Welcome to this week's presentation & conversation hosted by the **Canadian Association for the Club of Rome**, a Club dedicated to intelligent debate & action on global issues.

The Evolution of Agrometeorological Research in Canada: Emphasis on Mitigating Climate Change.

Our speaker today is Dr. Raymond Desjardins, emeritus scientist at the Ottawa Research & Development Centre, Science & Technology Branch, Agriculture & Agri-Food Canada. He has an HBSc in Physics (Ottawa U), an MSc in Meteorology (U Toronto), & a PhD in Agronomy (Cornell U). He is renowned for his innovative techniques to quantify greenhouse gas emissions & has worked with national & international teams on the role of terrestrial ecosystems in North America on climate change. He also worked with scientists, producers, & consumers to help minimize the impact of the agriculture sector on the environment.

DESCRIPTION: Dr. Desjardins here reviews research done in Agricultural Meteorology in Canada in the last 70 years. He describes the techniques that he & his research colleagues developed to quantify greenhouse gas emissions. He presents estimates of the carbon footprint of the main agricultural products in Canada & demonstrates the potential role of producers & consumers to help reduce agricultural greenhouse gas emissions. He discusses the positive or negative feedbacks on the earth's energy budget associated with biogeochemical & biogeophysical effects from a whole series of management practices. He presents pathways in agriculture that could help mitigate climate change.

The presentation will be followed by a conversation, questions, & observations from the participants.

CACOR acknowledges that we all benefit from sharing the traditional territories of local Indigenous peoples (First Nations, Métis, & Inuit in Canada) and their descendants.

Website: canadiancor.com
Twitter: @cacor1968
YouTube: Canadian Association for the Club of Rome
2024 Jan 17 Zoom #180

Outline

1. History of agrometeorology in Canada
2. Measurements of mass and energy exchange over North America terrestrial ecosystems
3. Measurements and estimates of GHG emissions from agricultural sources
4. Estimates of the carbon footprint of agricultural products
5. Discuss the impact of agriculture on climate
6. Present potential Natural Climate Solutions for agroecosystems
7. Concluding remarks and acknowledgements

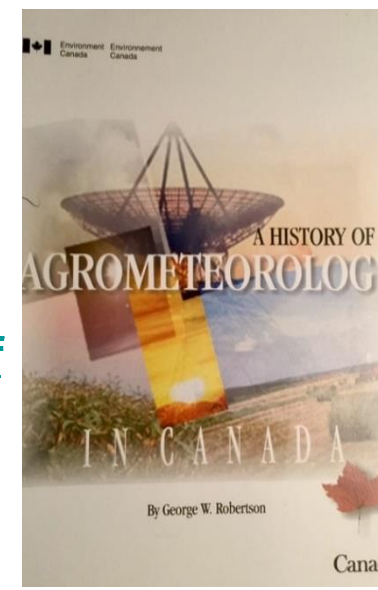
History of Agrometeorology in Canada

George Robertson (1951-1969)

- **Crop development and weather**
- Project- An investigation of the growth and development of the main crops in relationship to their meteorological environments for eight locations

- **“A Biometeorological Time Scale for Cereal Crop Involving Day and Night Temperatures and Photoperiod” by George W. Robertson, International Journal of Biometeorology (1968) 12:191–223**

- http://cmosarchives.ca/History/History_Agrometerology_Robertson_1989.pdf



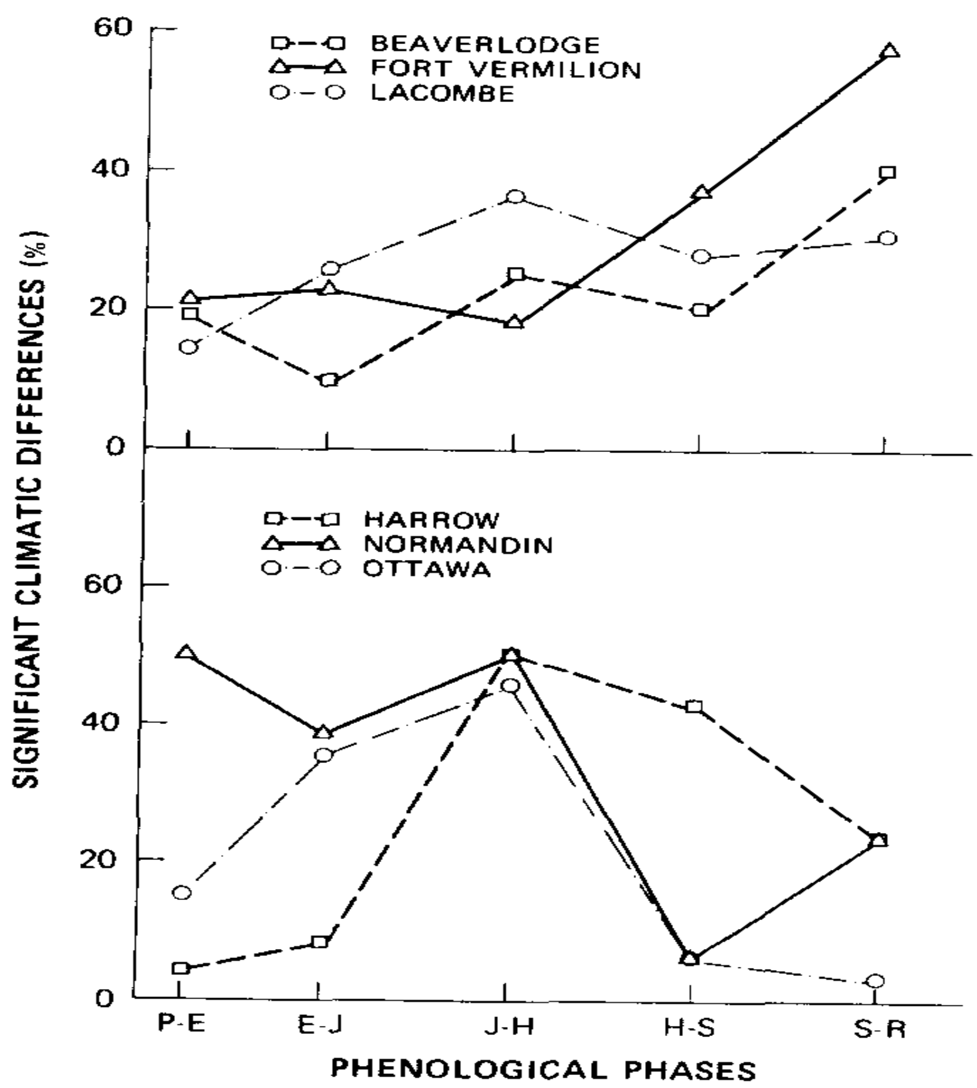
1961 & 1962 summer student seconded by CMS to Agriculture Canada

Overview of Canadian Agriculture:

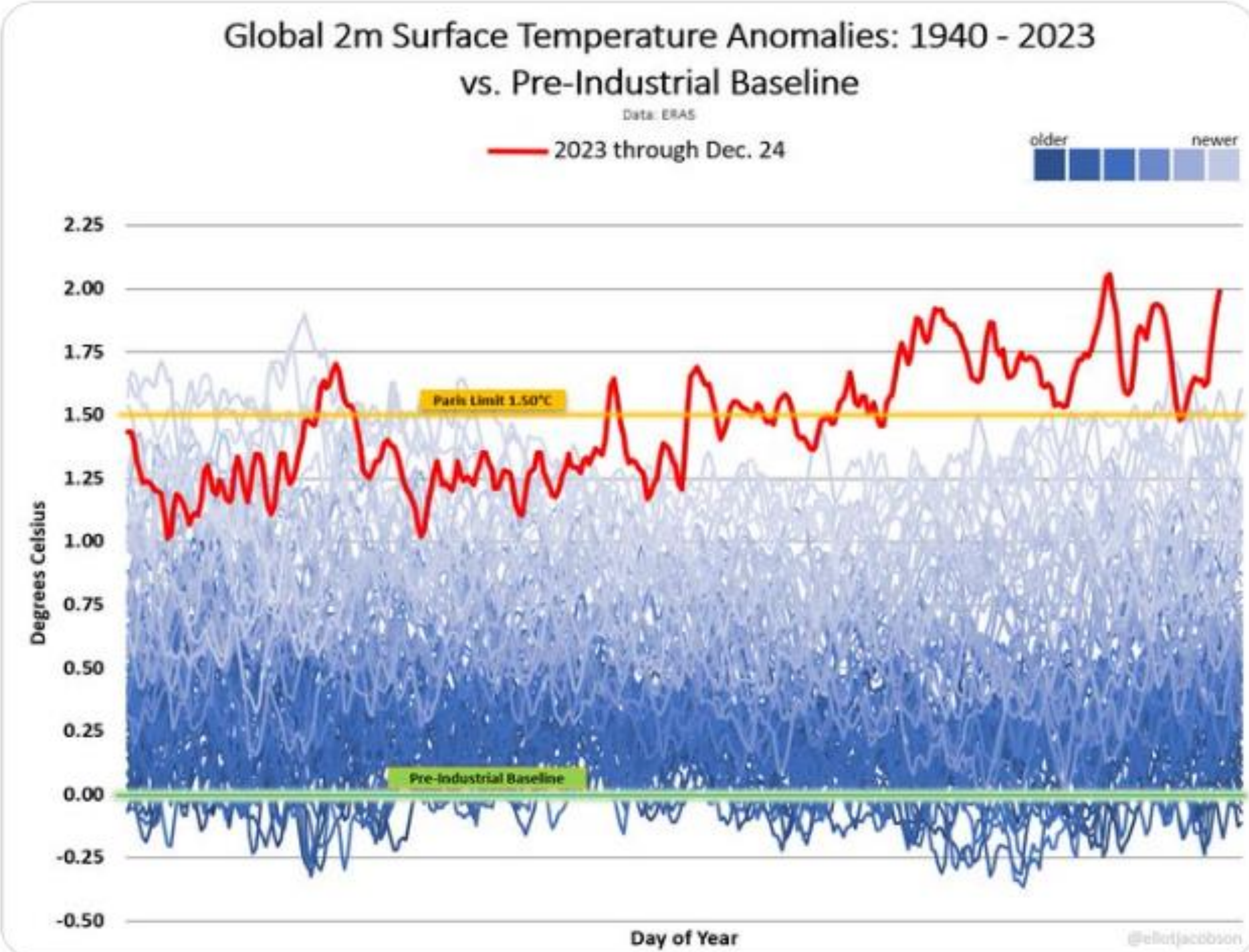
Top Commodities by Province and Territory

- 64.8 million hectares of farmland 40 mha intensively cultivated
- Crops and livestock are regionally concentrated - reflecting Canada's different landscapes, soils, climates, and history..

The relative importance of various stages of development on wheat production in six regions in Canada for the period between 1960-1970.



Desjardins, R.L. and Ouellet, C.E. 1980. J. *Agr. Meteorol.* 22: 129-136.



Global 2m Surface Temperature Anomalies: 1940 - 2023
vs. Pre-Industrial Baseline
Data: ERA5
2023 through Dec. 24
older
newer
Paris Limit 1.50°C
Pre-Industrial Baseline
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
Degrees Celsius
Day of Year

Even some of our recent agrometeorological studies are either outdated or will soon be

Smith et al. 2013. Assessing the effects of climate change on crop production and GHG emissions in Canada, *Agriculture, Ecosystems and Environment, 179*, pp. 139-150.

At temperatures over 32.8 degrees Celsius, important enzymes in wheat start to break down.

Kaharabata, S., and R.L. Desjardins (2021). An indicator of freeze-kill damages to fruit trees during flowering. Int. J. of Biometeorology 65, 813-825.

1965 – 2023 Research with respect to mitigating climate change

Measured and estimated mass and energy exchange associated with some of the major ecosystems in North America

Measured and estimated GHG emissions associated with the agriculture sector and other sectors

Estimated the carbon footprint of most agricultural products and the differences in radiative forcing associated with several management practices

Quantified the impact of agriculture on climate and identified ways to reduce it.

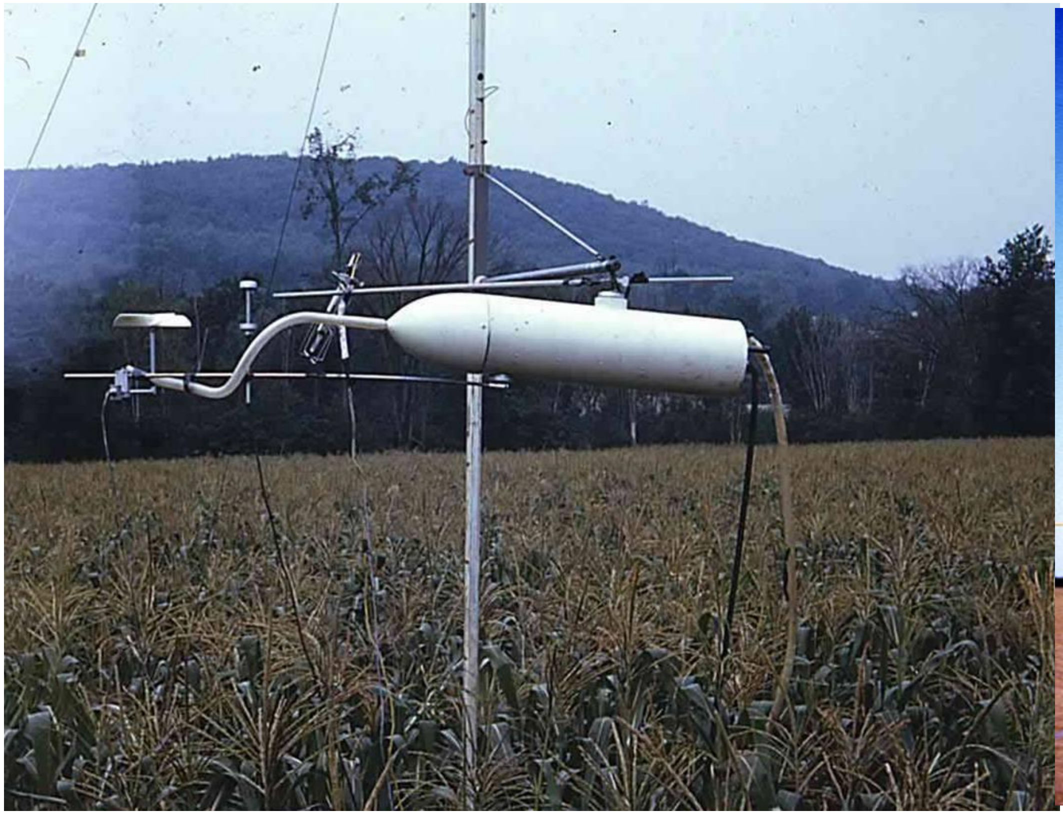
2. Measured the instantaneous rate of photosynthesis at the field scale using the EC technique

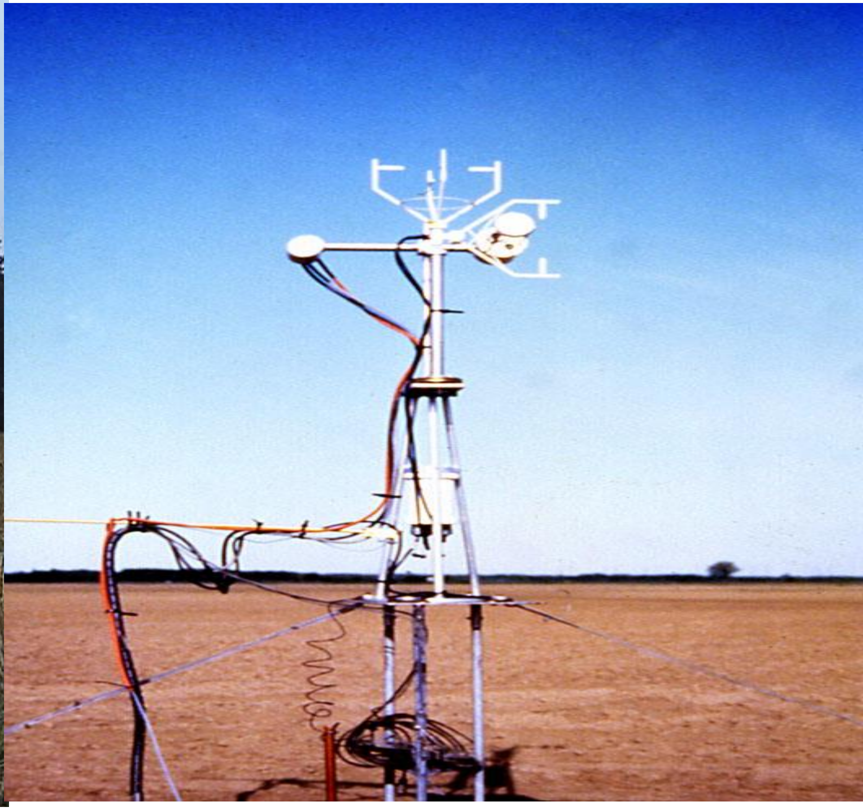
1.5 g of CO2= 1 g of dry plant material

$6\ CO_2 + 6\ H_2O$ + light energy = $C_6H_{12}O_6 + 6\ O_2$

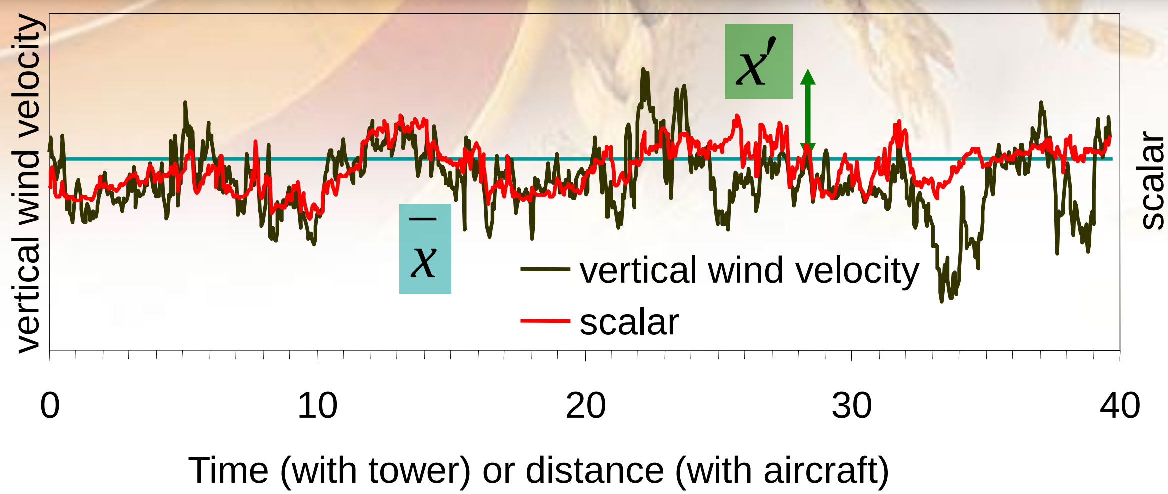
Desjardins, R.L. 1972. A study of carbon dioxide and sensible heat fluxes using the eddy correlation technique. Ph.D. Thesis, Cornell University, Ithaca, N.Y. 175 pp.

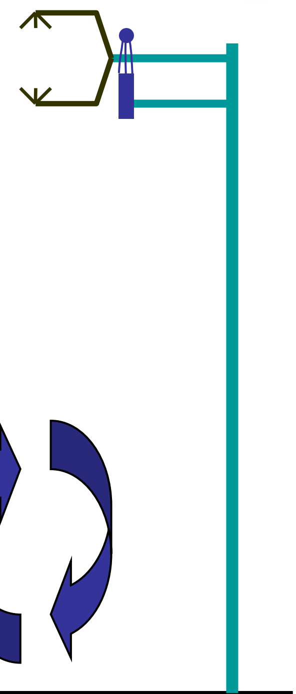
Chahuneau, F., Desjardins, R.L., Brach, E.J. and Verdon, R. 1989. A micrometeorological facility for eddy flux measurements of CO_2 and H_2O. *J. Atmosp. & Oceanic Tech.* 6: 193-200..





Flux measurements using the Eddy Covariance Method

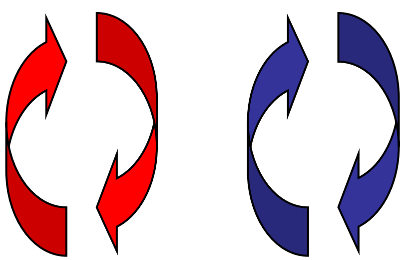




Reynolds: $x=\overline{x}+x',\ \ \overline{x'}=0,\ \ \overline{xy}=\overline{x}\,\overline{y}+\overline{x'y'}$

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

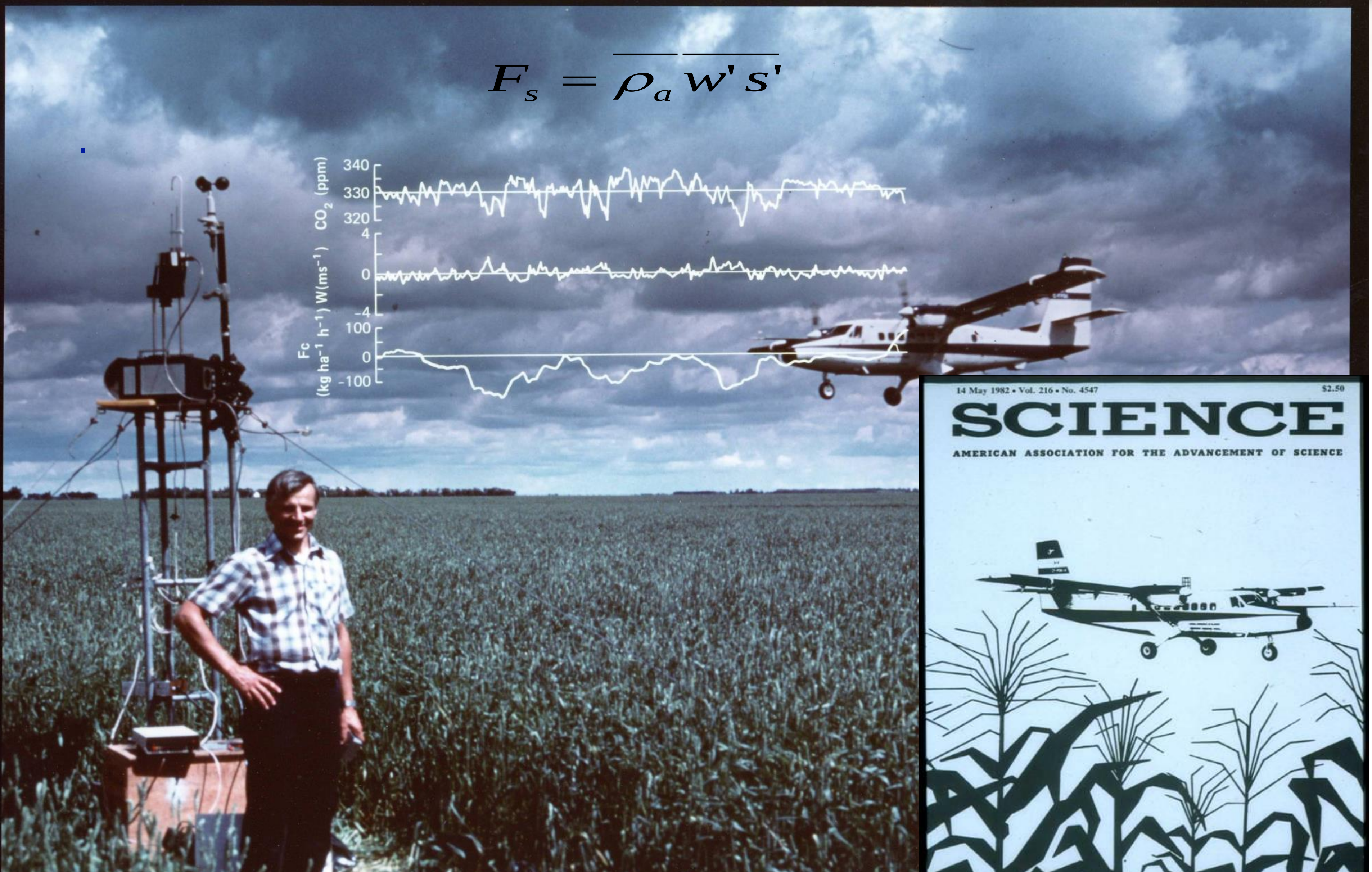
$$\boxed{\overline{w}=0}$$



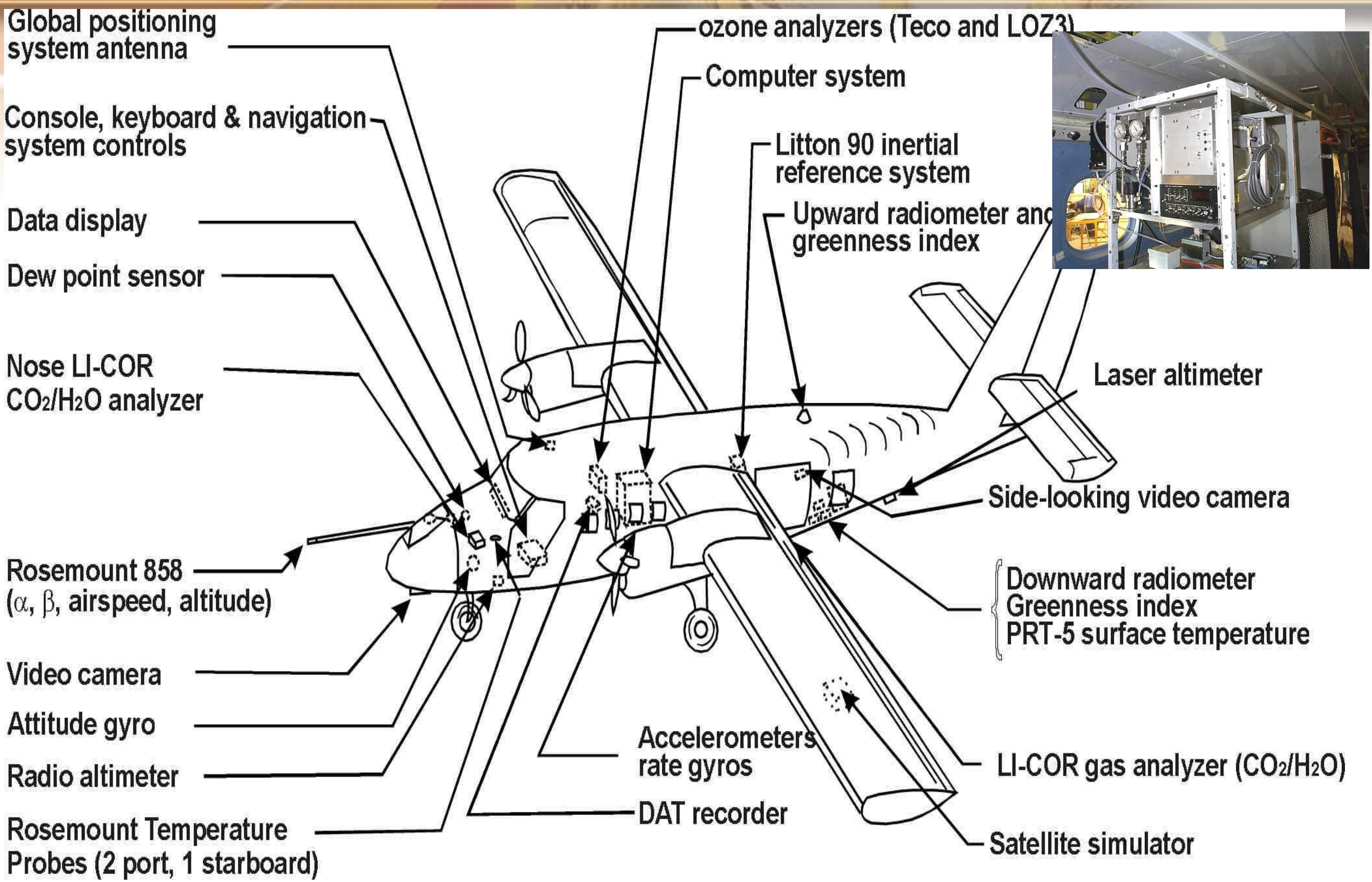
EC technique is a useful tool because it permits to quantify fluxes for an entire ecosystem without disturbing it. It is based on assumptions of stationarity and horizontal homogeneity.

Measured gas exchange at a regional scale using aircraft-based EC technology

$$F_s = \overline{\rho_a}\,\overline{w's'}$$

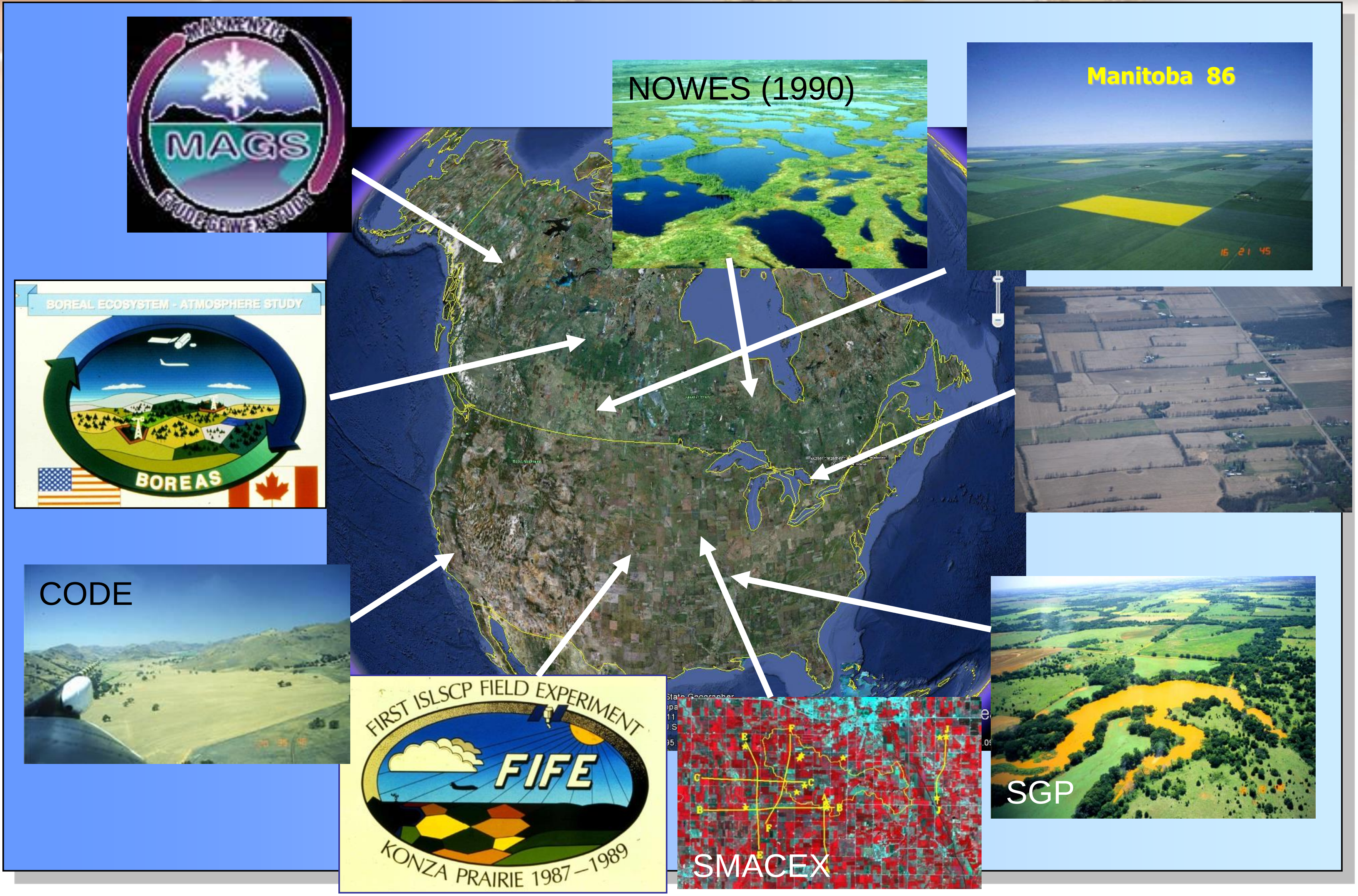


National Research Council Twin Otter Research Aircraft



Quantified mass and energy exchange over major terrestrial ecosystems in North America

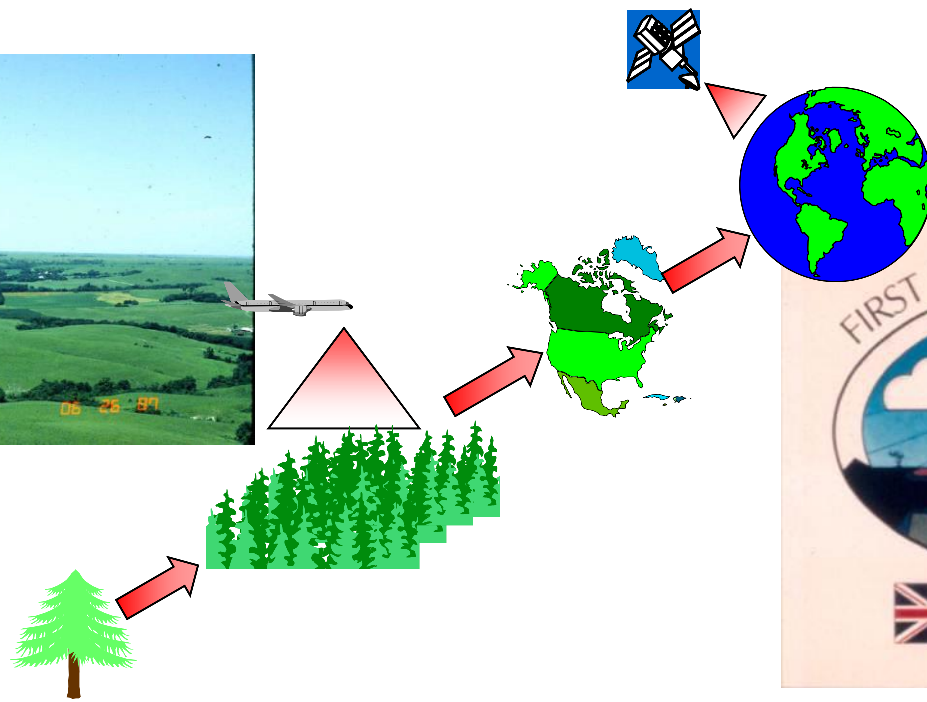
Desjardins et al. 2016. "Flux measurements using the NRC Twin Otter atmospheric research aircraft 1987-2011.", ***Advances in Science and Research, 13,*** **43-49. doi : 10.5194/asr-13-43-2016.**



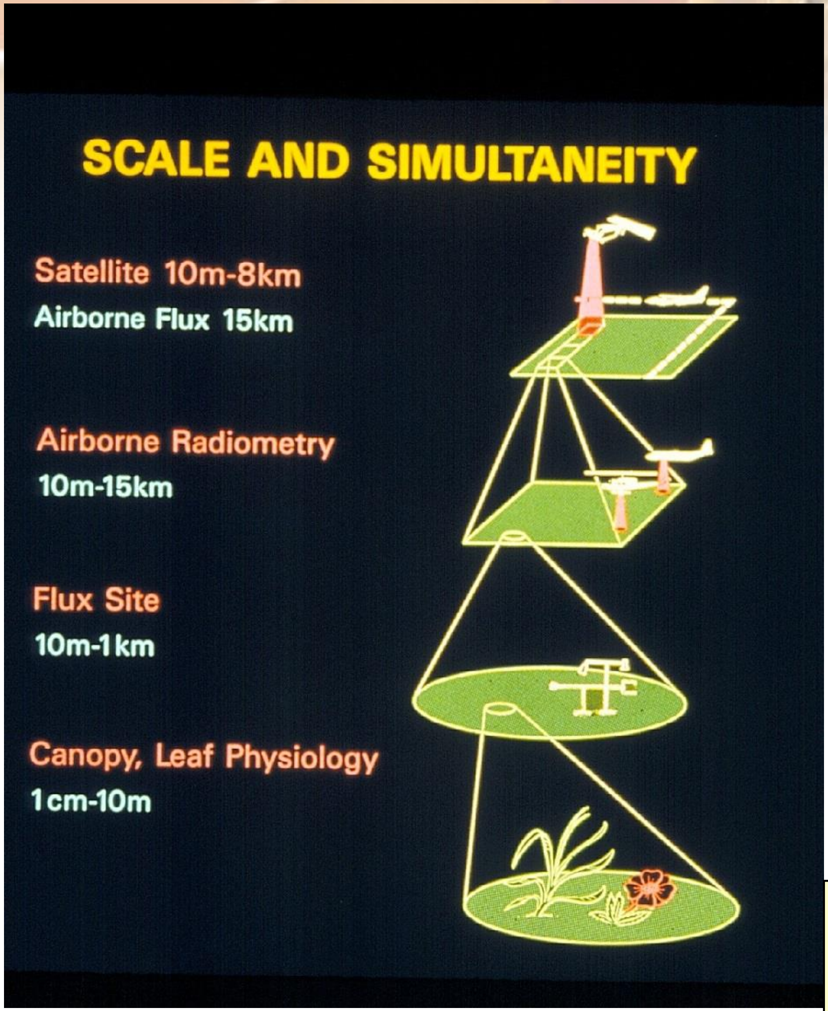
First ISLSCP Field Experiment

1987-1989 FIFE

First International Satellite Land Surface Climatology Project Field Experiment whose main objective was to investigate the role of biology in controlling the interactions between a grassland ecosystem and the atmosphere.

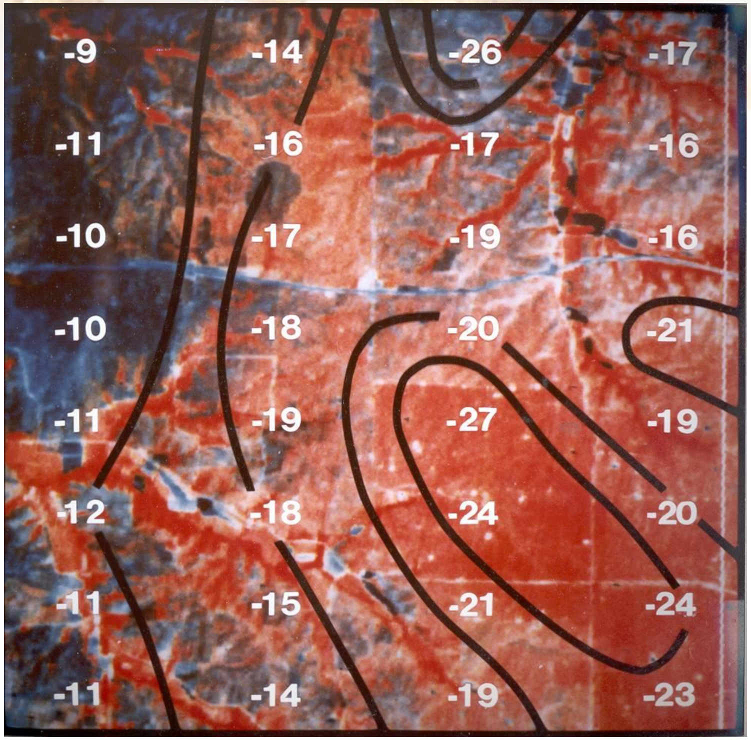


FIFE project provided flux measurements at a wide range of scales using a multidiscplinary approach



Carbon, energy, and water fluxes from leaf to regional scales

Desjardins, R.L., et al. 1992. *J. Geophys. Res.* 97: 18467-18476.



CO_2 Fluxes (kg CO_2 ha^{-1} h^{-1})

Carbon dioxide exchange measured over a 15 km x 15 km grassland area using the Canadian aircraft, flying a grid pattern at 90 m above the surface. The data is superimposed on a satellite image of NIR/IR.

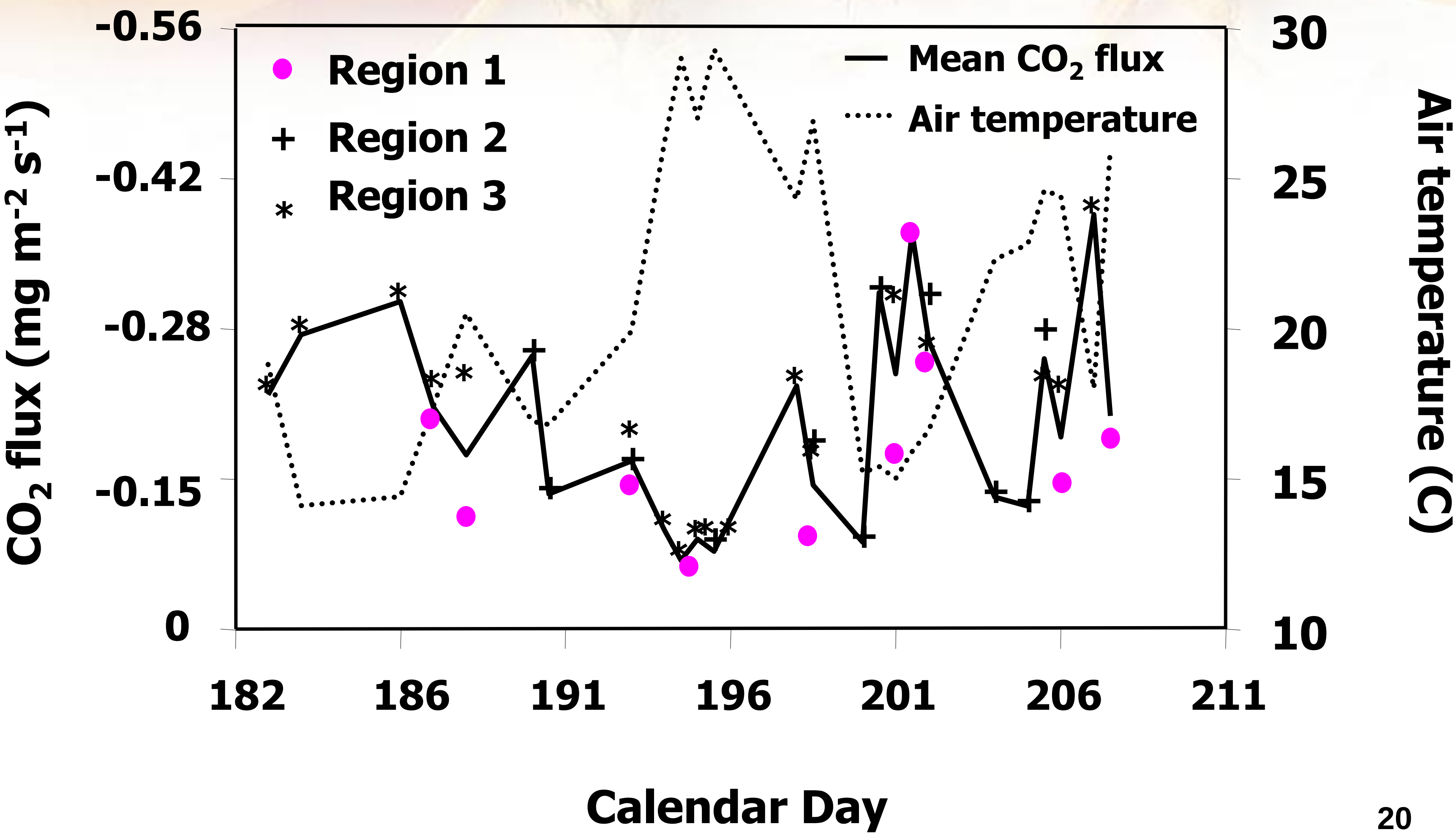
Evapotranspiration measured using the Twin Otter aircraft over a 15 km by 15 km section of the Konza Prairies

Northern Wetlands Study (1990)

- Roulet, N., Reeberg, W., Alperin, M., Desjardins, R.L., Galchenko, V., Glooschenko, W., Lassiter, R., Lassey, K., Moore, T., Schiff, H., Svensson, B., Wahlen, M., and Zarvarzin, G. 1991. High latitude ecosystems: sources and sinks of trace gases. *Ecological Bulletin* 42: 86-97.

Carbon dioxide fluxes measured over 3-80 km transects at 30m above the northern wetlands

It is clear from this graph that air temperature is one of the dominant factor controlling the carbon dioxide exchange over these wetlands

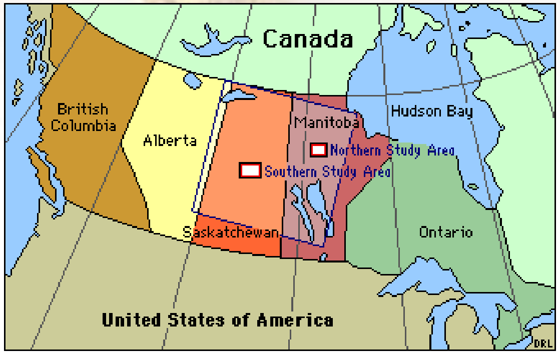


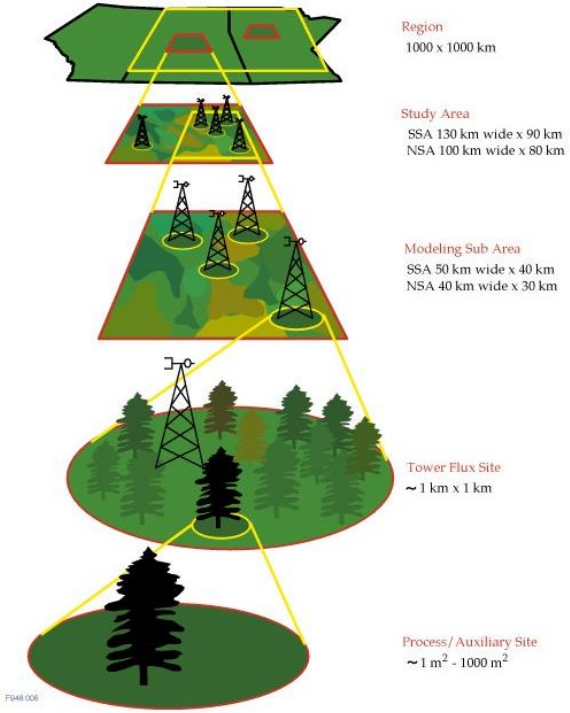
Desjardins et al. 1994. Airborne flux measurements of CO_2 and H_2O over the Hudson Bay Lowlands. *J. Geophys. Res.* 99: 1551-1561

BOREAS: BOReal Ecosystem Atmospheric Study

Land Cover within a 15 x 15 km grid in the BOREAS SSA

Lakes	Black Spruce	Rock	Jack Pine	Aspen	Fen
0.2%	57.6%	1.2%	18.5%	15.4%	6.4%

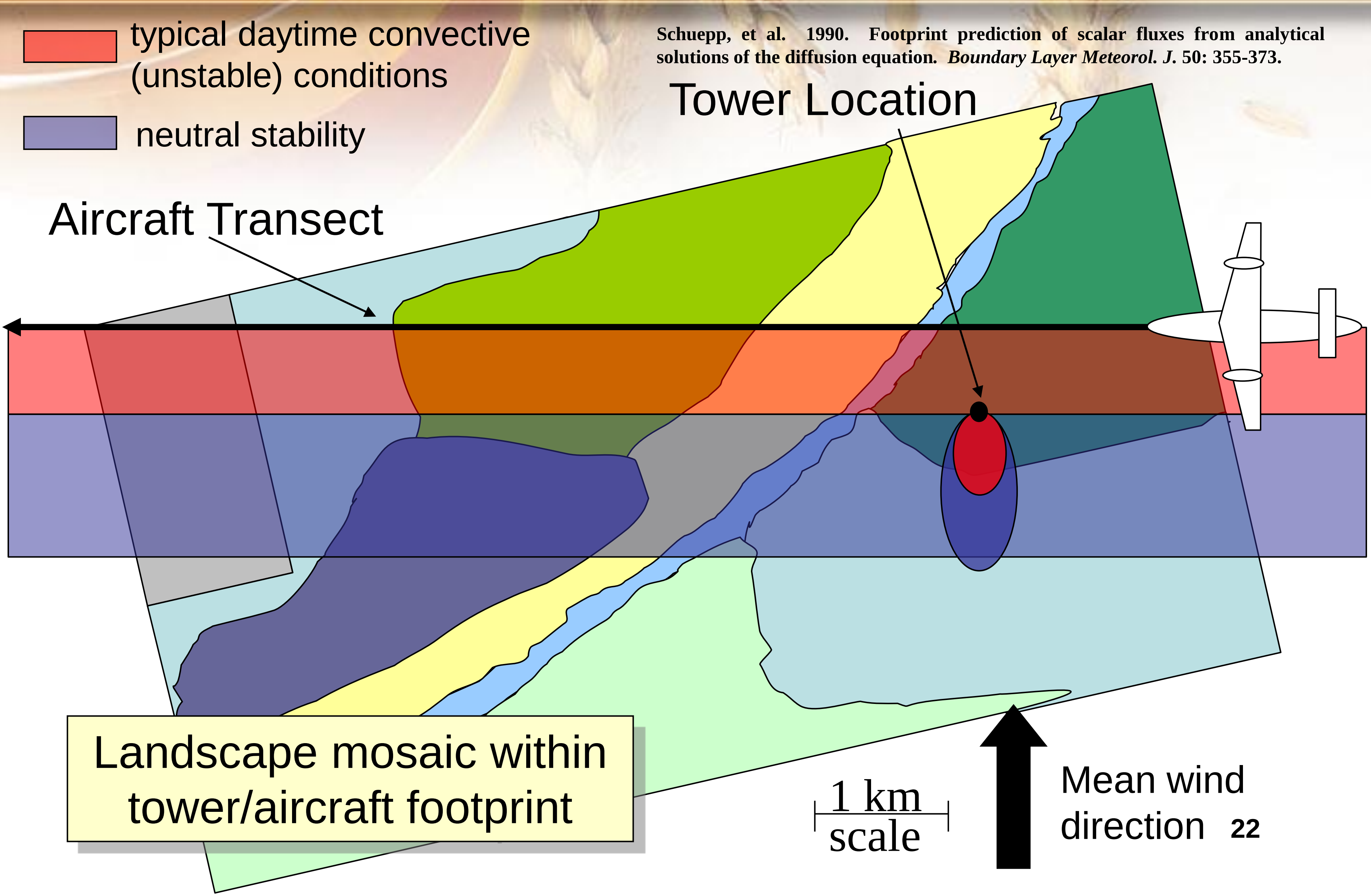




Desjardins et al. (1997)

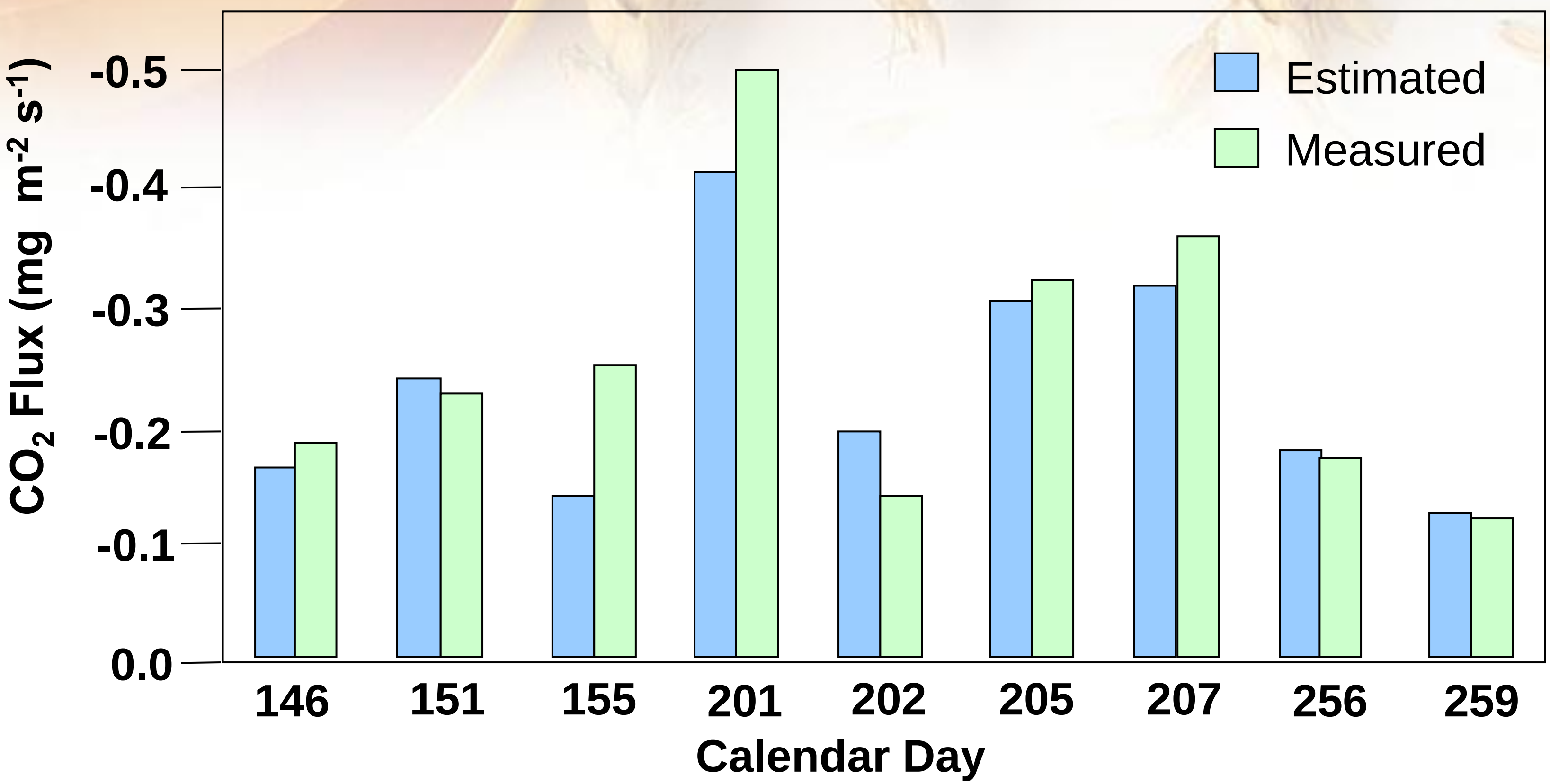
Footprint of tower and aircraft-based flux measurements

Schuepp, et al. 1990. Footprint prediction of scalar fluxes from analytical solutions of the diffusion equation. *Boundary Layer Meteorol. J.* 50: 355-373.



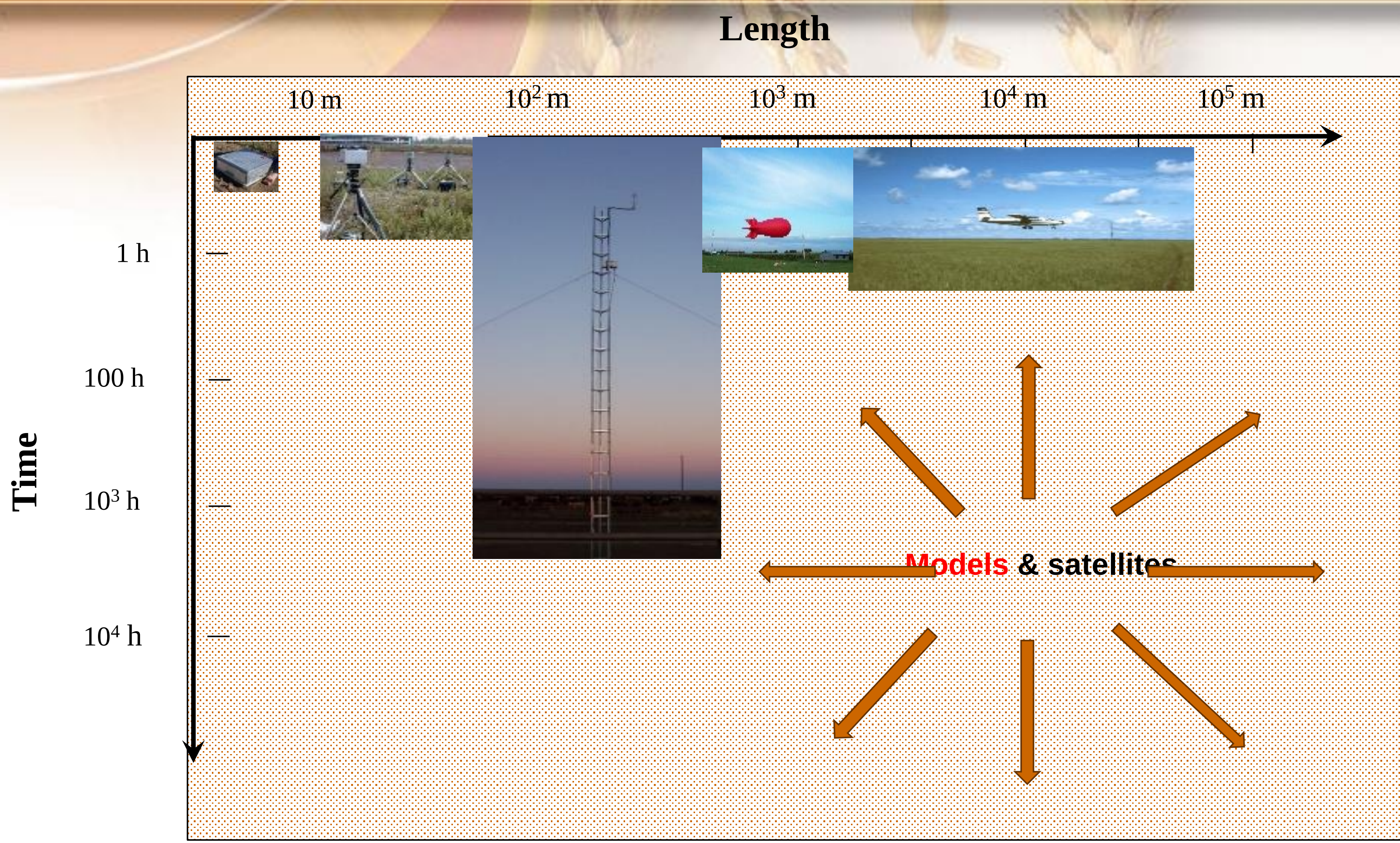
Verifying regional CO_2 flux estimates based on tower-based measurements for SSA

Desjardins, R.L., et al. 1997. Techniques for obtaining regional estimates of gas exchange. *J. Agric. Meteorol.* 52: 445-452.



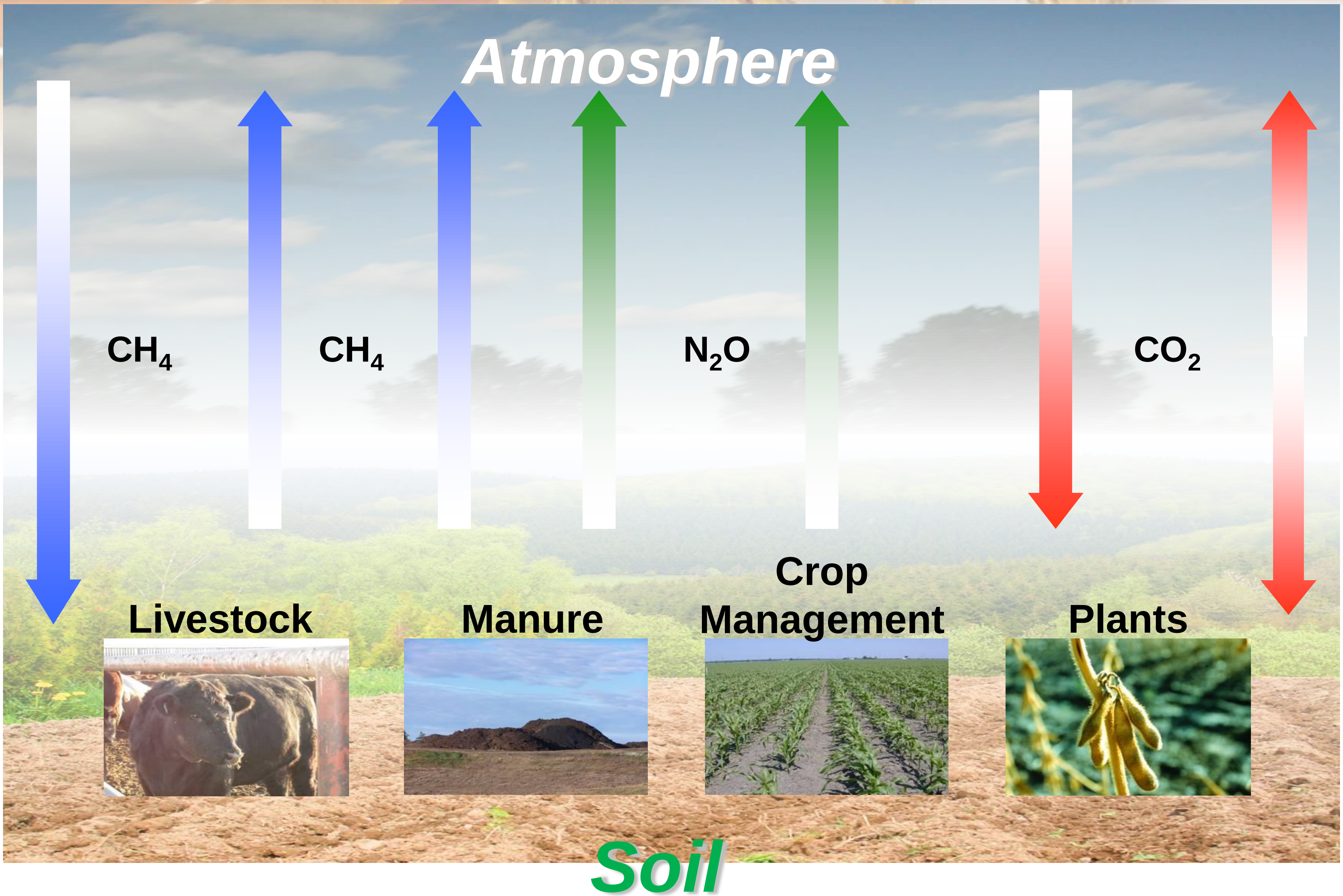
Lakes	Black Spruce	Rock	Jack Pine	Aspen	Fen
0.2%	57.6%	1.2%	18.5%	15.4%	6.4%

3. Quantifying agricultural GHG emissions



Desjardins, R. L., Worth, D.E., Dyer, J.A., Verge, X.P.C. & McConkey, B.G. (2020). The Carbon Footprints of Agricultural Products in Canada pp 1-34 S.S. Muthu (ed.), Carbon Footprints, Environmental Footprints and Eco-design of Products and Processes, http://doi.org/10.1007/978-981-13-7916-1_1

Greenhouse gas exchange in agroecosystems



Measuring GHG emissions using manual and automated chambers

Chambers are the most commonly used technique to measure GHG emissions from agricultural soils

Manual

Automated

e.g. LI-COR survey chambers

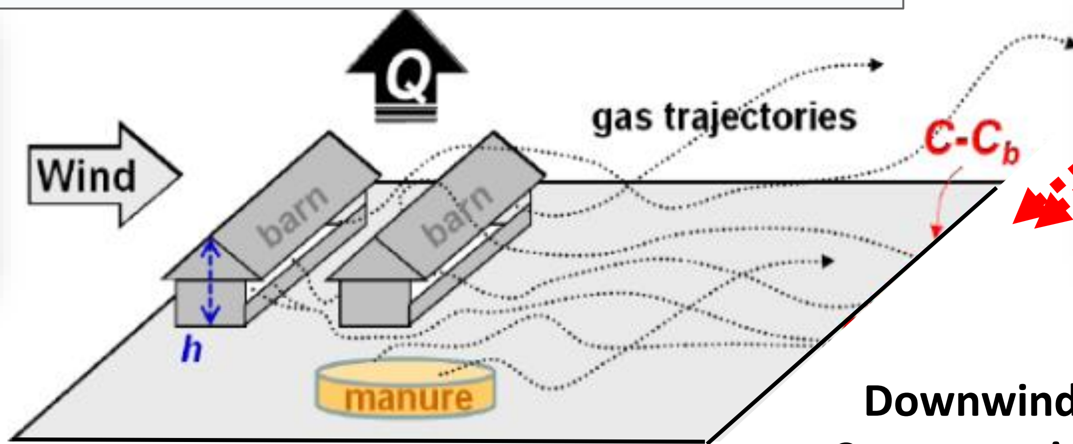
•Rochette et al. 1993. *Can. J. Soil Sci.* 72: 591-603.

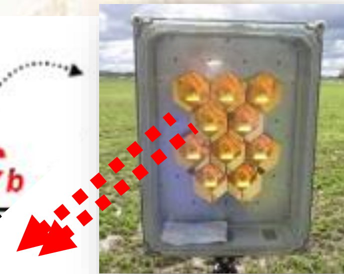
•Pennock et al. 2005. *Canadian Journal of Soil Science* 85: 113-125

Methane emission measurements for on farm situations

- **Method developments highly transferable to other sectors (Oil & Gas)**
  WindTrax can be downloaded from:
  http://www.thunderbeachscientific.com/windtrax.html

VanderZaag et al. 2018. Environmental Technology. 39 (7), 851-858. DOI: 10.1080/09593330.2017.1313317

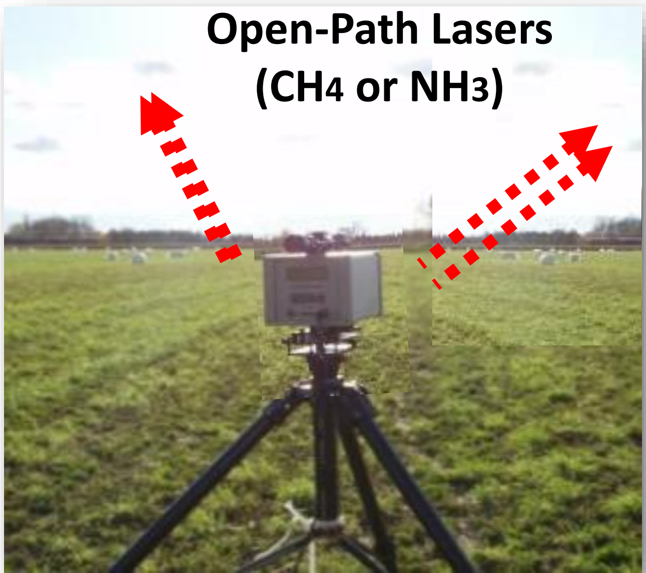




Upwind Concentration

Downwind Concentration

Open-Path Lasers (CH_4 or NH_3)

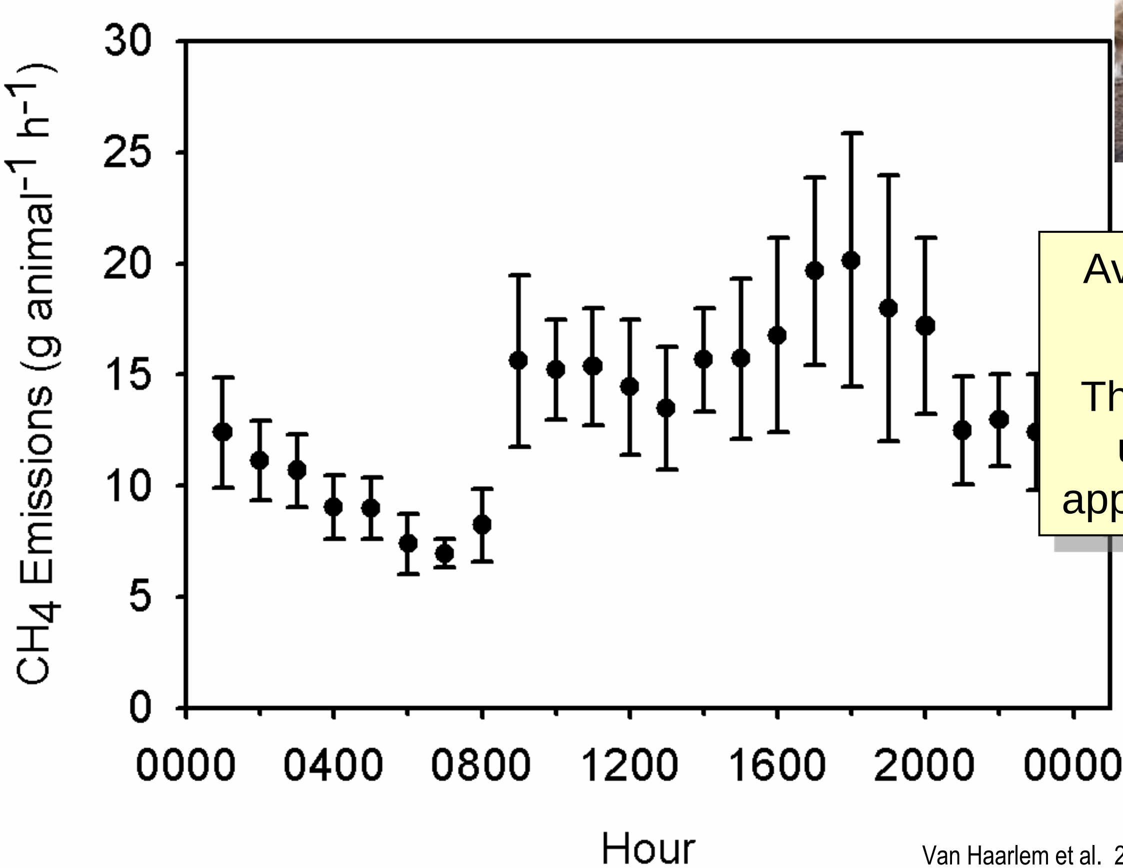


3D Sonic Anemometer

Flesch et al. 2013. J. of Animal Science. 93: 1-14.

Measurements of CH_4 emissions from a feedlot using the bls method

Diurnal Cycle in CH_4 emissions, corresponding with feeding times



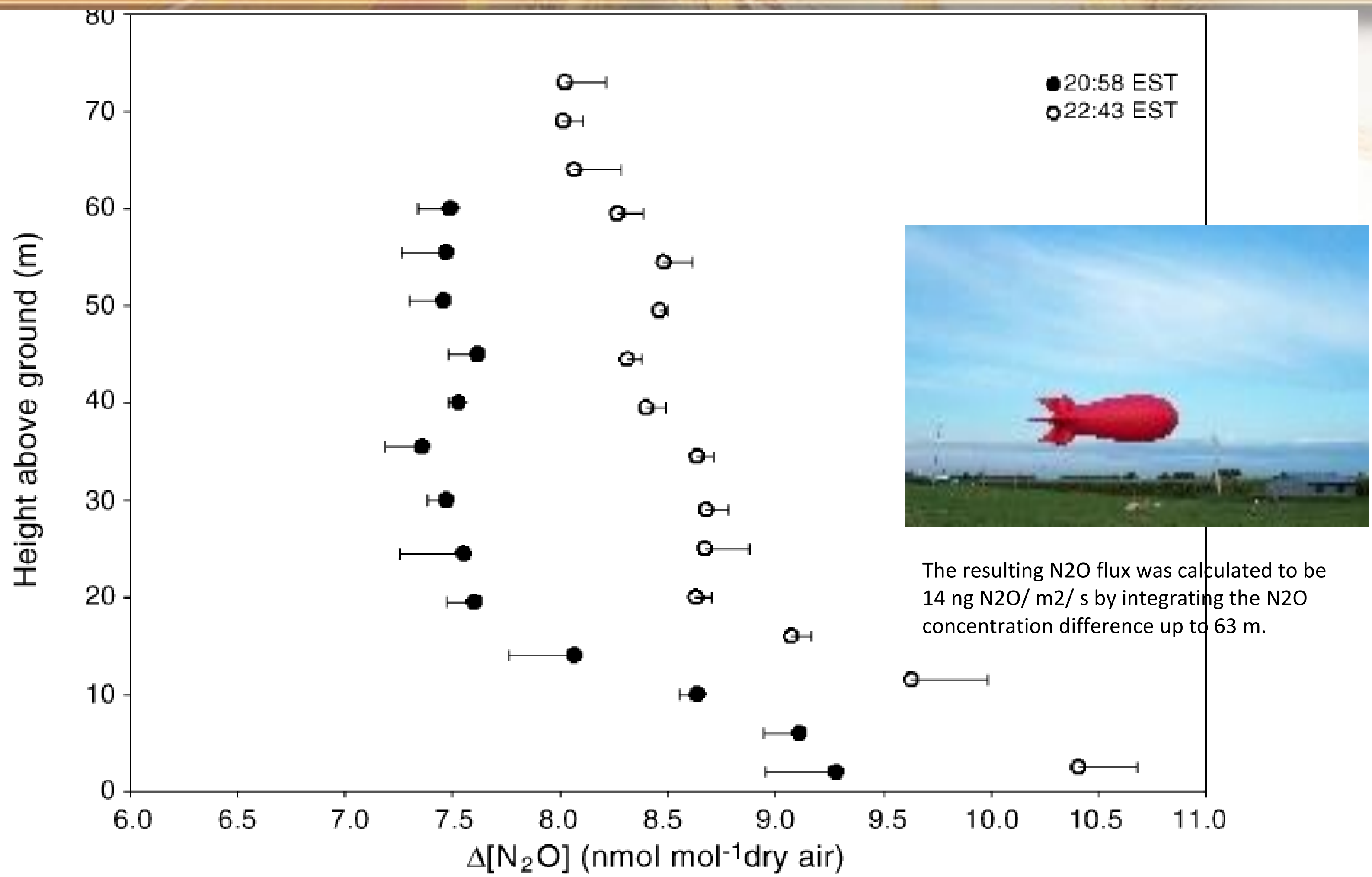
Average daily emission rate: 320 g CH_4 animal^{-1} d^{-1}

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

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

Van Haarlem et al. 2008. *Canadian Journal of Animal Science*. 88: 641-649.

Measuring nitrous oxide emissions from an agricultural area

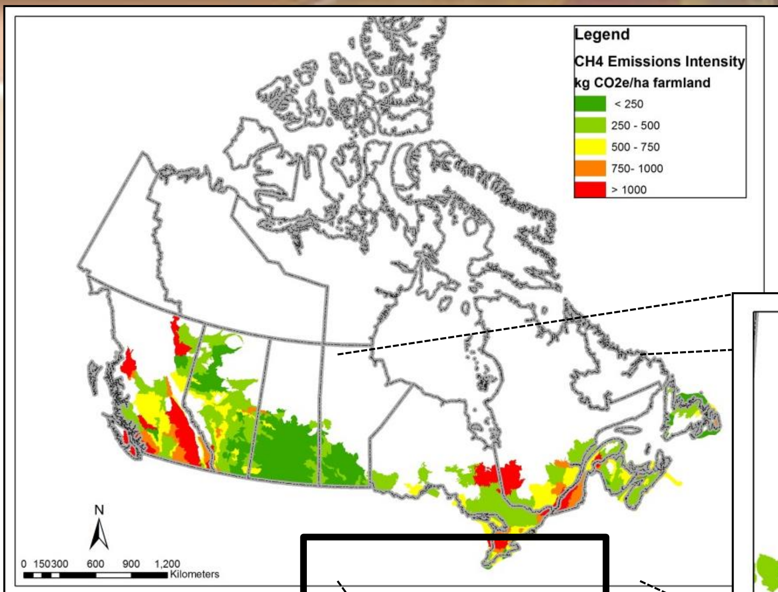


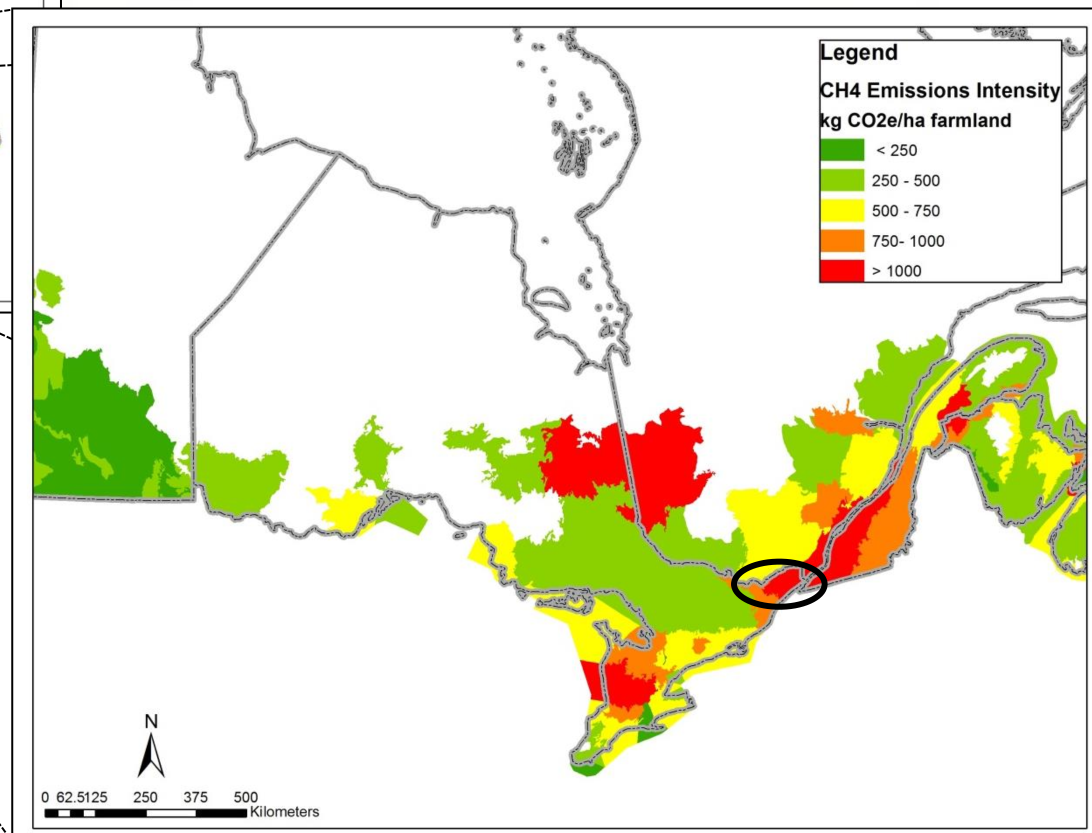
The resulting N2O flux was calculated to be 14 ng N2O/ m2/ s by integrating the N2O concentration difference up to 63 m.

Pattey et al. 2006. *Agricultural and Forest Meteorology* 136: 222-236

Desjardins, R.L., et al. 1992. *J. Geophys. Res.* 97: 18467-18476.

Agricultural CH_4 emission inventory estimates in eastern Canada

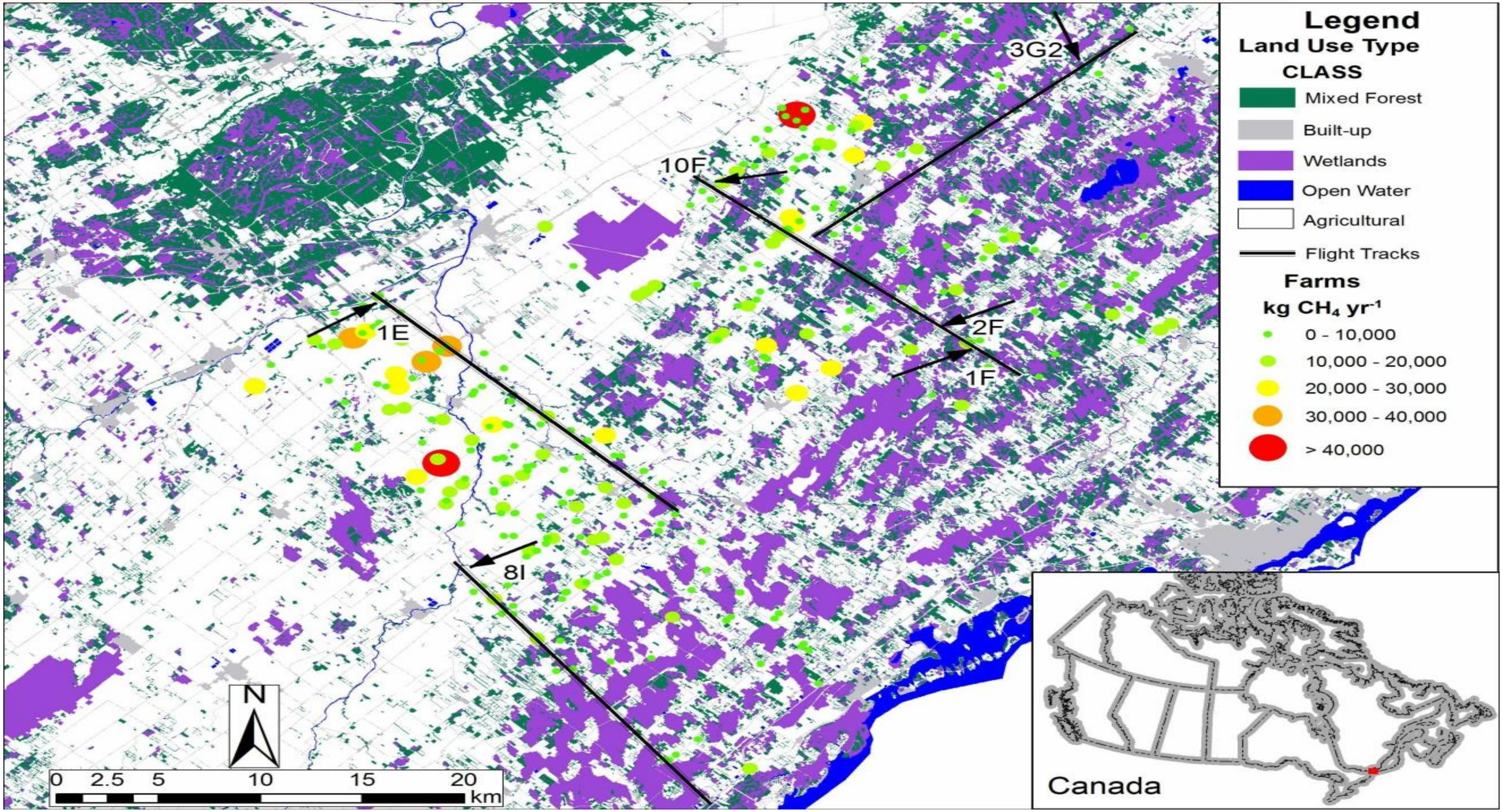




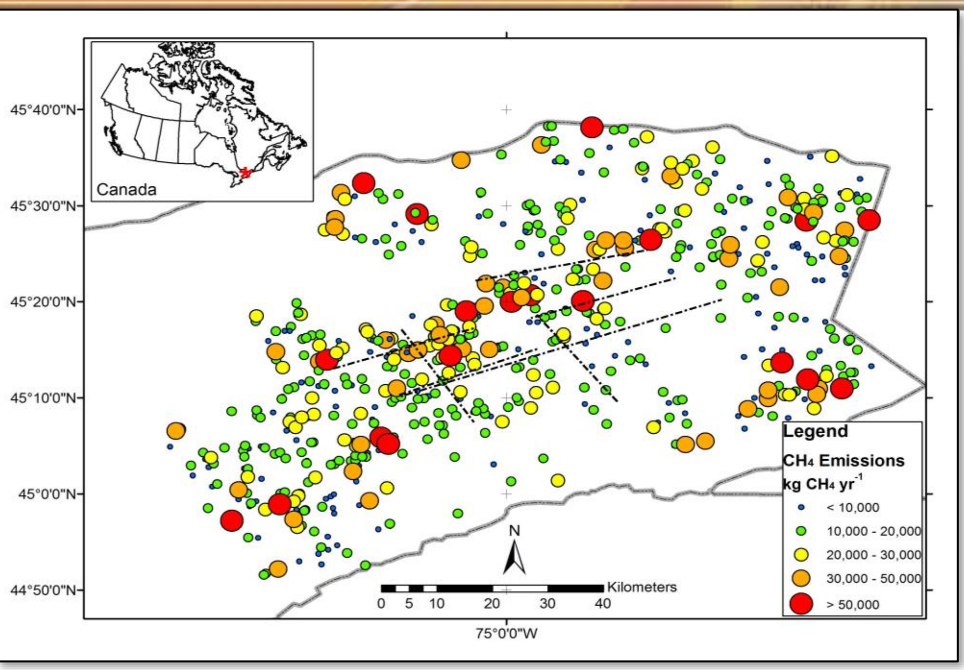
Desjardins et al. (2018). *Agricultural and Forest Meteorology,* 248: 48-59.

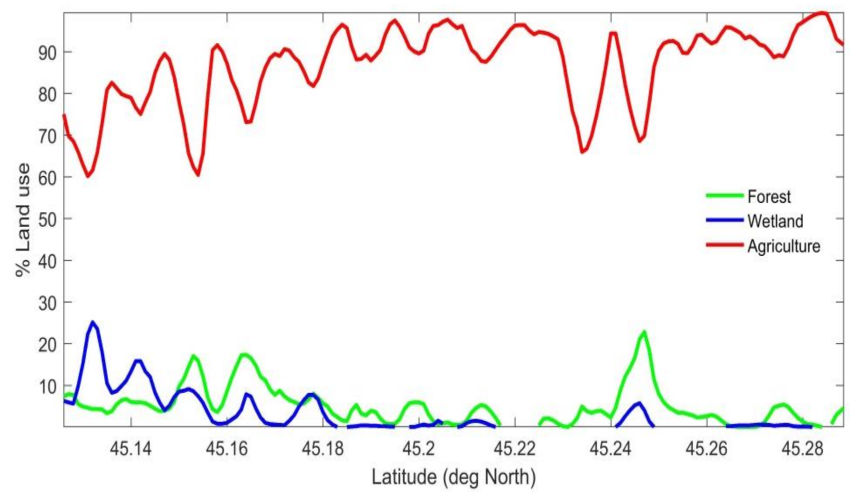
Flight tracks over an agricultural region in eastern Ontario

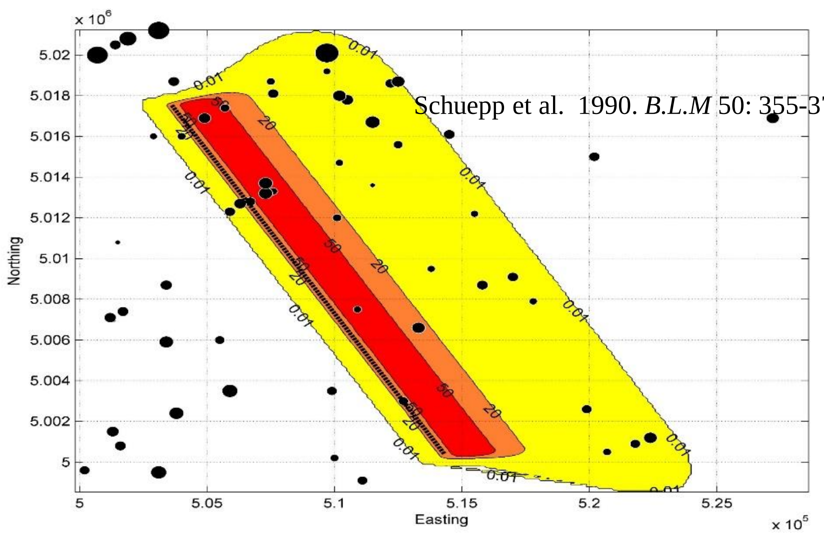
AAFC, NRC and EC worked across biome borders to determine the impact of wetlands and agriculture on GHG emissions.



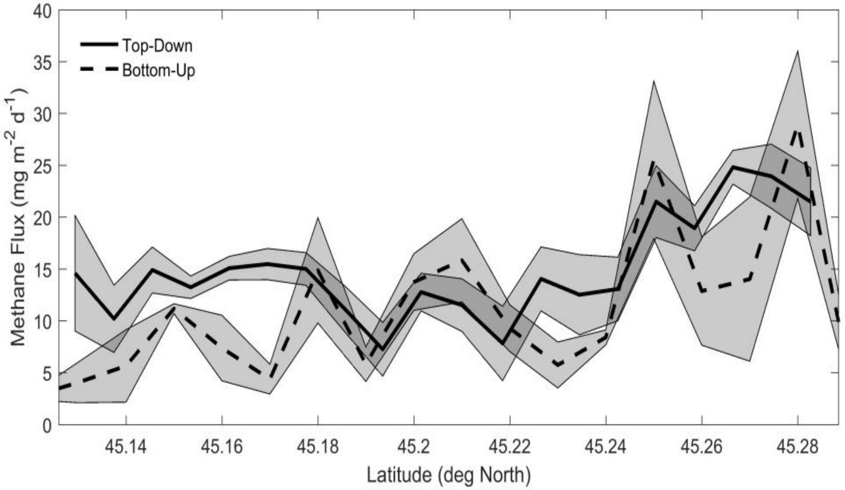
Aircraft-based CH_4 flux density measurements versus estimated CH_4 emissions







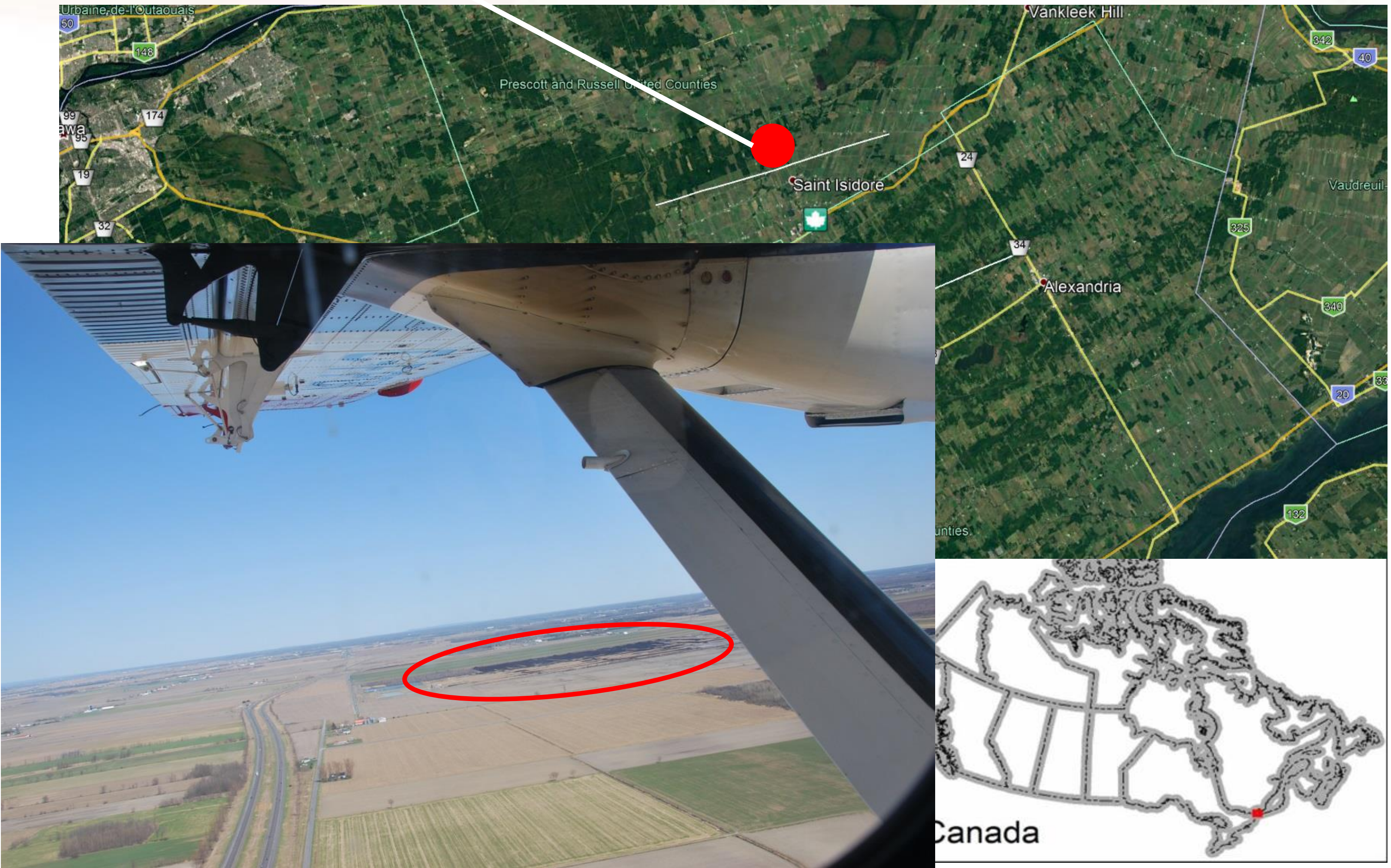
Schuepp et al. 1990. *B.L.M* 50: 355-373.



Desjardins et al. (2018). *Agricultural and Forest Meteorology*, 248: 48-59.

Measuring methane emissions from a point source

Lafleche Environmental, Waste Treatment and Composting Facility



Point sources of methane influence regional emission estimates

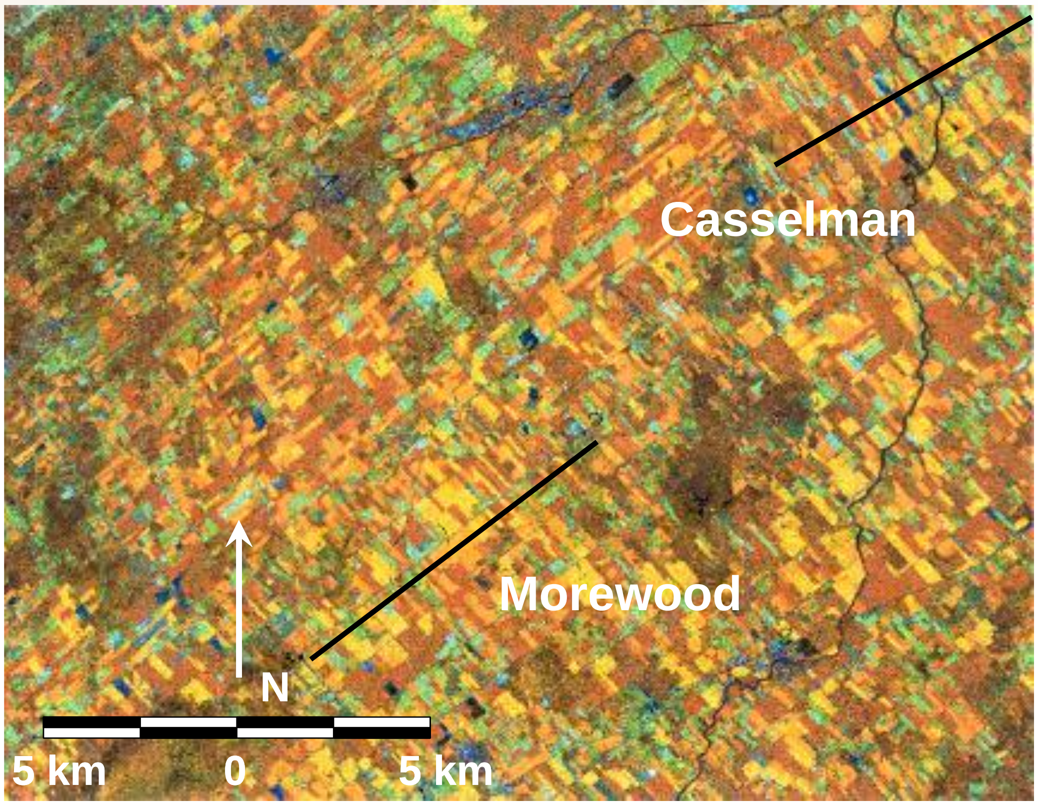
- Cai et al. 2020. Methane emissions from a waste treatment site: Numerical analysis of aircraft-based data. Agriculture and Forest Meteorology, 292-293, 2020,108102.

- We measured emissions of 2393 kg methane per hour which is equivalent to the emissions from about 130,000 dairy cows.

- Methane emissions escaping from Alberta oil wells were recently reported to be 50 percent underestimated. (Matthew Johnson, Carleton Univ.)

- Flesch et al. 2011. Fugitive methane emissions from an agricultural biodigester. Biomass and Bioenergy J. 35: 3927-3935.

Measuring N_2O emissions at a regional scale

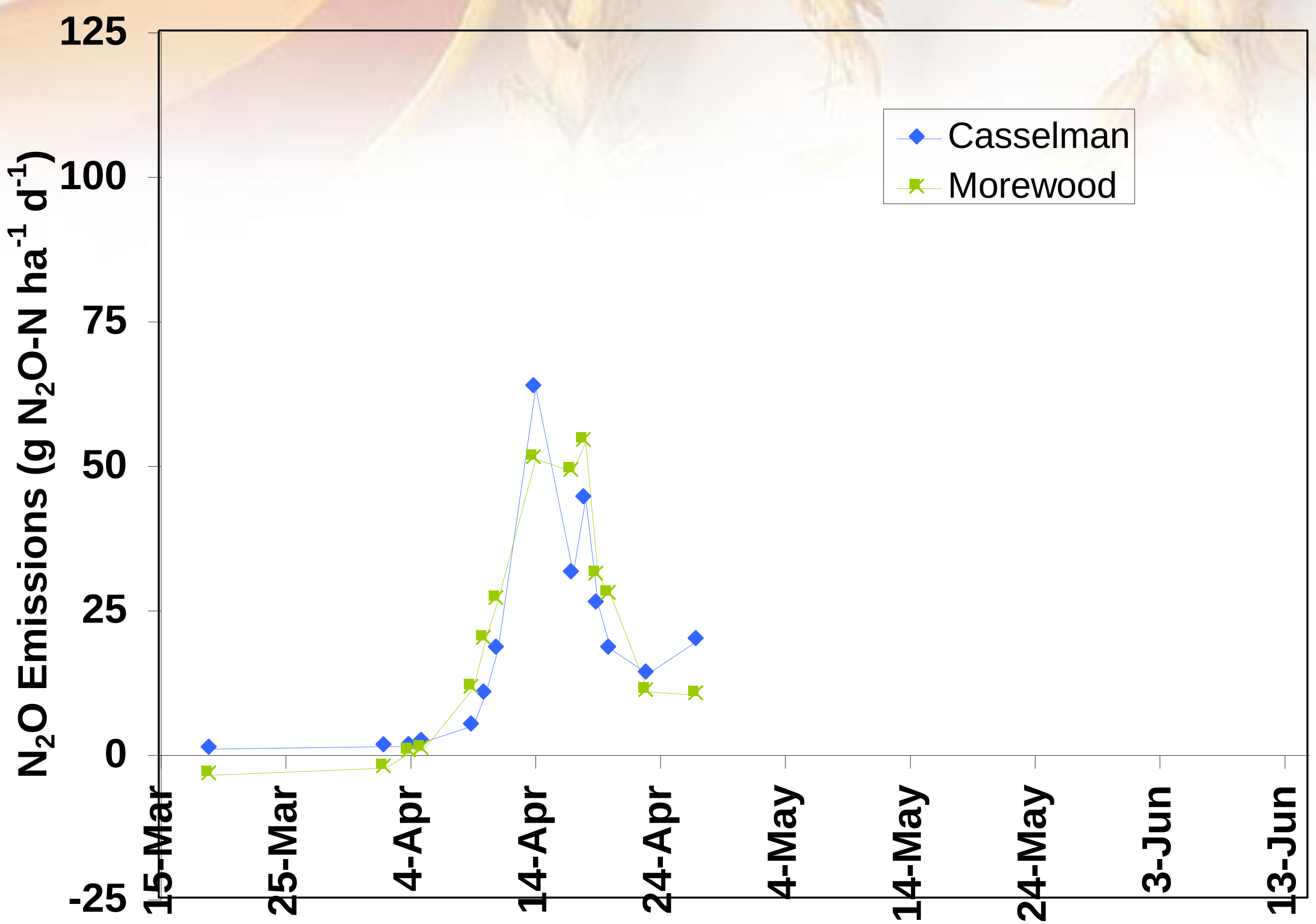


LEGEND

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

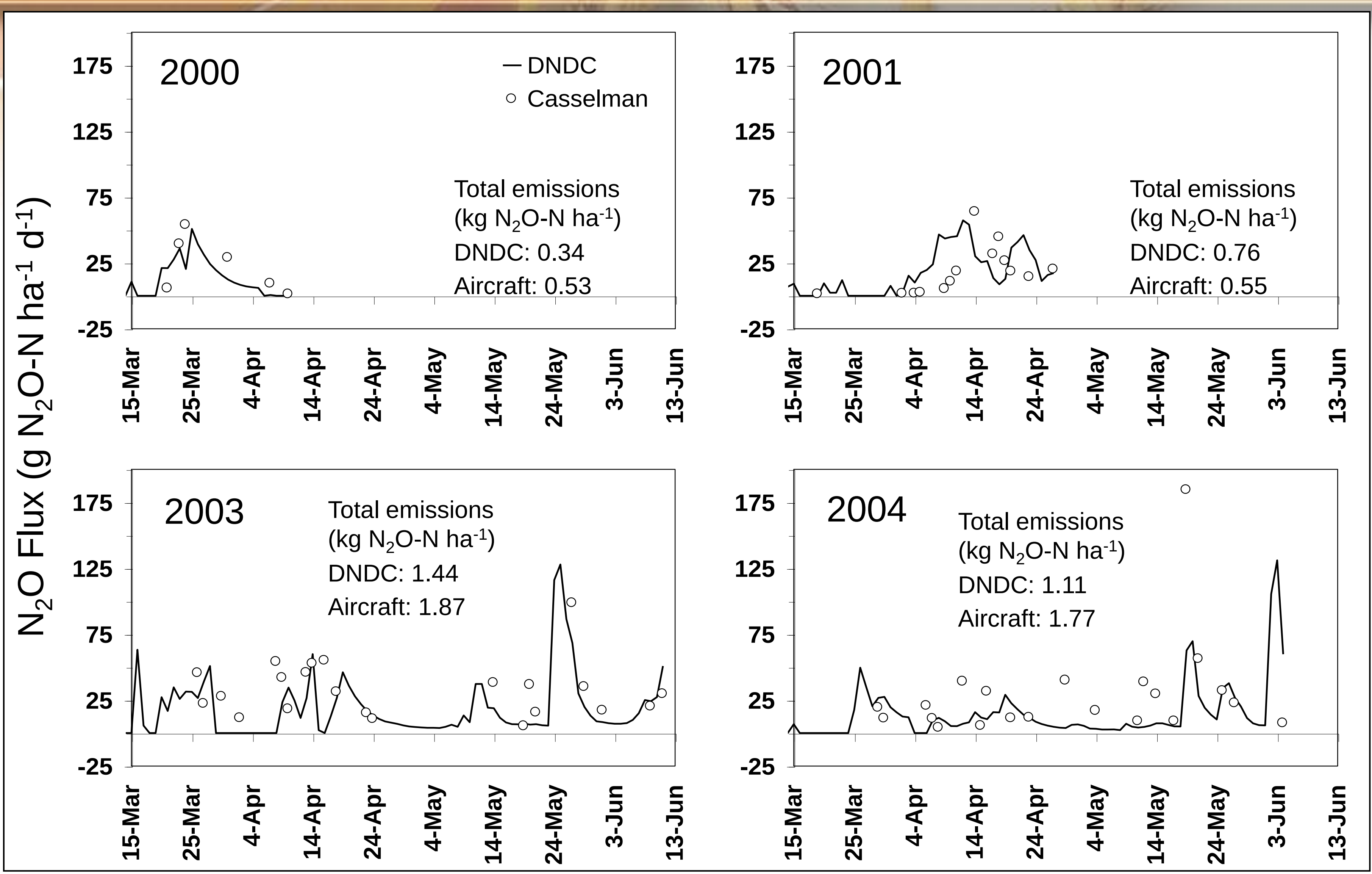
Pattey E., Edwards, G.C., Desjardins, R.L., Pennock, D., Smith W., Grant B., MacPherson, J.I., 2007. Tools for quantifying N_2O emissions from Agroecosystems. *Agric. Forest Meteorol.*142(2-4): 103-119.

Regional N_2O fluxes during and right after snowmelt in Eastern Canada 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)

Multi-year comparison of N_2O emissions using aircraft-based systems and model estimates



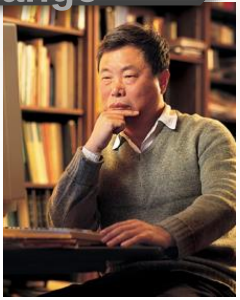
Desjardins, R.L., Pattey, E., Smith, W.N., Worth, D., Grant, B., Srinivasan, R., MacPherson, J.I., and Mauder, M., 2010. Multiscale estimates of N_2O emissions from agricultural lands. *Agric. Forest Meteorol.*, 150: 817-824.

DNDC

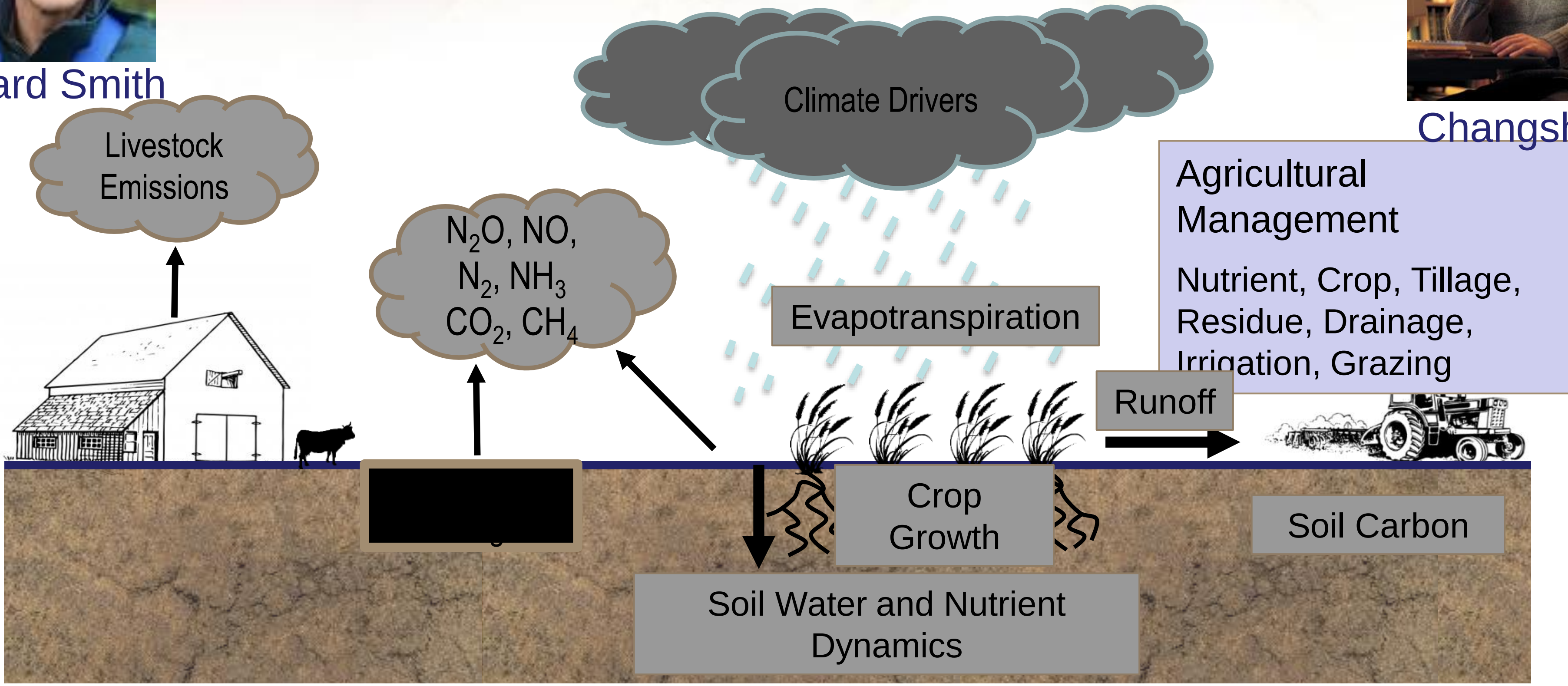
A process-based model for integrated farm systems

Models | **DNDC** | Improvement | Verification | Scaling Up | Climate Change

Ward Smith

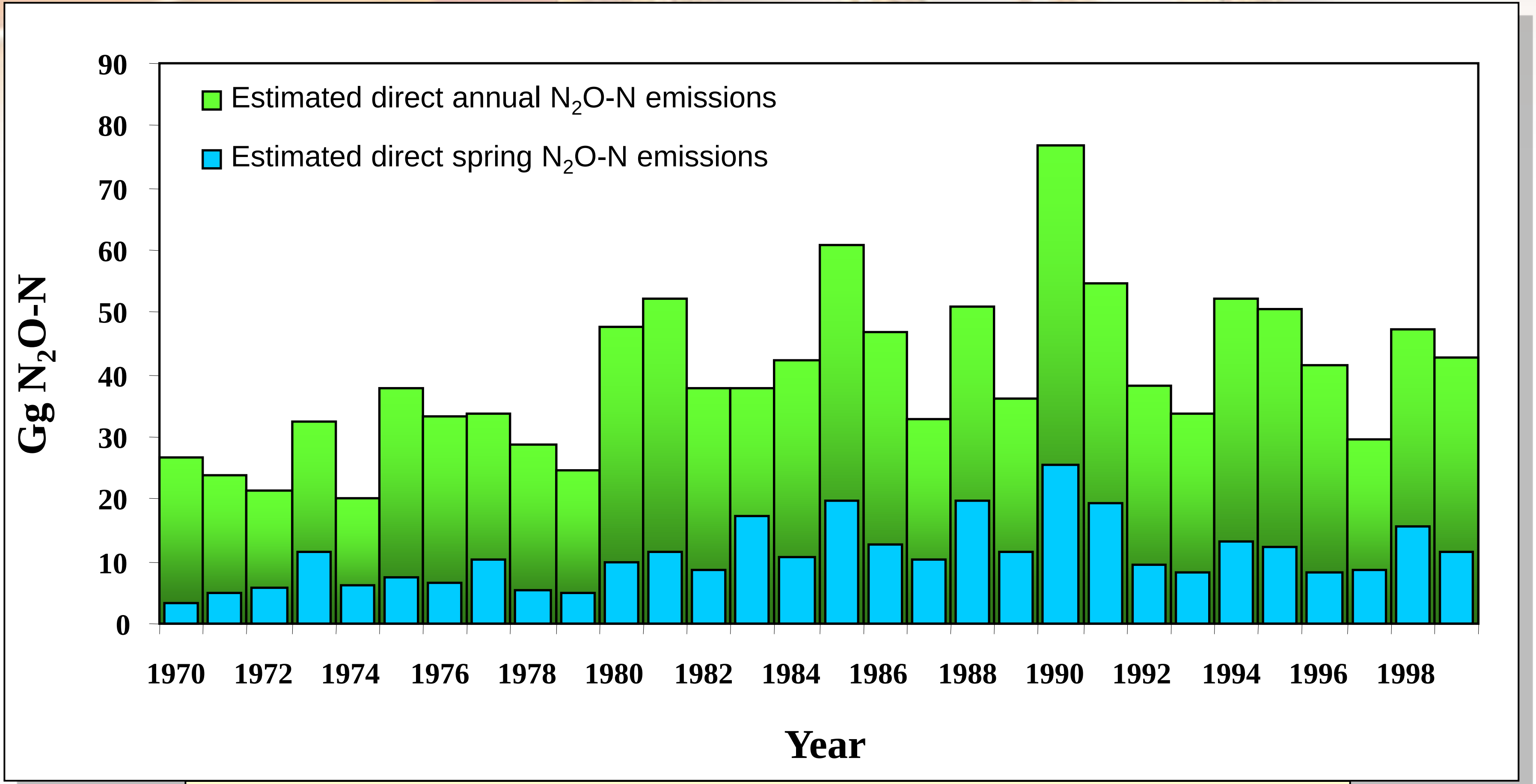


Changshen



Smith, Grant et al. 2010. A tool to link agricultural activity data with the DNDC model to estimate GHG emission factors in Canada. Agriculture, Ecosystems and Environment 136 (3-4), 301-309.

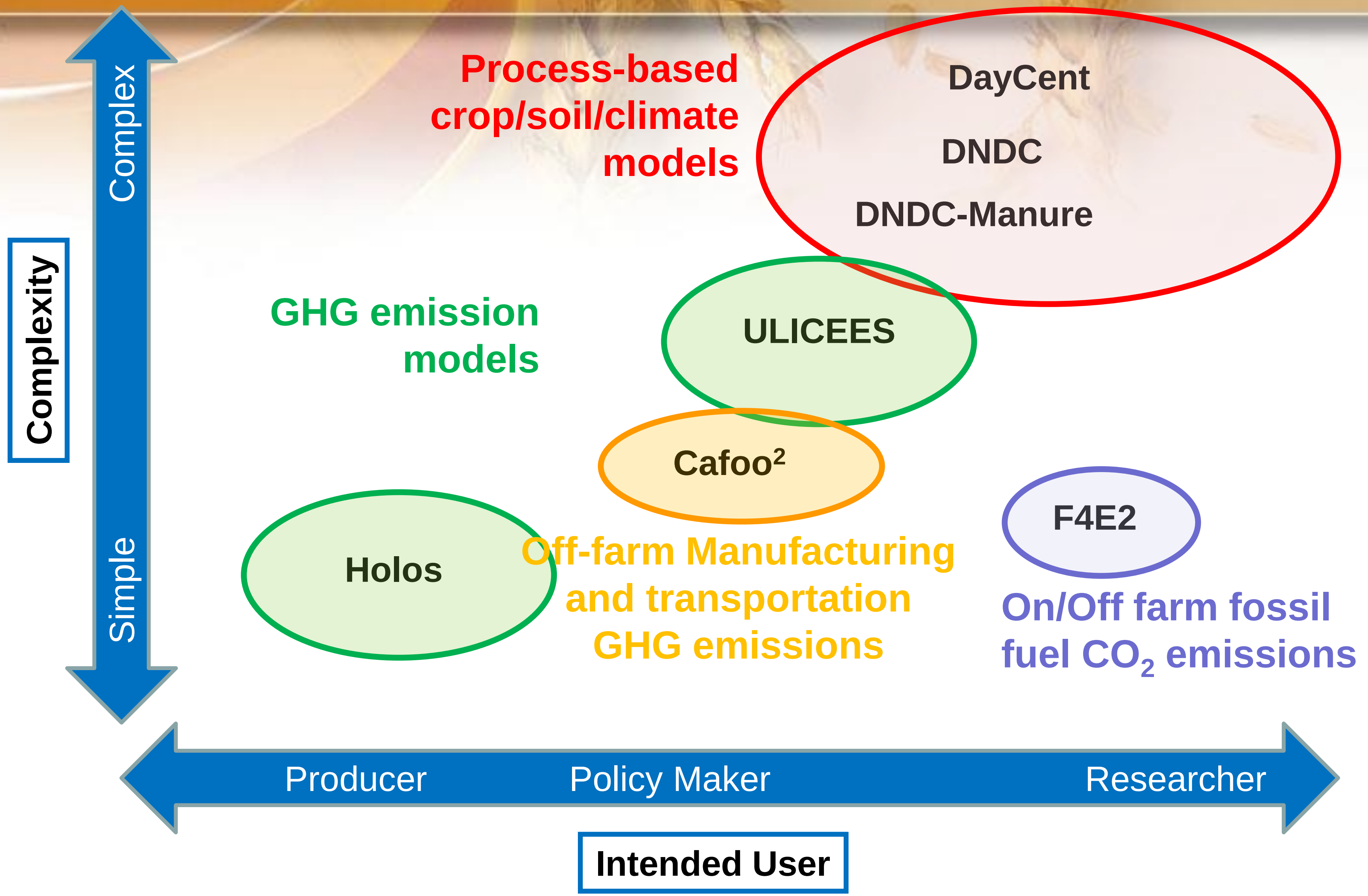
Interannual variations of N_2O emission estimates from agriculture soils in Canada using DNDC (1970-1999)



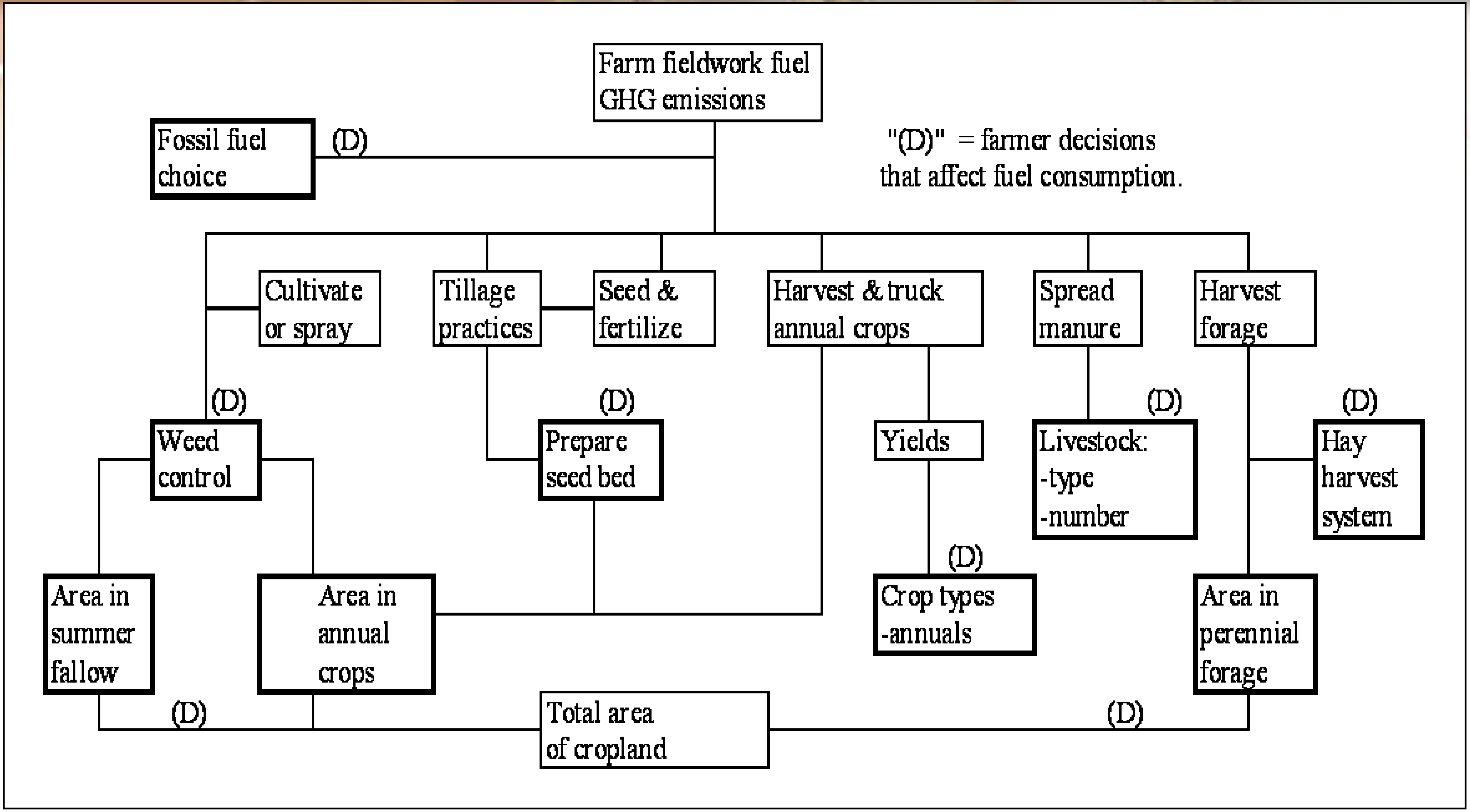
On average, in Canada, spring emissions represent 30% of annual emissions. The contribution of freeze-thaw cycles to annual emissions ranged from 8 to 81% in northern countries (Wang et al. 2008).

Smith, W.N., B. Grant, R.L. Desjardins, R. Lemke, and C. Li. 2004. Estimates of the interannual variations of N_2O emissions from agricultural soils in Canada *Nutrient Cycling in Agroecosystems.* 68: 37-45.

4. Models developed to estimate agricultural GHG emissions and the carbon footprint of agricultural products in a Canadian market



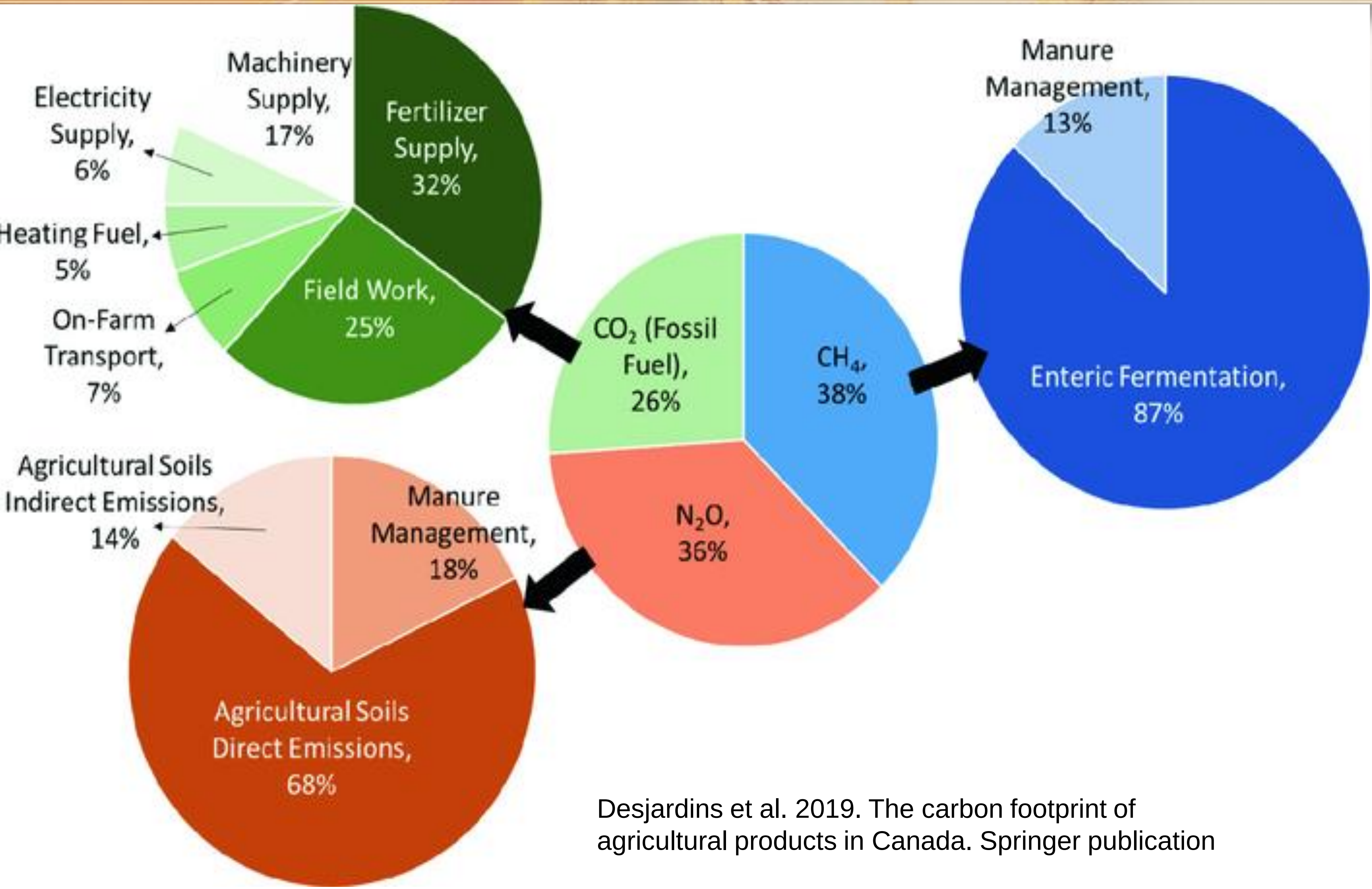
The F4E2 model



Schematic diagram of controlling resources and activities of fossil fuel use for farm fieldwork that affect the GHG emissions from fossil fuel on a typical farm in Canada.

Dyer J. and R.L. Desjardins. 2005. J. of Sustainable Agriculture 27(1): 71-90.

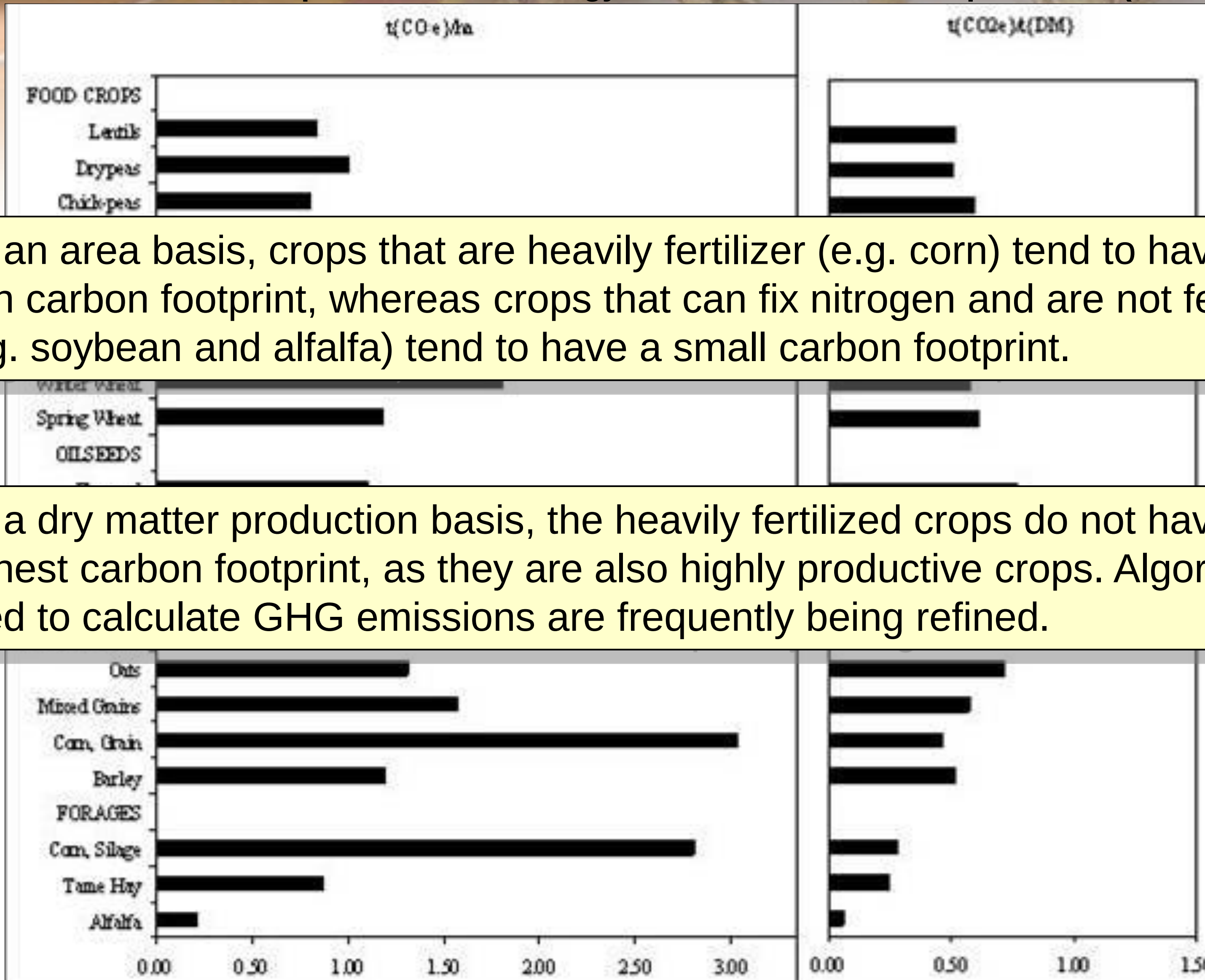
Greenhouse Gas Emission Estimates from Canadian Agriculture (2015)



Desjardins et al. 2019. The carbon footprint of agricultural products in Canada. Springer publication

Carbon footprint of crops in Canada

Dyer et al, 2010. The impact of increased biodiesel production on the greenhouse gas emissions from field crops in Canada. Energy for Sustainable Development 14 (73-82)



On an area basis, crops that are heavily fertilizer (e.g. corn) tend to have a high carbon footprint, whereas crops that can fix nitrogen and are not fertilized (e.g. soybean and alfalfa) tend to have a small carbon footprint.

On a dry matter production basis, the heavily fertilized crops do not have the highest carbon footprint, as they are also highly productive crops. Algorithms used to calculate GHG emissions are frequently being refined.

GHG emission intensities of crops for various provinces

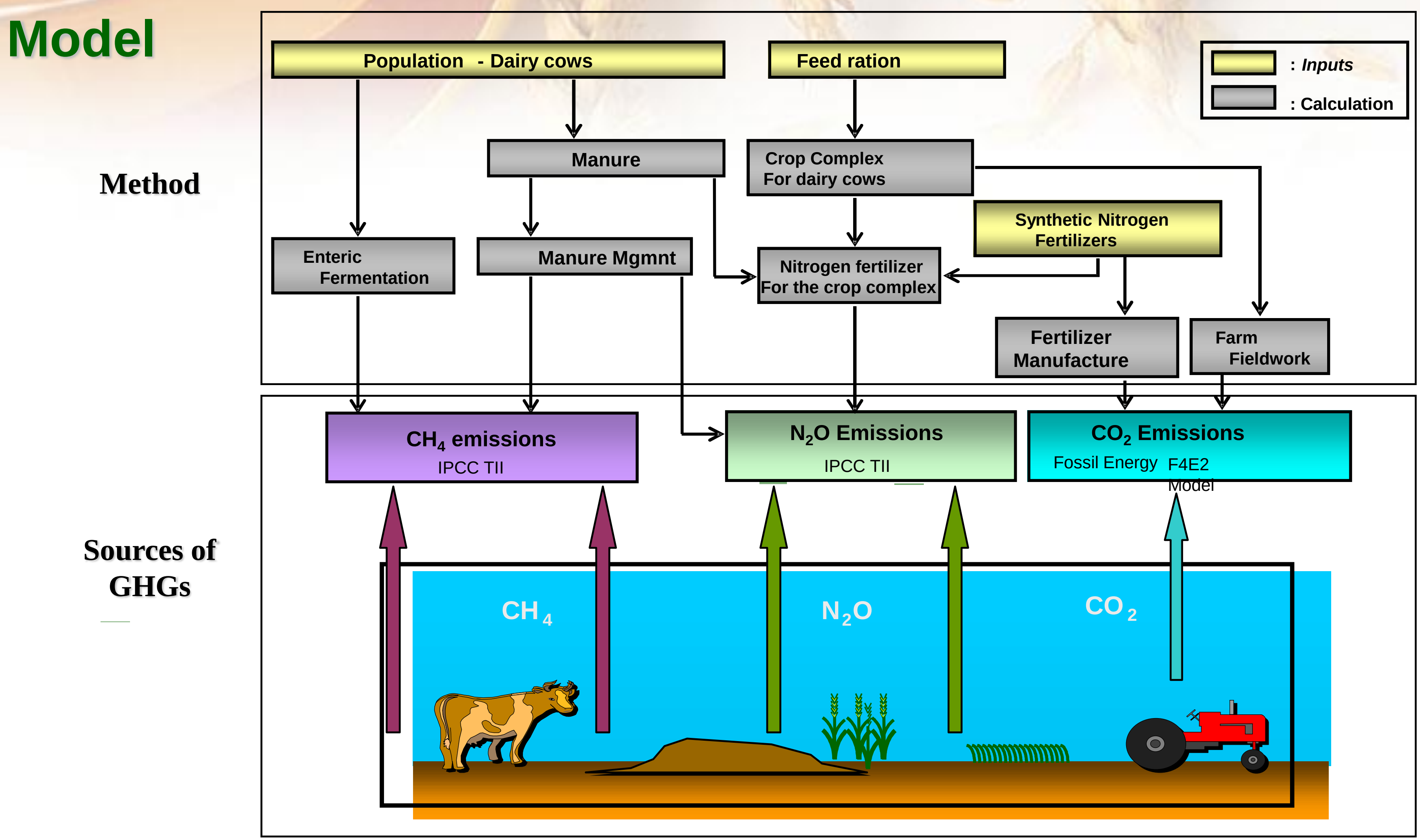
t CO_2e ha^{-1}

	Group Averages					Oilseeds			
	Oilseeds	Pulses	Roots	Forages	Cereals	Canola	Flaxseed	Soybeans	Sunflower
Atlantic Provinces	0.78		3.22	1.36	1.95			0.78	
Québec	1.72		3.28	1.53	2.42	2.45		0.99	
Ontario	1.69	1.07	2.60	1.48	2.04	2.45		0.93	
Manitoba	0.95	0.62	1.78	0.93	1.28	1.28	0.93	0.42	1.19
Saskatchewan	0.91	0.60	1.21	0.33	0.67	1.04	0.78		
Alberta	1.18	0.83	1.63	0.87	1.06	1.30	1.07		
British Columbia	1.68		2.48	1.29	1.27	1.68			
Canada	1.06	0.68	2.01	1.27	1.45	1.36	0.85	0.84	1.19

	Pulses and Roots						Forages		
	Chickpeas	Dry Peas	Beans	Lentils	Potatoes	Sugar Beets	Alfalfa	Tame Hay	Corn Silage
Atlantic Provinces					3.22		0.30	1.24	2.53
Québec					3.28		0.33	0.99	3.28
Ontario			1.07		2.60		0.31	1.02	3.10
Manitoba		0.74	0.51		1.78		0.16	0.79	1.83
Saskatchewan	0.53	0.69		0.57	1.21		0.13	0.54	
Alberta	0.72	0.99	0.76		1.85	1.40	0.16	0.68	1.77
British Columbia					2.48		0.24	0.95	2.70
Canada	0.58	0.78	0.79	0.57	2.62	1.40	0.21	0.86	2.74

	Cereals							
	Barley	Grain Corn	Mixed Grains	Oats	Spring Wheat	Winter Wheat	Durum Wheat	Fall Rye
Atlantic Provinces	1.57	2.70	1.57	1.88	1.94	2.05		
Québec	2.00	3.38	2.02	2.34	2.36	2.45		
Ontario	1.64	3.19	1.65	1.95	1.81	2.16		1.91
Manitoba	1.11	1.83		1.18	1.17	1.23		1.16
Saskatchewan	0.69			0.71	0.68	0.67	0.65	0.64
Alberta	0.98	1.72	1.04	0.98	0.98	0.93	0.92	0.89
British Columbia	1.24			1.28	1.31			
Canada	1.12	3.03	1.58	1.24	1.12	1.72	0.73	1.03

An example of the sources of greenhouse gases associated with dairy production



Verge et al. 2013. Carbon footprint of Canadian dairy products: calculations and issues. J. Dairy Sci.96. 6091e6104

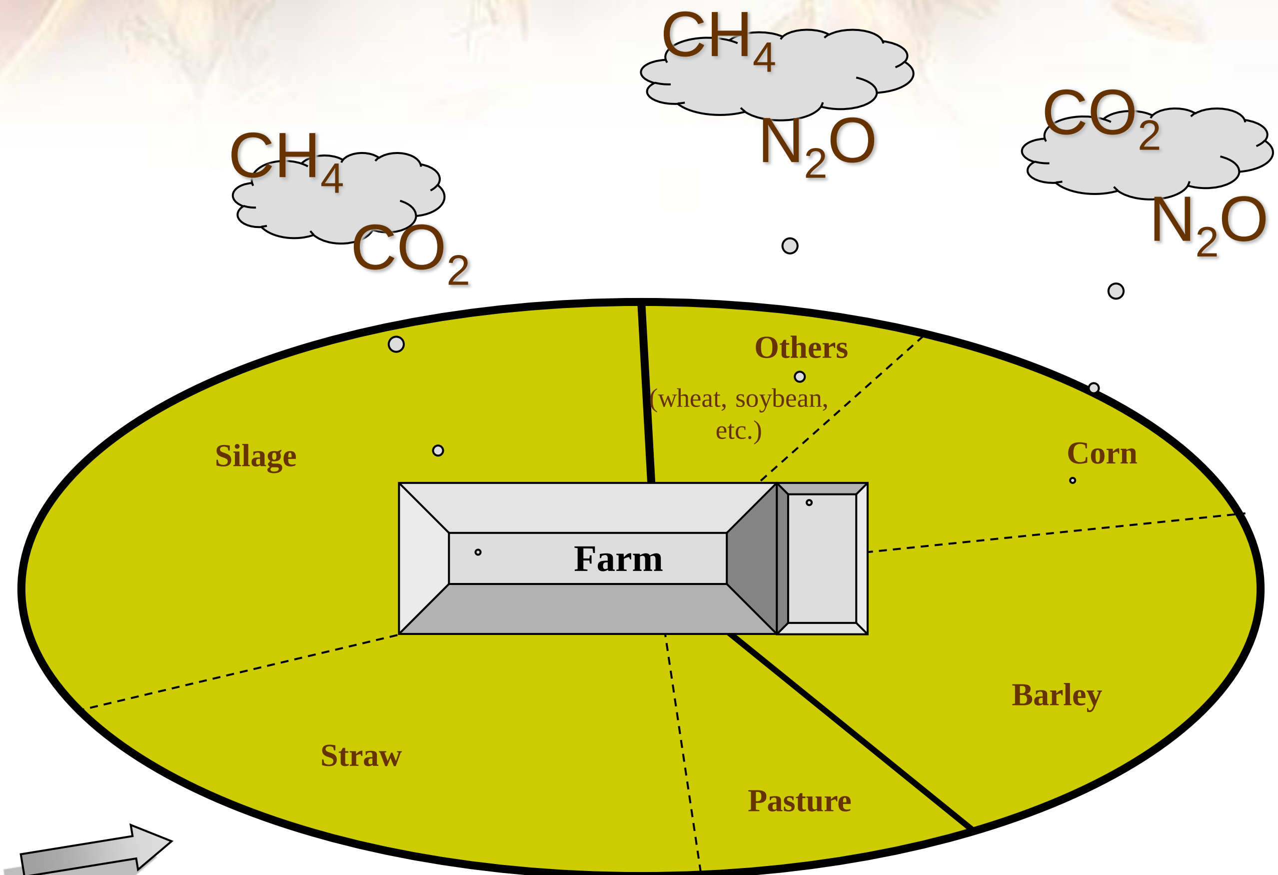
Livestock Crop Complex is the ensemble of crops and their area required to feed a given animal population for a year

Principle

Feed Rations

Dairy cows (2001)	
Crops	(kg/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"

Verge et al. 2013. Carbon footprint of Canadian dairy products: calculations and issues. J. Dairy Sci.96. 6091e6104

Carbon footprint for several of Canadian dairy products in 2006

Dairy products (GHG per kg of product)

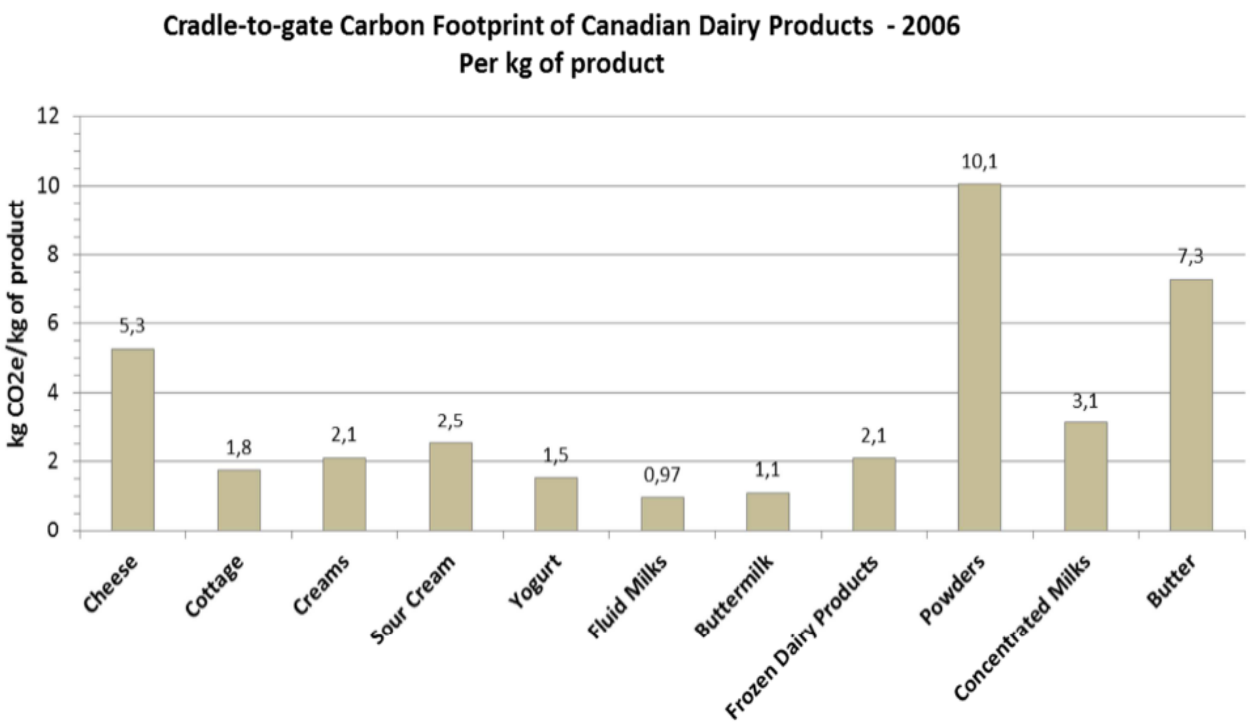
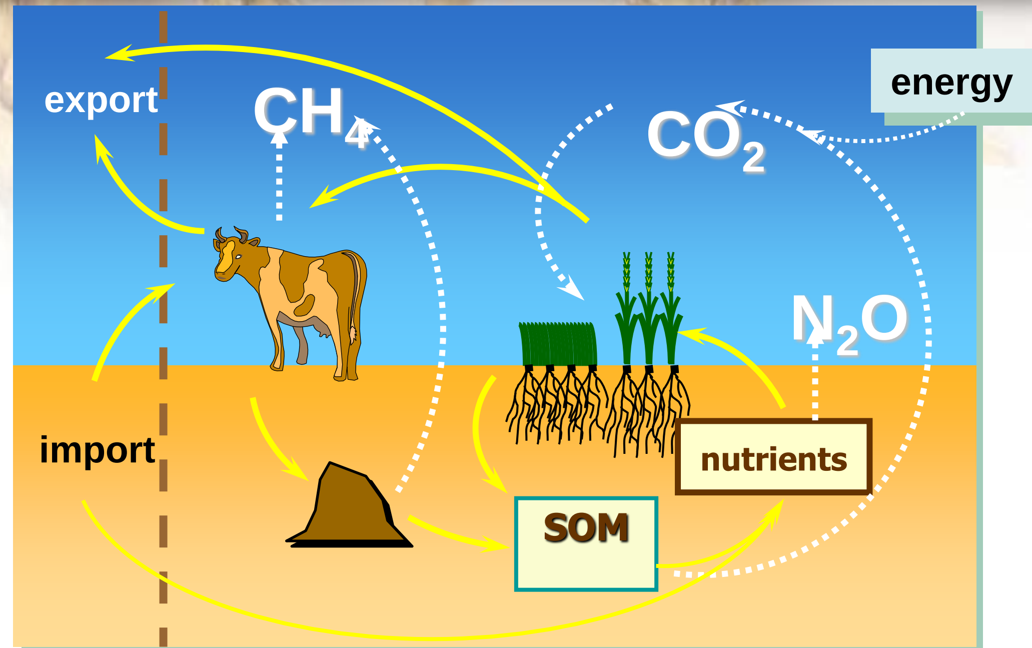


Figure 5: Carbon footprint for several Canadian dairy products in 2006

Verge et al. 2013. Carbon footprint of Canadian dairy products: calculations and issues. J. Dairy Sci.96. 6091e6104

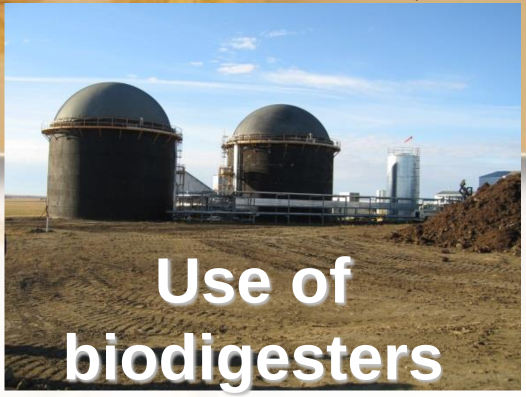
Holos: A tool to help farmers calculate their on-farm GHG emissions

- Estimate GHG emissions of any farm in Canada
- Look for ways to reduce emissions

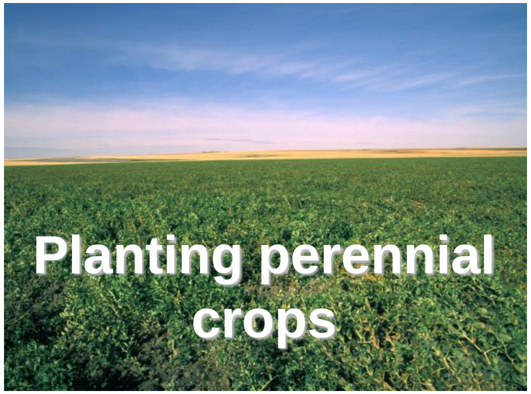


Management practices, Conditions, etc. → GHG Calculator → **GHG emissions**

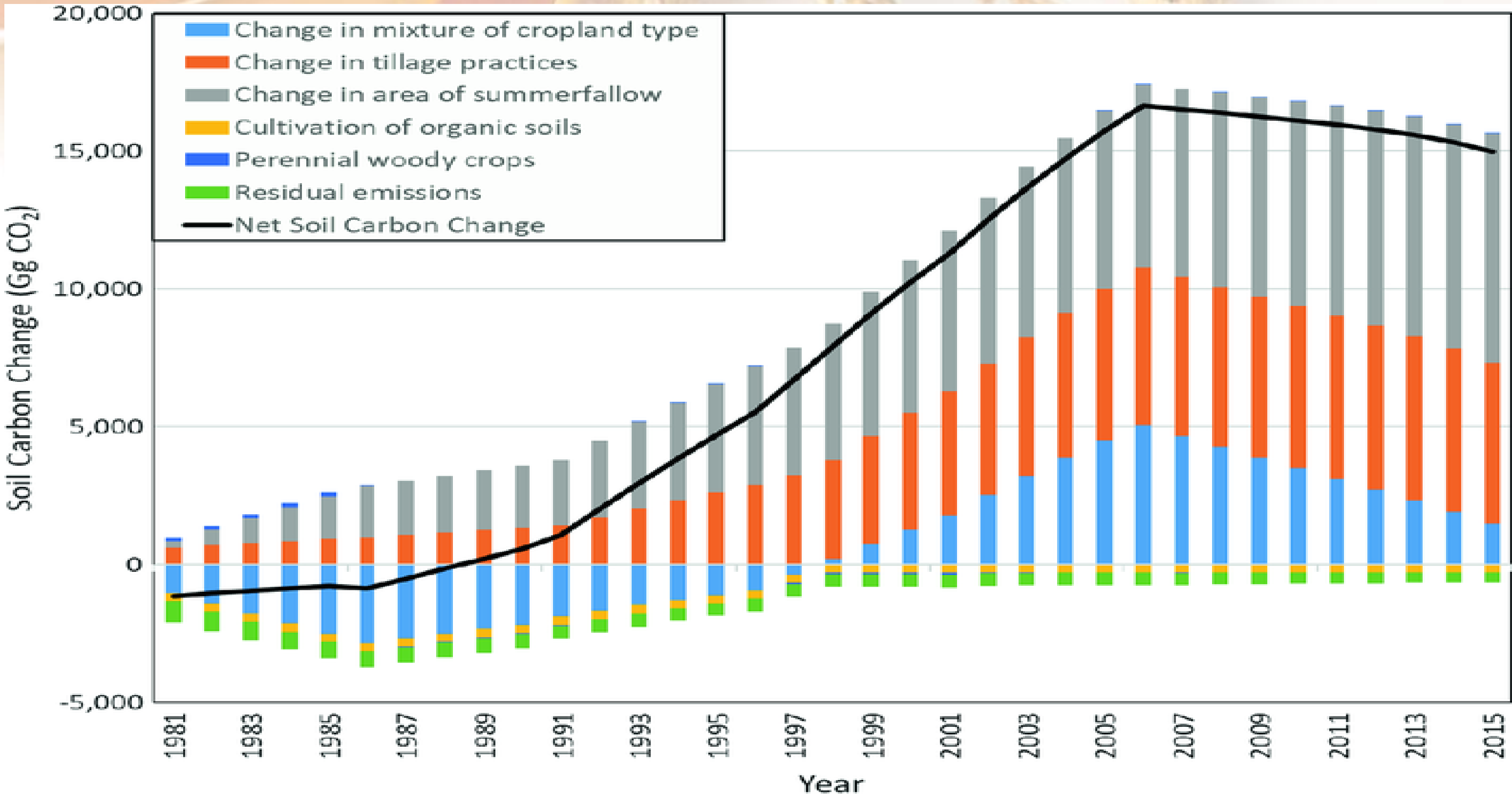
Janzen, H.H., Angers, D.A., Boehm, M., Bolinder, M., Desjardins, R.L., Dyer, J.A., Ellert, B.H., Gibb, D.J., Gregorich, E.G., Helgason, B.L., Lemke, R., Massé, D., McGinn, S.M., McAllister, T.A., Newlands, N., Pattey, E., Rochette, P., Smith, W., VandenBygaart, A.J., and Wang, H. 2006. A proposed approach to estimate and reduce net greenhouse gas emissions from whole farms. *Canadian Journal of Soil Science*. 86: 401-418.



Numerous agricultural practices result in less GHG emissions and an increase in soil C sequestration



Soil carbon change due to changes in management practices in Canada

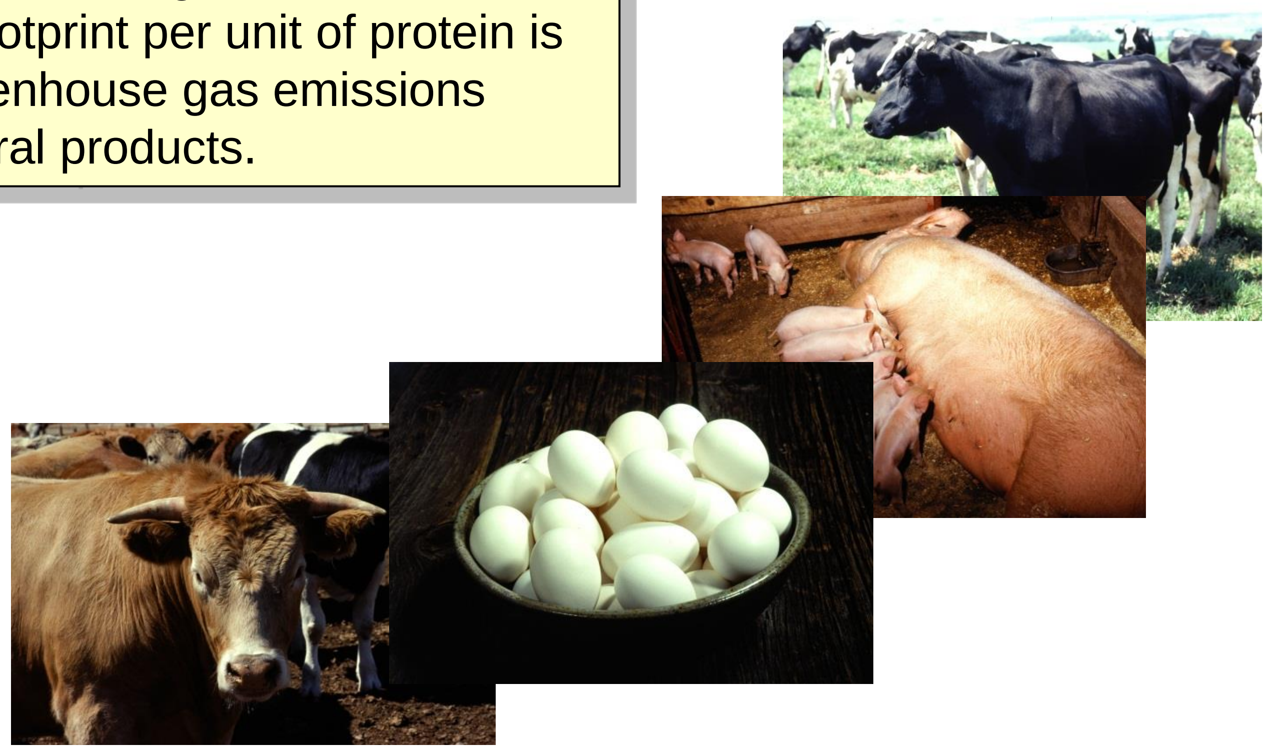


Desjardins., and D. Greenhouse Gas Sinks: A Science Assessment. Eds. Hengeveld, H. Bourbonniere, R. Braithwaite, L., Chen, W.Worth 2008. Moving canadian agricultural landscapes from GHG source to sink. In Enhancement of Desjardins, R.L., and P. Hall. Chapter 2 pp 19-33.

Comparing emission intensity of various agricultural products

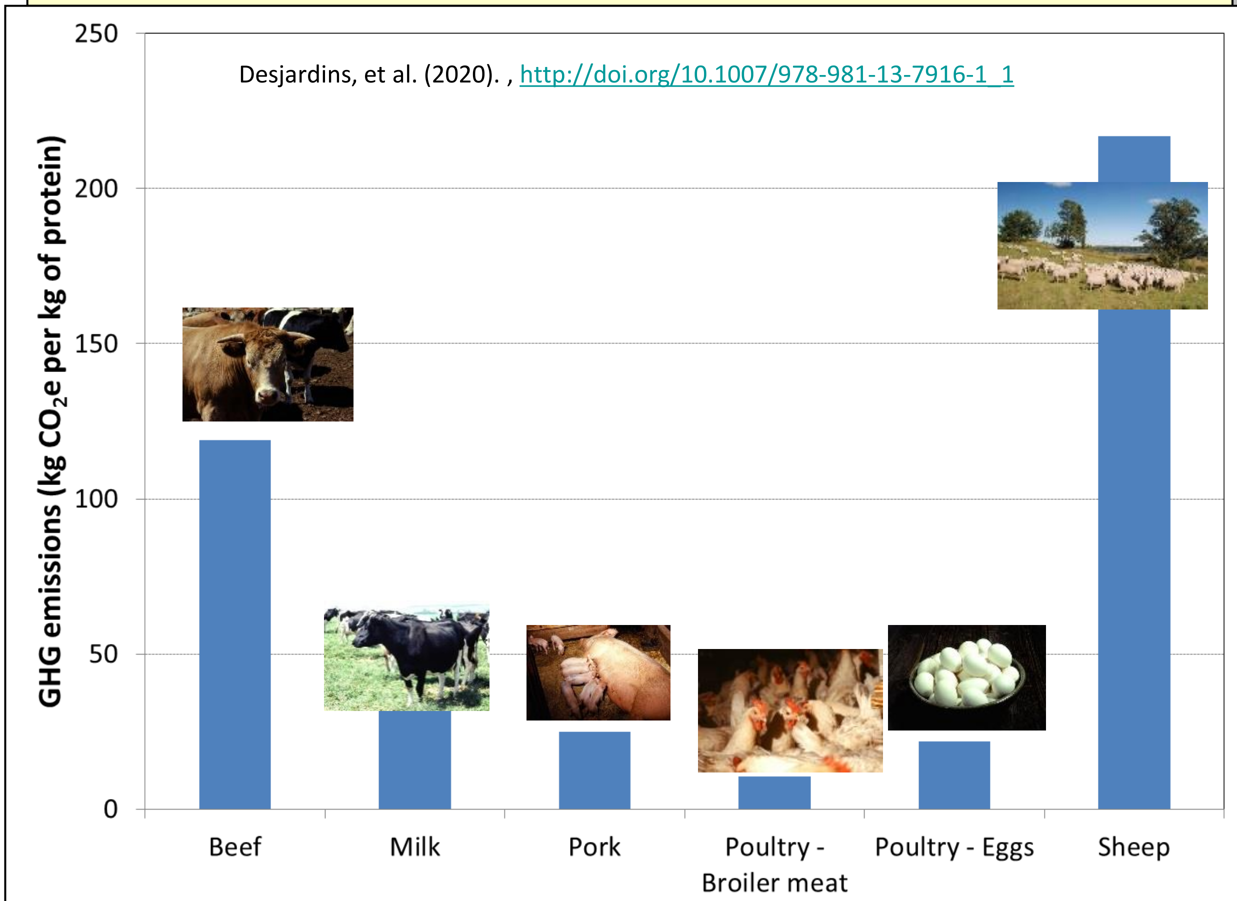
Comparing the carbon footprint between agricultural products is not necessarily fair, because they are functionally different in terms of the energy, nutrient content, etc.

However, one of the primary functions of agricultural products is to provide protein for growth. Therefore, expressing the carbon footprint per unit of protein is one way to compare greenhouse gas emissions associated with agricultural products.



GHG emission intensity for different animal products

Since the primary functions of animal products is to provide protein for growth, expressing the carbon footprint per unit of protein is the best way to compare GHG emissions between animal products.



GHG emissions associated with protein production of agricultural products

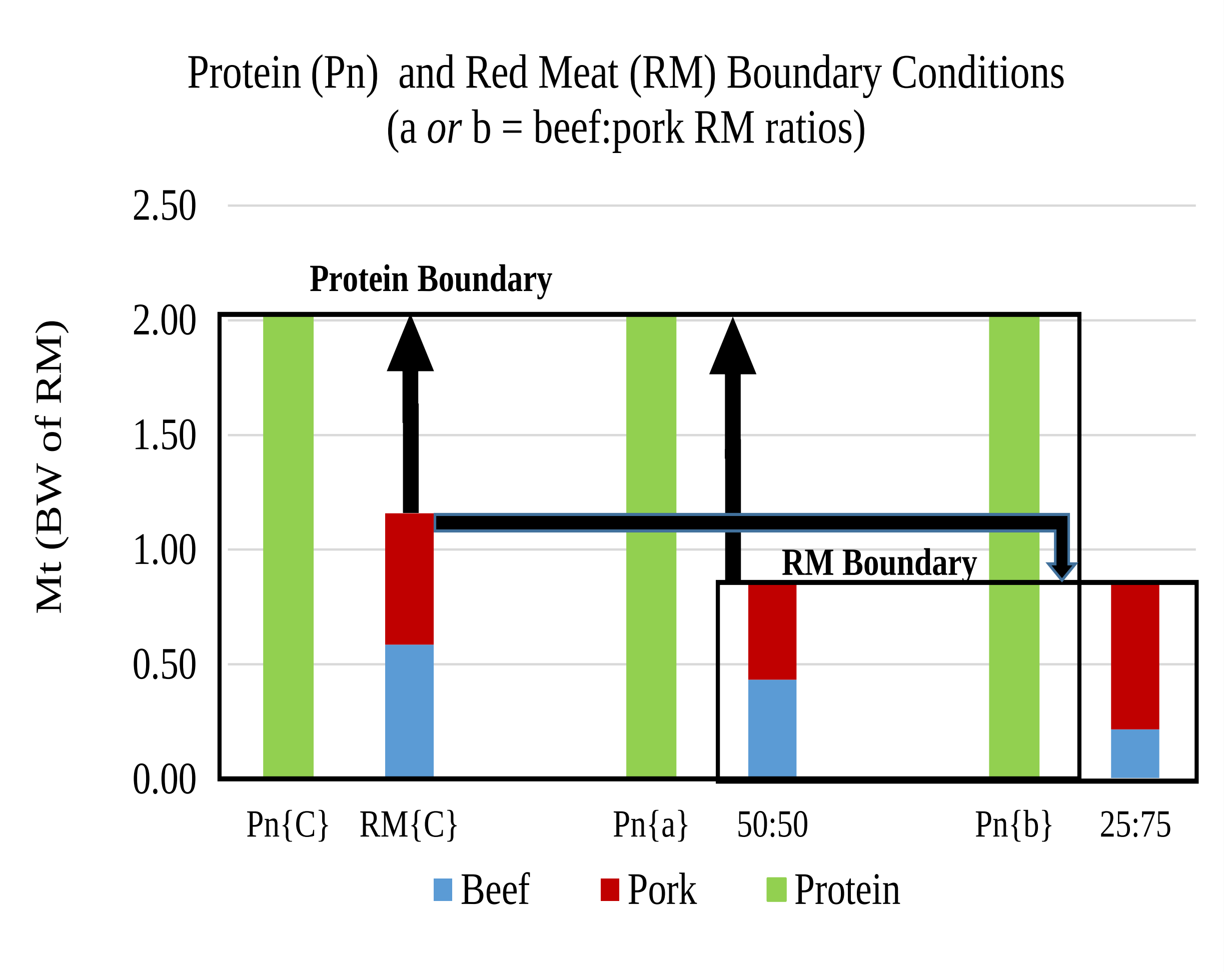
Protein Sources:	tCO_2/ha		Kg (protein)/ha		tCO_2/t (protein)	
Animal:	**East**	**West**	**East**	**West**	**East**	**West**
Ruminants	15.17	11.33	263	103	57.77	109.83
Non-ruminants	3.13	1.82	167	83	18.79	21.97
Plant:	**East**	**West**	**East**	**West**	**East**	**West**
Soybeans	0.30	0.26	1077	630	0.28	0.42
Other legumes	0.41	0.34	207	139	1.98	2.46

Source: Dyer and Verge (2015)

Pulses and soybeans represent a far less carbon intensive method of producing protein, as compared to ruminant and non-ruminant sources. For example, the amount of feed input for ruminants equate to 15 to 30 times the mass of the final meat product.

Verge, et al. (2018). *Journal of Cleaner Production,* 200: 858-865. https://doi.org/10.1016/j.jclepro.2018.08.016

Potential role of consumers to reduce Canadian agricultural GHG emissions

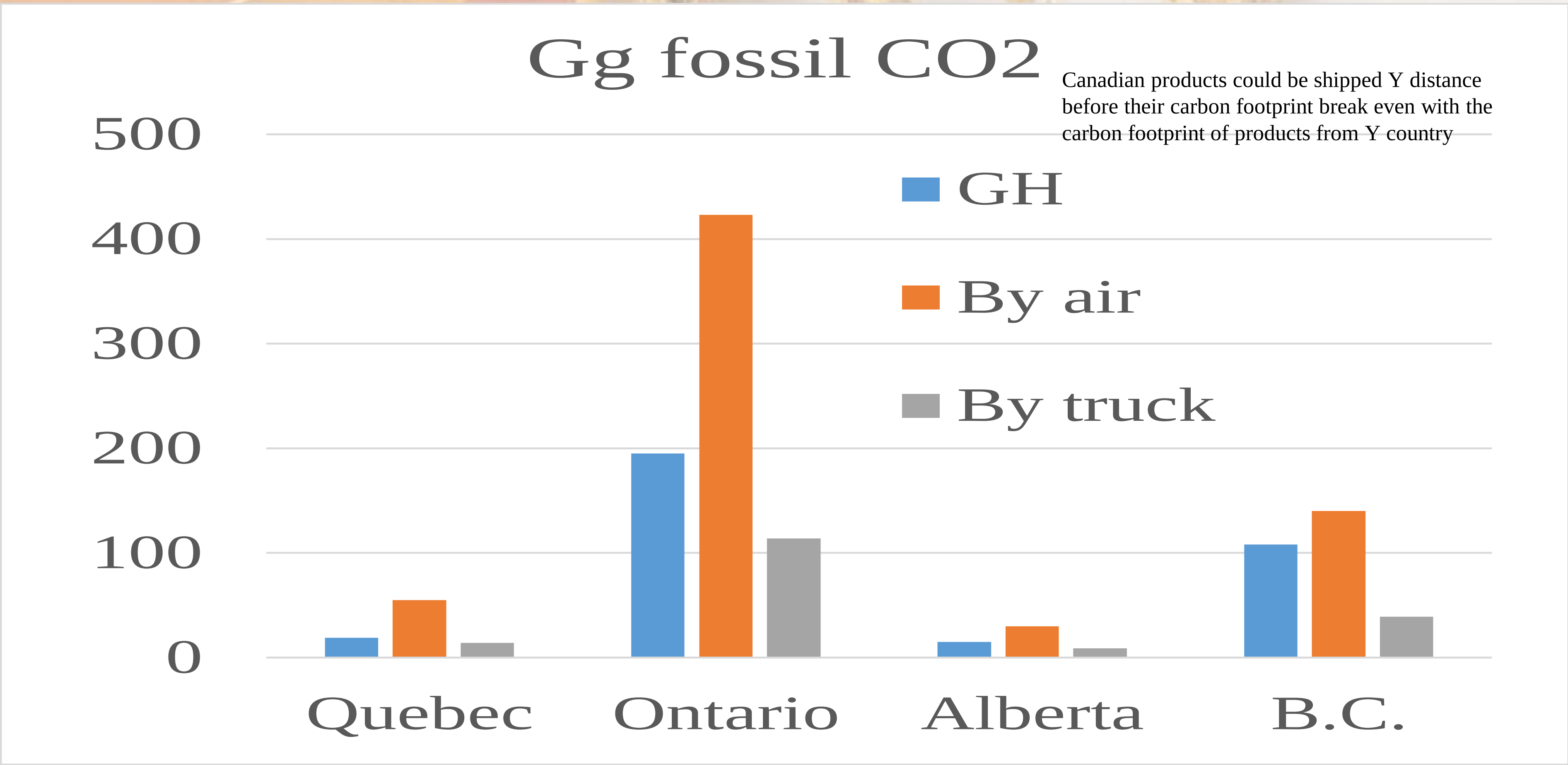


391 kt proteins/yr
Reducing RM C by 24%
50-50 split of red meat
4 MT CO2e
Split pork 75%-beef 25%
9 Mt CO2e

https://scitube.io/james-dyer-raymond-desjardins-using-protein-as-a-unifying-measurement-of-livestock-carbon-footprints/

Dyer, J.A., Desjardins, R.L (2020). Protein as a unifying metric for carbon footprinting livestock. Earth & Environment Research Outreach Connecting Science with Society Issue 118 pp 142-144.

Comparing GHG emissions for US production (Florida and California) of equivalent weights of vegetables grown locally in Canadian greenhouses during the winter.

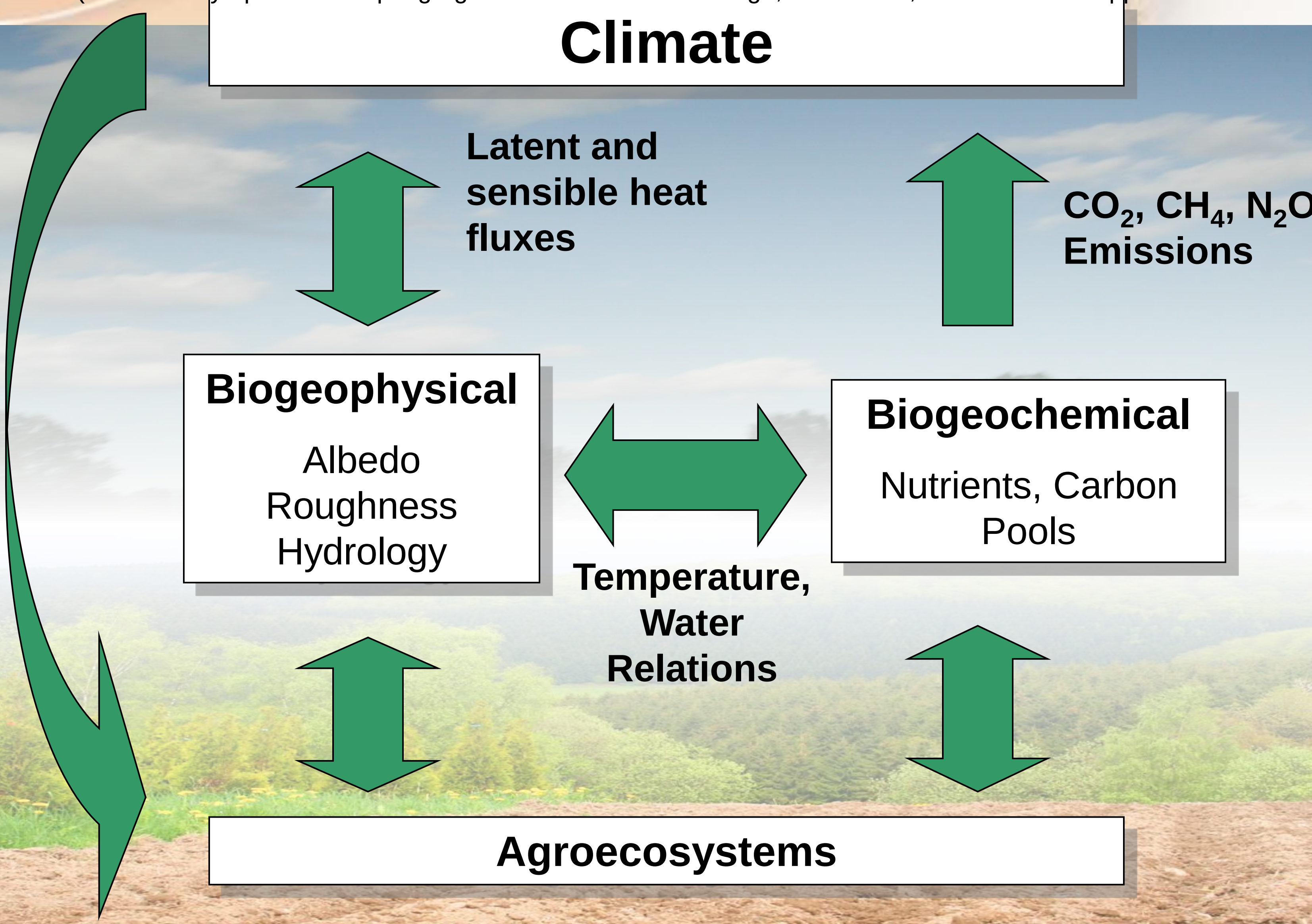


Dyer, et al. (2011). E*nergy for Sustainable Development*, *15*(4), pp. 451-459. doi : 10.1016/j.esd.2011.08.004.

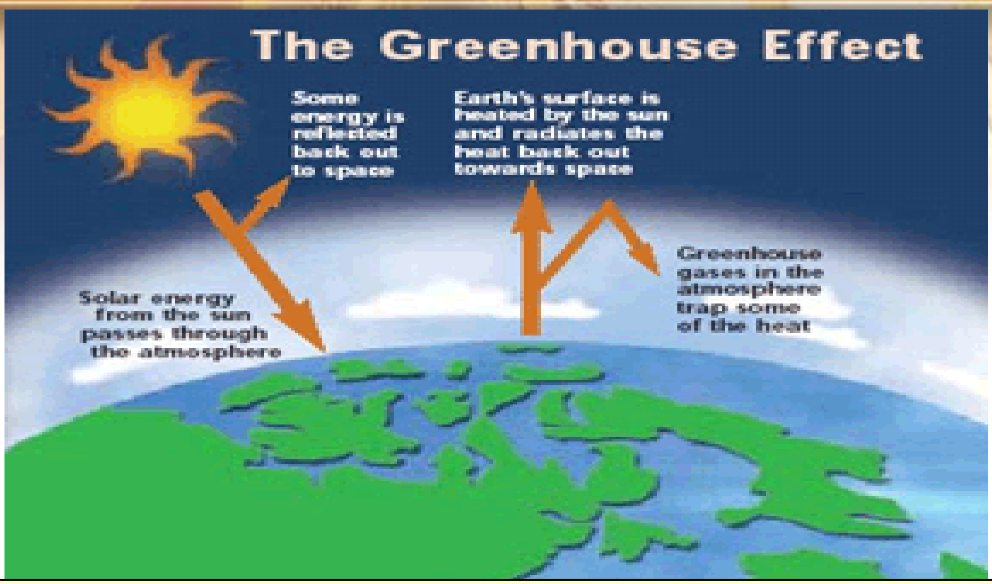
Dyer, J. A., & Desjardins, R. L. (2018). *Energy for Sustainable Development*, 47: 23-33. https://doi.org/10.1016/j.esd.2018.08.006

5. Quantifying the impact of agroecosystems on climate

•Desjardins, R.L. 2010. The impact of agriculture on climate change. In the proceedings of the North American Biotechnology Conference (NABC 21 symposium Adapting Agriculture to Climate Change, Saskatoon, Saskatchewan. pp 29- 39.



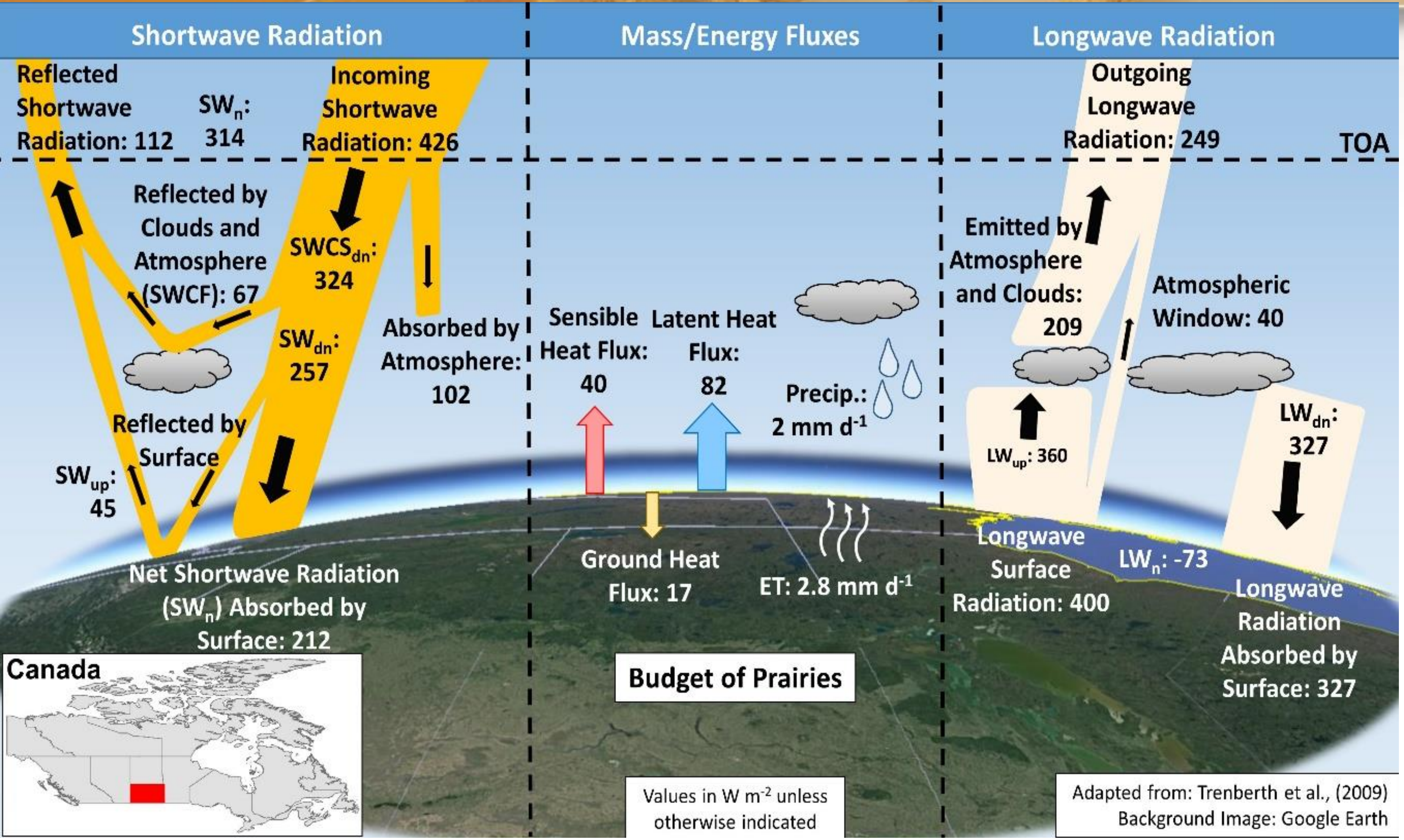
What causes radiative forcing/ climate forcing?



- Earth receives approximately 342 W m^{-2} of solar energy (mean over seasons, surface area)
- ~31% reflected away, remaining 235 W m^{-2} absorbed
- Surface emits 390 W m^{-2} as long-wave radiation, 90% is absorbed & re-emitted by atmospheric greenhouse gases, with 235 W m^{-2} emerge from the top of the atmosphere
- Radiative forcing or climate forcing is the change in the energy flux in the atmosphere, measured in watts per meter square, caused by either natural or anthropogenic factors affecting climate change
- note: 1 W m^{-2} extra forcing $\rightarrow$ ~0.5° C mean temp increase

Atmospheric and surface energy budget for summer months for Saskatchewan (Betts and Desjardins, 2020)

A doubling of the carbon dioxide concentration results in a change in the radiation budget of 3.7 W m^{-2}

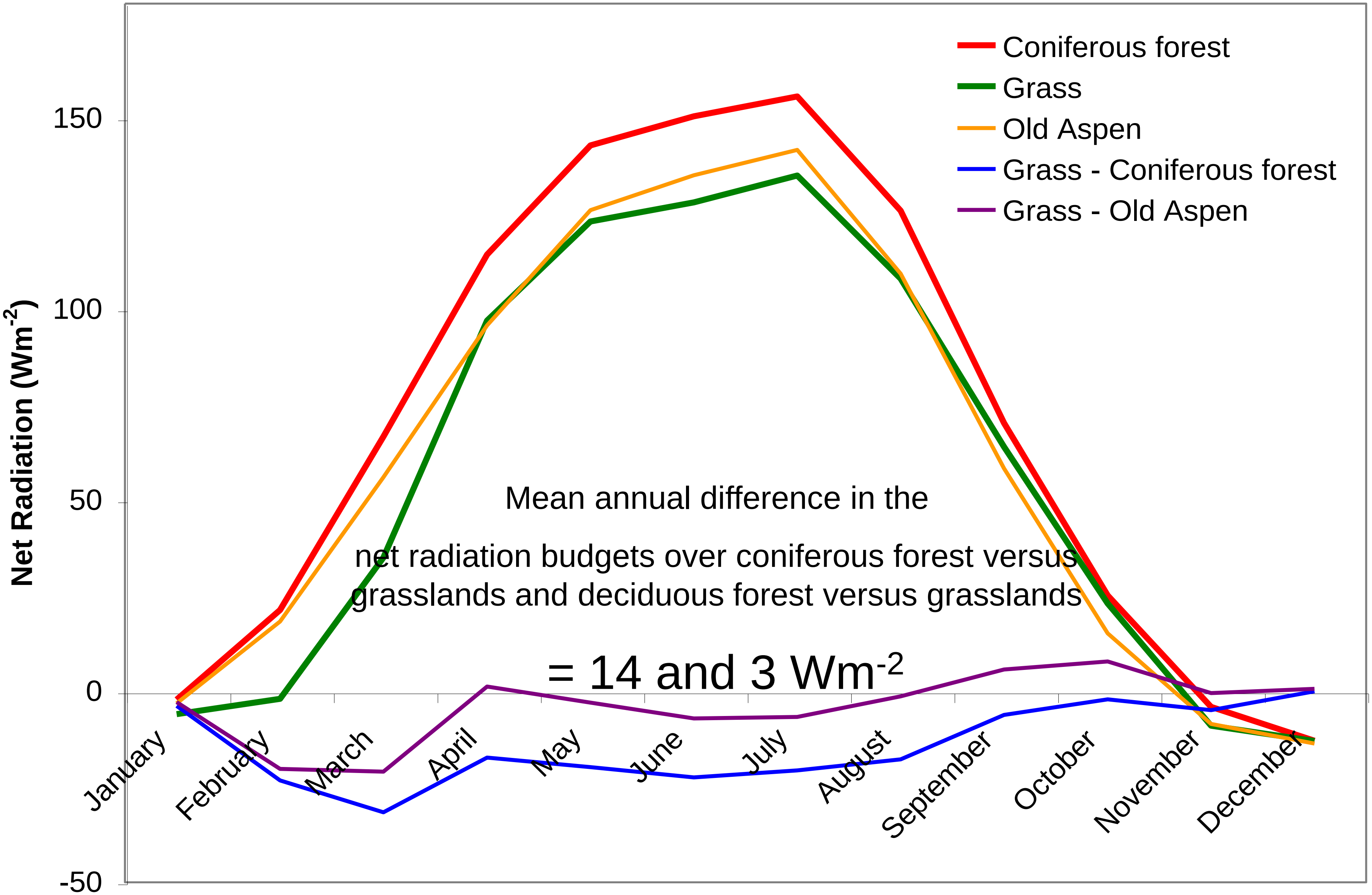


Effects on radiative forcing associated with various management practices in Canada (Desjardins 2009)

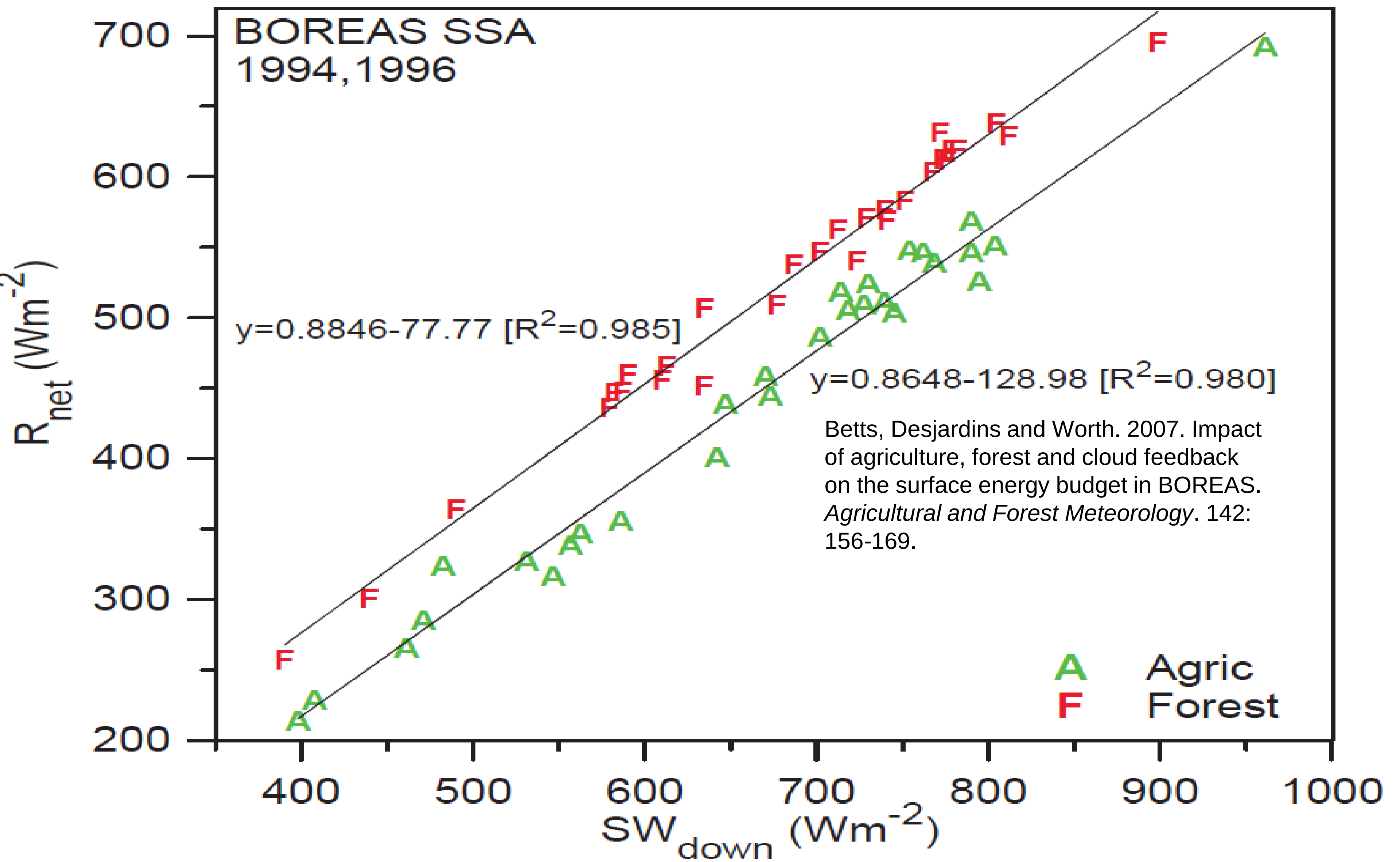
Practices	Biogeophysical forcing	Biogeochemical forcing	Net Effect
Reduced tillage	–	– –	– –
Afforestation	+ +	– –	
Deforestation	– –		
Planting forage crops	–	– –	– –
Irrigation	–	– +	–
Biochar	+	– –	–
Leaf albedo bio-geoengineering	–	–	– –
Production of biofuel	–	– +	–
Reduce RM consumption	–	– –	– – –
Reduced fallow	–	– –	– – –
Cover crops	–	–	– –
Leave long stubble for snow trapping	–	–	– –

Differences in the annual net radiation budgets over three types of vegetation

Betts et al. 2007. *Agricultural and Forest Meteorology* 142: 156-169.

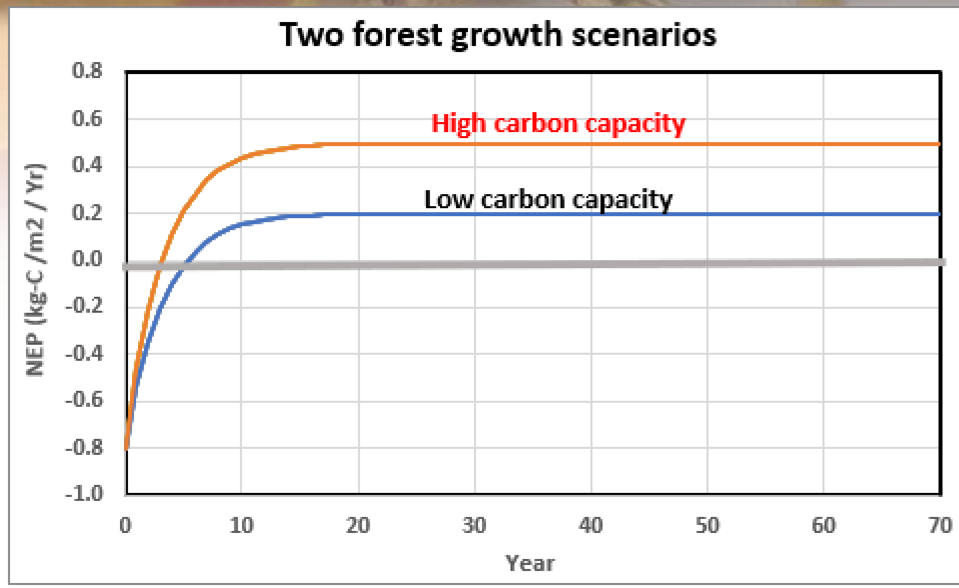


Relationship between net radiation and downward solar radiation over coniferous forest versus over agricultural crops



Betts, Desjardins and Worth. 2007. Impact of agriculture, forest and cloud feedback on the surface energy budget in BOREAS. *Agricultural and Forest Meteorology*. 142: 156-169.

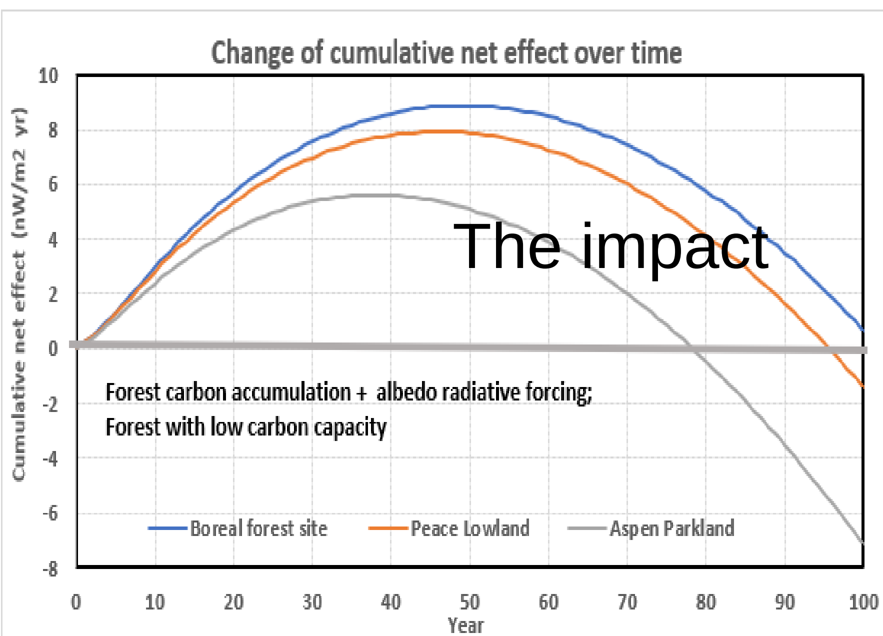
The impact over time on radiative forcing associated afforestation (prepared by Jianqui Liu)

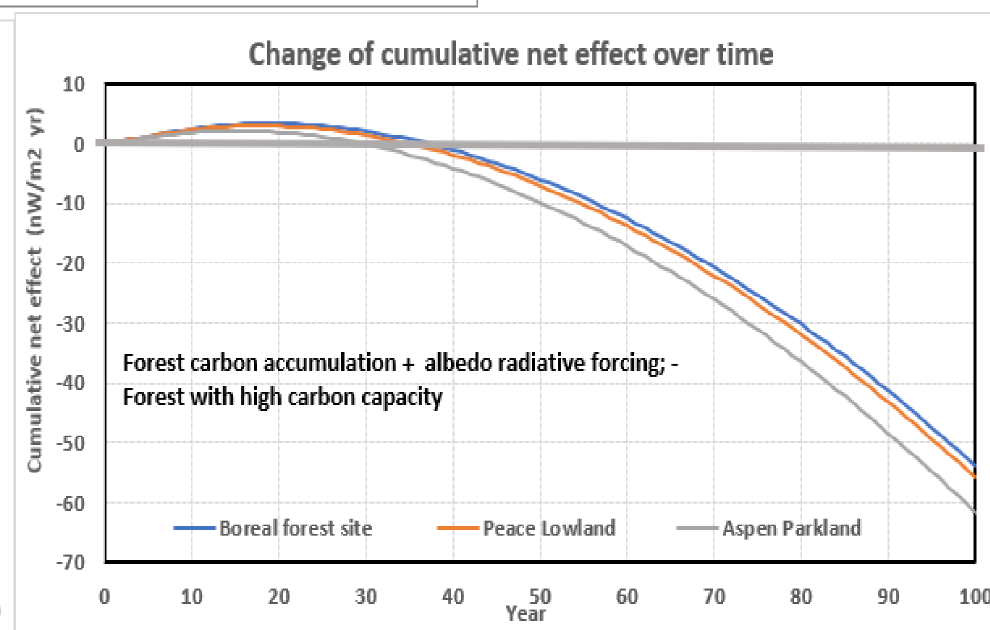


5 tons C/ha/yr.

2 tons C/ha/yr

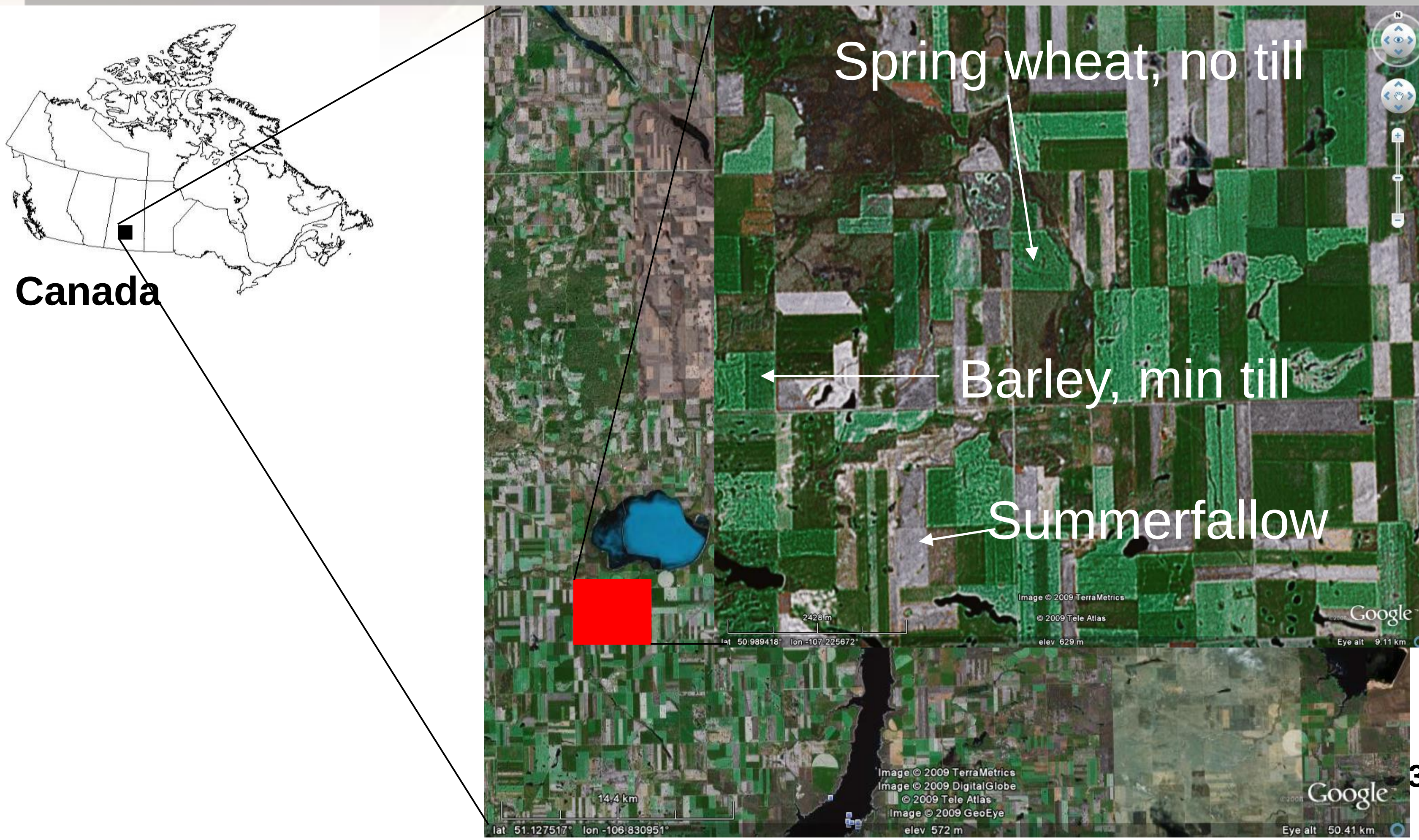
Bernier, P. Y., R.L. Desjardins, Y. Karimi-Zindashty, D. Worth, A. Beaudoin, Y. Luo and S. Wang 2011. Boreal lichen woodlands: A possible negative feedback to climate change in eastern North America. Agriculture and Forest Meteorology 151: 521-528.





How can we assess the impact of agricultural land management on biophysical forcing?

Identify fields with known crop type and management, estimate annual albedo from satellite imagery and scale up to national scale using crop/management distribution

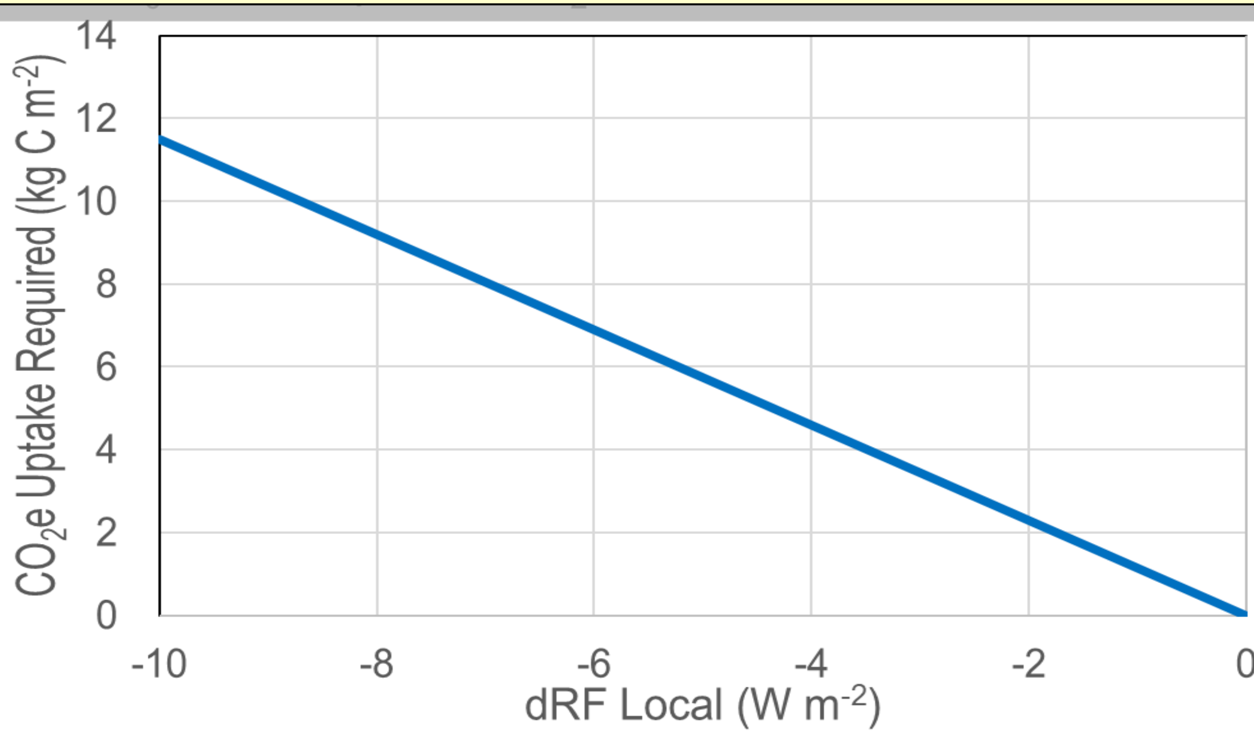


What is the impact of a change in the reflectivity of the surface?

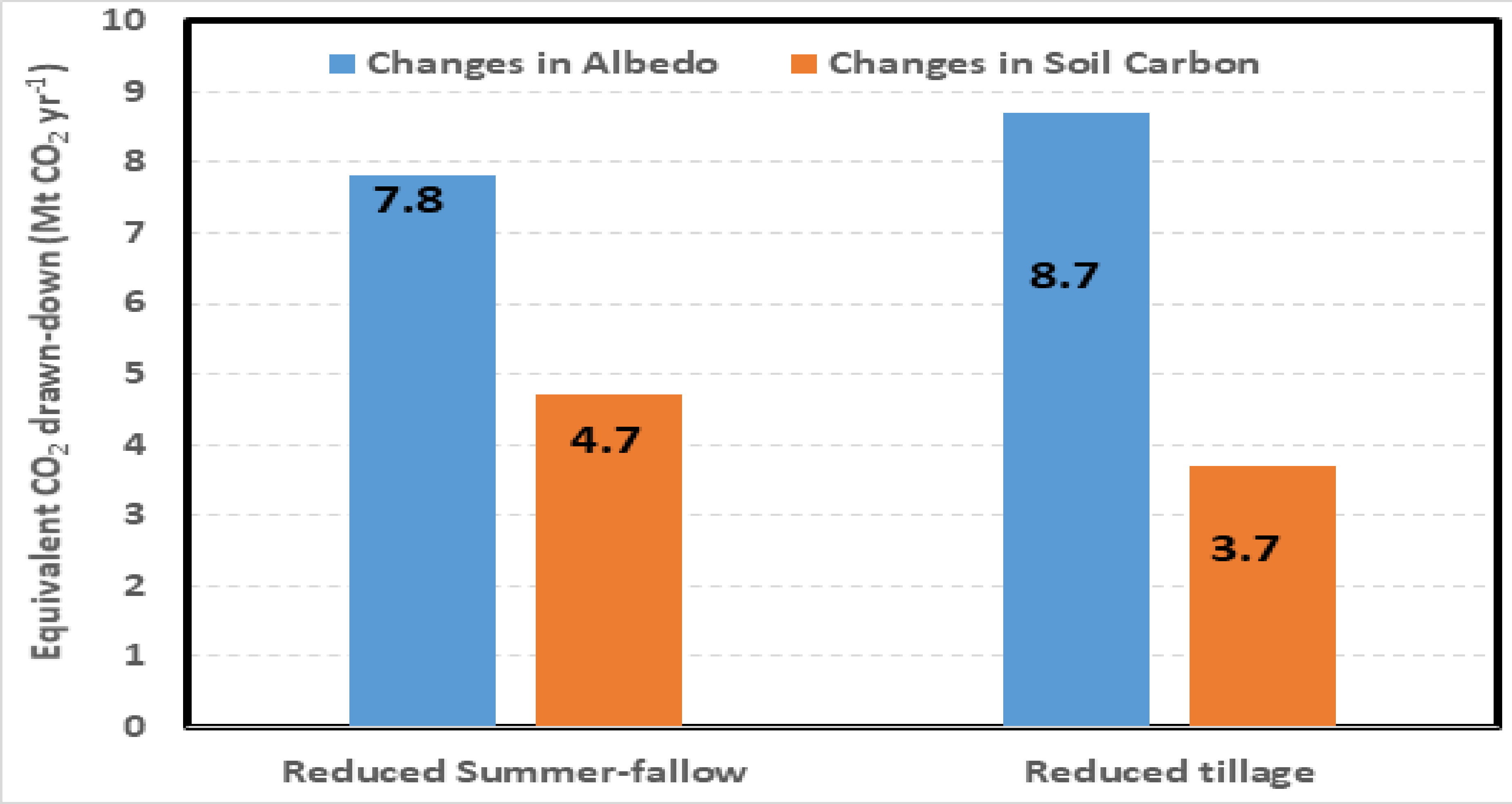
Therefore, knowing the radiative forcing impact of a management practice on albedo (δa), the carbon equivalent impact (δa_{CO2}) can be calculated as follows:

$$\delta a_{co2} = C_0(\exp^{\frac{\delta a}{5.35}} - 1)$$

Where, C_0 is atmospheric CO_2 concentration.



Influence of two management practices in the Canadian Prairies on radiative forcing - Average annual CO_2 drawdown 1981-2016

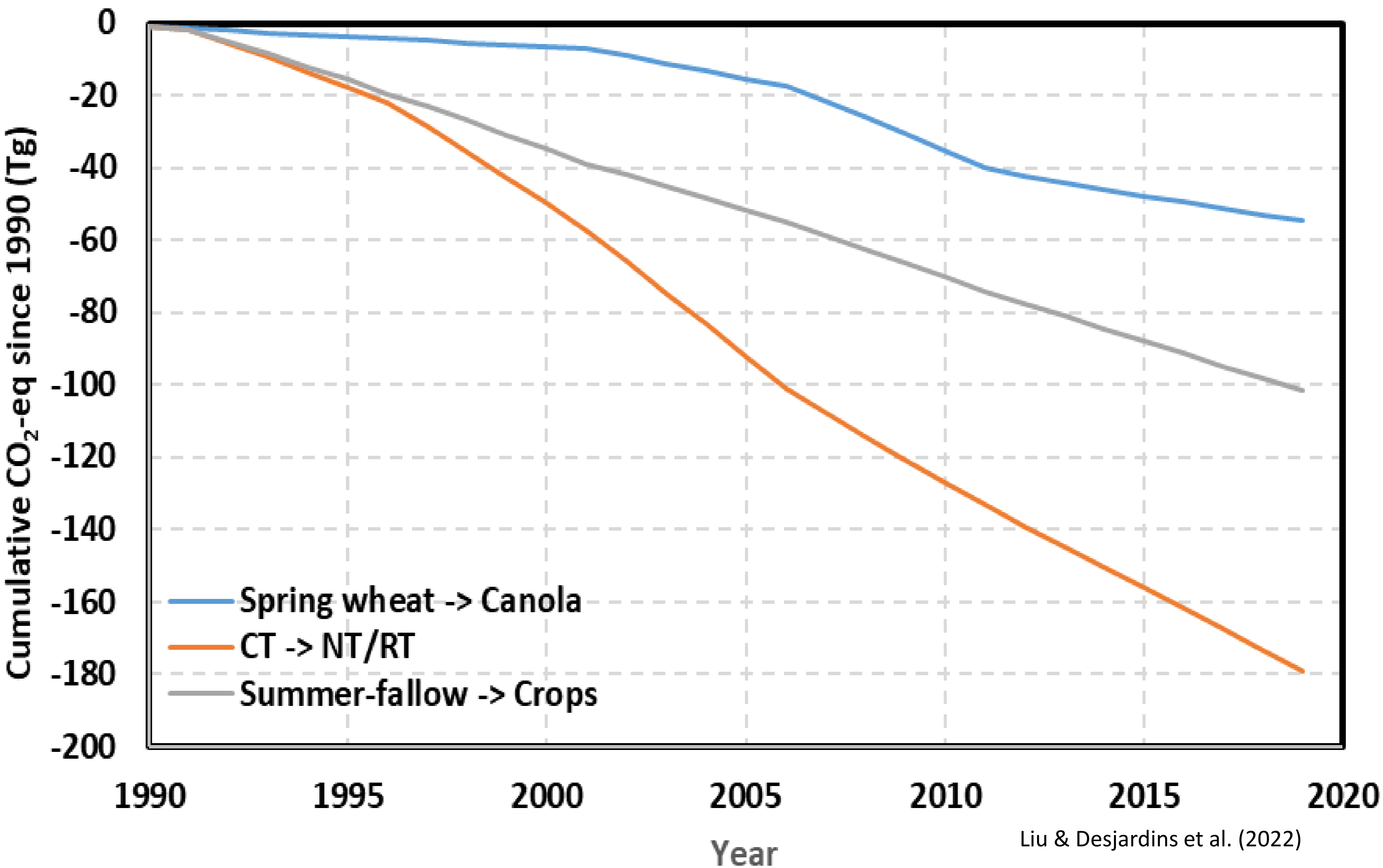


Albedo effect
RF=62% and RT= 70%

Liu et al. 2022. https://doi.org/10.1016/j.jenvman.2021.113938

Acreage of canola increased from 2.9 to 8.4 Mha while wheat decreased from 11.6 to 5.7 Mha.

Equivalent CO_2 drawdown in the Prairies from 1990 to 2019 due to albedo change associated with reduced tillage, reduced summer fallowing and a shift to more canola and less wheat.



Liu & Desjardins et al. (2022)

6. Pathways to help reduce GHG emissions

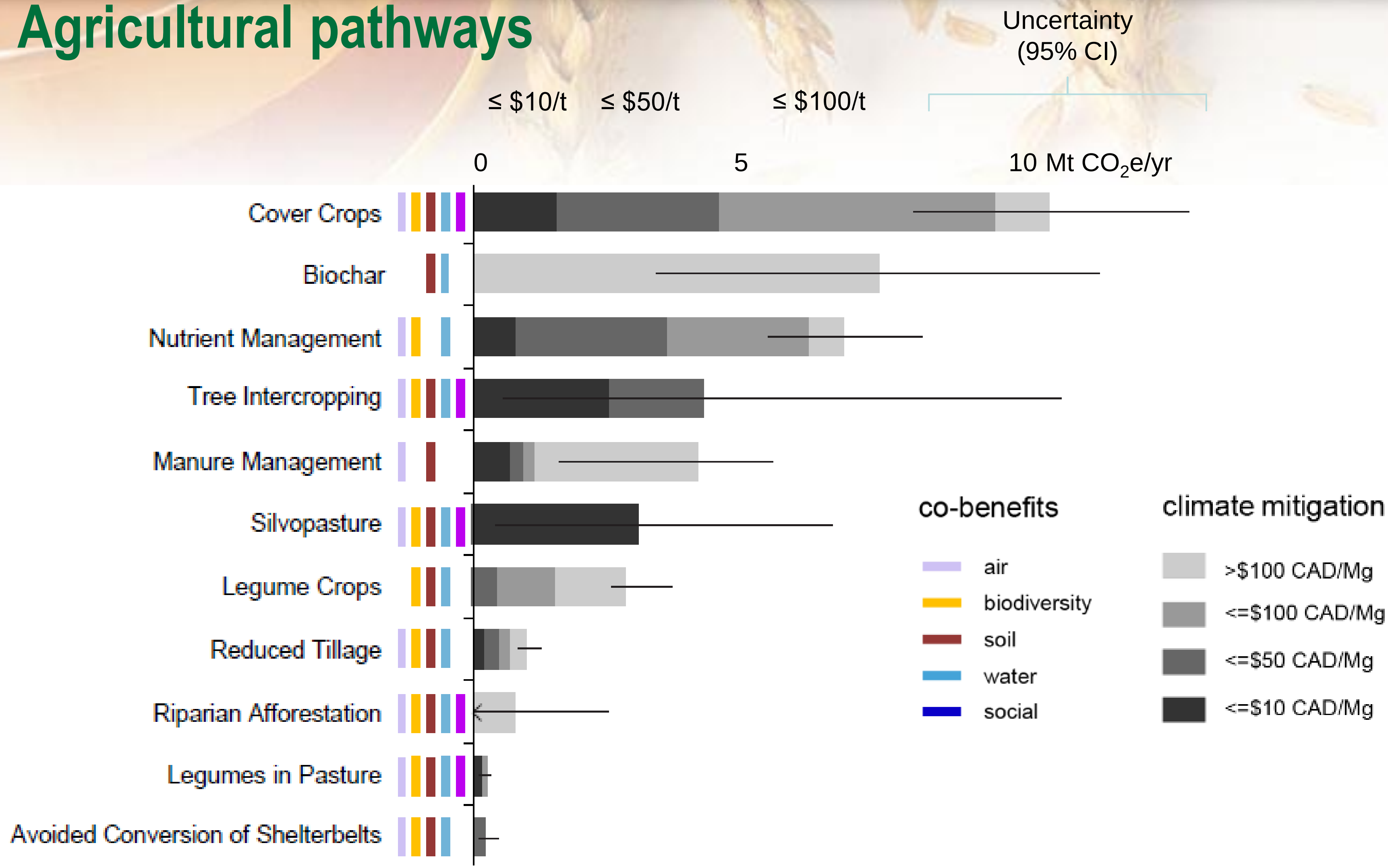
AAFC scientists with a team from Nature United have proposed 11 ‘Natural Climate Solutions’ through agricultural pathways that could result in a reduction of 76 Mt CO_2e/yr by 2030 (Drever et al. 2021)

These pathways include:

- reduced tillage,
- cover crops,
- legume crops,
- legumes in pasture,
- silvopasture,
- nutrient management,
- avoided conversion of shelterbelts,
- tree intercropping,
- riparian afforestation,
- biochar,
- manure management

Climate mitigation potential by 2030 (Mt CO_2e/yr)

11 Agricultural pathways



•Drever et al. 2021. Natural climate solutions for Canada. Science Advances, 2021, 7(23), https://advances.sciencemag.org/content/7/23/eabd6034

Manure management

Avoided methane emissions from reduced methanogenesis through acidification of manure in handling facilities of dairy and swine farms

Drever et al. 2021. Science Advances, 2021, 7(23), https://advances.sciencemag.org/content/7/23/eabd6034

Per head mitigation	Total Mitigation Potential
1.1 t CO_2e/yr	0.4 Mt CO_2e/yr by 2030
0.2 t CO_2e/yr	2.6 Mt CO_2e/yr by 2030

7. Concluding remarks

Considerable progress has been achieved in agricultural meteorology in Canada during the last seventy years.

The multidisciplinary approach of measuring mass and energy exchange has greatly helped improved our understanding the biosphere-atmosphere interactions at the ecosystem scale.

We made considerable progress in quantifying GHG emissions from a wide range of sources and in estimating the carbon footprint of agricultural products.

We showed how producers and consumers could help reduce GHG emissions from the agriculture sector.

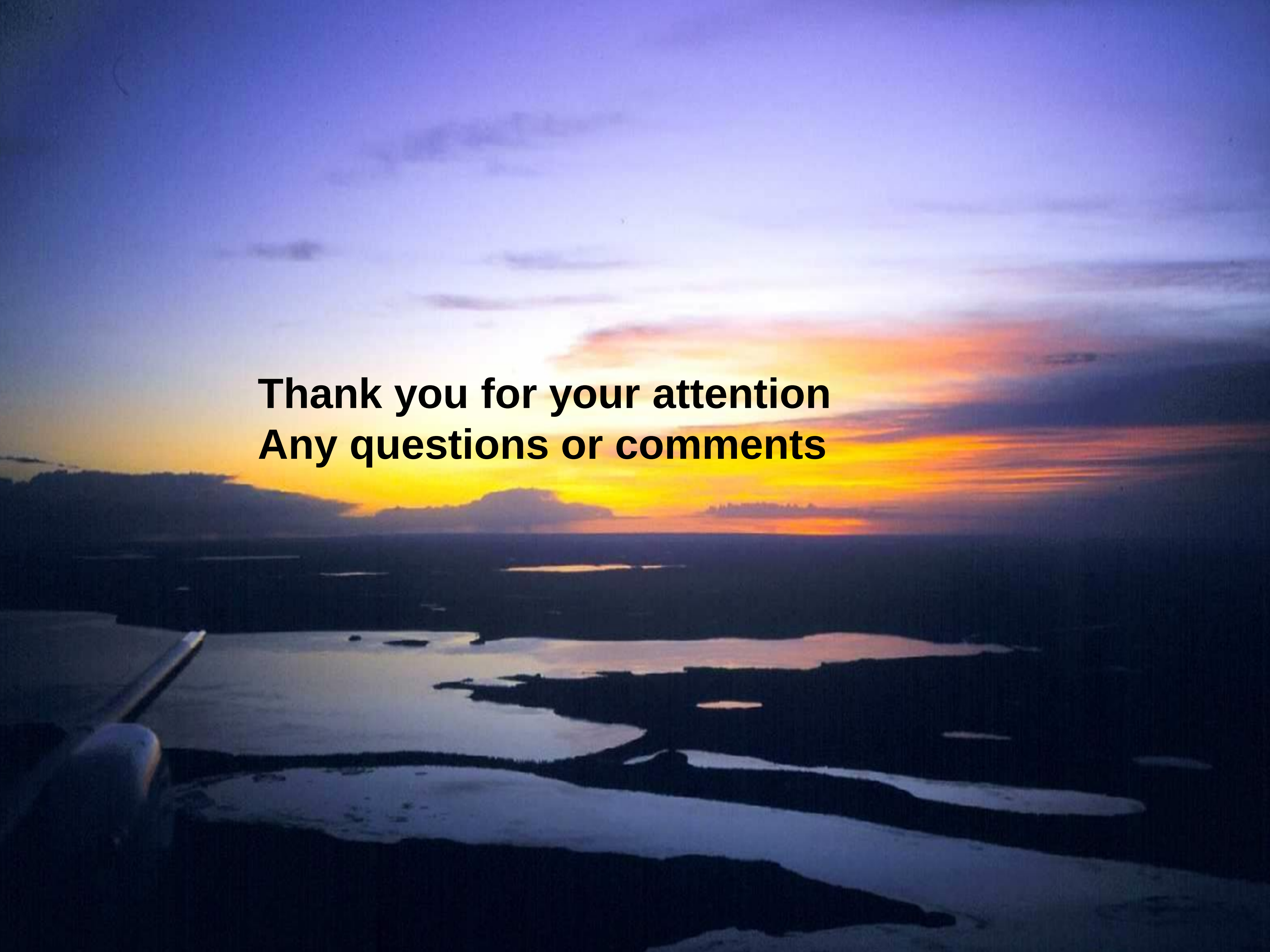
Pathways that could reduce the agricultural GHG emissions by more than the current agricultural GHG emissions in Canada have been identified.

Agroecosystems represent only 7% of the terrestrial biosphere in Canada, it is then important to understand the role of all major ecosystems with respect to climate change.

Estimates of radiative forcing/ climate forcing need to be greatly improved.

Acknowledgements

H. Allen, P. Alvo, B. Amiro, W. Baier, H. Balde, P. Bernier, A. Betts, M. Boehm, E. Brach, A. Brewer, D. Buckley, B. Dutta, C. Campbell, P. Caramori, D. Cerkowniak, F. Chahuneau, C. Champagne, J. Chen, J. Cihlar, K. Congreves, C. deKimpe, T. Denmead, D. Dow, J. Dyer, J. Dumanski, B. Dutta, C. Flechard, T. Flesch, S. Gameda, Z. Gao, P. Goglio, B. Grant, G. Guest, L. Harper, K. Haugen-Kozyra, W. He, A. Howard, J. Hutchinson, S. Kaharabata, F. Karanja, Y. Karimi-Zindashty, J. Keng, B. Kimball, K. King, R. Kroebel, H. Janzen, G. Jego, E. Lemon, R. Lessard, J. Liu, I. MacPherson, D. MacDonald, L. Mahrt, M. Mauder, B. McConkey, S. McGinn, C. Mitic, E. Pattey, P. Poirier, B. Qian, W. Reid, R. Riznek, G. Robertson, P. Rochette, J. Salinger, J. Sansoulet, P. Schuepp, P. Sellers, B. Shrestha, T. Sinclair, S. Sivakumar, W. Sly, W. Smith, G. St-Amour, J. Sun, C. Taylor, G. Thurtell, K. Uzoma, A. VanderZaag, R. Verdon, X. Verge, C. Wagner-Riddle, D. Worth, T. Zhu


Thank you for your attention
Any questions or comments