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Impact of uncertainty of land management practices on carbon sequestration

Brian McConkey

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Canada

Uncertainty Analysis

- Quantifying uncertainty is good practice
- Quantifying uncertainty is difficult
  - Need studies that purposely provide repeated, independent estimates to assess uncertainty
  - Typically science investment to increase understanding not to increase knowledge to quantify

Sources of Uncertainty 1

Source of Uncertainty	Nature of Uncertainty	Impact on Offset System	Impact on national GHG inventories
Process uncertainty (uncertainty if situation well defined and well described)	Random	Important for individuals, canceling out such that total variance reduces proportionally to number of fields included	Canceling out at national scale so typically not as important as other sources of uncertainty, estimated from controlled experiments
	Systematic	Correct for part known but usually somewhat unknowable, biased estimates	Correct for part known but usually somewhat unknowable, biased estimates, overall effect depends on whether biases different in different regions/situations, estimated from controlled experiments

Sources of Uncertainty 2

Source of Uncertainty	Nature of Uncertainty	Offset System	National GHG inventories
Farming practice (uncertainty due to practice not being applied in the way described or interacting with other practices such that the quantified C change does not refer to the real farm practice)	Random	This should be small if consistent and clear definitions and practices are well documented	Hard to estimate, some canceling out at national scale
	Systematic	This should be small if consistent and clear definitions and practices are well documented	Hard to estimate, biased estimates, overall effect depends on whether biases different in different regions/situations

Sources of Uncertainty 3

Source of Uncertainty	Nature of Uncertainty	Offset System	National GHG inventories
Area in farming practice (uncertainty that the area is correct)	Random	This should be small if consistent and clear definitions and practices are well documented	Can be estimated from validation work involving independent estimates, usually hard to estimate at broad scale
	Systematic	This should be small if consistent and clear definitions and practices are well documented	Correct for part known but usually somewhat unknowable, biased estimates, if biases different in different regions/situations there may be some canceling out

Sources of Uncertainty 4

Source of Uncertainty	Nature of Uncertainty	Offset System	National GHG inventories
Initial soil characteristics including SOC quantity and quality when a farm practice is adopted such that the C quantification becomes incorrect	Random	Usually reduced by some information available from the farmer on land history and possibly of total SOC.	Can be estimated to extent have data describing a range of soil situations, some canceling out at national scale
	Systematic	Usually reduced by some information available from the farmer on land history and possibly of total SOC.	Correct for part known but usually somewhat unknowable, biased estimates, overall magnitude depends on direction and magnitude of other biases in the systems

C change Process Uncertainty

- Obtained from controlled field experiments
- SOC measurement is destructive and extreme spatial variability of SOC introduces uncertainty in change in SOC stock that is confounded with other causes of variability
  - Large number of measurements helps reduce effect of spatial variability
  - Meta-analyses across many sites provides a practical way to reduce effects
- C Change process uncertainty of models can be estimated by comparing modeled SOC stock with measured SOC stock
- In practice, process uncertainty of models can not be estimated from uncertainty of model parameters because many related parameters for which describing uncertainties is infeasible

- Process uncertainty also occurs because of inadequacies or missing processes in models

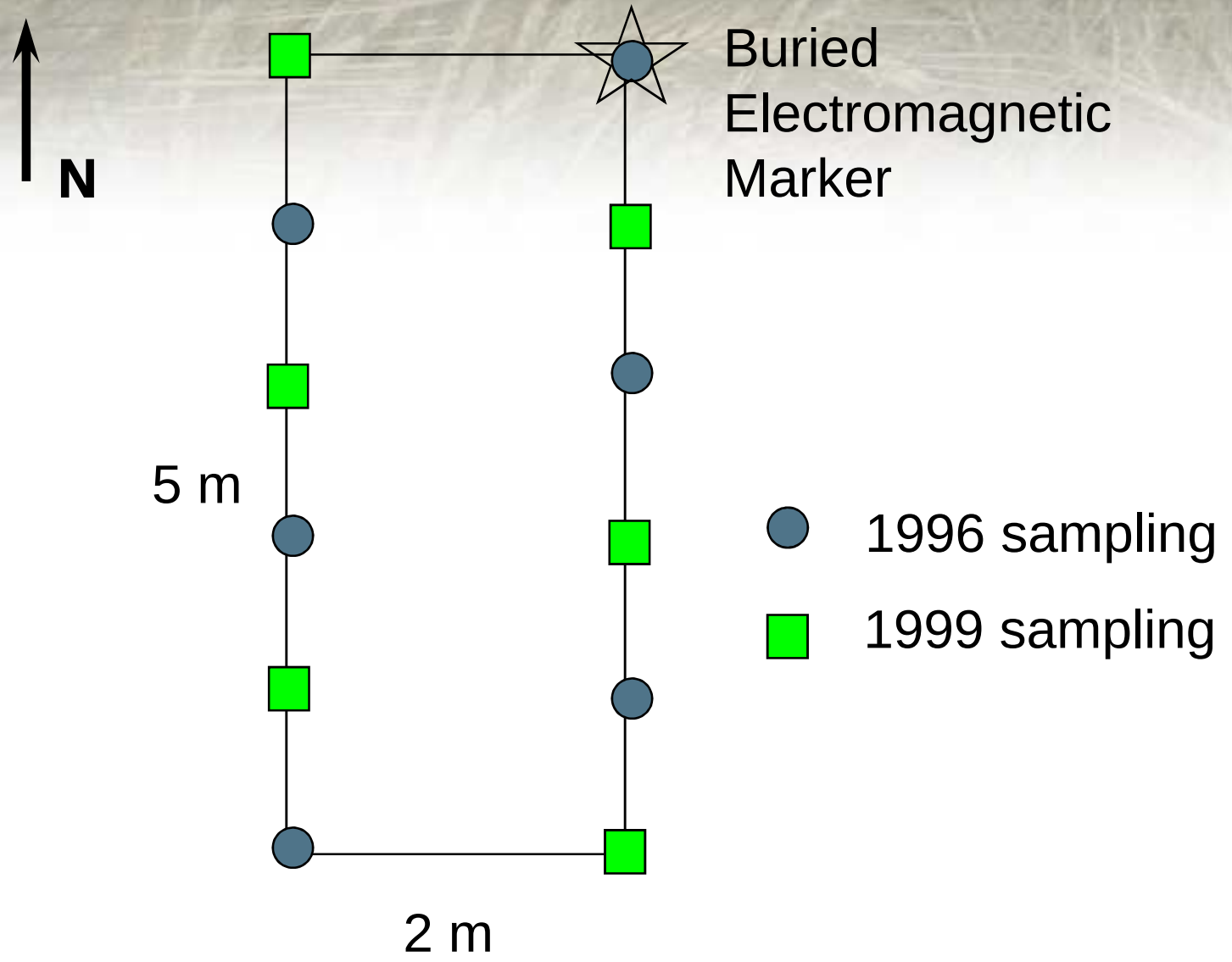
- Field measurements over-represent gently sloping, well drained field conditions
  - Meta-analyses over many sites also includes some of uncertainty due to range of soil conditions

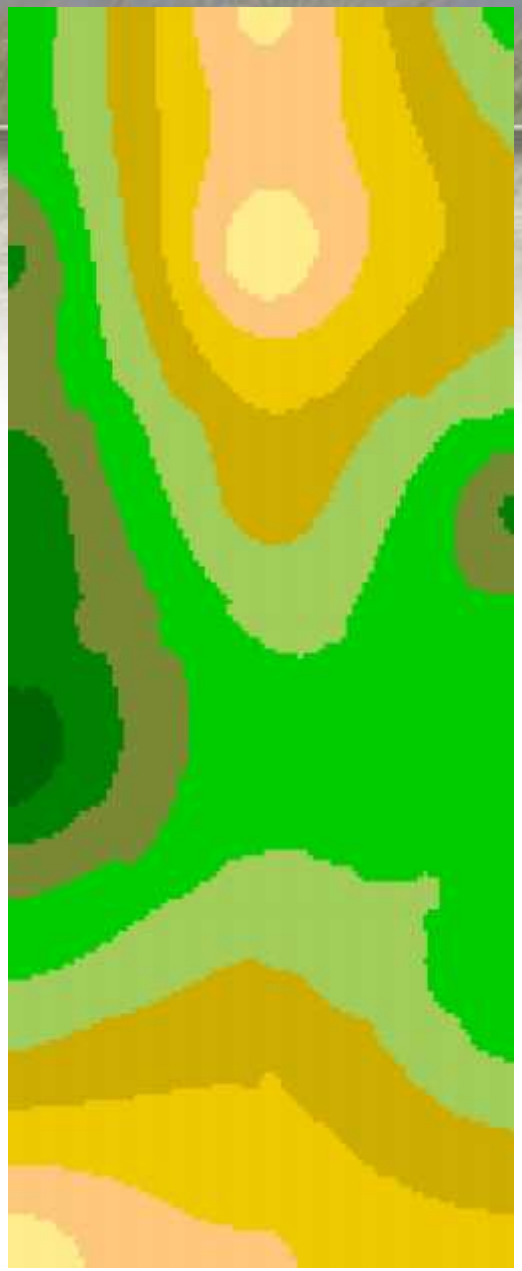
- E.g. Canadian Prairies
  - Adoption of no-till increases C by

    0.32 ±0.15 Mg/ha/yr

  (VandenBygaart et al. 2003)

Benchmark

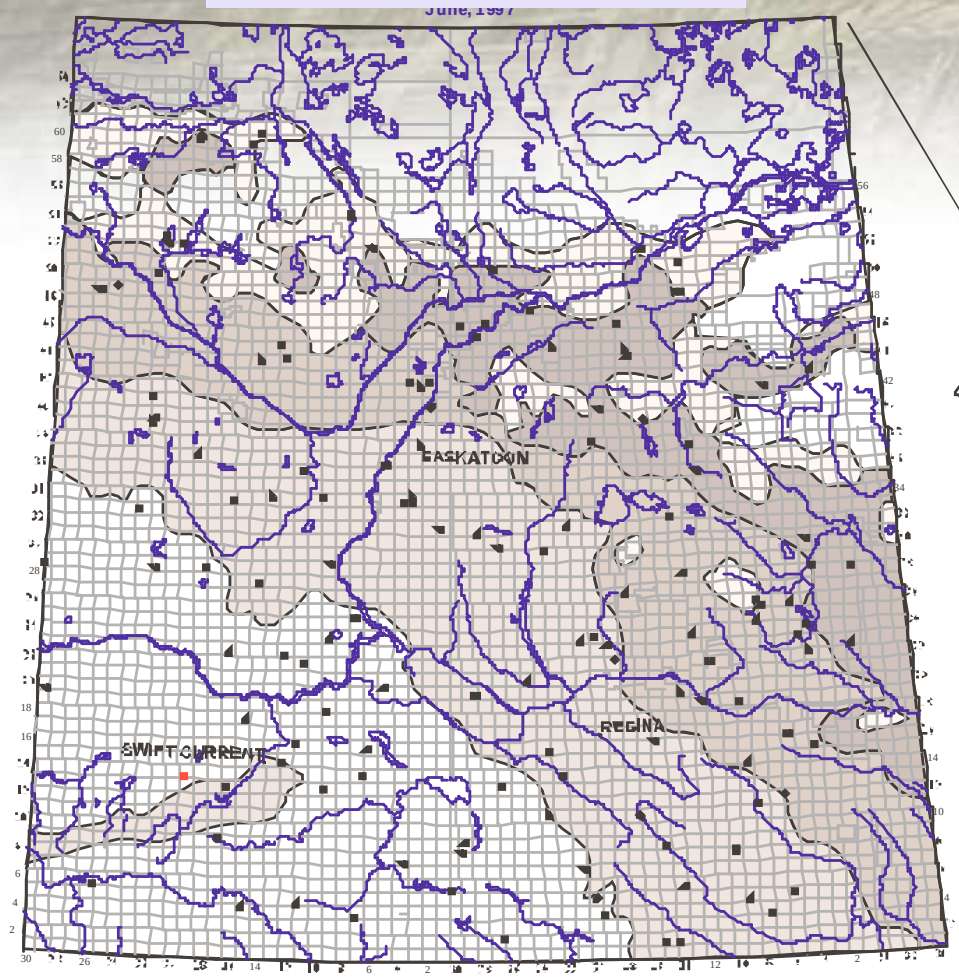

N
Buried
Electromagnetic
Marker
5 m
2 m
1996 sampling
1999 sampling


Soil Carbon (MgC/ha)
43.8 - 45.6
45.6 - 47.3
47.3 - 49.0
49.0 - 50.7
50.7 - 52.5
52.5 - 54.2
54.2 - 55.9
55.9 - 57.7
57.7 - 59.4
5m
2 m

Site 143

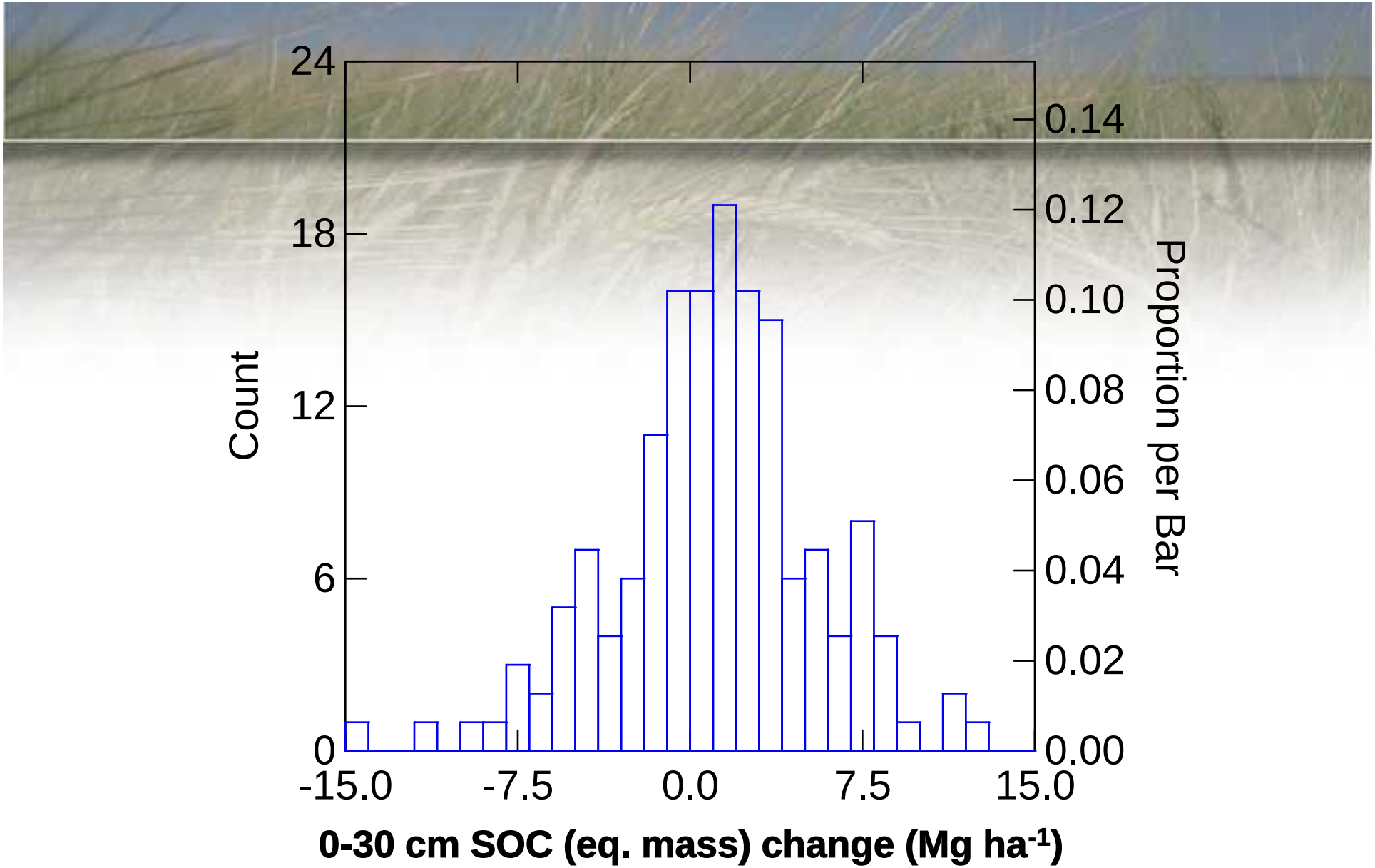
Saskatchewan

Benchmark Locations



CANADA

Depth (cm)	SOC (eq. mass) (Mg ha^{-1})		
	1996	1999	p
0-10	30.09	30.47	0.071
0-20	50.68	51.70	0.003
0-30	63.85	65.06	0.004
0-40	73.96	75.58	<0.001



- Large (unexpected) differences consistent with normal distribution
- obviously due to within-benchmark spatial variability rather than temporal change

Uncertainty of farm practice

- Variations in practice at field level not seen at plot level
  - E.g. spot tillage to level wheel ruts when crop harvested under wet soil conditions
  - Wide range of dates of field operations
- Interactions with other practices
  - E.g. manure application, sequences of annual crops, periodic perennial forages in rotation with annual crops, different fertility regimes, liming, irrigation, drainage, crop residue removal or burning , etc.
  - Bewildering number of combinations of practices
- Important interactions with weather for exact timing of combination of practices
- Huge effort needed to describe thoroughly and quantify C change for those combinations
  - Particularly problematic for C change since need the area of changes in practices so need knowledge of how all practices changed together
- Interacts with process uncertainty so increases overall uncertainty

Uncertainty of Area of Practice

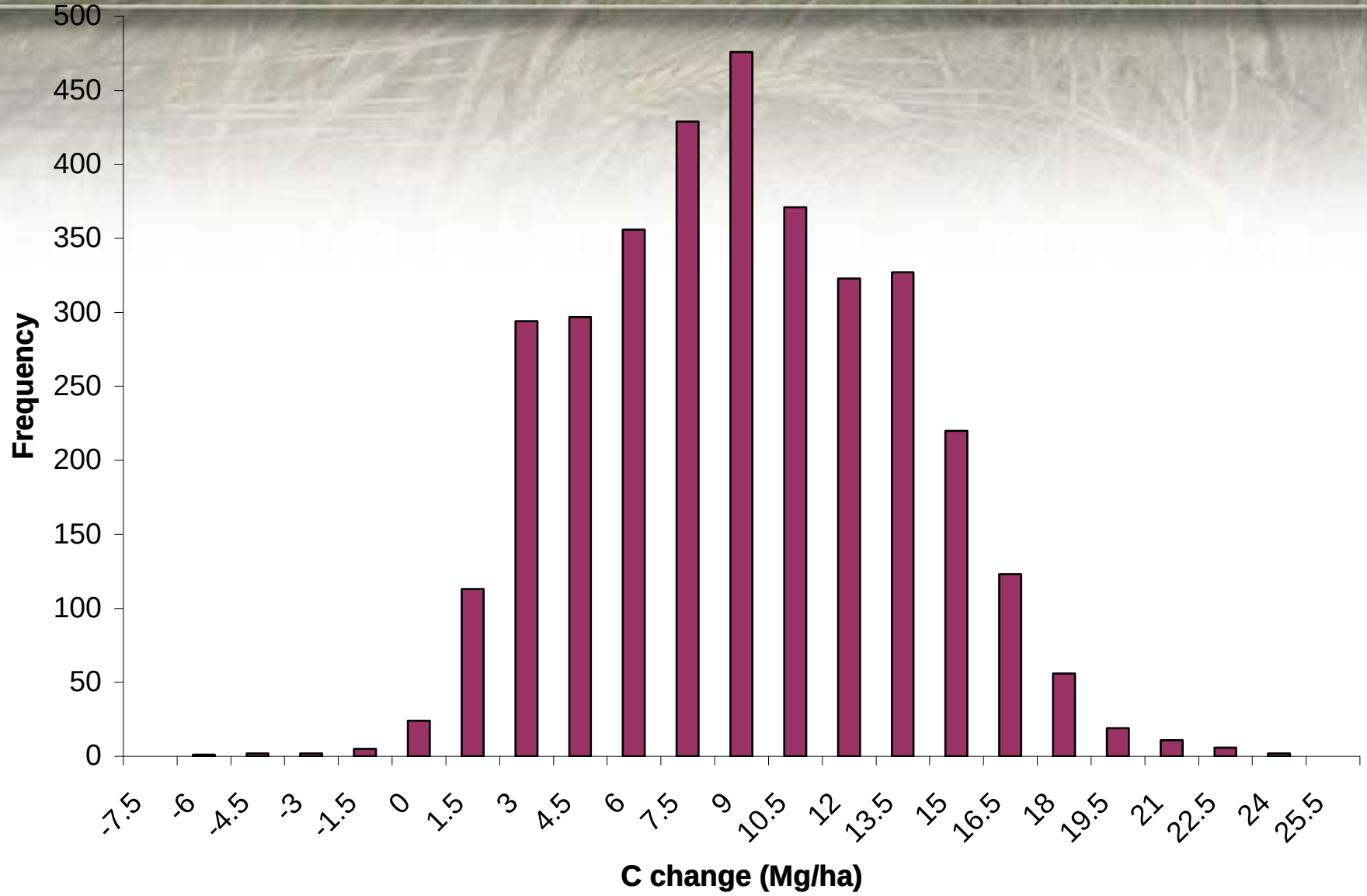
- Uncertainty of area of a well defined and described practice
  - (not uncertainty due to variability in the practice)
- All methods to quantify area of practice have uncertainty so unavoidable and important as proportional effect
- Should not be a problem with offset systems
- The relative uncertainty of area is larger for C change than for other GHG emissions since it is an area of change in practice that is important for C change rather than the simple area of the practice that is important for other GHG emissions
  - E.g. area of no-till in semiarid Canadian prairies in 2006 = 9 549 198 ±260 659 ha
  - area of conversion from full to no-till in same region in 2006 = 181 665 ±15 365 ha
- Independent of process uncertainty

Uncertainty of Soil Situation or Conditions

- The amount and quality of SOC at time of practice change has huge effect on subsequent C change
  - Saturated SOC little opportunity to gain
  - Low SOC high propensity to gain SOC
  - Much of the uncertainty in initial SOC is due to uncertainty in historical land management
- Soil erosion and deposition cause large differences in SOC
- Soil textures, drainage conditions, salinity, pH, etc can all vary in
- Interacts with process uncertainty so increases overall uncertainty

- Using model to simulate C change for a wide variety of known soil conditions and range of interacting practices can provide some estimate of situational uncertainty

Variation in 23-yr aC_{LMC} for Century modeled annual to perennial crop conversion for 1000 soils and crop mixes in Eastern Canada



Usual Focus on Process Uncertainty

- Experimenters
  - Process uncertainty critically important for publishability and for interpreting results from controlled field experiments
- Modelers
  - Process uncertainty most important for model building
- Not surprisingly, scientific literature focuses on process uncertainty
- Quantifiers
  - Situational uncertainty (exact practice, area of practice, and soil conditions) is much more important, especially for large-area GHG inventories
  - Not knowing history of practices, areas of practices, the exact nature and mix of practices

Canadian Circumstances

- Largest uncertainty overwhelms smaller uncertainties

$$U_{total} \approx \sqrt{U_{process}^{2} + U_{area}^{2} + U_{practice}^{2} + U_{conditions}^{2}}$$

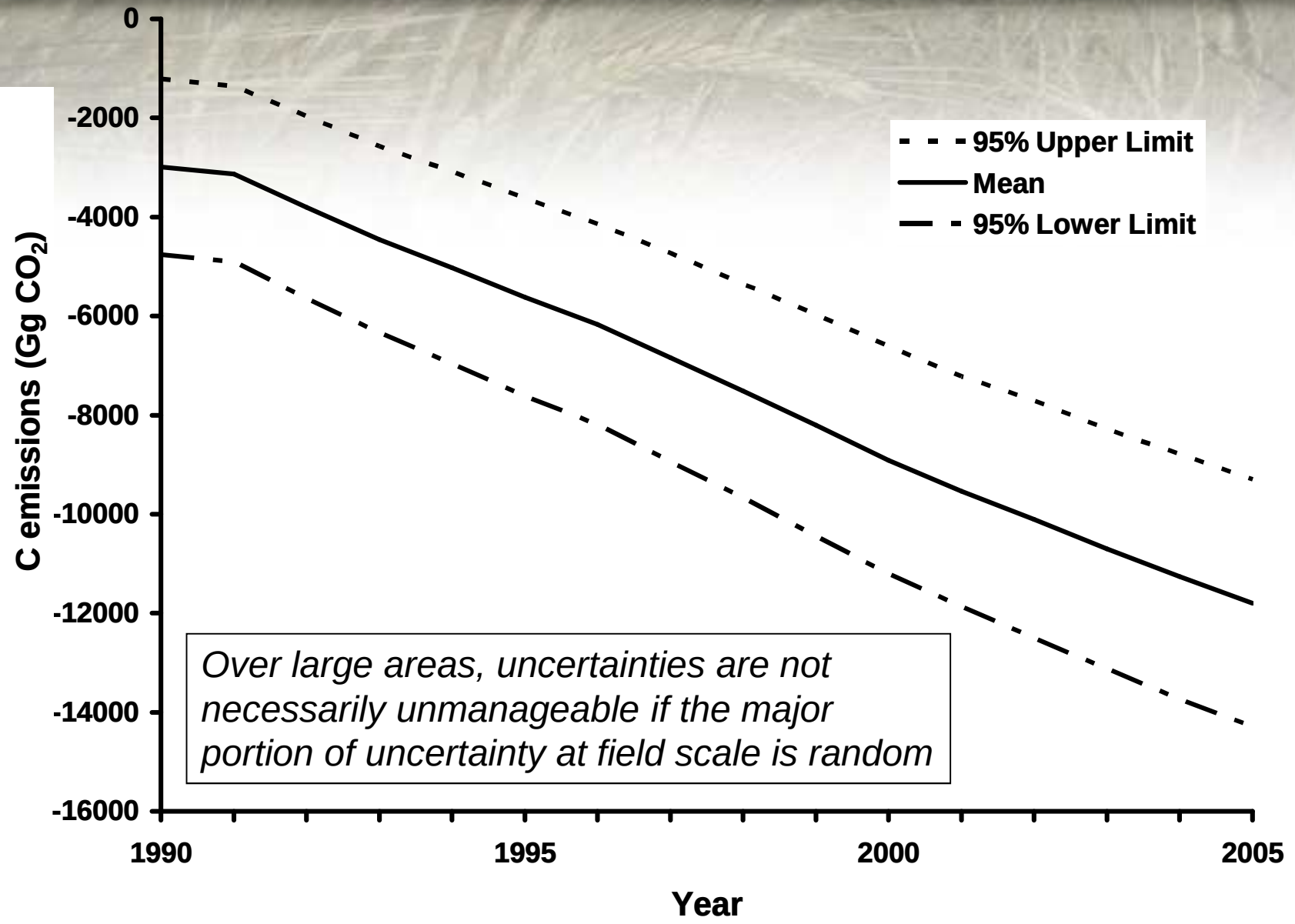
  - Once one uncertainty is greater than about twice others, it completely dominates

- It is also important to do detailed sensitivity and focus on largest sources of uncertainty with practices and regions.
  - In Canada conversions between annual and perennial crops are most important to soil C change

- Our estimates suggest that situational uncertainty dominates

- Much work now on how to better describe farming systems changes and field management regimes within farming systems in Canada

Confidence Limits for C Sink for Canada's Agricultural Land



Offset System

- Situational uncertainty would be less important because better information on current and historical land management
- C change process uncertainty dominates
- Offset systems have not considered uncertainty well
- Measurement based offset systems are not practical due to measurement uncertainty
  - Buyers only want reasonable assurance of not overestimating the sink but
  - Sellers want high probability of detecting a sink if there is one and that requires a huge number of samples
  - To have reasonable costs, sellers have to pool land together and accept the average measured change for that land pool so might as well use a model-based estimates

Summary

- Analyze uncertainty carefully
- Focus on those uncertainties that dominate in terms of total C stock change
  - Make strategic investments to reduce
- In Canada, situational uncertainty due to variability in practice, area of practice, and soil conditions dominates uncertainty of total C change
  - Focus of improvements is on gaining better knowledge of farm practices
- Over large areas, if there are not systematic biases, uncertainties will often be surprisingly small even though uncertainties at field scale are large