Experiences in quantifying the uncertainty of the estimates of Canada's National Forest Carbon Monitoring, Accounting, and Reporting System, NFCMARS

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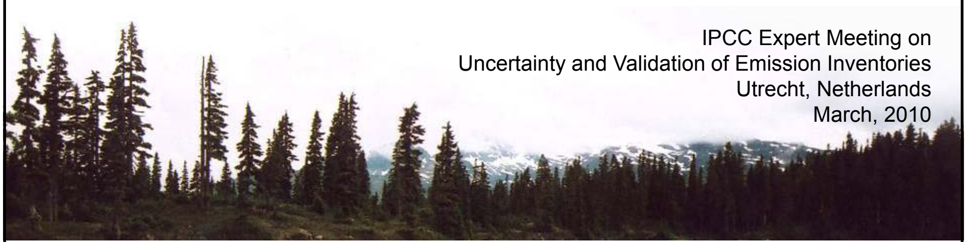
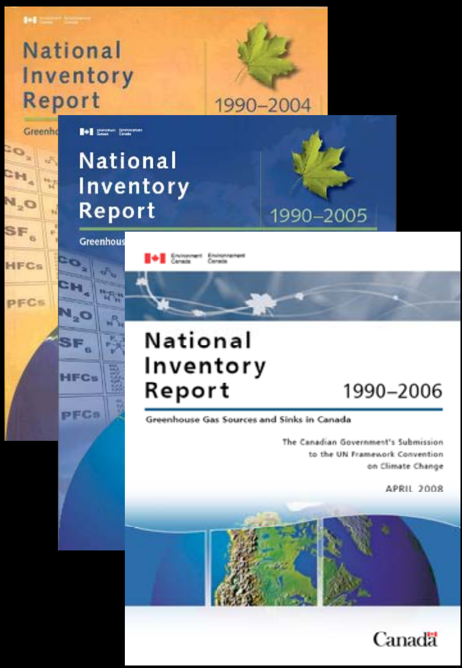
IPCC Expert Meeting on
Uncertainty and Validation of Emission Inventories
Utrecht, Netherlands
March, 2010



Natural Resources Canada   Ressources naturelles Canada   Canada

Overview

- Canada’s National Forest Carbon Monitoring, Accounting, and Reporting System, NFCMARS
  - Brief Overview
- Quantifying Uncertainty
  - Why we did it
  - How we did it
  - The results



Canada's
National
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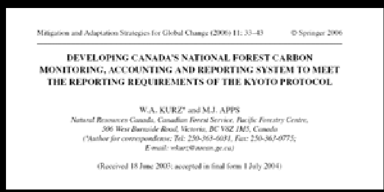
Carbon
Monitoring,
Accounting and
Reporting
System
(NFCMARS)


Mitigation and Adaptation Strategies for Global Change (2006) 11: 33–43 © Springer 2006

DEVELOPING CANADA'S NATIONAL FOREST CARBON MONITORING, ACCOUNTING AND REPORTING SYSTEM TO MEET THE REPORTING REQUIREMENTS OF THE KYOTO PROTOCOL

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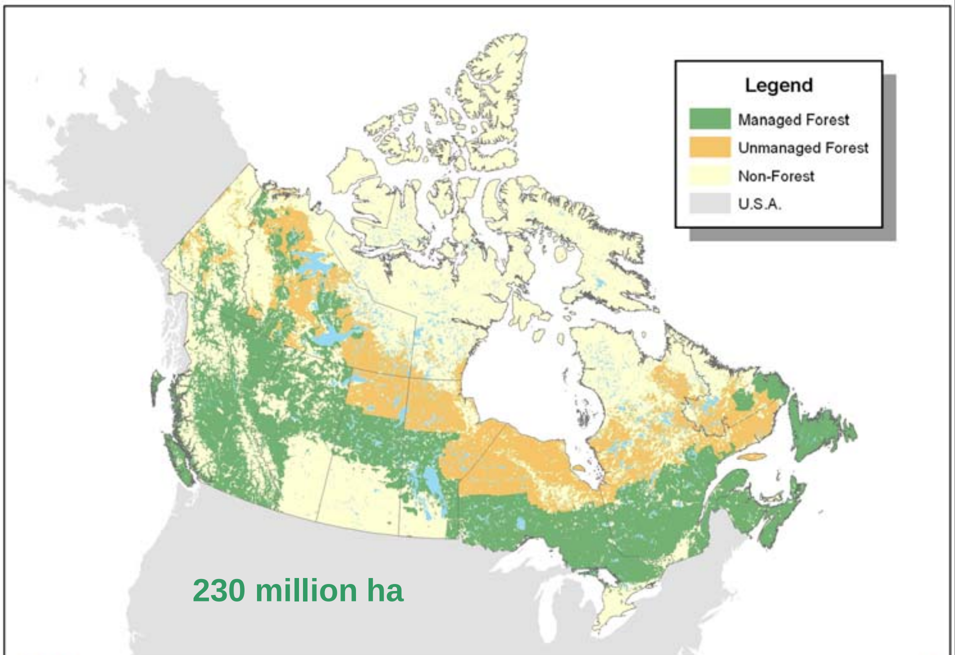

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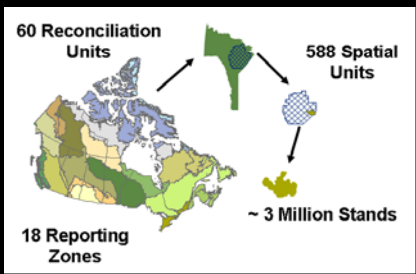
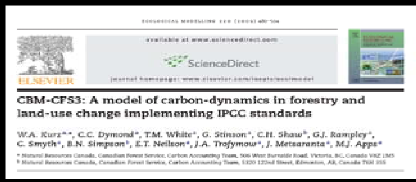
Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3)

- Stand to Landscape-scale model of forest ecosystem C dynamics developed to assess the past, present and future role of Canada's forests in the global C cycle.
- http://carbon.cfs.nrcan.gc.ca
- Uses empirical data from forest management planning

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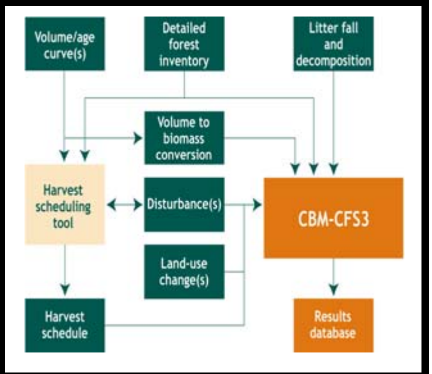
CBM-CFS3: A model of carbon-dynamics in forestry and land-use change implementing IPCC standards



National Data Synthesis and Integration

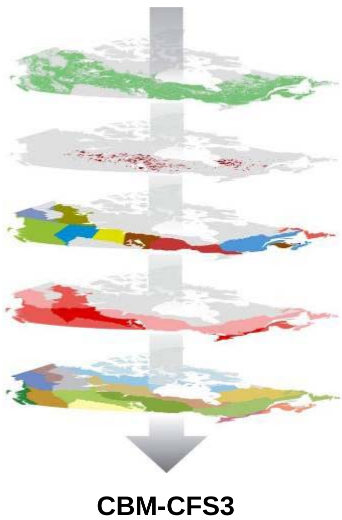
Forest inventory and growth & yield data

Natural disturbance monitoring data

Forest management activity data

Land-use change data

Ecological modelling parameters



Overview

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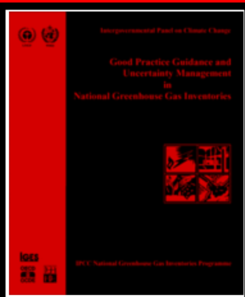
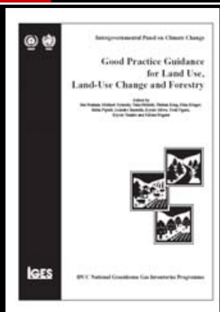
Context for Uncertainty Assessment

- Assessment of uncertainty in GHG inventories is required
- Uncertainty should be reduced "as far as is practicable"
- Not meant to judge validity of estimates
- Meant to provide guidance on where to direct efforts towards reducing uncertainty



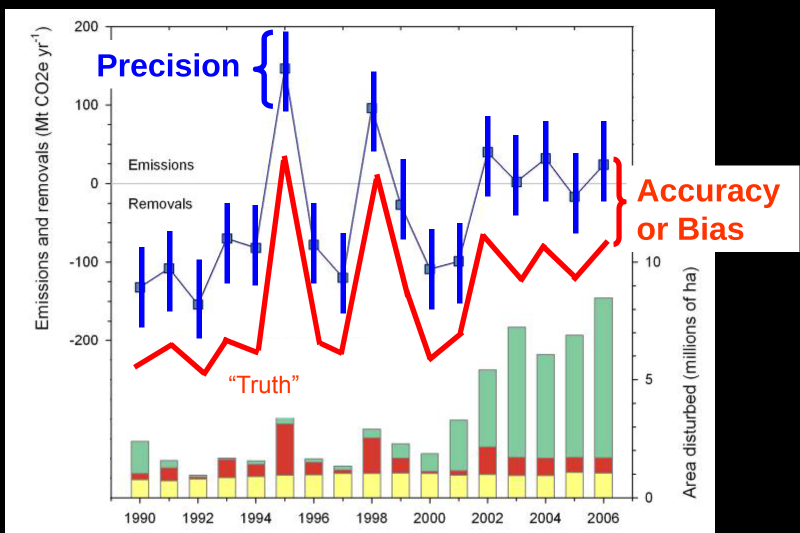


BOX 5.2.4
UNCERTAINTIES OF ESTIMATES BASED ON MODELS

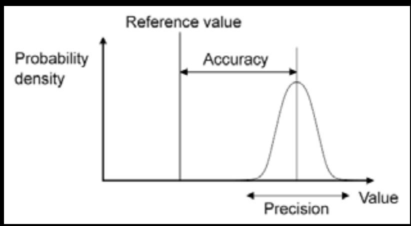
Models used in inventory construction can range from purely empirical/statistical relationships to detailed process based models. In practice, most models are constructed with elements of both. There are many issues to consider in quantifying the uncertainties in the estimates produced by these models. A few general comments can be made although it is beyond the scope of this document to review all relevant models. Overall uncertainty in models can be derived from two main components: uncertainty in the structure of the model and uncertainty in the parameter values. The first source of uncertainty is difficult to quantify. Comparison with observational field data can indicate that either the structure of the model or the parameter values or both are incorrect (Oreskes *et al.*, 1984). It is therefore important to test the validity of the models, and to use only models that are validated for the intended purpose. If a model is not well validated, a validation programme should complement its use. The uncertainty associated with parameter values can be more easily quantified by combining statistical estimates or expert judgments of parameter uncertainty with sensitivity, or Monte Carlo analysis. A sensitivity analysis should be performed before a model is used so as to determine its usefulness for prediction. A model that is highly sensitive to a parameter with high uncertainty may not be the best choice for inventory purposes. Given that the model structure is adequate, the final point to consider is the uncertainty of estimates produced by models. In this case, there are typically two error components to consider: uncertainty due to parameter uncertainty and uncertainty due to inherent variation in the population that cannot be captured by the model. When making these estimates, both sources of uncertainty should be considered in any calculation.

No mention of model input data

Components of Uncertainty



Components of Uncertainty



- Attempting to quantify precision
- Accuracy is improved by model and data improvements (we think)
- Very difficult to quantify because a "true" reference value will never exist
- Increased accuracy may have no effect on precision
- (Vice versa is also true)

- **Model intercomparison**
  - Canadian Carbon Program
  - North American Carbon Program
  - Others
- **Model validation**
  - Comparison to measurements at Canadian National Forest Inventory plots

Sensitivity Analysis


ECOLOGICAL MODELLING 219 (2008) 373–382

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journal homepage: www.elsevier.com/locate/ecolmodel

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A practical approach for assessing the sensitivity of the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3)

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[b] Faculty of Forestry and the Forest Environment, Lakehead University, Thunder Bay, ON, P7B 5E1 Canada
[c] Natural Resources Canada, Canadian Forest Service, Laurentian Forestry Centre, 1055 du P.E.P.S., Stn. Ste. Foy, Quebec, QC, G1V 4C7 Canada

Model is most sensitive to:
- The base decay rate of the slowly decomposing soil C pools
- How much of the very quickly decaying soil C pools is released directly to the atmosphere
- Model initialization assumptions

Data and sensitivity interact:
- Some parameters more important in some landscapes than others
- The most important parameters change over time

Sources of Uncertainty in CBM-CFS3

Model inputs:
- Forest Inventory and Growth Data *
- Activity Data *

Model parameters:
- Litterfall, decay, and transfer *
- Biomass estimation *
- Disturbance Impacts

Model Structure:
- Incorrectly specified or excluded processes
- Model algorithms

Human Error

Analysis

Monte Carlo Simulation
- 100 simulations of all of Canada
- 20 CBM-CFS3 projects
- ~ 1 month, ~10 PC's, ~1 TB of results

Varied disturbance data:
- fire (+/- 10%),
- harvest (+/- 10%),
- insects (+/- 25%), and
- deforestation (+/- 38%)

Varied biomass increment
- +/- 50%

Analysis

Varied some litterfall, decay and C transfer parameters

Table 1 – Variation in the parameters of interest for an uncertainty analysis using the CBM-CFS3 model in northwestern Ontario, Canada

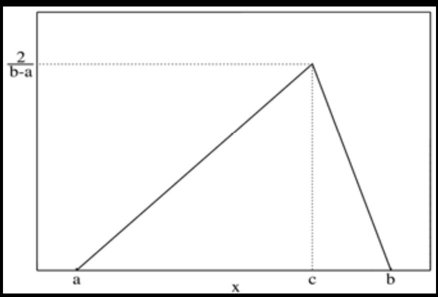
Parameters	Default	Minimum	Maximum	Reference/comments
Branch turnover rate	0.04	0.012	0.04	Adapted from Peltoniemi et al. (2006)
Coarse root turnover rate	0.02	0.007	0.023	Peltoniemi et al. (2006)
Fast above-ground base decay rate	0.1435	0.1	0.29	Adapted from Liski et al. (2005)
Fast above-ground proportion of C respired	0.83	0.7	0.9	Liski et al. (2005) and Smyth (submitted)
Fast below-ground base decay rate	0.1435	0.1	0.29	Adapted from Liski et al. (2005)
Fast below-ground proportion of C respired	0.83	0.7	0.9	Liski et al. (2005) and C. Smyth, personal communication
Fine root turnover	0.641	0.6	0.92	Adapted from Peltoniemi et al. (2006)
Foliage turnover rate for hardwoods[a]	0.95	0.8455	0.999	
Foliage turnover rate for softwoods[a]	0.1	0.1	0.2	Adapted from Peltoniemi et al. (2006)
Mean annual temperature	−0.435	−3.555	2.684	Mean ± 2S.D. for ecological unit
Medium base decay rate	0.0374	0.01	0.08	Adapted from Yatskov et al. (2003) and Bond-Lamberty et al. (2003)
Medium proportion of C respired	0.83	0.7	0.9	Liski et al. (2005)
Slow above-ground base decay rate	0.015	0.002	0.02	Liski et al. (2005)
Slow below-ground base decay rate	0.0033	0.0008	0.004	Adapted from Liski et al. (2005)
Stand-replacing disturbance interval	75	65	85	Used only in the spin-up sub-routine
Stem annual turnover	0.005	0.003	0.007	Peltoniemi et al. (2006), Hennon and McClellan (2003)
Stem snag turnover	0.032	0.032	0.14	Based on 1/2 life or rates reported in Vanderwel et al. (2006), Wilson and McComb (2005), Russell et al. (2006), Garber et al. (2005)
Very fast above-ground base decay rate	0.355	0.284	0.426	±20%
Very fast above-ground proportion of C respired	0.815	0.742	0.888	Smyth (submitted)
Very fast below-ground base decay rate	0.5	0.4	0.6	±20%
Very fast below-ground proportion of C respired	0.83	0.55	0.85	

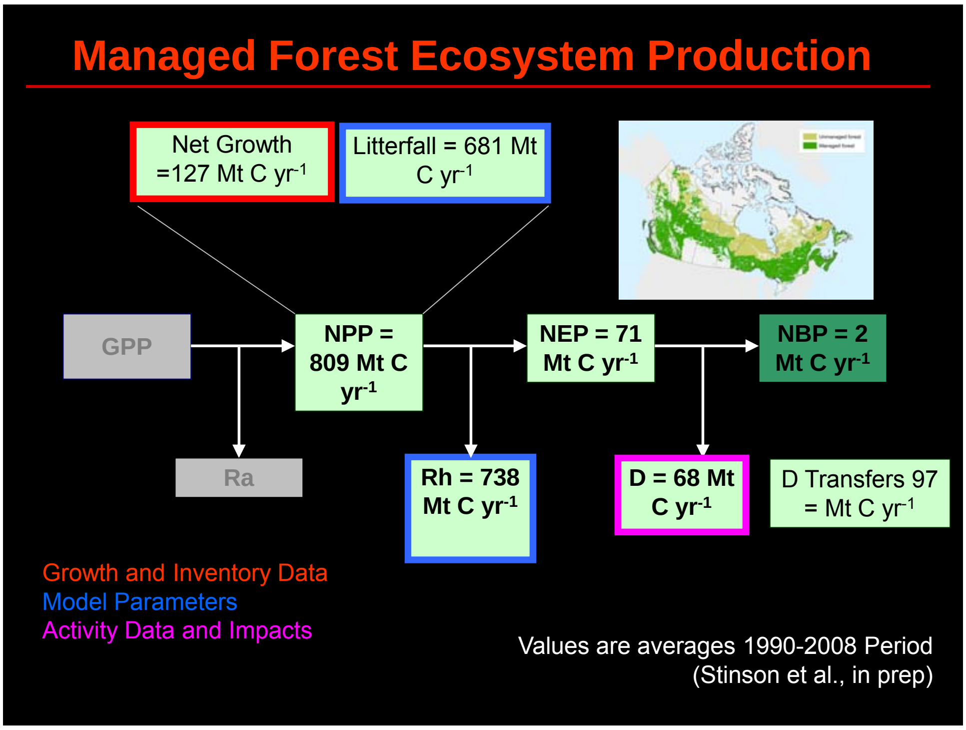
Unit for turnover rates and decay rate is yr^{-1}.

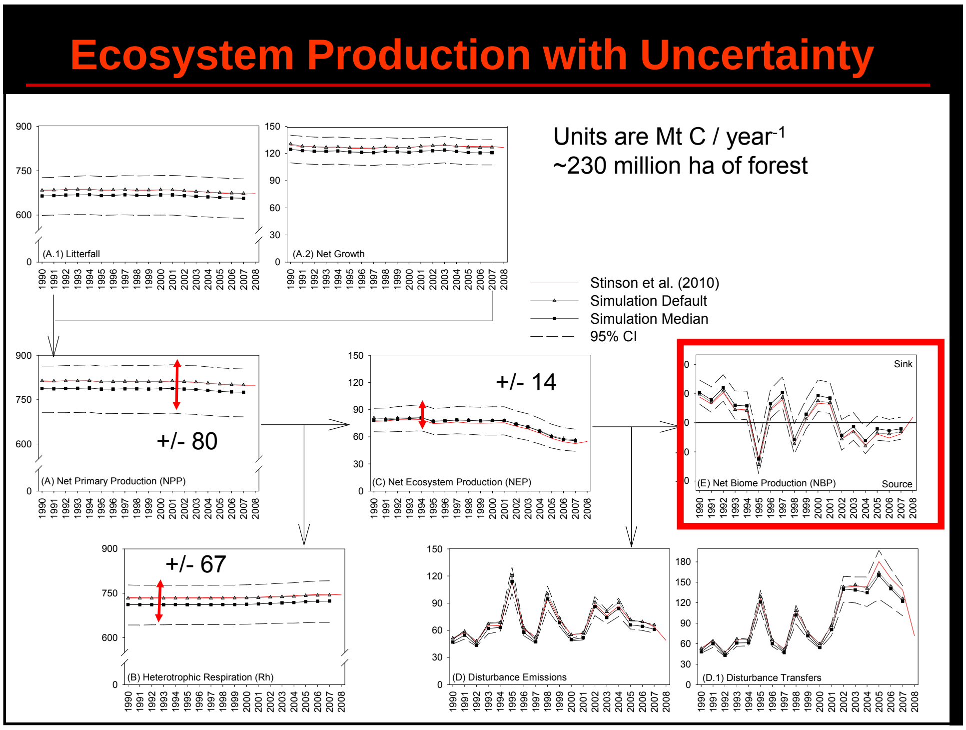
[a] None of the scenarios included both softwoods and hardwoods.

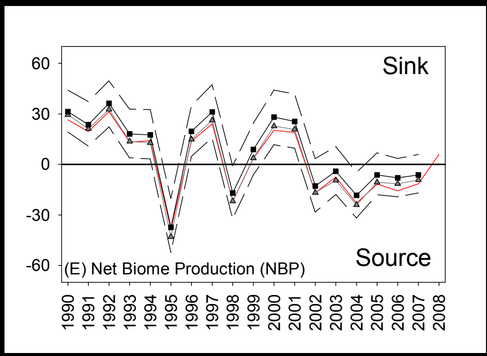
Analysis

- Assumed triangular distribution for uncertain variables
- Most variables were assumed to be independent

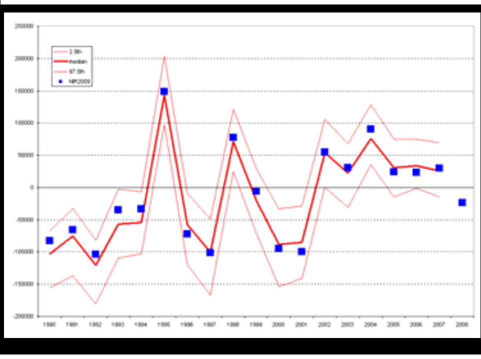



Managed Forest Ecosystem Production
Net Growth =127 Mt C yr-1
Litterfall = 681 Mt C yr-1
GPP
NPP = 809 Mt C yr-1
NEP = 71 Mt C yr-1
NBP = 2 Mt C yr-1
Ra
Rh = 738 Mt C yr-1
D = 68 Mt C yr-1
D Transfers 97 = Mt C yr-1
Growth and Inventory Data
Model Parameters
Activity Data and Impacts
Values are averages 1990-2008 Period
(Stinson et al., in prep)


Ecosystem Production with Uncertainty
Units are Mt C / year-1
~230 million ha of forest
(A.1) Litterfall
(A.2) Net Growth
Stinson et al. (2010)
Simulation Default
Simulation Median
95% CI
(A) Net Primary Production (NPP)
+/- 80
(C) Net Ecosystem Production (NEP)
+/- 14
Sink
(E) Net Biome Production (NBP)
Source
(B) Heterotrophic Respiration (Rh)
+/- 67
(D) Disturbance Emissions
(D.1) Disturbance Transfers



- Typically, 95% CI is ~+/- 14 Mt C



- Equivalent to LFL total CO_2 reporting value
- +/- 53 Mt when expressed as CO2e (p=0.05)
- ~7% of total GHG emissions in Canada (2007)

Uncertainty for reporting values

Reporting Value	*2008 Estimate*	*Uncertainty*
I) FLFL Total - CO_2	-23861	± 50107
I.1) FLFL Annual Processes - CO_2	-201986	± 45336
I.2) FLFL Immediate emissions from natural disturbances - CO_2	43003	± 9236
I.3) FLFL Immediate emissions from harvesting - CO_2	135301	± 2536
II) FLFL Total - CH_4	3870	± 777
II.1) FLFL Immediate emissions from natural disturbances - CH_4	3317	± 712
II.2) FLFL Immediate emissions from harvesting - CH_4	553	± 148
III) FLFL Total- N2O	2400	± 480
III.1) FLFL Immediate emissions from natural disturbances - N_2O	2060	± 443
III.2) FLFL Immediate emissions from harvesting - N_2O	340	± 103
IV) LFL Total - CO_2	-837	na[1]

Etc.

Issues in Interpretation

- Probability distributions used in the MC simulations are uncertain
- Some variable parameters may be correlated, or differently correlated that what we assumed
- Some model parameters were held constant
  - Disturbance impacts
  - Soil Carbon initialization

Uncertainty estimates area also uncertain

Conclusions

- Only brief guidance provided for uncertainty estimates based on models
  - No specific mention of uncertainty due to errors in input data
- Uncertainty due to model structure (~bias) is difficult to quantify
  - Can be approached by model intercomparision and validation
- Uncertainty due to model parameters (~precision) can be quantified with MC simulation
  - Computationally intensive

Uncertainty is a property of our minds, not of nature

Our minds interpret probability-based statements very badly

Issues in Interpretation

- Probability distributions used in the MC simulations are uncertain
- Some variable parameters may be correlated, or differently correlated that what we assumed
- Some model parameters were held constant
  - Disturbance impacts
  - Soil Carbon initialization

Uncertainty estimates area also uncertain

Psychonomic Bulletin & Review
2001, 8 (2), 191-202

Why is $p = .90$ better than $p = .70$? Preference for definitive predictions by lay consumers of probability judgments

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Eindhoven University of Technology, Eindhoven, The Netherlands

and

KARL HALVOR TEIGEN
University of Tromsø, Tromsø, Norway

What do people regard as an informative and valuable probability statement? This article reports four experiments that show participants to have a clear preference for more extreme and higher probabilities over less extreme and lower ones. This pattern emerged in Experiment 1, in which no context was provided, and was further explored in Experiment 2 within a positive and a negative context. The findings were further confirmed in Experiment 3, which employed a Bayesian framework with revisions of opinions. Finally, Experiment 4 showed how preference for high probabilities can lead people to prefer an overconfident to a more well-calibrated (accurate) forecaster. The results are interpreted as manifestations of a *search for definitive predictions* principle, which asserts that high probabilities are preferred to medium ones and often favored over the corresponding complementary low probabilities on the basis of their capacity to predict the occurrence of single outcomes.

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Organizational Behavior and Human Decision Processes 107 (2008) 179–191

ORGANIZATIONAL BEHAVIOR AND HUMAN DECISION PROCESSES

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Overconfidence in interval estimates: What does expertise buy you? ☆

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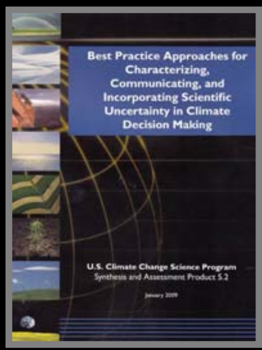
Abstract

People's 90% subjective confidence intervals typically contain the true value about 50% of the time, indicating extreme overconfidence. Previous results have been mixed regarding whether experts are as overconfident as novices. Experiment 1 examined interval estimates from information technology (IT) professionals and UC San Diego (UCSD) students about both the IT industry and UCSD. This within-subjects experiment showed that experts and novices were about equally overconfident. Experts reported intervals that had midpoints closer to the true value—which increased hit rate—and that were narrower (i.e., more informative)—which decreased hit rate. The net effect was no change in hit rate and overconfidence. Experiment 2 showed that both experts and novices mistakenly expected experts to be much less overconfident than novices, but they correctly predicted that experts would provide narrower intervals with midpoints closer to the truth. Decisions about whether to consult experts should be based on which aspects of performance are desired.

Keywords: Overconfidence; Expertise; Interval estimates

Biases

- **Optimism bias**
  – Over-estimate likelihood of positive events, under-estimate the likelihood of negative events
- **The overconfidence effect**
  – Answers rated as “95% certain” are true only about 50% of the time (both experts and non-experts)
- **Confidence heuristic**
  – People are more likely to believe confident estimates, over those that turn out to be accurate



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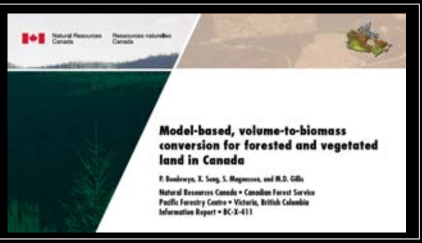
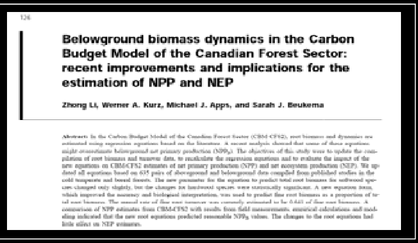
Biomass Estimation Uncertainty

Growth and yield models (province)

Merchantable Volume (m3/ha) yield curves



Above-ground biomass by component

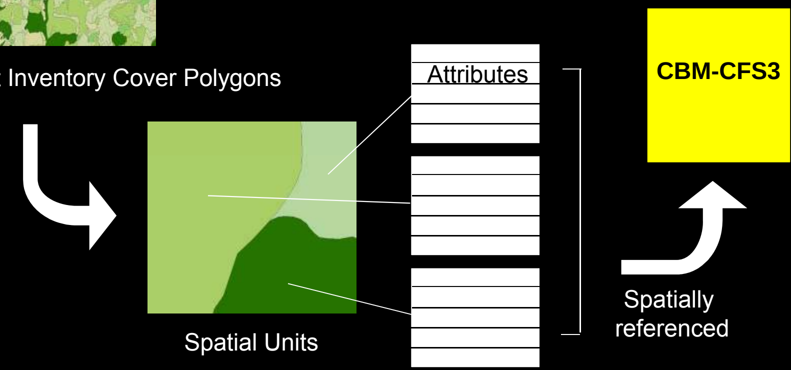


Below-ground biomass by component

Forest Inventory Uncertainty

- Error is up to 60% for some attributes and is not compensatory (Thompson et al. 2007)
- Low correspondence between inventory and ground species composition (Pinto et al. 2007)

Forest Inventory Cover Polygons

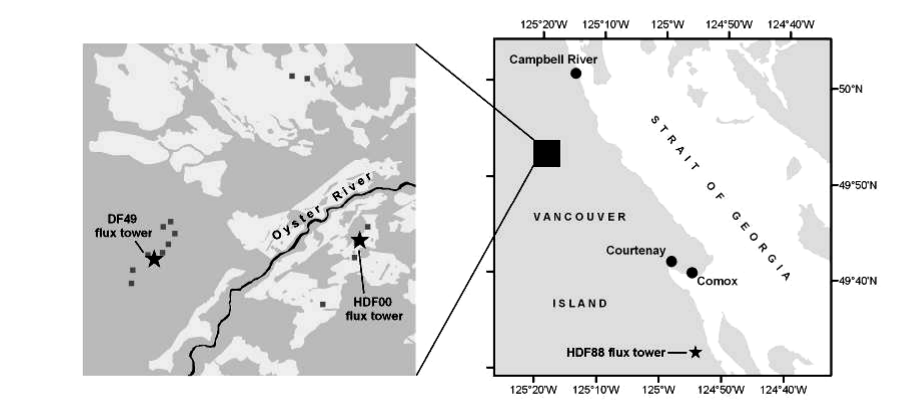


Canada Carbon Program

- Scaling up flux-tower measurements to the landscape
- Model intercomparisons
  - CBM-CFS3
  - ECOSYS (Z.Wang & R.Grant – U of Alberta)
  - Can-IBIS (D.Price – CFS)
  - InTEC (A.Govind & J.Chen – U of Toronto)
  - C-Class (A.Arain – McMaster U)
  - 3PG (R.Hember & N.Coops – UBC)
- Focus on 2 Fluxnet-Canada Research Network sites
  - Chibougamau (Quebec, Boreal Shield)
  - Oyster River (British Columbia, Pacific Maritime)

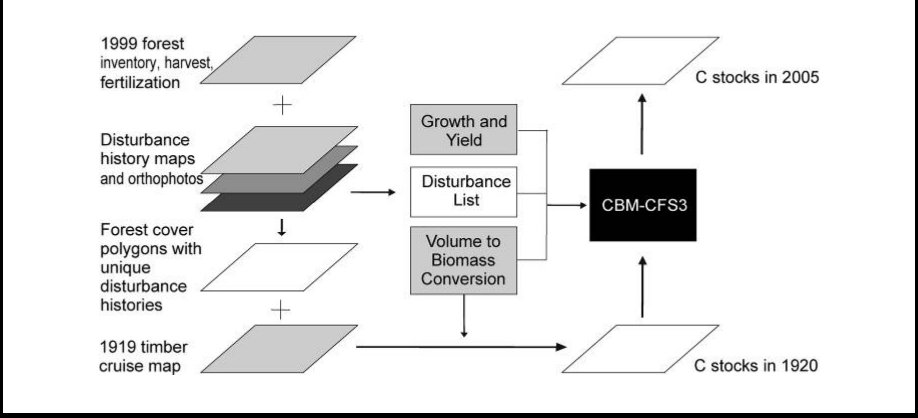
Canada Carbon Program

- Oyster River study
  - First phase of research now in press (Trofymow et al., Forest Ecology & Management)



Comparisons with flux tower estimates

- Oyster River study
  - First phase of research now in press (Trofymow et al., Forest Ecology & Management)
- Chibougamou study



National-scale comparisons

- Inventory-based modelling (CBM-CFS3)
- Process-based modelling (BEPS/InTEC)
- Inversion modelling (NOAA Carbon Tracker)