Uncertainty Analysis and Inventory Verification in IPCC 2006 Guidelines

Simon Eggleston

IPCC Task Force on National Greenhouse Gas Inventories

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This presentation

- Overview of guidance in 2006 GL
  - Introduction
  - Data Collection
  - Error Propagation
  - Monte-Carlo Method
- Some thoughts on this guidance in practice
- Overview of verification in 2006 GL

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Introduction

Approach and Definitions

Uncertainty

"Lack of knowledge of the true range of a variable that can be described as a probability density function (PDF) characterising the range and likelihood of possible values. Uncertainty depends on the analyst's state of knowledge, which in turn depends on the quality and quantity of applicable data as well as knowledge of underlying processes and inference methods."

IPCC 2006 Guidelines

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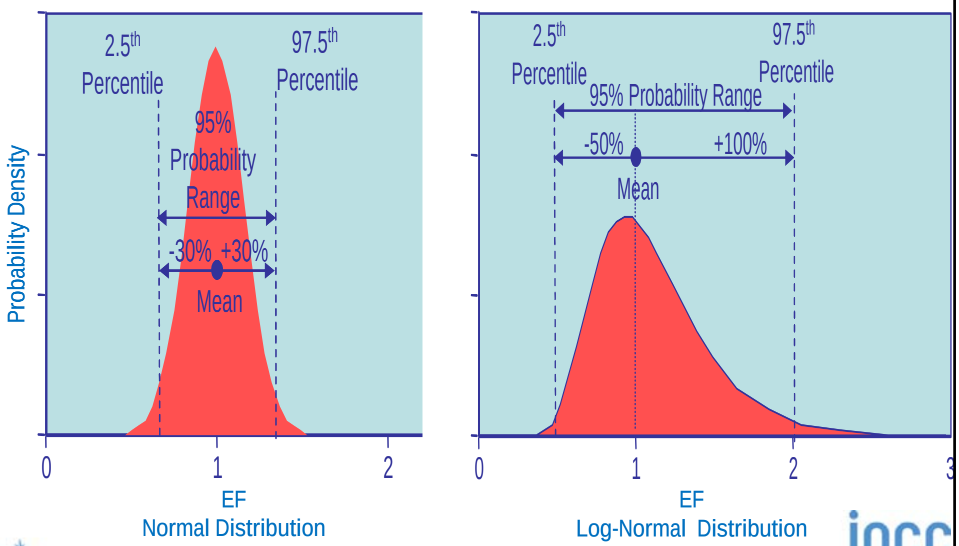
Specifying Uncertainty

- Uncertainty is quoted as the 2.5 and 97.5 percentile i.e. bounds around a 95% confidence interval

- This can be expressed as
  - 234 ± 23%
  - 26400 (- 50%, + 100%)
  - 2000 (a factor of 2) *(i.e. - 50%, + 100%)*
  - 10 an order of magnitude *(i.e. 1 to 100)*

Probability Density



Causes of uncertainty

	Bias	Random Errors	*Comment*
Lack of Completeness	§		*Either no data available or source/sink unrecognised*
Model	§	§	*Models are simplification of reality, can be very simple (e.g. E= A.F) or more complex*
Lack of data	§		*Use proxy or extrapolation/interpolation to replace missing data may*
Data is not representative	§		*Data may not cover full situation (e.g. may not include start-up conditions)*
Statistical random sampling error		§	*Data are random sample of population*
Measurement error	§	§	*Errors in measurement, recording etc.*
Misreporting or misclassification		§	*Unclear definitions, mistakes. Need QA/QC*
Missing data	§	§	*Measurements made but no data available e.g. below detection limit*

Three ways to deal with uncertainty

Calculation errors

- Use good QA/QC to avoid these
- Both checks during calculation and review and comparison of complete inventory

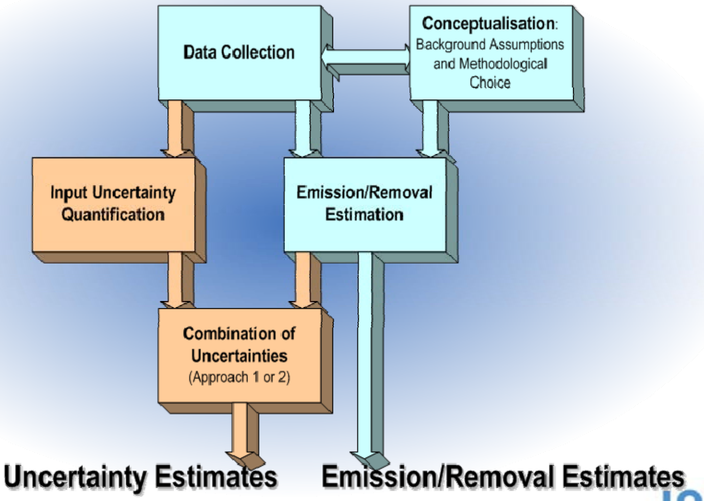
Input data

- Measured values have errors
- Sample and census errors
- Random errors treated analytically

Assumptions and methods

- Methods may not accurately reflect the emission.
- Guidelines aim to be unbiased and complete.
- Review and expert input to ensure assumptions correct.
- Guidelines aim to be unbiased

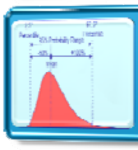
Generic Uncertainty Analysis



Uncertainty estimation in 2006 GL

Decide approach to use

- Error Propagation
- Monte Carlo



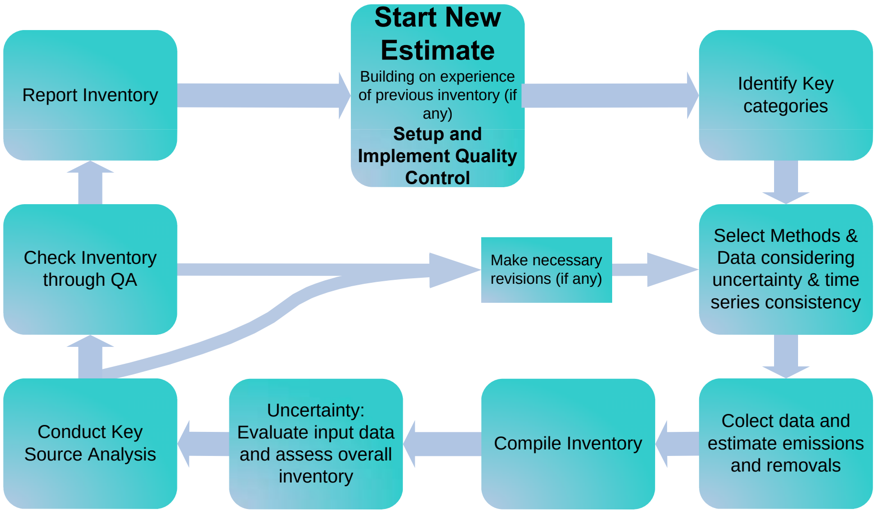
Gather information

- Collect uncertainty information on activity data and emission factors

Perform inventory analysis

- Spreadsheet
- Software tool

Inventory Cycle



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Data Collection

Data uncertainty

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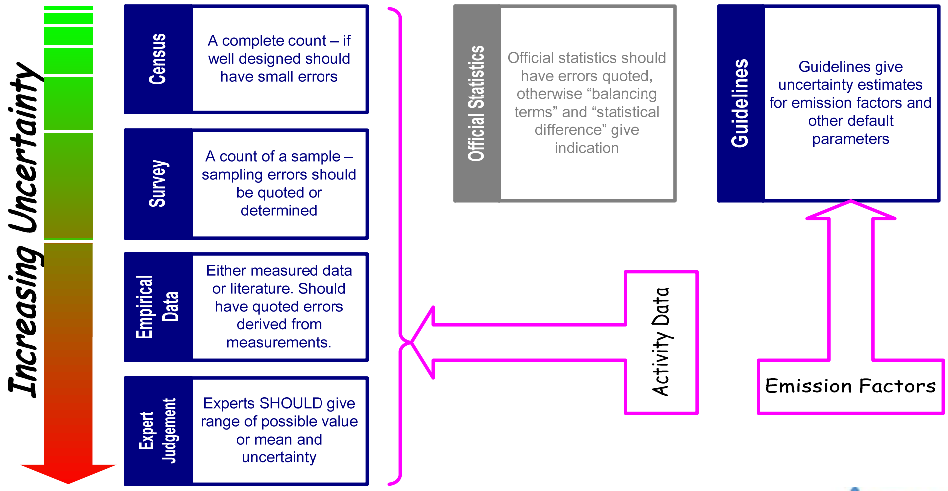
Uncertainty Information



Sources of data

- National Statistics Agencies
- Sectoral experts, stakeholder organisations
- Other national experts
- IPCC Emission Factor Database
- Other international experts
- International organisations publishing statistics e.g., United Nations, FAO, the International Energy Agency, OECD and the IMF (which maintains international activity as well as economic data)
- Reference libraries (National Libraries)
- Scientific and technical articles in environmental books, journals and reports.
- Universities
- Web search for organisations & specialists
- National Inventory Reports from Parties to the United Nations Framework Convention on Climate Change

Expert judgement

- Expert judgement on methodological choice and choice of input data to use is ultimately the basis of all inventory development.
- Experts with suitable backgrounds can be found in government, industrial trade associations, technical institutes, industry and universities.
- The goal of expert judgement may be:
  - choosing the proper methodology;
  - the parameter value and uncertainty from ranges provided;
  - the most appropriate activity data to use;
  - the most appropriate way to apply a methodology;
  - or determining the appropriate mix of technologies in use.
- Expert judgement is always required since one must judge whether the data are a representative random sample and, if so, what methods to use to analyze the data.
- This requires both technical and statistical judgement.
- Formal Expert Elicitation procedures help collect unbiased results

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Combining Uncertainties

Approaches to estimating overall uncertainties

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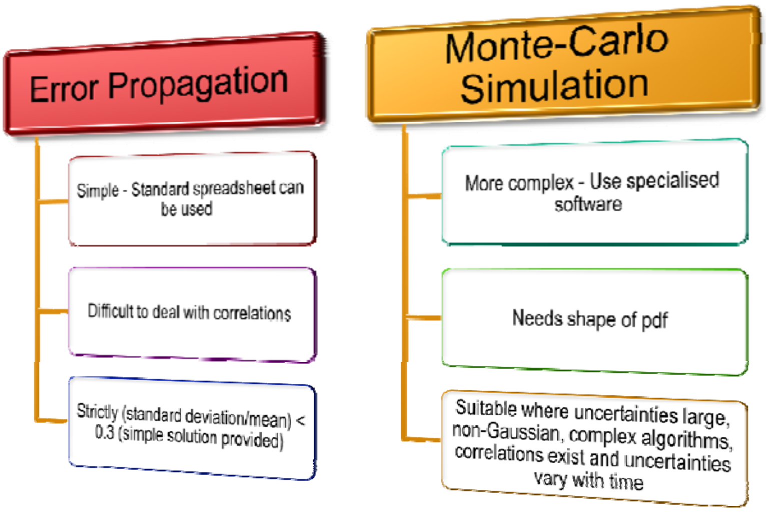
Methods to combine uncertainties



Error Propagation

- Key Requirements
  - Need mean and uncertainty
  - Assumes uncertainties symmetrical
  - Strictly uncertainties should be approximately <30% but 2006 GL have method to deal with larger uncertainties.
  - Difficult to deal with correlations
- Principle
  - Uses standard statistical error propagation equations
  - Spreadsheet applies this simply in a way that requires little experience

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From 2006 Guidelines:

Data calculated using simple equations

Enter emissions data

TABLE 3.2 APPROACH 1 UNCERTAINTY CALCULATION												
A	B	C	D	E	F	G	H	I	J	K	L	M
IPCC category	Gas	Base year emissions or removals	Year t emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to Variance by Category in Year t	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
		Input data	Input data	Input data Note A	Input data Note A	$\sqrt{E^2+F^2}$	$\frac{(G \bullet D)^2}{(\sum D)^2}$	Note B	$\left\lvert\frac{D}{\sum C}\right\rvert$	$I \bullet F$ Note C	$J \bullet E \bullet \sqrt{2}$ Note D	K^2+L^2
		Gg CO_2 equivalent	Gg CO_2 equivalent	%	%	%		%	%	%	%	%
E.g., 1.A.1. Energy Industries Fuel 1	CO_2											
E.g., 1.A.1. Energy Industries Fuel 2	CO_2											
Etc...	...											
Total		$\sum C$	$\sum D$				$\sum H$					$\sum M$
					Percentage uncertainty in total inventory:		$\sqrt{\sum H}$				Trend uncertainty:	$\sqrt{\sum M}$

Enter uncertainties

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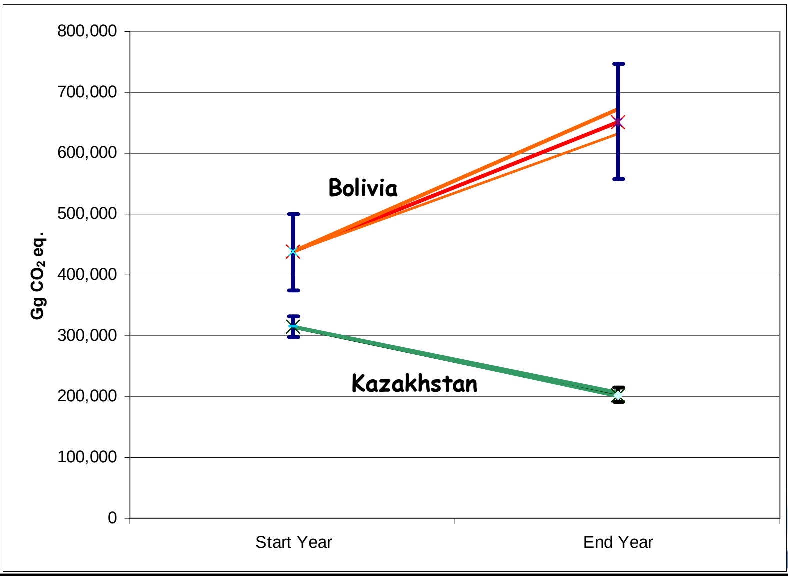
Activity Data uncertainties based on source of data

EF uncertainties based on defaults in guidelines

Note short list of source/sinks

Approach 1 uncertainty calculation												
A	B	C	D	E	F	G	H	I	J	K	L	M
IPCC category	Gas	Base year emissions or removals	Year t emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to Variance by Category in	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national	Uncertainty in trend in national	Uncertainty introduced into the trend in total national emissions
			Input data	Input data	Input data	$\sqrt{E^2+F^2}$	$\frac{(G \bullet D)^2}{(\sum D)^2}$	Note B	$\left\lvert\frac{D}{\sum C}\right\rvert$	$I \bullet F$	$J \bullet E \bullet \sqrt{2}$	K^2+L^2
		Gg CO_2 equivalent	Gg CO_2 equivalent	%	%	%		%	%	%	%	%
1.A.1. Energy Industries	CH4	35.5346662	32.9951217	5	25	25.50	0.0	3.20506E-05	0.00010495	0.000801264	0.000742109	1.19275E-06
1.A.2. Manufacturing Industries and Constructior	CH4	57.0302899	51.8776096	5	25	25.50	0.0	4.80131E-05	0.000165011	0.001200328	0.001166804	2.80222E-06
1.A.3. Transport	CH4	81.7067834	37.1466612	5	25	25.50	0.0	-4.94664E-05	0.000118155	-0.00123666	0.000835483	2.22736E-06
1.A.4. Other Sectors	CH4	1041.24025	428.554682	5	25	25.50	0.0	-0.000772946	0.001363136	-0.019323647	0.009638828	0.00046631
1.A.5. Other	CH4	330.338228	97.5658895	5	25	25.50	0.0	-0.000367351	0.000310335	-0.009183772	0.002194401	8.91571E-05
1.B.1. Solid Fuels	CH4	24867.6834	12364.38	10	25	26.93	2.7	-0.011678579	0.039328314	-0.291964463	0.556186352	0.394586505
1.B.2. Oil and Natural Gas	CH4	12570.348	4022.34735	10	25	26.93	0.3	-0.012988732	0.012794183	-0.324718297	0.180937071	0.138180196
2.B. Chemical Industry .	CH4	40.53	37.5018	10	25	26.93	0.0	3.61373E-05	0.000119285	0.000903433	0.001686942	3.66196E-06
4.A. Enteric Fermentation.	CH4	14054.9863	734[illegible]	[illegible]	[illegible]	[illegible]	1.5	-0.005462727	0.023368679	-0.163881819	0.495724537	0.272600067
4.B. Manure Management.	CH4	1903.28061	1199.6[illegible]	[illegible]	[illegible]	[illegible]	0.0	-8.88245E-05	0.003815756	-0.002664735	0.080944413	0.006559099
4.C. Rice Cultivation.	CH4	522.9	33[illegible]	[illegible]	[illegible]	[illegible]	0.0	5.3609E-06	0.001078092	0.000160827	0.015246523	0.000232482
4.F. Field Burning of Agricultural Residues.	CH4	64.3314	[illegible]	[illegible]	[illegible]	[illegible]	0.0	-1.24107E-05	0.000119565	-0.000372321	0.003381819	1.15753E-05
6.A. Solid Waste Disposal on Land.	CH4	1959.72	373[illegible]	[illegible]	[illegible]	[illegible]	0.4	0.00787088	0.011891742	0.236126385	0.252261939	0.119391756
6.B. Wastewater Handling.	CH4	787.08	747.18[illegible]	[illegible]	30	33.54	0.0	0.000761896	0.002376612	0.022856865	0.050415547	0.003064164
1.A.1. Energy Industries	CO2	102607.31	9596[illegible]	5	5	7.07	11.2	0.094441853	0.305249301	0.472209267	2.158438506	4.881838378
1.A.2. Manufacturing Industries and Constructior	CO2	33991.06	[illegible]4.34	5	5	7.07	1.1	0.02618491	0.095945987	0.130924551	0.678440577	0.477422855
1.A.3. Transport	CO2	23987.07	8406.48	5	5	7.07	0.1	-0.022453294	0.026739124	-0.11226647	0.189074157	0.048352797
1.A.4. Other Sectors	CO2	44332.52	11784.04	5	5	7.07	0.2	-0.053800014	0.037482383	-0.269000072	0.265040472	0.14260749
1.A.5. Other	CO2	8370.16	4124.19	5	5	7.07	0.0	-0.004052209	0.013118122	-0.020261045	0.092759127	0.009014766
1.B.2. Oil and Natural Gas	CO2	3408.21	5171.49583	10	15	18.03	0.2	0.009456387	0.016449366	0.141845811	0.232629165	0.074236563
2.A. Mineral Products.	CO2	5744.63	2507.20146	10	15	18.03	0.0	-0.003809586	0.007974844	-0.057143788	0.112781331	0.015985041
2.B. Chemical Industry .	CO2	1355.56	171.93456	10	15	18.03	0.0	-0.002233954	0.000546885	-0.033509311	0.007734125	0.001182691
2.C. Metal Production.	CO2	12932.6799	10507.4715	10	15	18.03	0.9	0.006887639	0.033421905	0.103314586	0.47265712	0.234078657
5.A. Changes in Forest and Other Woody Bioma	CO2	97.19		50	80	94.34	0.0	-0.000199385	0	-0.015950798	0	0.000254428
5.A. Changes in Forest and Other Woody Bioma	CO2	-7810.79	-7721.7341	50	80	94.34	12.9	-0.008539362	0.024561101	-0.683148991	1.736732102	3.482930938
5.B. Forest and Grassland Conversion.	CO2	6.26	280.43888	25	75	79.06	0.0	0.00087917	0.000892013	0.065937785	0.031537424	0.005342401
1.A.1. Energy Industries	N2O	388.516902	328.741673	5	50	50.25	0.0	0.000248607	0.001045653	0.012430334	0.007393886	0.000209183
1.A.2. Manufacturing Industries and Constructior	N2O	112.709781	114.844426	5	50	50.25	0.0	0.000134069	0.000365294	0.006703468	0.002583021	5.16085E-05
1.A.3. Transport	N2O	57.3319301	21.6195922	5	50	50.25	0.0	-4.88495E-05	6.87671E-05	-0.002442474	0.000486257	6.20212E-06
1.A.4. Other Sectors	N2O	194.497577	46.1816455	5	50	50.25	0.0	-0.000252117	0.000146893	-0.01260587	0.001038693	0.000159987
1.A.5. Other	N2O	27.4386549	13.5195061	5	50	50.25	0.0	-1.3288E-05	4.30025E-05	-0.000664398	0.000304074	5.33886E-07
4.B. Manure Management.	N2O	375.1	198.4	15	30	33.54	0.0	-0.000138451	0.000631066	-0.004153541	0.013386927	0.000196462
4.D. Agricultural Soils(2).	N2O	25217.694	9798.17	20	30	36.06	3.0	-0.020551916	0.031165777	-0.616557485	0.881501284	1.157187646
4.F. Field Burning of Agricultural Residues.	N2O	24.304	21.297	20	30	36.06	0.0	1.78812E-05	6.7741E-05	0.000536437	0.001916004	3.95884E-06
6.B. Wastewater Handling.	N2O	452.6	384.4	15	30	33.54	0.0	0.000294175	0.00122269	0.008825264	0.025937172	0.000750622
Keep Blank!	...									0		
Total		314388.7626	202771.1719			$\sum H$	34.6				$\sum M$	11.4670044
					Percentage uncertainty in total inventory:		5.880740472				Trend uncertainty:	3.386296561

Example Results



Monte-Carlo Method

- Key Requirements
  - Not just uncertainties but also probability density function (pdf)
    - Mean
    - Width
    - Shape (e.g. Normal, Log-normal, Weibul, Gamma, Uniform, Triangular, Fractile, …)
- Principle
  - Select random values of input parameters from their pdf and calculate the corresponding emission. Repeat many times and the distribution of the results is the pdf of the result, from which mean and uncertainty can be estimated

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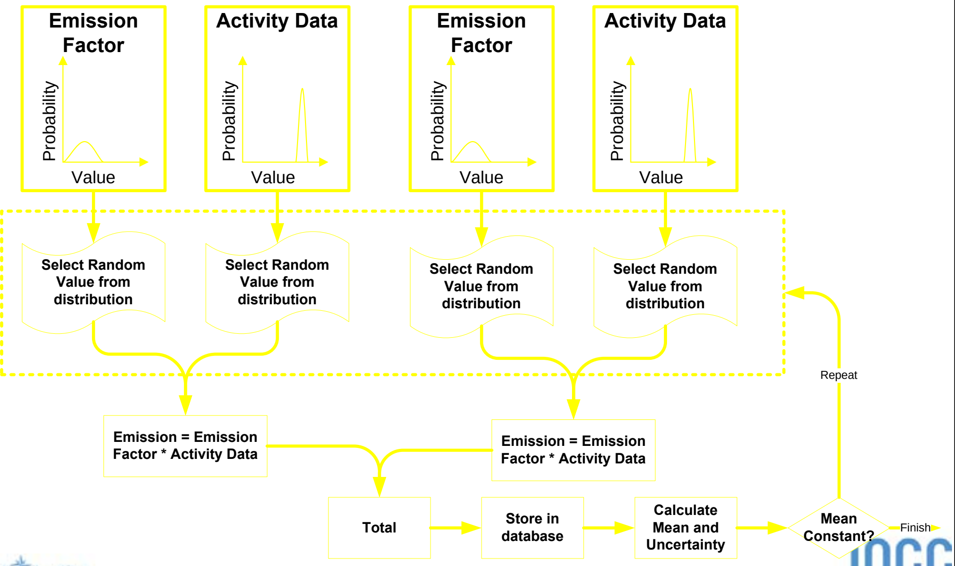
Monte-Carlo Method



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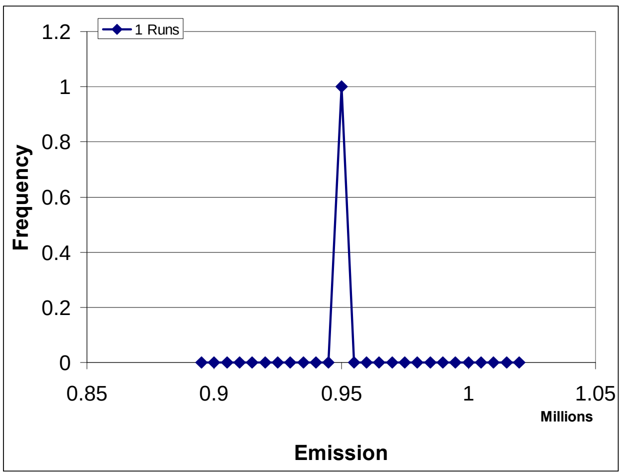

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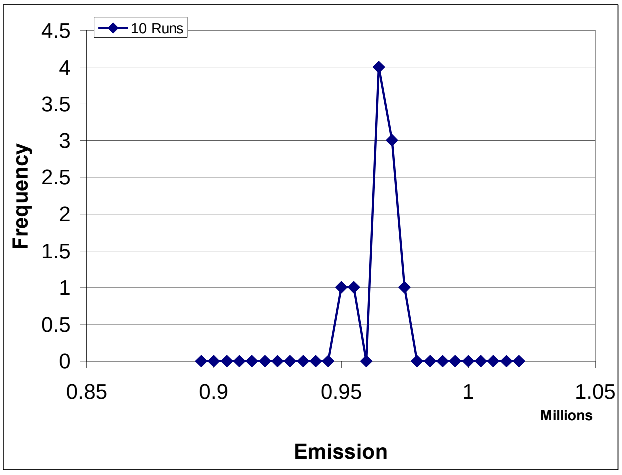

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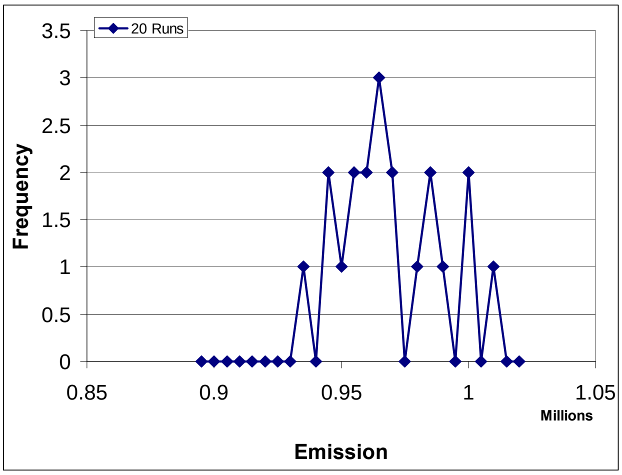

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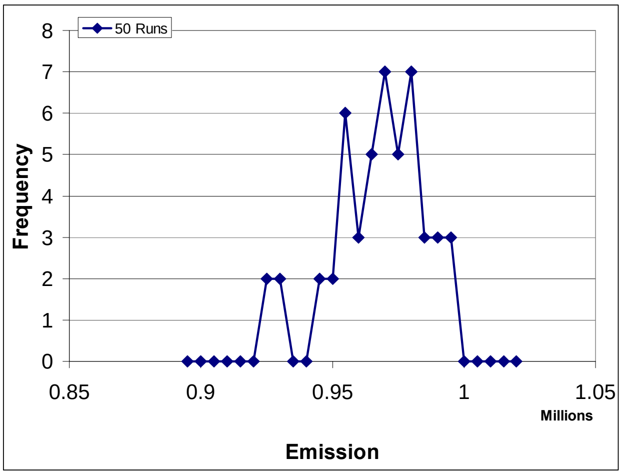

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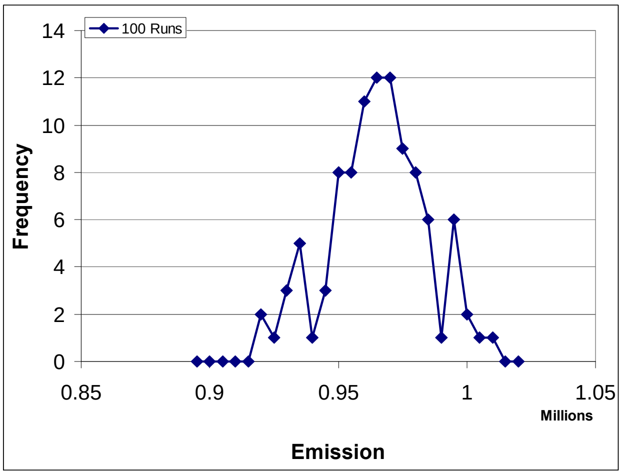

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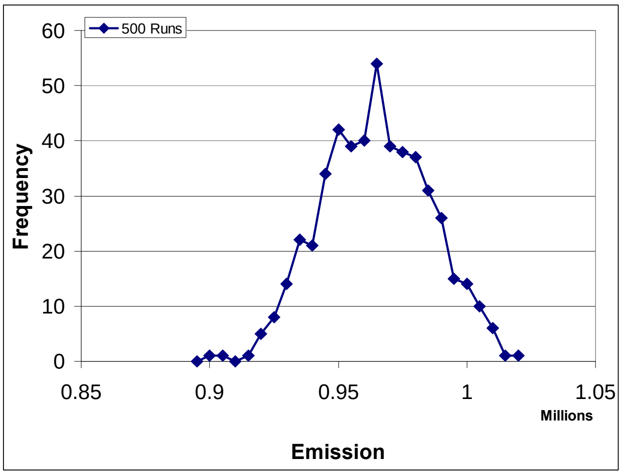
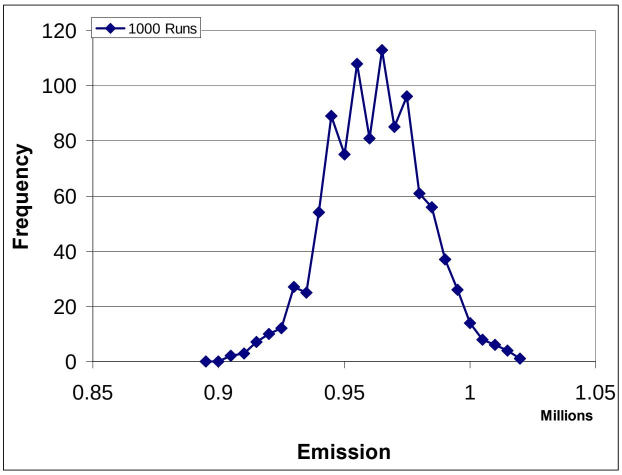
500



1 000



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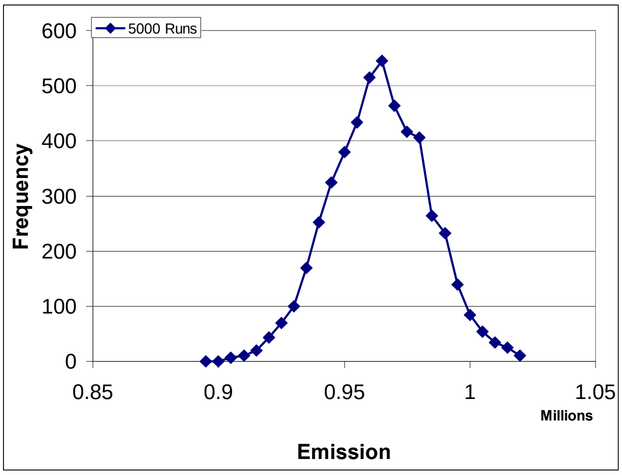
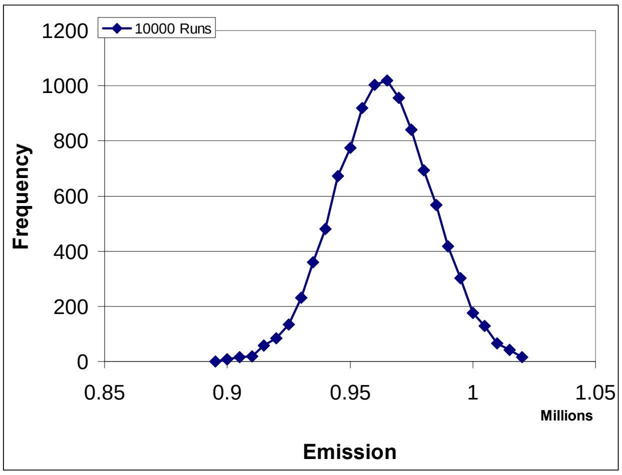
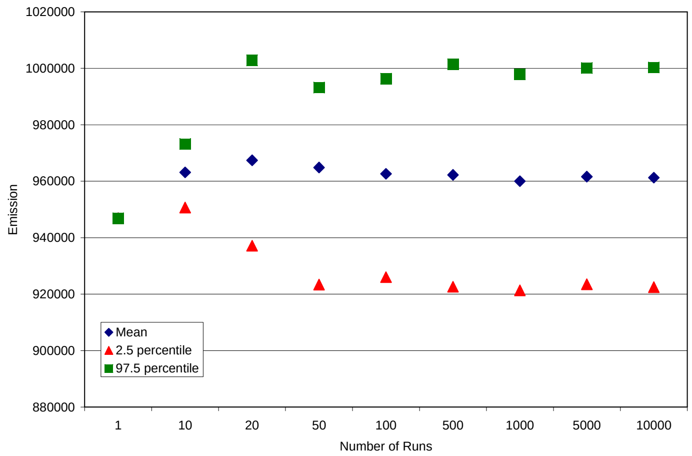
5 000


5000 Runs
Frequency
600
500
400
300
200
100
0
0.85
0.9
0.95
1
1.05
Millions
Emission

10 000


10000 Runs
Frequency
1200
1000
800
600
400
200
0
0.85
0.9
0.95
1
1.05
Millions
Emission

Summary Results



Some thoughts

Where emissions and removals balance…

– EQUATION 3.2, COMBINING UNCERTAINTIES – APPROACH 1 – ADDITION AND SUBTRACTION

$$U_{total} = \frac{\sqrt{(U_1 \bullet x_1)^2 + (U_2 \bullet x_2)^2 + \ldots + (U_n \bullet x_n)^2}}{|x_1 + x_2 + \ldots + x_n|}$$

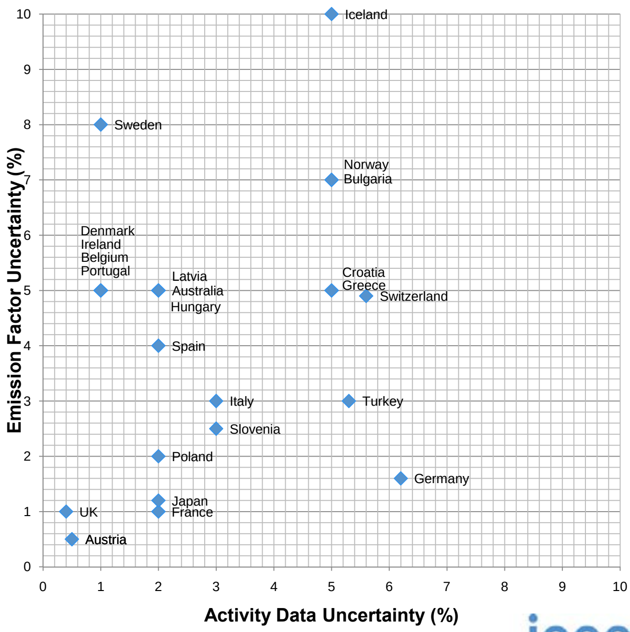
– If emissions and removals balance

$$|x_1 + x_2 + \ldots + x_n| \rightarrow 0$$

– …

Electrical Power Generation - Solid Fuel

- Data from 2009 submissions to UNFCCC
- Some variability due to differences in national circumstances
  - BUT can that explain all the variation?
- Not all parties report data at this level of detail
- Can we give advice on how to determine data uncertainty in a consistent way and to increase the consistency and transparency of reporting uncertainties?



Other Potential Issues

- Determining the uncertainty of input data
  - This should be done as part of the data collection to assess the activity data and emission factors
  - Need for consistency
- Treatment of correlations
  - An area for misunderstandings
  - Often not well treated
  - Simple guidance needed

Other Questions:

- Why?
  - Why is this needed? Is it important?
  - We need clear justification
- What?
  - What is involved. What do the results mean?
  - We should show this is practical for all
  - The method chosen should be match resources and expertise, while giving useful information
- When?
  - This should be an integral part of inventory compilation –not an “add on” at the end!
- How
  - We need to ensure the guidance is useable by all

Benefits of Uncertainty Analysis

Credibility

Inventories are estimates – uncertainty analysis gives a clear statement on what we do and do not know.

Utility

Users of the inventory need to know how reliable the numbers are – especially if they are input into policy or inventory improvement actions

Requirement

Uncertainty analysis is a requirement of all good practice inventories

Scientific

All scientific analysis should include an uncertainty assessment

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Remember…

- Most important is producing high quality “Good Practice” emission and removal estimates
- Effort on uncertainty analysis should be small in comparison to effort on inventory estimates themselves
- Data collection activities should consider data uncertainties
  - This will ensure the best data is collected & ensures good practice estimates
  - As you collect data you should assess how “good” it is
- At its simplest a well planned uncertainty assessment should only take a few extra hours!

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Outline report - BOG on guidance

- Why make Uncertainty Estimates?
  - Credibility/ Scientific Understanding/ Aid to users/ Required
- Process:
  - An integral Part of data collection
  - Choice of approach
  - Resources
- Specific Issues
  - Use of Guidelines Equations / Approach 1
  - Correlations (simple definition and step-by-step approach to dealing with them)
  - Consistent estimation of Uncertainty Data
  - Stratification and combined Approach 1 and 2
  - Others…
- Interpretation of uncertainty assessment
- Tier 3 model uncertainty assessment – meeting in August (tbc)

Summary

- Even simple uncertainty estimates give useful information - If they are performed well!
- Assessment of uncertainty in the input parameters **should** be part of the standard data collection QA/QC
  - careful consideration will improve estimates as well as providing input data for uncertainty analysis
- If resources limited: amounts spent on uncertainty analysis should be small compared with total effort.
- Inventory compilers find this a difficult area and will benefit from additional advice
- e.g. (For simple estimates):
  - Asses uncertainty in activity data as data collected
  - Uncertainty in emission factors from guidelines when not readily available
  - Aggregate categories/gases to independent groups of sources/sinks
  - Use Approach 1 – the spreadsheet requires little statistical knowledge

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Verification in the 2006 Guidelines

A limited discussion in the 2006 Guidelines!

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Comparisons with other estimates

- Compare with lower tier method if using higher tier method (e.g. Tier 3)
- Energy emission use reference approach to compare with national energy balances
- Comparison with incomplete “bottom-up” (higher tier) approaches
- Comparison with independently compiled estimates
  - E.g. IEA, CDIAC, EDGAR…
- Comparisons of intensity indicators between countries

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Comparisons with atmospheric measurements

- 2006 GL: "comparisons with atmospheric measurements cannot therefore be a standard tool for [inventory] verification"
- Measurements may be ground based, aircraft or satellite
- Techniques include:
  - Inverse modelling
  - Continental Plumes
  - Use of Proxy Emission databases
  - Global Dynamics Approaches
- Issues include:
  - Inclusion of natural fluxes and international transport
  - Timescales (measurement and analysis!)
  - Need for continuous measurements
  - Complexity and uncertainty

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BOG Report - Verification

- What are the current capabilities and limitations of ambient measurement systems (e.g. satellite, aircraft, flux towers, ground based measurements) for inventory verification
- What are the anticipated improvements of these systems over time in respect of their capabilities to validation/verification of emission inventories?
- What analytic methods are available to compare these measurements with inventory estimates and what are their limitations?
- In the context of specific IPCC categories how can these systems be used to validate/verify emission estimates?
- Comparisons with other estimates

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Thank you - any questions?

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