Expert Meeting on Uncertainty and Validation of Emission Inventories

23-25 March 2010

Utrecht, the Netherlands

Task Force on National Greenhouse Gas Inventories

INTERGOVERNMENTAL PANEL ON climate change

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FOREWORD

The IPCC's Task Force on National Greenhouse Gas Inventories has, as part of its mandate, the objective of encouraging users to adopt the IPCC methodological guidelines for estimating national inventories of greenhouse gases. This report is one of a series, developed through expert meetings, which aims to assist users of the guidelines by addressing specific problem areas.

In this case the expert meeting focused on dealing with uncertainty and with emission inventory validation. Since the 2006 IPCC Guidelines for National Greenhouse Gas Inventories was produced the science of remote sensing and ambient measurements has developed through the use of techniques such as inverse modeling to increase the potential applicability of the techniques to inventory validation. In addition, it has become clear that some users of the guidelines on uncertainty management need additional help to apply the methods in the guidelines correctly. This meeting aimed at considering both issues.

We would like to thank all those involved in this meeting. In particular we would like to express our sincere thanks and appreciation to TNO and the Government of the Netherlands for their support by hosting this meeting.

Thelma Krug
Co-Chair Task Force Bureau

Taka Hiraishi
Co-Chair Task Force Bureau

Executive Summary

The meeting reviewed both the use of the current IPCC guidelines on uncertainty management and recent developments related to inventory validation.

On the current IPCC guidelines on uncertainty management, the meeting agreed that the current guidelines still reflect the state of the art but need to be supplemented by easy-use advice on how to approach uncertainties for those with less experience. A first set of Q&A was provided for the TFI web site.

There was consensus that, while remote sensing, ambient measurement and inverse modelling techniques have been successfully demonstrated they are currently not sufficiently developed to provide comprehensive verification at the required accuracy, much is to be gained from working together, to improve verification techniques as well as gain better understanding of inventory estimates, and of natural emissions and removals. The meeting acknowledged that growing international interest in monitoring and verification is increasing the importance of dealing properly with uncertainty and is suggesting new initiatives for emissions inventories that can improve prospects for independent verification.

The participants looked forward to future collaboration and identified a number of areas for possible prioritization over the next few years and hoped that the group would meet again in a similar forum in say two years' time to review progress.

1. Introduction

The expert meeting of Intergovernmental Panel on Climate Change (IPCC) reviewing the use of the IPCC guidance on emission inventories was held in May 2008 in Helsinki, Finland[1]. The meeting identified uncertainty as an area where inventory compilers were having difficulties in following the IPCC Guidelines and Good Practice Guidance and suggested holding an expert meeting to produce some additional material to assist inventory compilers.

Subsequently the IPCC's Task Force on National Greenhouse Gas Inventories (TFI) Bureau decided to expand the idea to include the linked concept of validation/verification of emission inventories and convene an expert meeting.

The IPCC expert meeting on Uncertainty and Validation of Emission Inventories was held in Utrecht, the Netherlands from 23 to 25 March 2010 and hosted by TNO (Netherlands Organization for Applied Scientific Research). A total of 50 participants including IPCC TFI Co-chairs, Task Force Bureau (TFB) members, invited experts/researchers and members of Technical Support Unit (TSU) attended the meeting.

The meeting discussed a number of topics in two main areas: the use of the uncertainty guidance in the IPCC Guidelines, and ambient measurements systems (e.g. satellite, aircraft, flux towers, ground based measurements etc.) for the validation/verification of emission inventories.

This report summarizes discussions and conclusions of the meeting, and aims to provide additional information to inventory compilers on how they should assess inventory uncertainty at all tiers, how this should be reported and how inventories may be validated and verified.

[1]The IPCC Expert Meeting on IPCC Guidance on estimating emissions and removals of greenhouse gases from land uses such as agriculture and forestry

2. Summary of Discussions

The meeting was opened by Mr. Taka Hiraishi, IPCC TFI Co-chair. He welcomed all participants and outlined the background of the meeting.

This was followed by the welcome speech of Mrs. Aukje Hassoldt, TNO. She noted the importance of the meeting and highlighted the TNO activities on environmental issues including climate change.

Welcome remarks were followed by introductory and invited presentations. The presentations and discussions dealt with a number of topics, specifically:

- Uncertainty assessments of emission inventories
- Treatment of uncertainties associated with remote sensing
- Use of ambient measurements and inverse modelling
- Current capabilities of ambient measurement systems - e.g. satellite, aircraft, flux towers, ground based measurements etc.
- Anticipated improvements of these systems over time in respect of their capabilities to validate emission inventories
- In the context of specific IPCC categories how can these systems be used to validate emission estimates

In the afternoon session on second day two breakout groups (BOGs) dealing with additional information on estimating uncertainties in GHG inventories (BOG1) and use of measurements and/or inverse modelling to validate emission inventories (BOG2) were convened to continue further deliberations. The BOGs presented the outcome of their discussions to the plenary in the afternoon on the final day.

2.1 Additional information on estimating uncertainties in GHG inventories

After considering the existing guidance on uncertainties given in the IPCC Guidelines (IPCC 2000, 2003 and 2006), the information presented and their experience in using the guidelines, the meeting participants came to the following conclusions:

- The guidance on uncertainty assessment provided in the 2006 IPCC Guidelines is technically correct. However, it presents a very technical description and therefore an easy-to-use guide is needed to assist users new to the topic. This can be written as Q&A and presented as linked pages on the TFI web site. A first version of the Q&A is presented in Annex 2.
- The participants highlighted the increasing emphasis and attention on uncertainty analysis as monitoring and verification of emissions are getting more important and financial mechanisms are put into place.
- The participants recognized that finer spatial and temporal resolution, plus inclusion of both anthropogenic and natural sources and sinks, might be desirable in emissions inventories in order to reduce uncertainty in comparisons with monitored concentrations and to improve prospects for independent monitoring and verification.
- Uncertainty assessment is more than just a calculation of uncertainty range. Users should try to understand the reasons for the uncertainty. Scientific understanding of uncertainties and their reasons will guide users towards improving emission inventory.

2.2 Use of measurements and/or modelling to validate emission inventories

The meeting participants considered how existing techniques using remote sensing and ambient data could be used to validate or assist inventory compilers, either now or in the foreseeable future.

There was consensus that, while remote sensing, ambient measurement and inverse modelling techniques have been successfully demonstrated they are currently not sufficiently developed to provide a comprehensive routine verification at the desired accuracy, much is to be gained from working together, to improve verification techniques as well as gain better understanding of inventory estimates, and of natural emissions and removals. The participants felt use of forward transport simulations of inventory-based (bottom-up) and inverse model (top-down) flux estimations should be conducted and validated against independent observations, as and when available.

The participants looked forward to future collaboration and identified a number of areas for possible prioritization over the next few years and hoped that the group would meet again in a similar forum in say two years' time to review progress.

The meeting also concluded that:

- Although encouraged rather than required by existing IPCC guidance, verification of GHG inventories, (defined here as the comparison of inventory estimates with independent estimates) is potentially a key element of ensuring inventory quality and increasing the confidence of results. This requires development of better techniques for observation and interpretation and better understanding of the relationship between inventory estimates and natural fluxes.
- Several techniques are available or planned that show promise for verifying the GHG inventories at different scales or levels of aggregation (i.e. regional, national, local or source-specific).
- These techniques include using measurements of atmospheric concentrations, often combined with inverse modelling techniques, and other observations that can be used to estimate the total fluxes of a given GHG.
- Currently, the direct applicability of these techniques to the GHG inventories is limited by the density of measurements, accuracy of the models, and the ability to attribute fluxes to anthropogenic versus natural sources and sinks. Bottom-up information on the fluxes not covered by the GHG inventories will be necessary for effective comparisons using these verification techniques.
- As a consequence, these techniques are at present usually limited to comparisons of the results of GHG inventories for selected gases in certain well-sampled regions (e.g. Europe, North America and Australia).
- The research community anticipates that capabilities will improve over time as measurement density improves (i.e., through new satellite sensors, expanded surface network and number of gases and isotopes sampled), as the atmospheric chemistry and transport and statistical models continue to be tested and improved.
- In order for techniques based on remote sensing (RS) or ambient measurements to be effective in verifying GHG inventories, improvement in our abilities to partition the fluxes into different components is necessary. Partitioning requires improvements in other observations (e.g. of various ecosystem and ocean parameters), integration with flux information and an overall synthesis.
- It is anticipated that with additional coordination and investment countries could make significant progress over the next decade toward a globally linked and integrated observational network. From the inventory compilers' point of view, the key issues include continuity of critical data records, new observational capabilities and data sharing.
- The inventory compiler community and the research communities would both benefit from continued discussion of the specific verification needs for GHG inventories and the evolving capabilities of these techniques. In particular, the communities would benefit from having a sustained interaction on specific and verification questions so that further research efforts can be policy-relevant.
- Some RS techniques, particularly for area and area change mapping, are sufficiently well-developed today that they could be used in combination with other data (e.g. in-situ measurements and other auxiliary information) to improve the quality of GHG inventories directly by contributing activity data (e.g., land conversion data). More work needs to be done in improving the availability, accessibility and processing of RS information (e.g. data, satellite images) and developing standards. Interpretation and data analysis may be resource-intensive.
- One use of the GHG emissions inventories is to attribute climate change as being anthropogenic per Article 2. Much of the uncertainty in that attribution, particularly at the national level, is now based on the inventories. A consistent treatment of uncertainty across both these inventories and inverse methods for deriving emissions is necessary for comparison. Also, transparent, research-based approach is needed to propagate uncertainties when combining sectoral and regional emissions.

- The inventory compiler also needs methods for comparing inventories to inversions. More research is needed to determine how to conduct verification and also case studies demonstrating applications of these methods.
- Some inventory verification challenges are presented below (Table 1) as an illustrative list of areas in which evolving techniques could be employed to verify and raise the quality of GHG inventories:

Table 1 Some inventory challenges where these verification techniques could be employed

Area	*Identified needs/gaps*
Emissions from the use of fluorinated gases	*ISSUE:* *Unclear if timing and location of emission estimates are correct. There is very little tracking of activity data for many end-use applications.* *NEED:* *Integrated totals at higher temporal resolution so that the inventory compilers can check the rates of emission and timing of release etc.;* *Better spatial resolution*
Fugitive and vented CH_4 emissions from oil and gas systems, coal mining and landfills	*ISSUE:* *Generic EFs or equivalent fail to characterize emission rates over different spatial and temporal scales* *NEED:* *Independent checks on emission factors and emissions estimates, particularly for upstream oil and gas production emissions.* *Observations that identify emissions but do not quantify them can also be helpful for indicating sources that are currently being missed.*
N_2O emissions from soils (direct and indirect)	*ISSUE:* *N_2O emission from soils very uncertain and unverified. So, try meso-scale to provide better spatial and temporal integration than plot level data* *NEED:* *Independent quantification of indirect emissions from volatilization and re-deposition, leaching and run-off. Assessment of emission rates from "other lands" e.g., water bodies, coastal areas etc.* *Process-based modeling has also been used successfully to reduce emissions. These models may use remote sensing and weather data to provide a more precise estimate of emissions. Combining these approaches with mesoscale model inversions could lead to more confidence in inventories of soil N_2O emissions*
Forest fires, biomass burning in other land uses and other disturbances	*ISSUE:* *Estimates of emissions from biomass burning in non-forest land uses and other disturbances are very uncertain and unverified.* *NEED:* *Identification of area burnt and mass of biomass fuel available for combustion, and combustion emission factors;* *Actual measurement of N_2O and CH_4 from fires. Measurement of CO, NOx etc. could serve as a proxy.*
Carbon Capture and Storage sites	*ISSUE:* *Leakage from geological storage sites are challenging to identify and even more difficult to quantify. Leakage may occur over a wide area which needs to be completely covered.* *NEED:* *Accurate time series of isotopically distinguishable background emission rates at appropriate scales (storage sites i.e. 10-100 km)* *Ability to identify leaks* *Quantification of diffuse emissions*

Overall inventory totals by gas	*ISSUE:* *Independent check on emission inventories currently largely lacking.* *NEED:* *Independent estimates of national fluxes of GHG*
Peatlands	*ISSUE:* *Diffuse emissions occurring over a wide area are poorly quantified and understood. Generic EFs fail to characterize the relationship to management practices* *NEED:* *Focus on estimating total CH_4 and N_2O emissions*
Methane from permafrost melting and clatharates	*ISSUE:* *A poorly understood source with no current estimation method.* *NEED:* *Magnitude of, and changes in, emissions from permafrost melting and methane clatharates (not necessarily an inventory issue)*
Black carbon and aerosols	*ISSUE:* *Spatial and temporal resolution of emission important. Can be very transient, making comparison difficult. Sources not well understood.* *NEED:* *Measurements to validate emission estimates*
Fluxes on coastal oceans	*ISSUE:* *Not currently included in inventories and data required to calibrate estimates.* *NEED:* *Concentration data. Inventory guidance needed; separation of anthropogenic and natural likely to be challenging*

Annex 1. **References**

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Annex 2. **Questions and Answers**

1. *Key Definitions*

1.1. How do we understand "uncertainty" in emission inventories? How to distinguish between variability and uncertainty?

Uncertainty: Lack of knowledge of the true value of a variable. Uncertainty comprises two parts:

- Random variation around a mean value. Generally these can be quantified and the IPCC guidelines give methods deal with the random errors.
- Bias cannot be quantified and so the IPCC guidelines give approaches to minimise bias.

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. Uncertainty may arise for an inability to quantify the variable. For example, soil nitrous oxide emissions can vary from year to year due to weather conditions, and if emission factors do not account for weather, then some of the uncertainty will be due to variability in emissions across time (and space) that is not quantified.

Variability: How a variable differs from time to time, place to place or between members of a population. A number of source categories, mainly in the AFOLU sector may show temporal variability on long time scales, due to for instance wild fires, rain fall, temperatures etc.

> *Uncertainty: Lack of knowledge of the true value 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.*
>
> *Variability: Heterogeneity of a variable over time, space or members of a population (...). Variability may arise, for example, due to differences in design from one emitter to another (inter-plant or spatial variability) and in operating conditions from one time to another at a given emitter (intra-plant variability). Variability is an inherent property of the system or of nature, and not of the analyst..*

IPCC 2006, Vol. 1, Ch 3, Section 3.1.3 Key concepts and terminology

1.2. What is the difference between accuracy and precision? Does uncertainty assessment relate to both?

Essentially accuracy is a measure of the lack of bias of an estimate while precision is a measure of the repeatability of the result. In general lack of precision is caused by random variation in input data (e.g. experimental error) while lack of accuracy results from biases from incomplete understanding (or modelling) of the process. So, for example:

- Estimates of CO_2 emissions from fuel use can be based on measurements of the carbon content of the fuel. Reductions in the random error in the measurements will lead to improvements in the precision of the result; however the accuracy may be limited by a bias caused by an incomplete knowledge of the oxidation rate of the combustion process.
- Emissions or removals from forests are modelled by changes in carbon stocks. The precision achieved will be the result of the uncertainty derived from the experimental error of the measured values of the various parameters used. On the other hand, there may be inaccuracy caused by such things as the measured parameters not being measured under the same climatic and ecological situation as the forest area being estimated; by an incomplete knowledge of all the processes removing carbon from the forest; or by the model of carbon stocks being incomplete. All these causes of inaccuracy lead to bias.
- Emissions of F-gases for refrigeration are estimated from monitoring the imports, exports, production and use of the chemicals. Data on these product flows often come from surveys, all of which are subject to random survey errors, which lead to a lack of precision. While biases in the surveys (e.g. caused by missing some sectors) or incorrect understanding of leakage processes lead to inaccuracy and bias.

The process of uncertainty estimation aims to quantify precision. Before this uncertainty estimation is performed all known or suspected biases should be removed or corrected.

Accuracy is improved by evaluating methods and assumptions as well as input data to ensure they are free from bias.

> *"Accuracy: Agreement between the true value and the average of repeated measured observations or estimates of a variable. An accurate measurement or prediction lacks bias or, equivalently, systematic error.*
>
> *Precision: Agreement among repeated measurements of the same variable. Better precision means less random error. Precision is independent of accuracy".*

IPCC 2006, Vol. 1, Ch 3, Section 3.1.3 Key concepts and terminology

> *"The quantitative uncertainty analysis tends to deal primarily with random errors based on the inherent variability of a system and the finite sample size of available data, random components of measurement error, or inferences regarding the random component of uncertainty obtained from expert judgement. In contrast, systematic errors that may arise because of imperfections in conceptualisation, models, measurement techniques, or other systems for recording or making inferences from data, can be much more difficult to quantify. As mentioned in Section 3.5, Reporting and Documentation, it is good practice for potential sources of uncertainty that have not been quantified to be described, particularly with respect to conceptualisation, models, and data and to make every effort to quantify them in the future.*
>
> *Good practice requires that bias in conceptualisations, models, and inputs to models be prevented wherever possible, such as by using appropriate QA/QC procedures. Where biases cannot be prevented, it is good practice to identify and correct them when developing a mean estimate of the inventory. In particular, the point estimate that is used for reporting the inventory should be free of biases as much as it is practical and possible. Once biases are corrected to the extent possible, the uncertainty analysis can then focus on quantification of the random errors with respect to the mean estimate".*

IPCC 2006, Vol. 1, Ch 3, Section 3.1.4 Basis for uncertainty analysis

1.3. How would uncertainty in activity data and/or emission factors be reflected in the emission estimate?

Where uncertainty in emission factors and activity data arise from random factors (e.g. experimental error, survey errors) then this will lead to a quantifiable uncertainty in the result. However if this uncertainty is systematic (e.g. where emission factors are estimated from a sub-population and so are not directly applicable to the entire population; or where a survey does not randomly sample the entire population, e.g. it misses small plant) it *might* lead to bias. Random errors are expressed as an uncertainty range. Bias should be minimised by thorough evaluation of the data and assumptions used, good QA/QC and review. In some cases, it is possible to correct for biases such as errors in measurements or analytical methods where the error has been quantified and can be used to adjust the estimates.

2. Why do we need uncertainty assessment of emission inventories?

2.1. Why uncertainty assessment is considered important in GHG inventory preparation? How should the result of uncertainty assessment be used?

Uncertainty assessment is needed to help guide inventory improvements.

> *"An uncertainty analysis should be seen, first and foremost, as a means to help prioritise national efforts to reduce the uncertainty of inventories in the future, and guide decisions on methodological choice. For this reason, the methods used to attribute uncertainty values must be practical, scientifically defensible, robust enough to be applicable to a range of categories of emissions by source and removals by sinks, methods and national circumstances, and presented in ways comprehensible to inventory users."*

IPCC 2006, Vol.1, Ch 3, Section 3.1.1 Overview of uncertainty analysis

> *"… Uncertainty information is not intended to dispute the validity of the inventory estimates, but to help prioritise efforts to improve the accuracy of inventories in the future and guide decisions on methodological choice, …"*

IPCC 2000, Ch 6, Section 6.1 Overview

Uncertainty information is used principally to identify planned improvements in emission inventories.Uncertainty assessment is also important in comparisons with atmospheric measurements and modelling. Without uncertainty estimates, it is difficult to determine the extent to which atmospheric measurements (such as atmospheric inversions of CO_2 concentrations) can be compared to emission estimates. Uncertainty of estimates or measurements may also assist in informing decisions about efforts to mitigate emissions.

2.2. Can we reduce uncertainties by using higher tier methods to estimate GHG emissions/removals? Sometimes higher tier methods result in wider confidence interval. How should this be interpreted?

Moving to a higher tier method should result in a better estimate with reduced uncertainty. However note that:

Sometimes the higher tier method better estimates uncertainty revealing the Tier 1 result underestimated the true uncertainty.

Using higher tiers aims to reduce bias (e.g. it uses more disaggregated data to move to a more detailed stratification) but this can sometimes decrease precision, giving a higher uncertainly value.

> *"Choice of methodological tier for emissions and removals estimation can affect the uncertainty analysis in two different ways. Firstly, moving to higher tier inventory methods should typically reduce uncertainties, provided the higher tier methods are well implemented, because they should reduce bias and better represent the complexity of the system. Secondly, moving to higher tier methods may result in increased estimates of uncertainty in some circumstances. Often, this increase in the estimated uncertainty does not actually represent a decrease in knowledge; rather, it typically reveals a more realistic acknowledgment of the limitations of existing knowledge. This may occur where there was an incomplete accounting of the greenhouse gas emissions in the lower tier method, or where application of higher tier methods reveals additional complexity and uncertainties that were not fully apparent in the lower tier method. This really means that the uncertainty was underestimated previously and moving to the higher tier method in reality produces a more accurate estimate of uncertainty. In some cases, an increase in uncertainty may occur for one inventory development method versus another because each method has different data requirements."*

IPCC 2006, Vol. 1, Ch 3, Section 3.1.7, Implications of methodological choice

2.3. Can we compare uncertainty estimates between counties?

Yes – the numbers should be comparable if both countries have followed the guidelines correctly. While Approach 2 should give a quantitatively better estimate of the confidence limits Approach 2 and Approach 1 give comparable results especially with respect to ranking the contributions to overall inventory uncertainty. Large differences in inventory uncertainties should reflect real differences in the uncertainties of the estimates. However, in practice, there are wide differences between the results that are not easily explained.

An inventory with a high uncertainty may result from a preponderance of sources with intrinsically high uncertainties (e.g. land use sectors) or from a lack of knowledge of the input data more generally. High uncertainty at the national, annual level is often the result of large variability (see Q&A 1.2).

2.4. How can we ensure consistency in uncertainty assessment among different sectors?

There is a need to ensure correct application of guidelines on uncertainty across sectors and source categories. All the inventory compilers for different sectors in the team should have close consultation and discussion so that they arrive at common understanding of "uncertainty". The uncertainty estimation should be explicitly included within the inventory planning process, based on a common understanding of uncertainty, and using similar definitions and ways to quantify uncertainty across sectors and source categories.

3. How do we you perform an uncertainty analysis as part of emission inventories?

3.1. How do you start an uncertainty assessment?

a. Decide on approach to use (look at expertise and resources available)

b. Collect uncertainty information for all data inputs. Where Approach 2 is used full probability density function (PDF) will be needed for activity data, emission factors and any other parameters used. If a full PDF is not available a normal or lognormal PDF can be based on the mean and uncertainty. Knowledge of the causes of uncertainty will inform this step.

c. Decide how to aggregate sources and sinks to minimise impact of correlations (or for Monte-Carlo develop method to incorporate correlations in activity data and emission factors)

d. Combine uncertainty information to estimate overall inventory uncertainty either using error propagation or Monte-Carlo methods as decided in step "a"

e. Report result and document method

f. Use uncertainly information in developing improvement plan for inventory

3.2. How should the data and information on uncertainty be collected?

Uncertainty information should be collected together with activity and emission factor data. Generally the experts providing both types of data have the best information and knowledge on the weaknesses and uncertainties in their data. Communication on understanding of uncertainties and the objectives of the uncertainty assessment with the data providers is crucial. In some cases data providers might be reluctant to provide uncertainty data. In such cases the inventory compiler could use a formal or informal “expert elicitation” process to help the experts to quantify their understanding of the quality of the data in terms of uncertainty ranges and/or PDFs.

As a fall back option when no data have been included by the data providers, the default uncertainty ranges given in the 2006 IPCC Guidelines could be used for a first uncertainty assessment. If these source categories appear to have major contributions to the overall inventory uncertainty, further work on these uncertainties could be planned for next inventory cycles.

“…Ideally, the inventory compiler should collect activity data, emission factors, and uncertainty information at the same time because this is the most efficient strategy.”

IPCC 2006, Vol. 1, Ch 1 p 1.11, Box 1.1

.“… Activity data are often collected and published regularly by national statistical agencies, which may have already assessed the uncertainties associated with their data as part of their data collection procedures. These previously developed uncertainty estimates can be used to construct PDFs. This information will not necessarily have been published, so it is recommended to contact the statistical agencies directly. Since economic activity data are not usually collected for the purpose of estimating greenhouse gas emissions and removals, it is good practice to assess the applicability of the uncertainty estimates before using them.”

IPCC 2006, Vol. 1, Ch 3, p 3.18

Anytime you have a survey or a census you must have a point estimate and an uncertainty interval. Surveys need a valid statistical design so that variances and co-variances can be empirically derived. Surveys may use stratification to sample more efficiently. Samples should be randomized within the strata. Weights may also be needed depending on the representativeness of each sample. An example of a statistically-based survey is the US National Resources Inventory. In order to start collecting such uncertainty data:

- Consult with your statistical agencies to collect this data
- Always ask for point estimates and uncertainty data, if necessary ask for uncertainty information in a second step
- If you don't get it: use your own expert judgment as a start; you can always improve in the next inventory cycle!
- As a start you can use information in the 2006 Guidelines and EFDB
- Make comparisons with other datasets and other countries. An example of collection of uncertainty information can be a comparison of two databases e.g. If in a country fuel consumption is recorded in energy balance and in parallel of CLRTAP emissions database
- Be aware that experts might be optimistic/subjective with respect to the quality of their data

3.3. How should we choose the approach to uncertainty assessment, Approach 1 or Approach 2? Can we use both approaches in the same GHG inventory?

You will always need to consider the resources and expertise available. Approach 1 requires fewer resources and limited expertise compared with Approach 2.

Approach 1 will usually be good enough if you only use uncertainty for inventory improvement. Approach 2 will be more appropriate for scientific applications where there are high uncertainty ranges and correlations.

Approach 2 can be nested in an Approach 1 for the overall inventory uncertainty assessment. Approach 2 can for instance be used for specific complex calculations in restricted source or sink categories. The resulting uncertainty range for this source or sink then can be used as input into Approach 1 to combine these results with the entire inventory.

Where Approach 2 is used the guidelines also encourage the use of Approach 1 as a QA/QC check.

“Where the conditions for applicability are met (relatively low uncertainty, no correlation between sources except those dealt with explicitly by Approach 1), Approach 1 and Approach 2 will give identical results. However, and perhaps paradoxically, these conditions are most likely to be satisfied where Tier 2 and Tier 3 methods are widely used and properly applied in the inventory, because these methods should give the most accurate and perhaps also the most precise results. There is therefore no direct theoretical connection between choice of Approach and choice of Tier. In practice, when Tier 1 methods are applied, Approach 1 will usually be used while the ability to apply Approach 2 is more likely where Tier 2 and 3 methods are being used, moreover for quantifying the uncertainty of emissions/removal estimates of complex systems such as in the AFOLU Sector. When Approach 2 is selected, as part of QA/QC activities inventory agencies also are encouraged to apply Approach 1 because of the insights it provides and because it will not require a significant amount of additional work. Where Approach 2 is used, its estimates of overall uncertainty are to be preferred when reporting uncertainties.”

IPCC 2006, Vol. 1, Ch 3, Subsection 3.2.3.5 Guidance on choice of Approach

> *"In some cases, most of the category uncertainties in an inventory might be estimated using Approach 2, with relatively few estimated using Approach 1. It is possible to incorporate Approach 1 estimates of uncertainty for some categories into an Approach 2 methodology for combining uncertainties for the total inventory. This is done by using the uncertainty half-range obtained from Approach 1 to specify an appropriate PDF model to represent uncertainty for each category as part of the Monte Carlo simulation."*

IPCC 2006, Vol. 1, Ch 3, Subsection 3.2.3.3 Hybrid combinations of Approaches 1 and 2

3.4. What are the key differences between Approach 1 and Approach 2

While Approach 1 technically is limited to specific circumstances the 2006 IPCC Guidelines give ways to deal with these situations and so it gives useful results for all emission inventories. Approach 2 does not have these limitations.

Approach 1 is only strictly correct when uncertainties are less than 0.3, distributions are normal and there are no correlations. However, the 2006 IPCC Guidelines give an empirical equation for dealing with large uncertainties and the impact of correlations can be reduced by grouping data.

Approach 2 can deal with all these situations. Approach 2 requires significantly more data and resources. It needs not just the uncertainty but also the probability density function, which can be non-symmetrical. Approach 2 will be required if a realistic quantitative uncertainty range is to be calculated in cases where large uncertainties in activity data and / or emission factors occur.

Where the standard deviation for any parameter is greater than about 0.3, normal probability functions will give non-negligible probabilities for negative values. In real life such negative values can obviously not occur. Another option would be to use a log-normal distribution in this case.

3.5. How to interpret and use the output data of the uncertainty assessment

A Tier 2 KCA uses the uncertainty data together with the magnitude of each source or sink category to highlight those that contribute to the overall inventory uncertainty. Thus improvements can be targeted to reduce overall inventory uncertainty.

Both approaches give estimates of the confidence intervals of the inventory that can be used in verification (comparison with other independent estimates).

4. Pitfalls

4.1. In the AFOLU sector, Approach 1 uncertainty assessment sometimes using Equation 3.2 sometimes results in extremely large uncertainty values because the denominator becomes close to zero when emissions and removals are nearly equal. Is this appropriate? Can we somehow avoid it?

This is because uncertainty is presented as a relative uncertainty (a fraction uncertainty divided by the point estimate). As sources and sinks balance the point estimate goes to zero but the absolute value of the uncertainties might still be significant. The calculated value of the relative uncertainty in such cases becomes very large and is not meaningful. It may be better to present absolute uncertainty values when emissions and removals nearly balance. Just show the absolute values of 95% confidence interval. These absolute values can be combined with absolute values of the rest of the inventory to give overall inventory uncertainty.

4.2. How should we treat correlation between factors in uncertainty assessment?

Assume there is no correlation unless there is evidence of correlation. If there is evidence, correlation should be taken into account. See IPCC 2006, Vol.1, Ch 3, p 3.25-3.26 "Dependence and correlations among inputs".

An example where correlation is likely to be important would be land use data. As the area of one land use is increasing, the areas of other land uses will by necessity be decreasing (assuming the land base is constant across the time series, which is a good practice). This relationship creates correlations in the data which can be derived if the land survey has a statistically-based design. In this case, the compiler would need to derive the covariances across all combination of land use and time in order to fully address the uncertainty.

Annex 3. **Agenda**

Tuesday 23 March

09:30 –10:00	REGISTRATION	
10:00 –10:30	Welcome	Co-Chairs (TFI) Mrs. Aukje Hassoldt (TNO)
10:30 –13:00	• Introduction (Simon Eggleston, TSU) • Uncertainty analysis and inventory verification in IPCC 2006 Guidelines (Simon Eggleston, TSU) • Uncertainty about Inventory Estimates: A Canadian perspective *(Frank Neitzert, Canada)* • Assessment of uncertainties in activity data and emission factors for Indian emission inventories (Amit Garg, India) • Experiences in Mexico with uncertainty analysis in AFOLU *(Bernardus de Jong, Mexico)*	
13:00 –14:00	LUNCH	
14:00 –17:00	• Experiences in quantifying the uncertainty of the estimates of Canada's National Forest Carbon Monitoring, Accounting, and Reporting System, NFCMARS (Juha Metsaranta, Canada) • Uncertainty in remote sensing data and their analysis for forest inventory (Yasumasa Hirata, Japan) • Direct measurement of GHG emissions: The case of fugitive methane from landfills (Antoine Babilotte, France) • Inverse modeling of GHG and aerosol precursor emissions using satellite measurements: Status and future perspectives (Sander Houweling and Martijn Schaap, The Netherlands) • Integrating observations & inventories to improve emission estimates: a framework for synthesis (Riley Duren, USA)	
18:00	RECEPTION	

Wednesday 24 March

10:00 –13:00	• Integrating observations from remote sensing, inventories and flux data with models for estimating terrestrial carbon sources and sinks (Beverly Law, USA) • Top down atmospheric and bottom up estimates of the European GHG balance (Philippe Ciais, France) • The successes, limitations and uncertainties of estimating emissions from measurements (Alistair Manning, UK) • Use of inverse modeling to evaluate emissions inventories (Stephen Ogle, USA) • Validation/verification capabilities of ambient mixing ratio measurements and inverse modeling (Lingxi Zhou, China) • Inverse modeling of European GHG emissions and verification of bottom-up inventories (Peter Bergamaschi, Italy)
13:00 –14:00	LUNCH
14:00 –17:00	Breakout Group 1: Additional information on estimating uncertainties in GHG inventories Breakout Group 2: Use of measurements and/or inverse modeling to validate emission inventories
18:00	RECEPTION

Thursday 25 March

10:00 –13:00	Breakout Groups continue and agree text for meeting report
13:00 –14:00	LUNCH
14:00 –17:00	Plenary: Agree Draft Meeting Report

Annex 4. **Participant list**

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Annex 5. **Presentations**

All presentations can be downloaded from: http://www.ipcc-nggip.iges.or.jp/meeting/meeting.html

• Introduction *(Simon Eggleston, TSU)*
• Uncertainty analysis and inventory verification in IPCC 2006 Guidelines *(Simon Eggleston, TSU)*
• Uncertainty about Inventory Estimates: A Canadian perspective *(Frank Neitzert, Canada)*
• Assessment of uncertainties in activity data and emission factors for Indian emission inventories *(Amit Garg, India)*
• Experiences in Mexico with uncertainty analysis in AFOLU *(Bernardus de Jong, Mexico)*
• Experiences in quantifying the uncertainty of the estimates of Canada's National Forest Carbon Monitoring, Accounting, and Reporting System, NFCMARS *(Juha Metsaranta, Canada)*
• Uncertainty in remote sensing data and their analysis for forest inventory *(Yasumasa Hirata, Japan)*
• Direct measurement of GHG emissions: The case of fugitive methane from landfills *(Antoine Babilotte, France)*
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