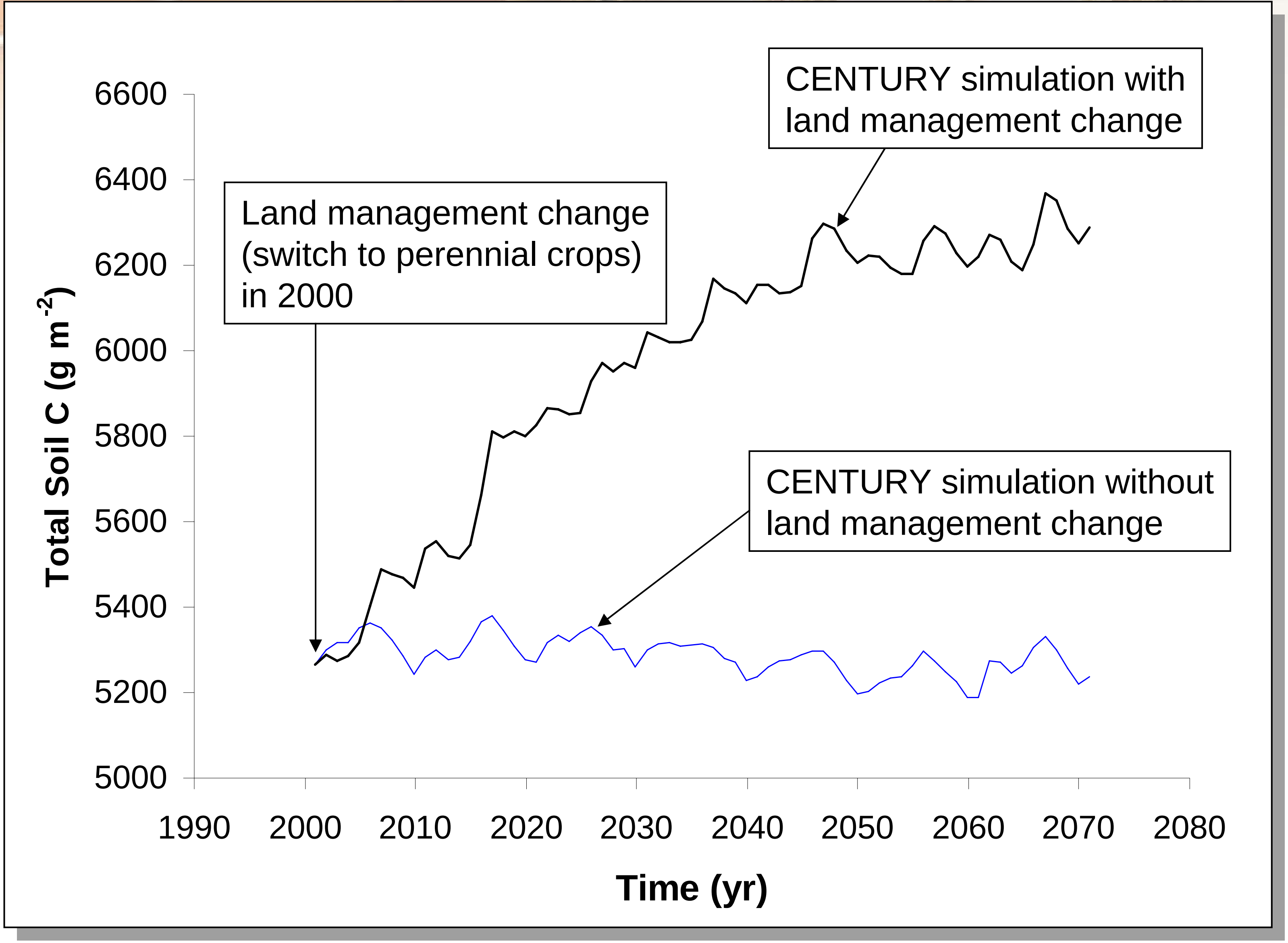
Management change

Effect on atmospheric CO_2	↑	~	↓

Estimating C factors

- Factors from empirical data and/or Century
- Century used extensively because need to obtain time effects (rate, duration) of C change

Estimating soil C factors

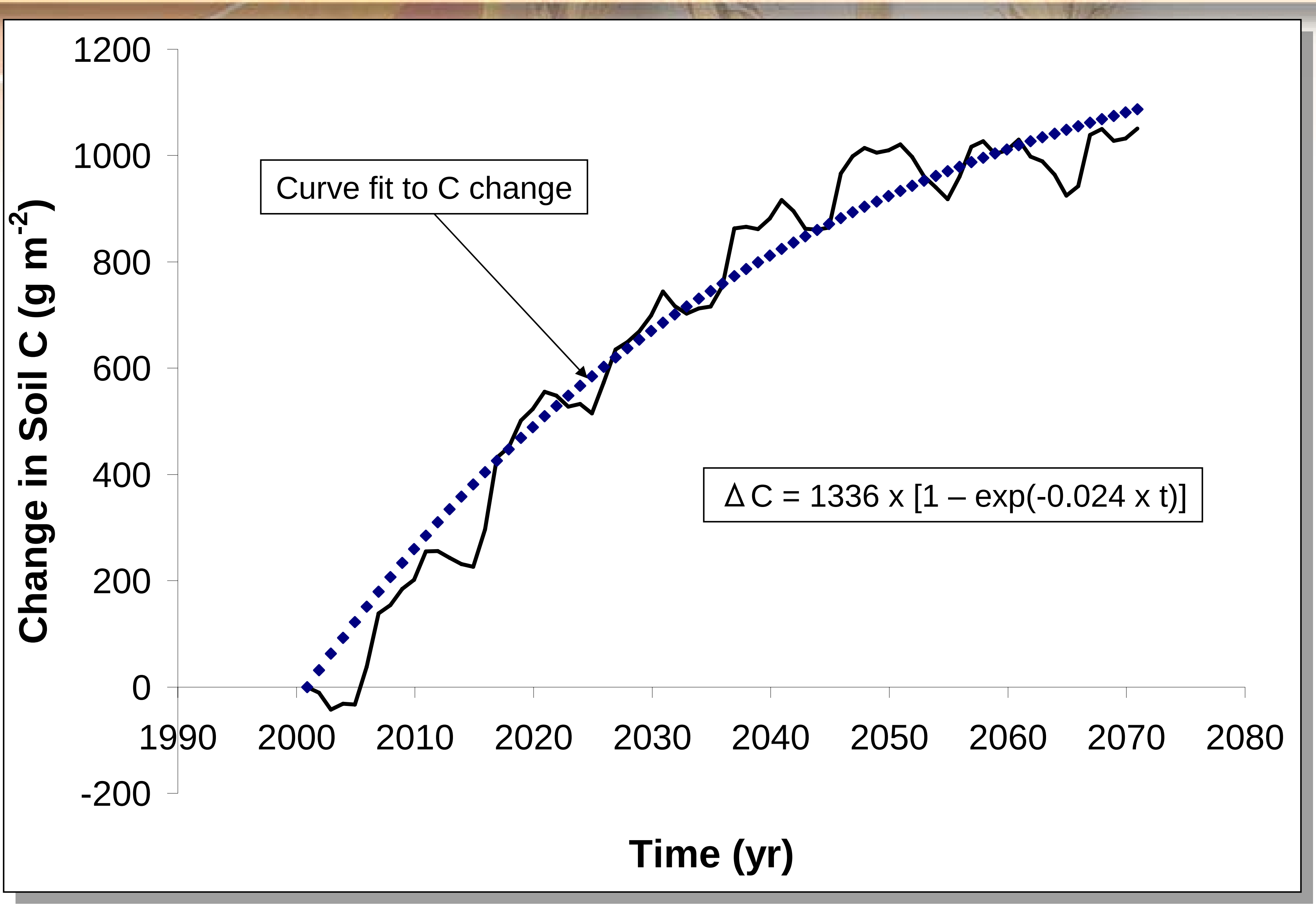


Land management change (switch to perennial crops) in 2000

CENTURY simulation with land management change

CENTURY simulation without land management change

Estimating soil C factors



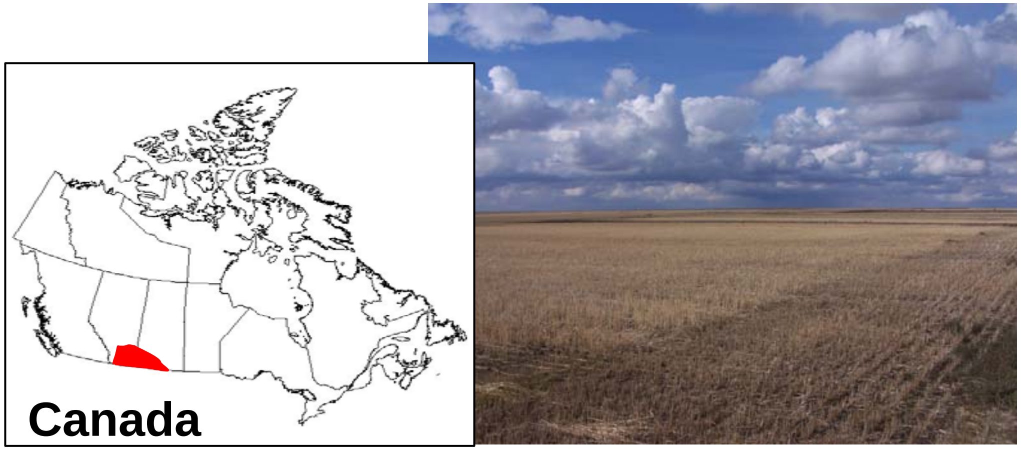
Curve fit to C change

$\Delta C = 1336 \times [1 - \exp(-0.024 \times t)]$

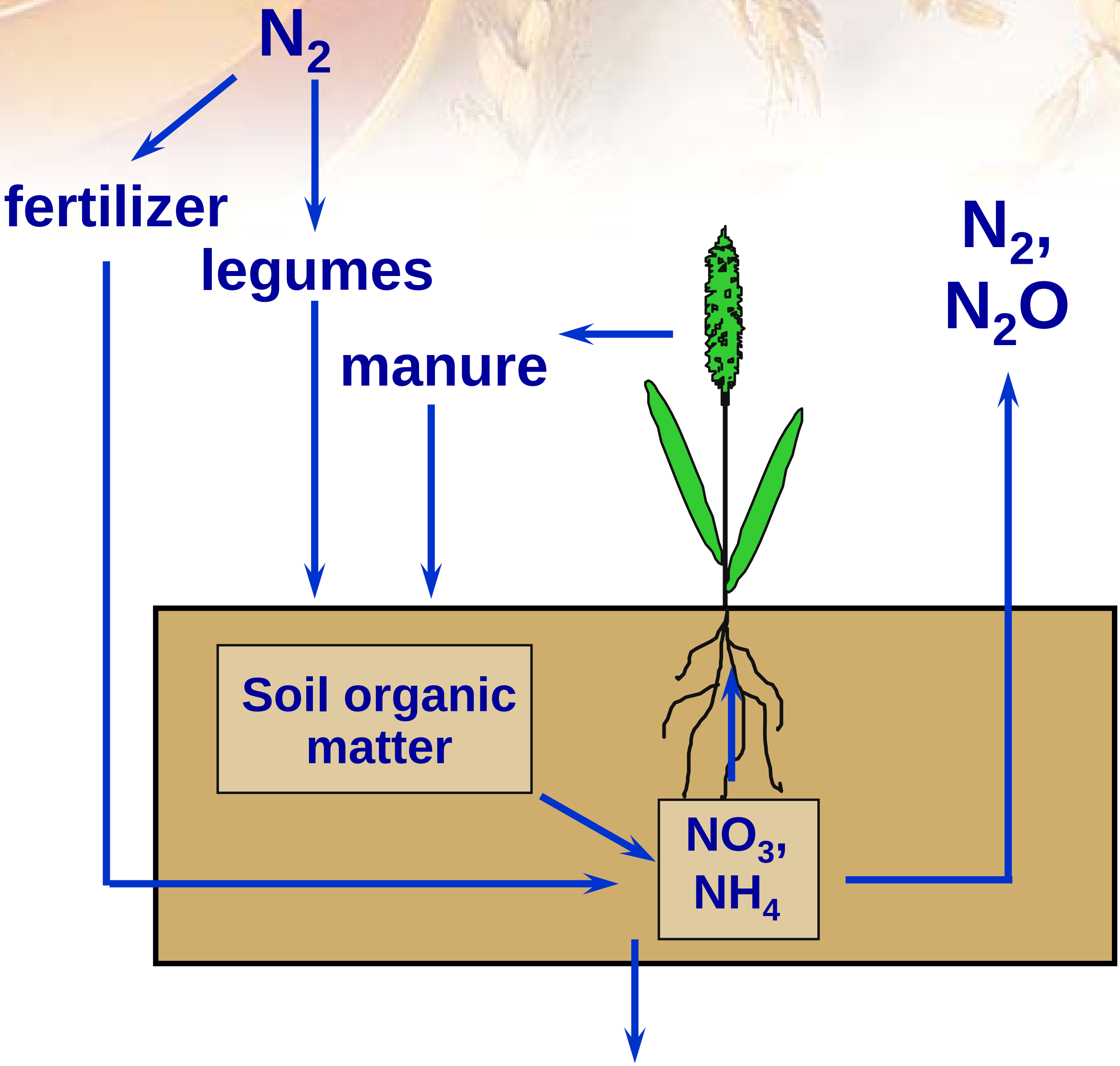
Soil Carbon Change Factors in Canada

Zone	LMC	K (/ year)	ΔC_{LMCmax} (Mg/ha)	Final Year of Effect after LMC	Mean annual Linear Coefficient over Duration of Effect of LMC (Mg/ha per year)	Mean Annual Linear Coefficient over First 20 years after LMC (Mg/ha per year)
Semi-Arid Prairies	IT to NT	0.0261	4.9	63	0.06	0.10
	IT to RT	0.0188	2.3	30	0.03	0.04
	Increase perennial	0.0281	26.1	120	0.21	0.56

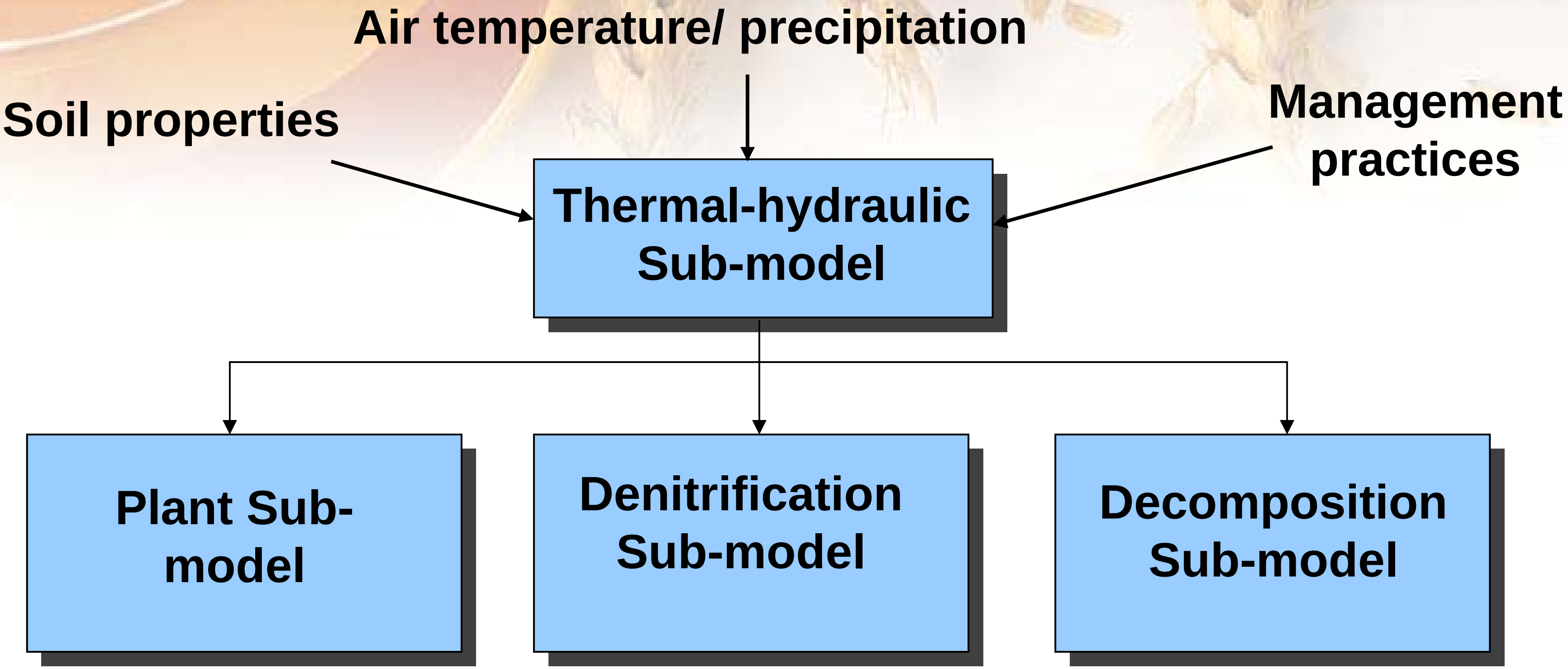
Reducing tillage, decreasing fallow and converting to permanent cover all increase soil carbon



The nitrogen cycle in agroecosystems



DNDC – DeNitrification and DeComposition model for estimating soil N_2O emissions



Air temperature/ precipitation

Soil properties

Management practices

Thermal-hydraulic Sub-model

Plant Sub-model

Denitrification Sub-model

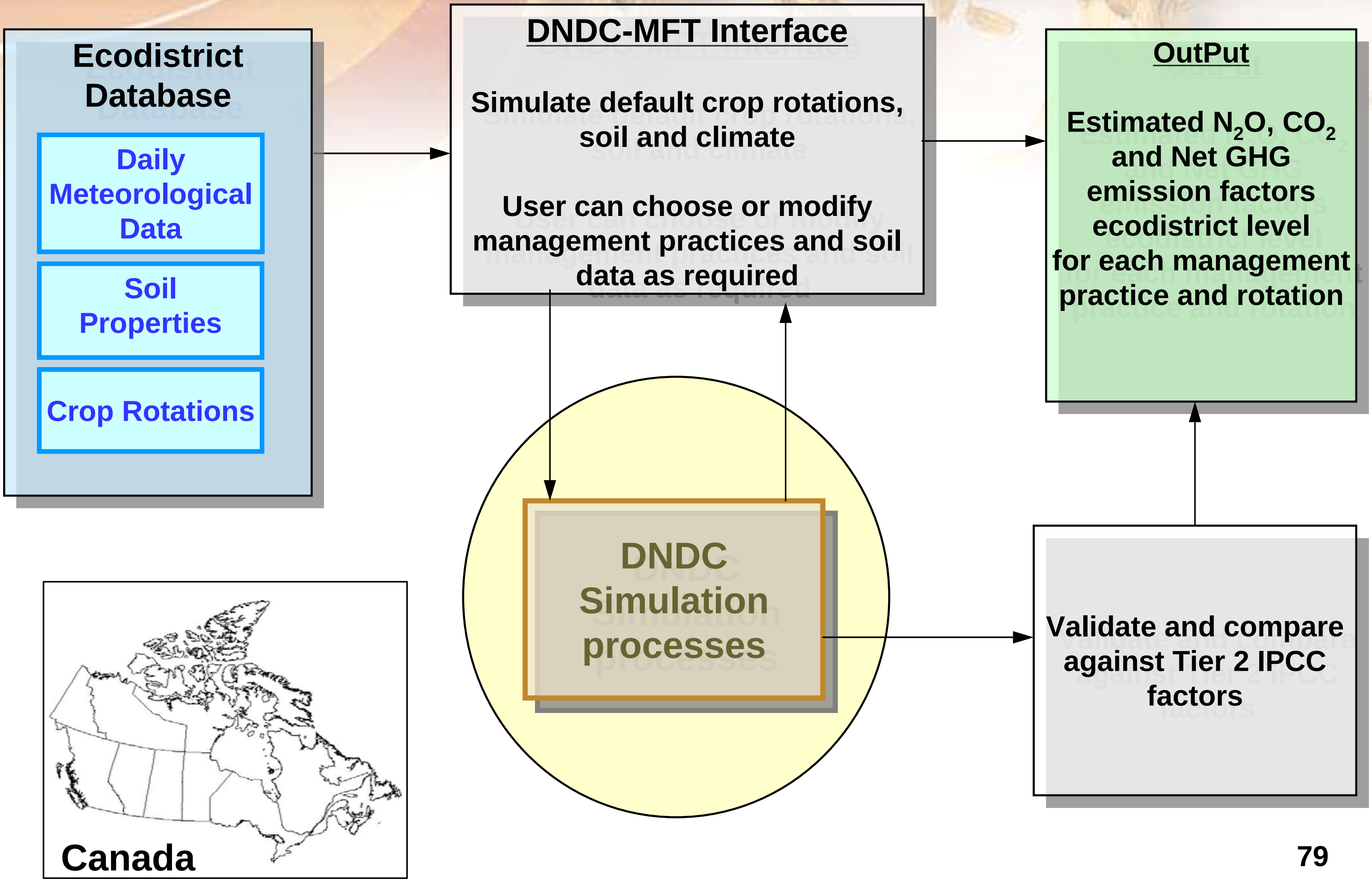
Decomposition Sub-model

- daily root respiration
- N utilization

- Hourly N_2O

- Soil microbial respiration
- Hourly N_2O
- C decomposition
- NH_3 volatilization

Integrating Process-based and Empirical Models



Ecodistrict Database

- Daily Meteorological Data
- Soil Properties
- Crop Rotations

DNDC-MFT Interface

Simulate default crop rotations, soil and climate

User can choose or modify management practices and soil data as required

OutPut

Estimated N_2O, CO_2 and Net GHG emission factors ecodistrict level for each management practice and rotation

DNDC Simulation processes

Validate and compare against Tier 2 IPCC factors

Estimated N_2O and CO_2 emissions as influenced by agricultural practices in Canada

- Century and DNDC

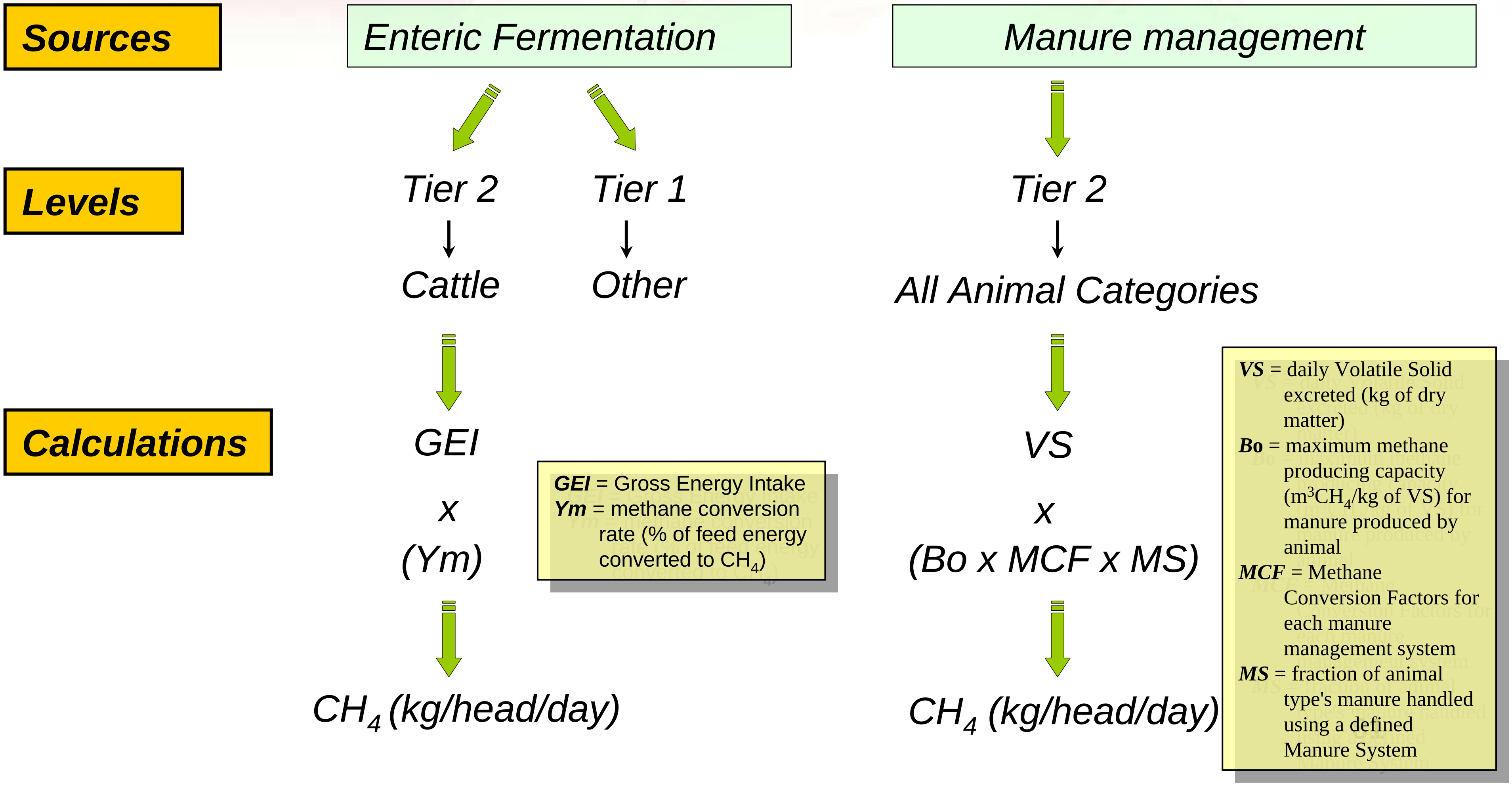
Combined CO_2 & N_2O coefficients (Mg CO_2 equiv. ha^{-1} y^{-1})

	No-tillage	Reduced Fallow	150% Fertilizer	50% Fertilizer	Fall Fertilizer	Permanent Grassland
Brown Chern.	-0.33	-0.43	0.04	0.01	0.03	-0.97
Dark Brown Chern.	-0.64	-0.80	-0.03	0.12	0.14	-1.33
Black Chern.	-0.72		0.19	0.01	0.28	-3.44
Dark Gray Luvisol	-0.80	-0.61	0.26	-0.09	0.46	-4.24
Gray Brown Luvisol	-0.54		-0.11	0.33		-2.56
Gray Luvisol	-0.55		-0.27	0.39		-2.13
Gleysolic	-0.40		0.21	0.12		-2.36

Minus sign represents a net reduction in GHG

Methane emissions calculations, IPCC Methodology

I - Methodology - Overview



Sources

Enteric Fermentation

Manure management

Levels

Tier 2 ↓ *Cattle*

Tier 1 ↓ *Other*

Tier 2 ↓ *All Animal Categories*

Calculations

GEI

x

(Ym)

CH_4 (kg/head/day)

GEI = Gross Energy Intake
Ym = methane conversion rate (% of feed energy converted to CH_4)

VS

x

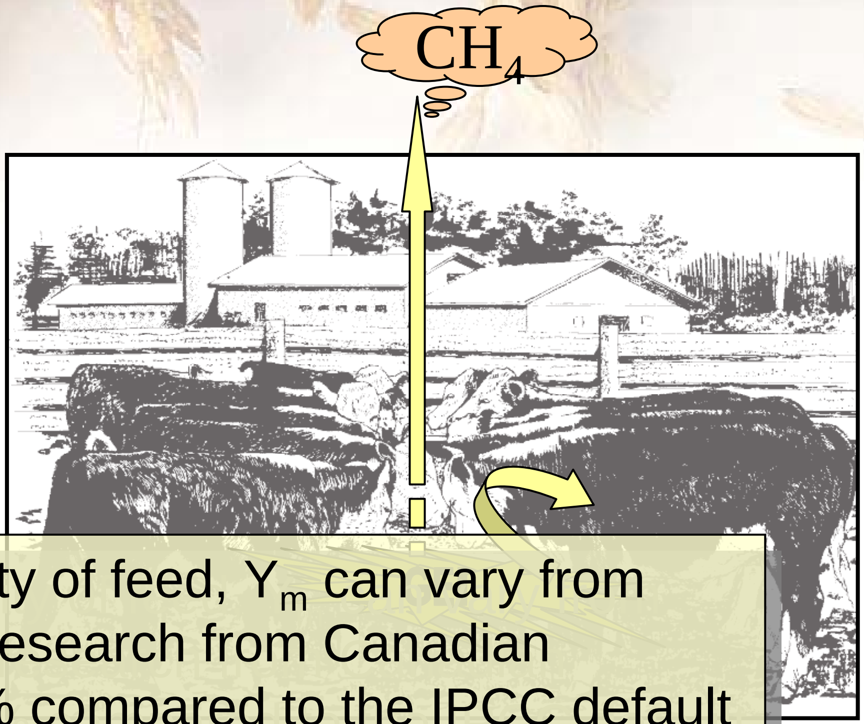
(Bo x MCF x MS)

CH_4 (kg/head/day)

VS = daily Volatile Solid excreted (kg of dry matter)
Bo = maximum methane producing capacity (m^3CH_4/kg of VS) for manure produced by animal
MCF = Methane Conversion Factors for each manure management system
MS = fraction of animal type's manure handled using a defined Manure System

Methane emissions from enteric fermentation

Calculation of the Emission Factor (EF)



CH$_4$ i

The

Depending on the type and quality of feed, Y_m can vary from about 2 to 12% of GEI. Recent research from Canadian feedlots suggests Y_m is about 4% compared to the IPCC default Y_m value for feedlot cattle of 3% (6.5% for grazing cattle). About 10% of Canadian beef cattle are housed in feedlots.

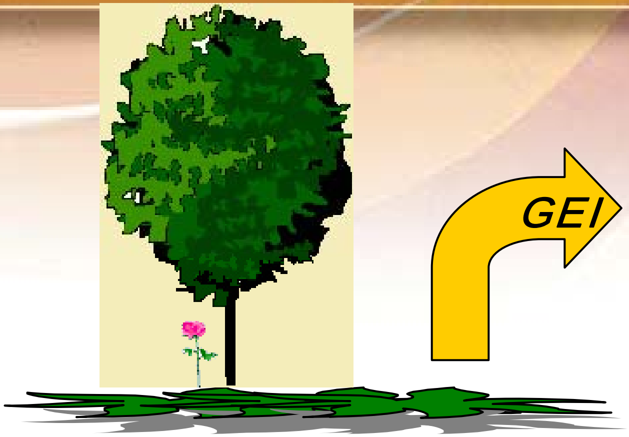
So:

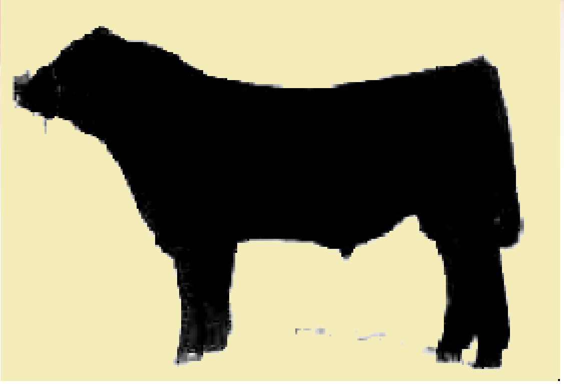
$$\mathbf{EF}_{(Gg/hd/yr)} = \frac{(\mathbf{GEI\ x\ y_m})\ \mathbf{x}\ 365}{55.65\ (Mj/kgCH4)}$$

GEI = Gross Energy Intake
Y_m = methane conversion rate
(% of feed energy converted to CH$_4$)

Enteric fermentation

$$\text{GEI (MJ/day)} = \frac{(\text{NEm} + \text{NEa} + \text{NEl} + \text{NEp} + \text{NEg}) \quad \times \text{F}}{\text{DE (\%GEI)}}$$





+

Digestible Energy

Fecal Energy

Net Energy

Other (heat, urine, CH4)

NEm (maintenance) + **NEa** (activity) + **NEl** (lactation) + **NEp** (pregnancy) + **NEg** (growth)

- NEm: Live weight
- NEa: Feeding situation
- NEl: Milk prod.; Fat content
- NEp: % female that give birth
- NEg: Live weight; Mature weight; Weight gain; Category (female, castrate, bull)

/ DE(%)

GEI

Digestible Energy (DE MJ/day) = Net Energy x F

Methane emissions from manure management

$$\mathbf{EF} = VS \times Bo \times \Sigma(MCF \times MS) \times 0.67 \times 365$$

EF **= annual emission factor (kgCH_4/hd/yr)**

VS **= daily Volatile Solid excreted (kg of dry matter)**

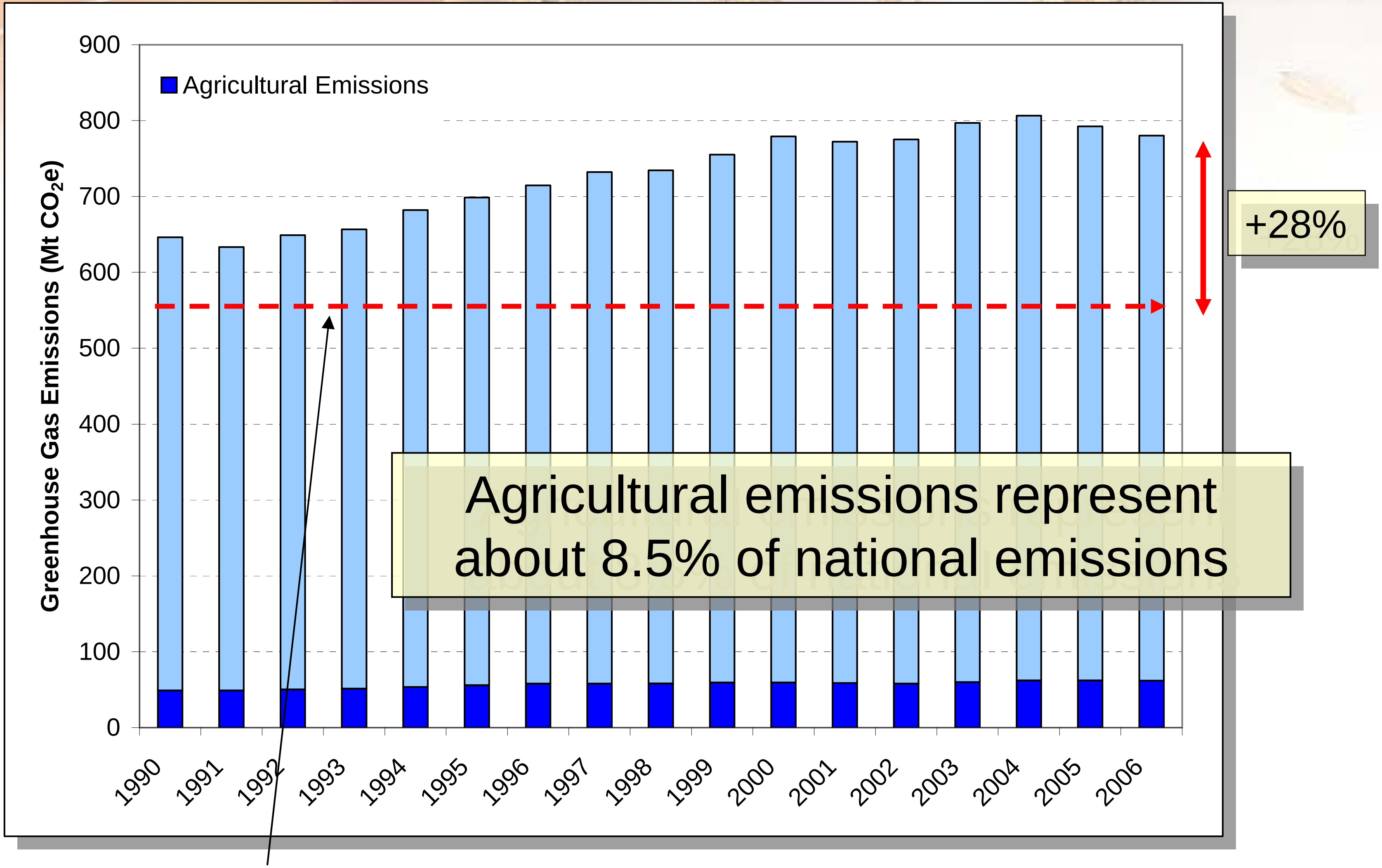
Bo **= maximum methane producing capacity (m^3CH_4/kg of VS) for manure produced by animal**

MCF **= Methane Conversion Factors for each manure management system**

MS **= fraction of animal type's manure handled using a defined Manure System**

0.67 = conversion factor of m^3 CH_4 to kilograms CH_4 (kg CH_4 /m^3 CH_4)

Greenhouse Gas Emissions in Canada, 1990-2006



+28%

Agricultural emissions represent about 8.5% of national emissions

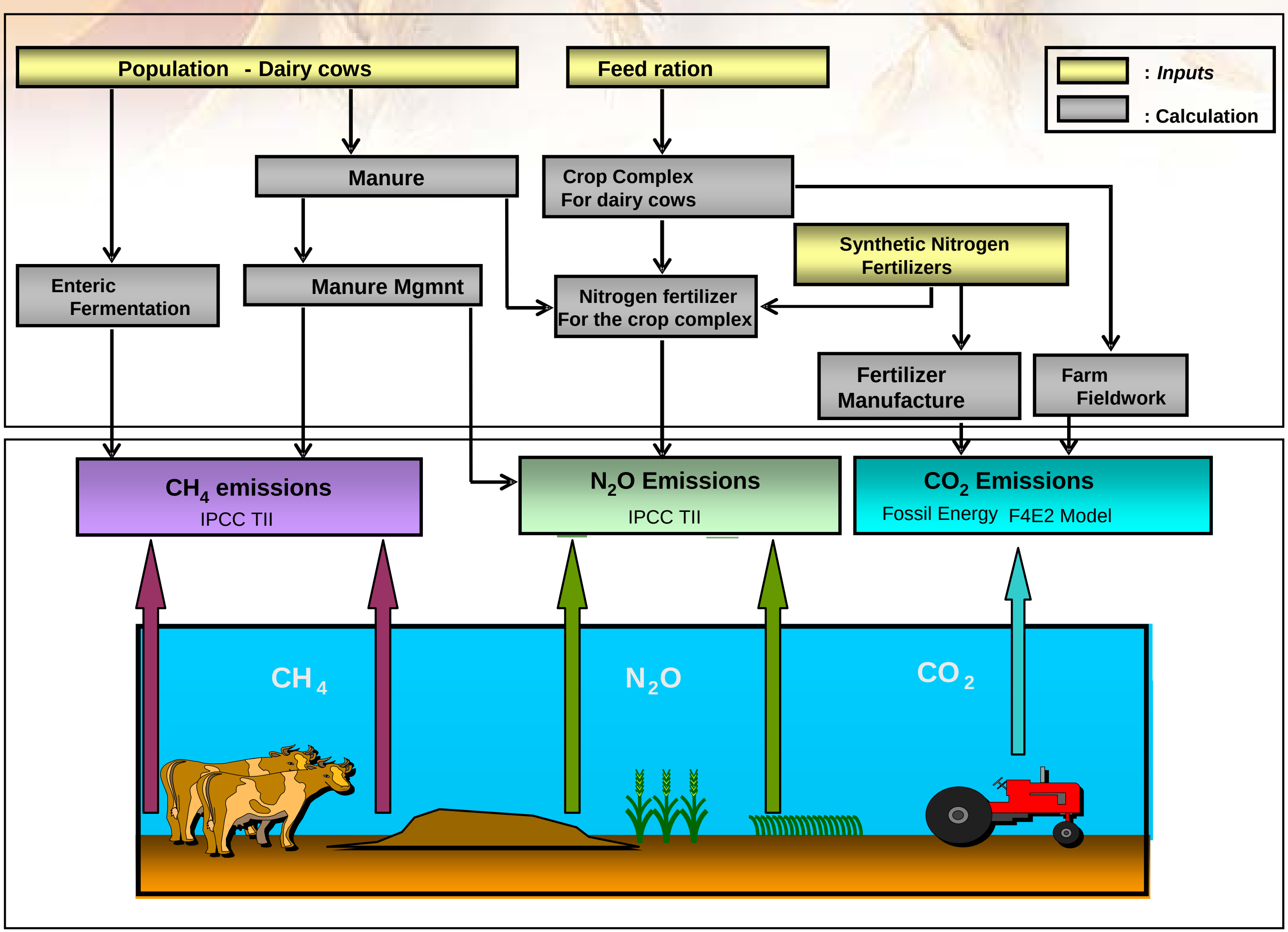
Kyoto Objective: -6% compared to 1990

Holistic Approach for Estimating GHG Emissions from the Dairy Sector

Model

Method

Sources of emissions



🟨 : *Inputs*

▨ : Calculation

Population - Dairy cows

Feed ration

Manure

Crop Complex For dairy cows

Synthetic Nitrogen Fertilizers

Enteric Fermentation

Manure Mgmnt

Nitrogen fertilizer For the crop complex

Fertilizer Manufacture

Farm Fieldwork

CH_4 emissions
IPCC TII

N_2O Emissions
IPCC TII

CO_2 Emissions
Fossil Energy F4E2 Model

Defining the Crop Complex

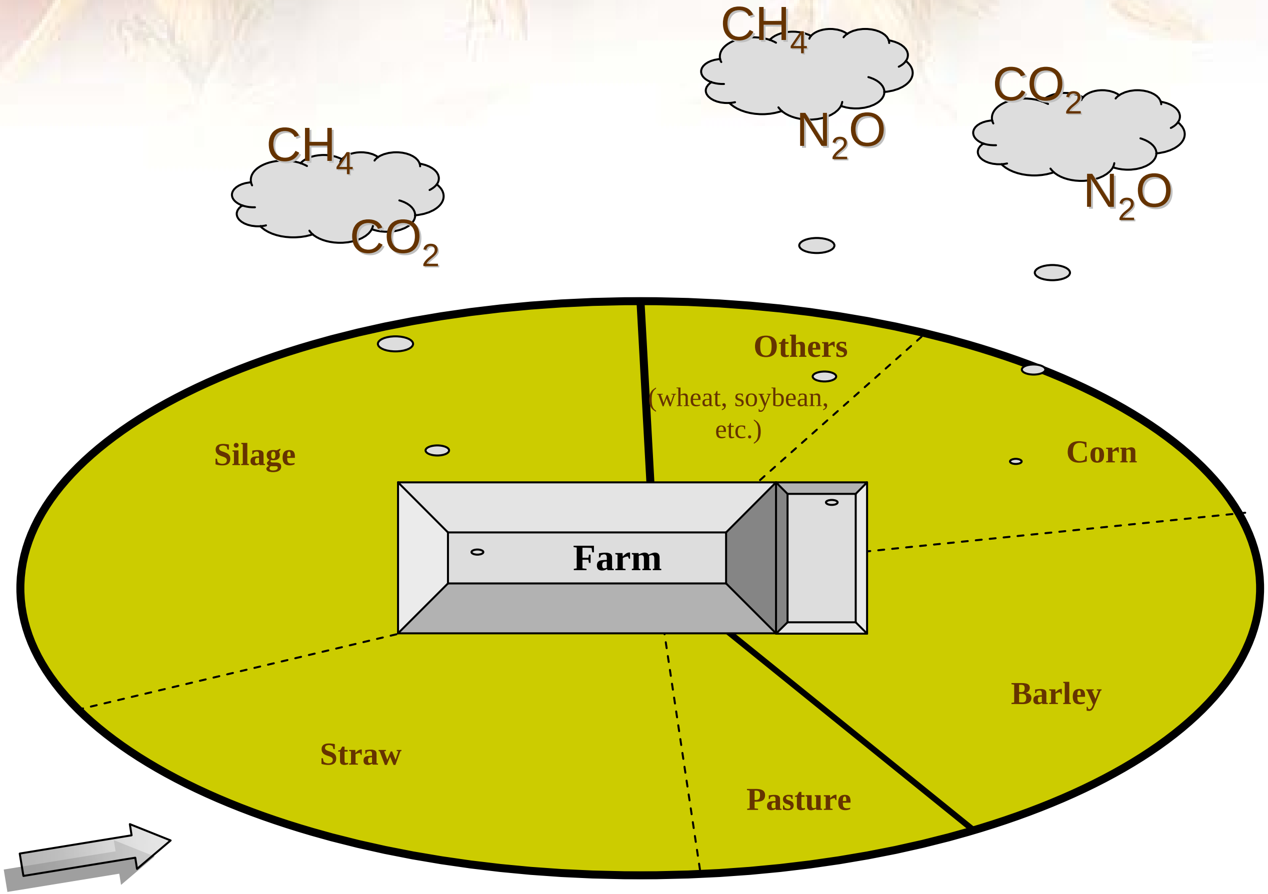
Intensity Indicator

Principle

Feed Rations

Crops	Dairy cows (2001) (kg/anl-yr)
Wheat	50
Oats	30
Barley	870
Corn	440
Dry peas	5
Soybean	90
Canola	125
Straw-Silage Pasture	Census

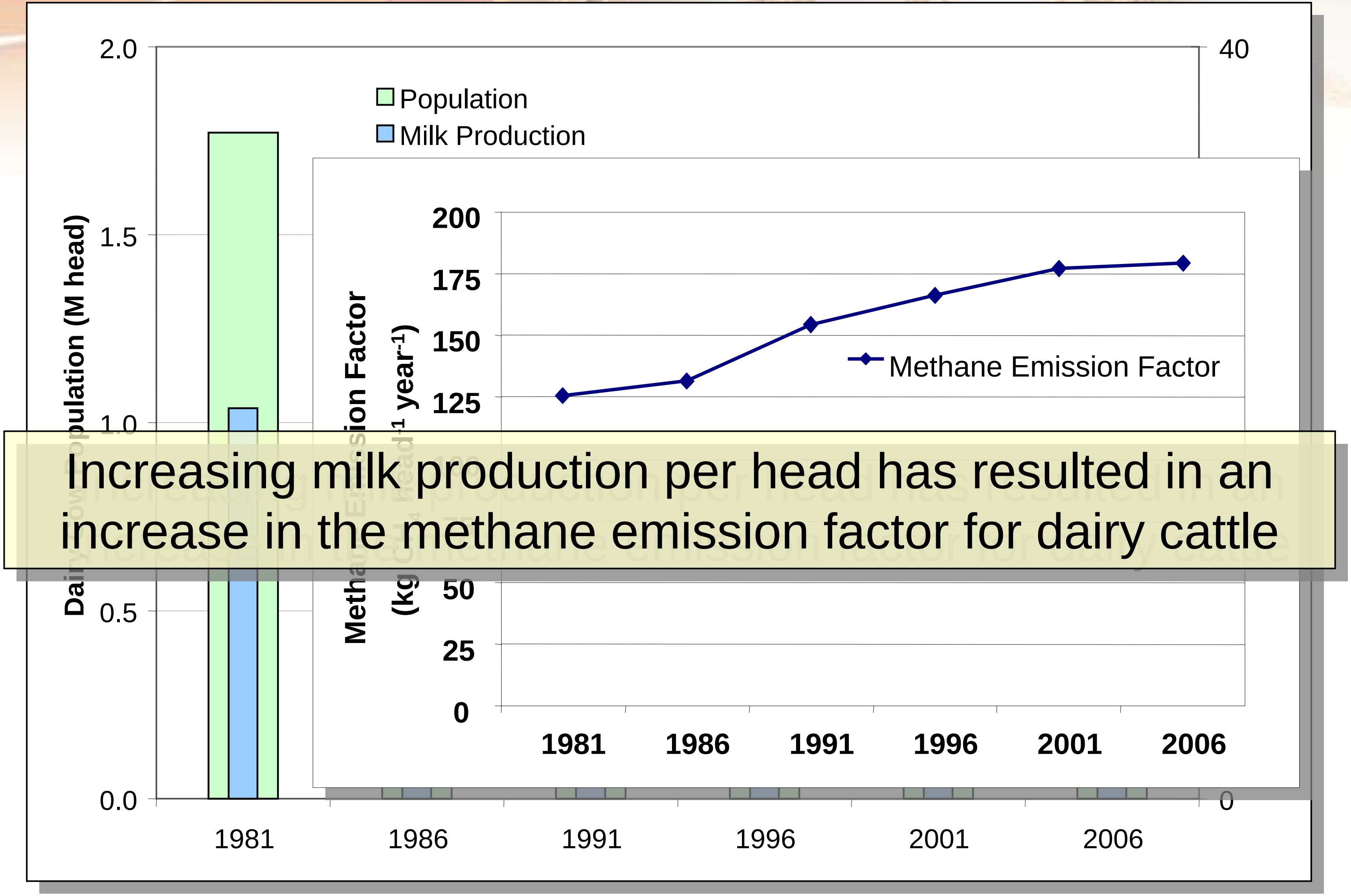
Yields kg / ha



Areas (ha)

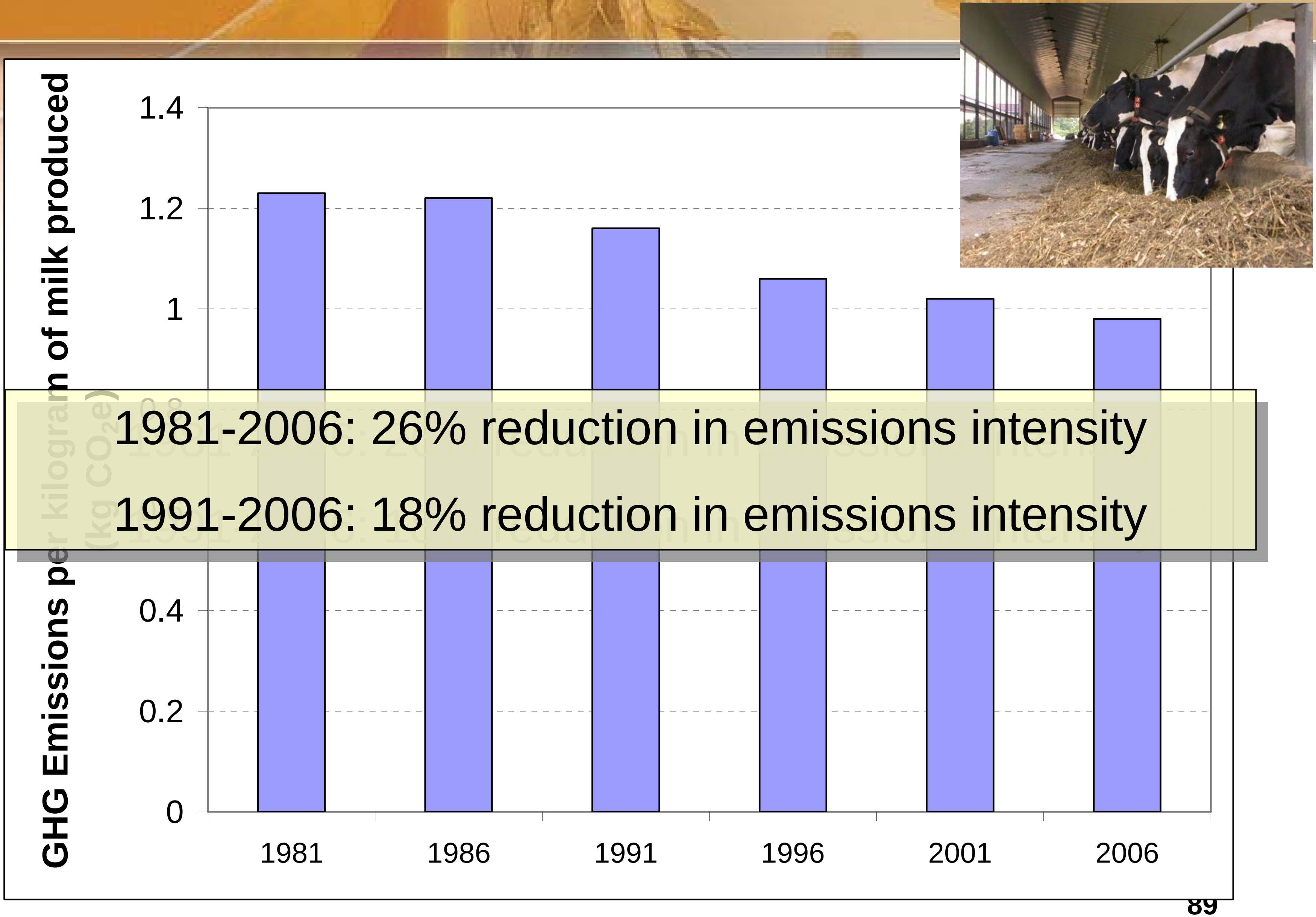
"Crop Complex"

Dairy Population and Milk Production



Increasing milk production per head has resulted in an increase in the methane emission factor for dairy cattle

GHG emissions intensity: Dairy Sector

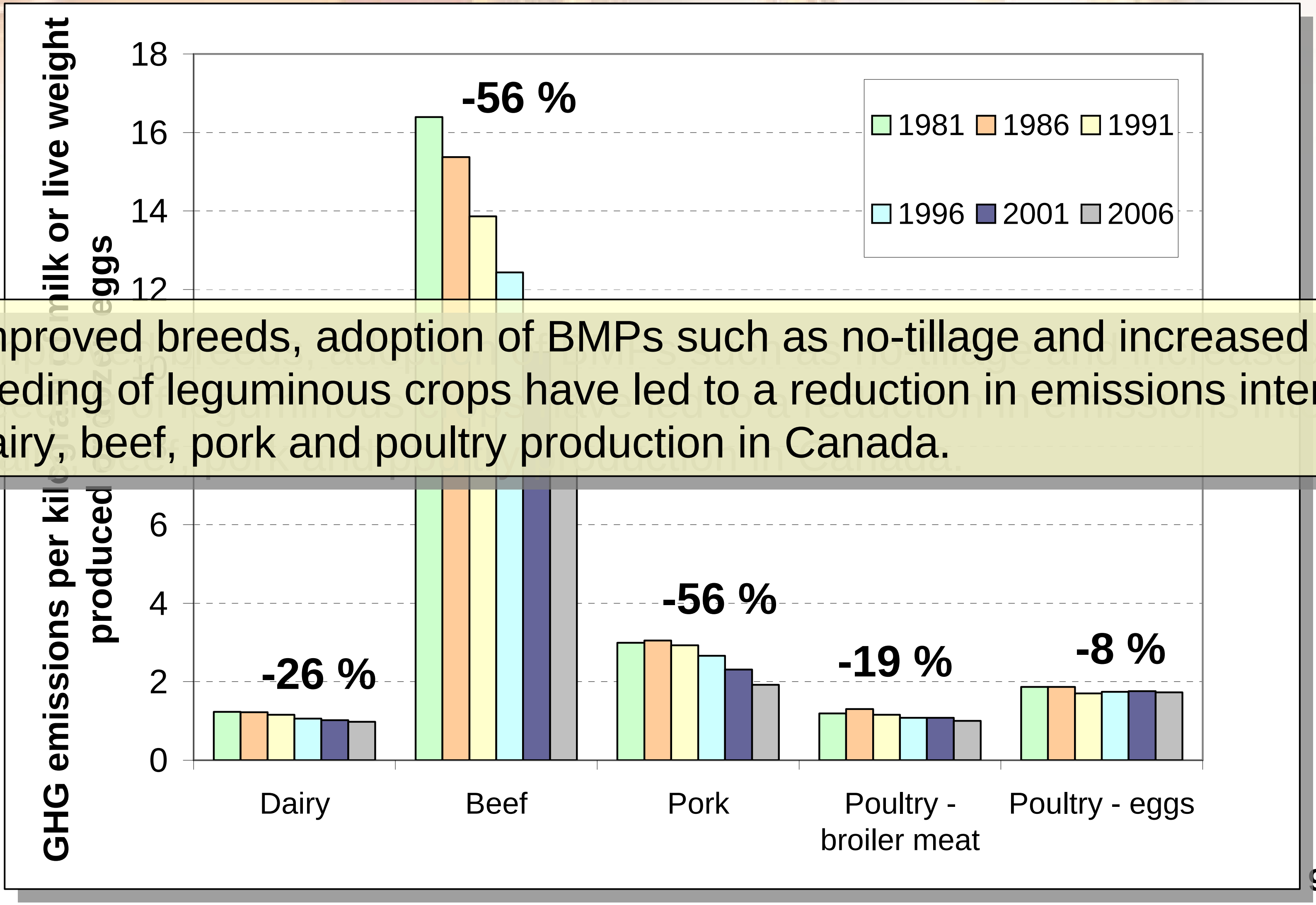


1981-2006: 26% reduction in emissions intensity

1991-2006: 18% reduction in emissions intensity

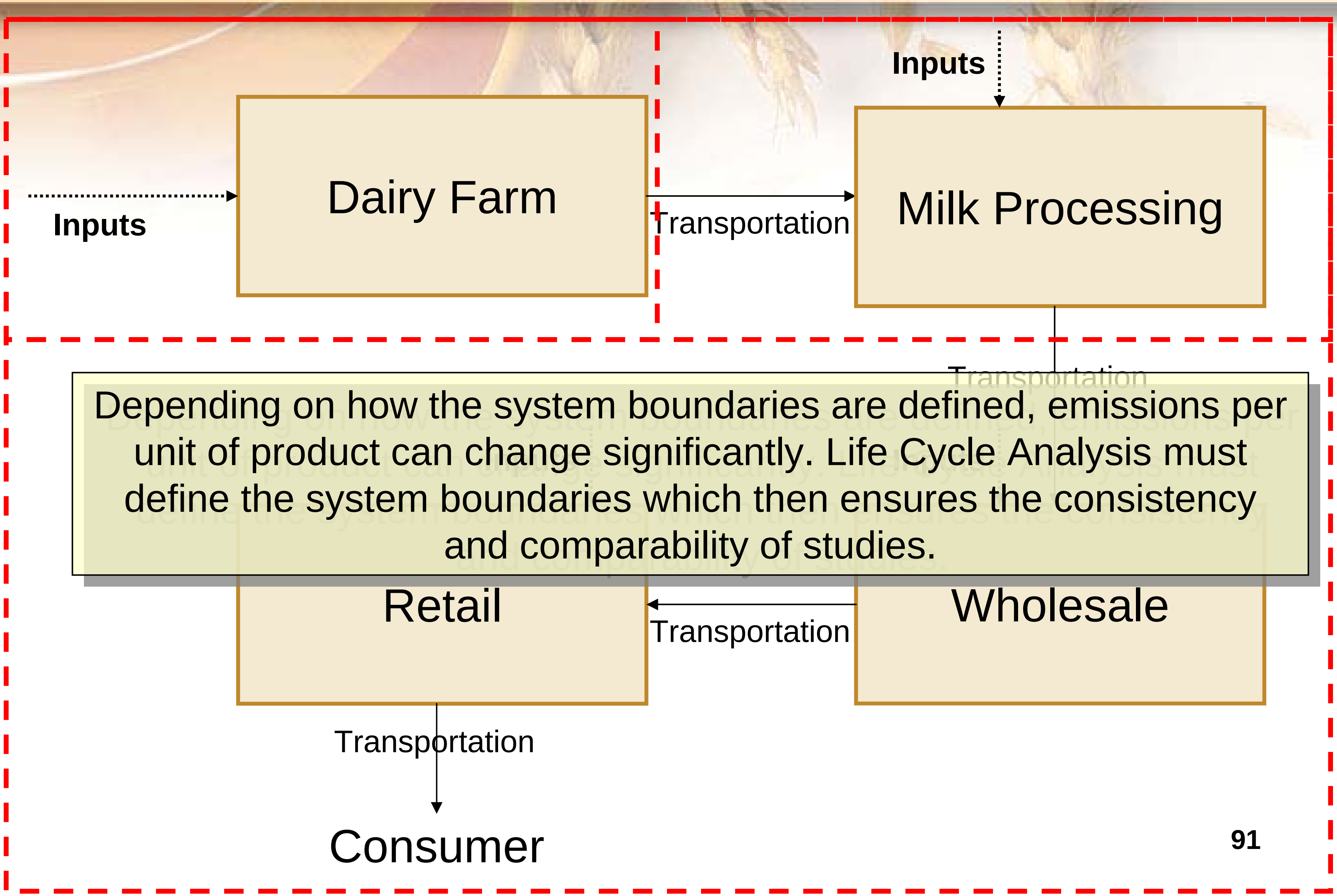
Source: Vergé et al (2007); Dyer et al (2008)

GHG Emissions Intensity in Canada



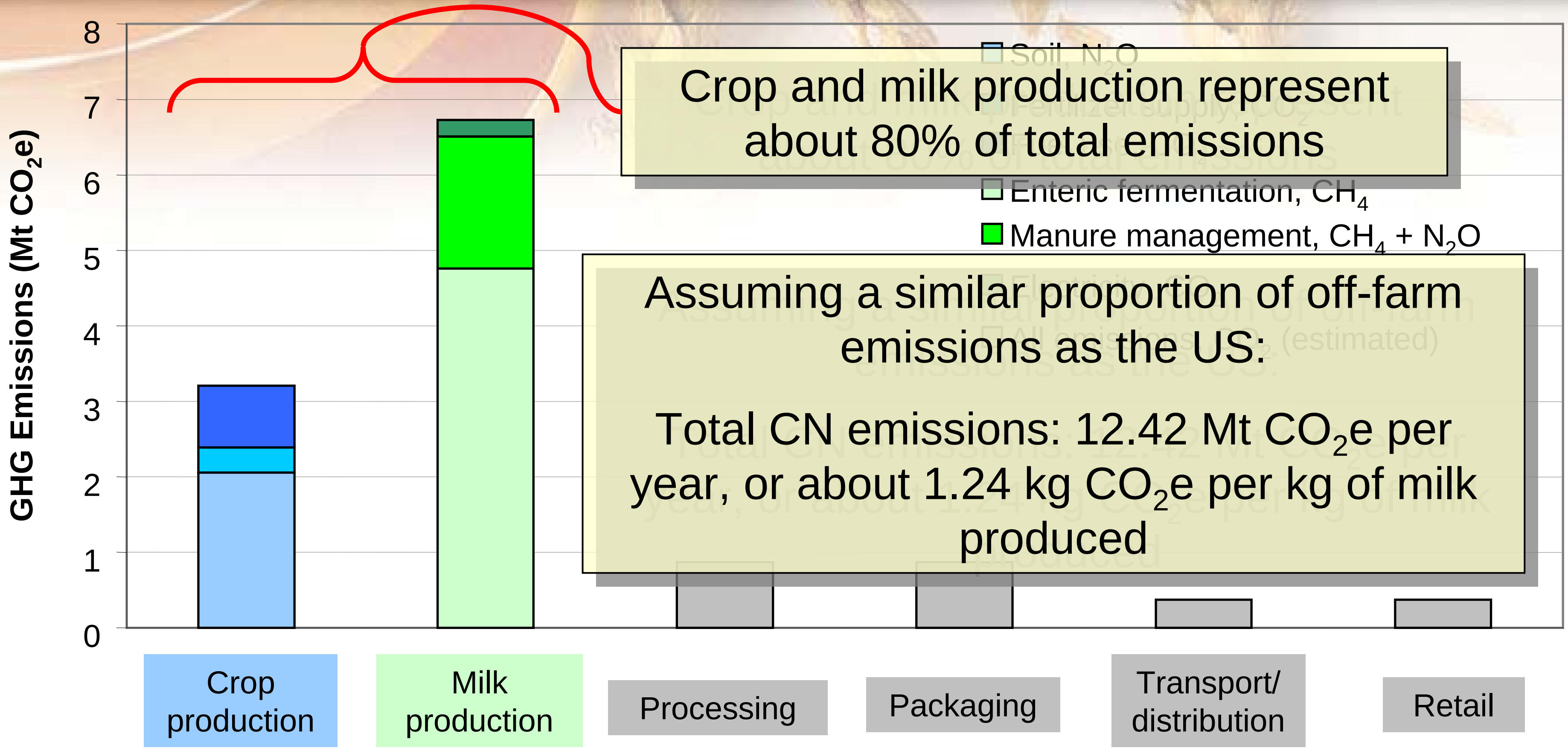
Improved breeds, adoption of BMPs such as no-tillage and increased feeding of leguminous crops have led to a reduction in emissions intensity dairy, beef, pork and poultry production in Canada.

System Boundaries for Emissions Calculations



Depending on how the system boundaries are defined, emissions per unit of product can change significantly. Life Cycle Analysis must define the system boundaries which then ensures the consistency and comparability of studies.

An estimate of the carbon footprint of milk production in Canada



Crop and milk production represent about 80% of total emissions

Assuming a similar proportion of off-farm emissions as the US:

Total CN emissions: 12.42 Mt CO_2e per year, or about 1.24 kg CO_2e per kg of milk produced

Modeling tools for producers

“Model Farm” was a Canadian agricultural research program that lasted from 2002-2006 and focused on improving estimates of GHG emissions from Canadian farms, and finding methods of mitigating those GHG emissions.

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

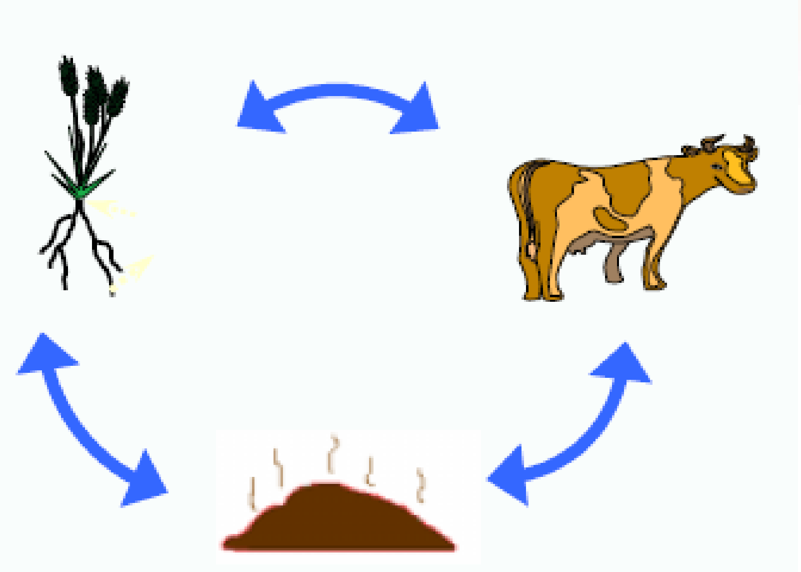
Holos

A tool to estimate and reduce GHGs from farms

Holos – Greek, meaning whole or complete

Holos: What is it?

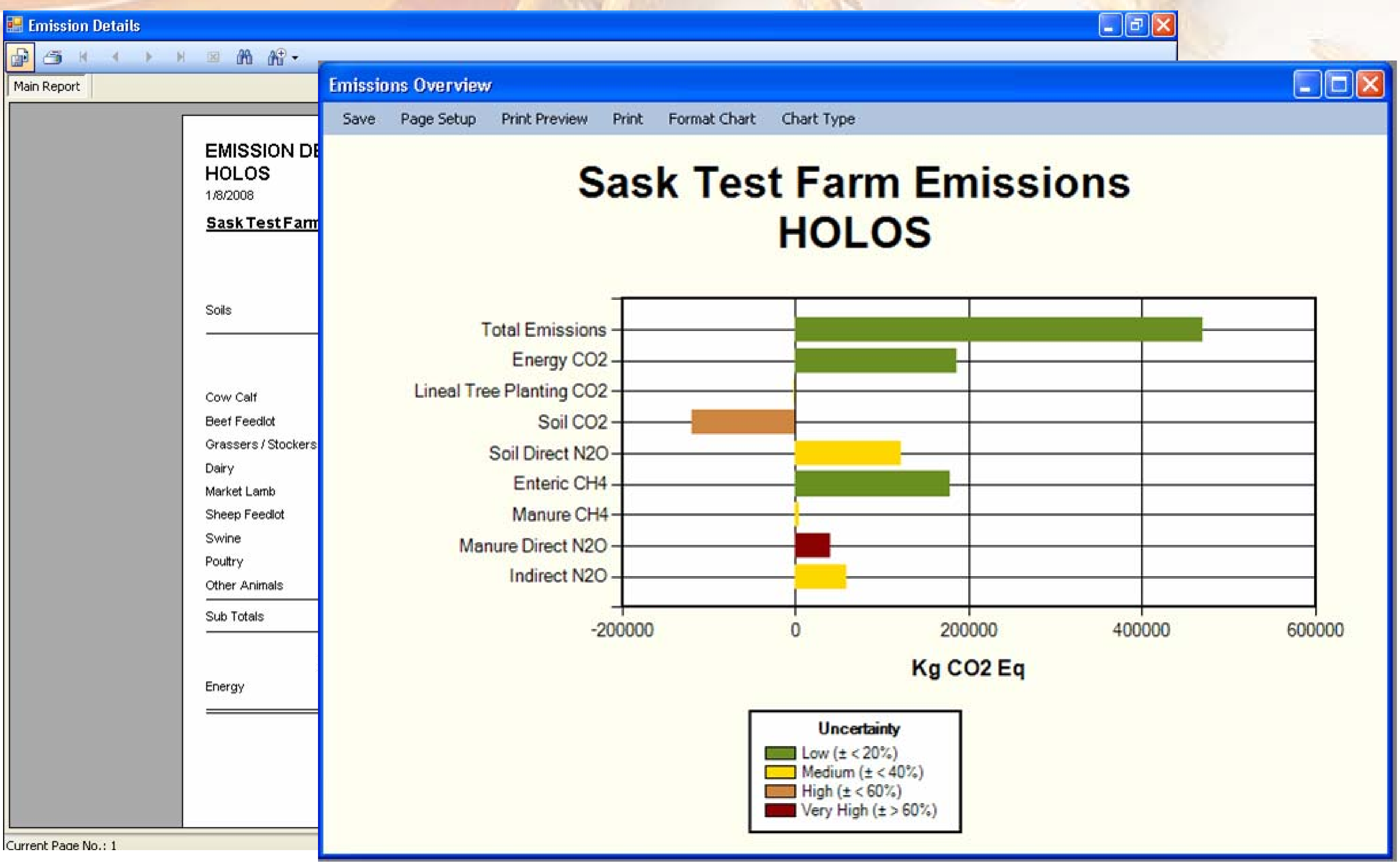
1. A simple, user friendly ecosystem model that estimates net-greenhouse gas emissions from individual Canadian farms
2. Describes best understood biophysical processes and their interconnections
3. Mathematical equations combined with expert knowledge and findings from experiments for a variety of farming practices
4. Allows for the evaluation of mitigation practices
5. Allows farmers to experiment with ‘what if?’ scenarios to reduce on-farm GHG emissions.



Holos

A tool to estimate and reduce GHGs from farms

Holos output



Summary

•Process-based models provide useful information on GHG emissions from agroecosystems

•Empirical models are sometimes used because our knowledge of processes is still fairly poor

•Management practices are changing rapidly in agriculture, hence we continuously need new measurements to improve the models

•Much progress has been achieved in reducing the GHG emission intensities from major animal production sectors

•Tools like Holos should help producers reduce GHG emissions on their farms

Conclusions

- Substantial progress has been made in measuring GHG emissions from agroecosystems
- Models have also been improved substantially
- Management practices are continuously changing, hence the need to measure emissions and modify our models accordingly
- Tools like Holos are increasing awareness among producers and are helping to reduce GHG emissions from farms
- Because of increasing demand for food, the greatest progress one can expect is a reduction in GHG emission intensities

Canada