



Meeting report of the ad-hoc
group for the modelling and
assessment of contributions
of climate change (MATCH)

11 to 12 April 2005
Rio de Janeiro, Brazil

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1. INTRODUCTION

As part of the negotiations on the Kyoto Protocol, the delegation of Brazil made a proposal, in May 1997, to set differentiated emissions reduction targets for Annex I Parties of the UNFCCC according to the impact of their historic emissions on temperature rise (FCCC/AGBM/1997/MISC.1/Add.3).

After two expert meetings held under the auspices of the SBSTA (28 – 30 May 2001 in Bonn, Germany; 25 - 27 September 2002 in Bracknell, UK), a third and fourth expert meeting were held on the initiative of the governments of UK, Brazil and Germany. In August 2003, the UK Department for the Environment (DEFRA) commissioned Ecofys to provide administrative, secretarial and scientific assistance as 'support unit' for the process until the end of 2005.

During the third expert meeting held in Berlin on 8/9 September 2003, draft terms of reference and a draft work plan for a process until 2005 were discussed for the now called "Ad-hoc group for the modelling and assessment of contributions to climate change (MATCH)". Participants for a scientific coordination committee were selected, which guides and coordinates the process.

This document is the report of the meeting of MATCH held on 11/12 April 2005 in Rio de Janeiro, Brazil. It was drafted by Simone Ullrich and Niklas Höhne, Ecofys, Germany and reviewed by the participants of the meeting.

The agenda of the meeting (see Annex A) consisted of three major parts. First, the paper #1 titled: "Analysing countries' contribution to climate change: Scientific uncertainties and methodological issues" was presented and the status quo reported. Second, the participating experts discussed content and approach of paper #2 "Attributing a fraction of climate change to a nation's historical emissions: closure and scientific uncertainty": Third, the experts discussed the way forward with paper #3 and #4 and developed new ideas how to continue the process beyond November 2005. All presentations held during the meeting are available on the web site www.match-info.net.

The meeting was hosted by IVIG (COPPE/UFRJ) and the Forum Brasileiro de Mudancas Climaticas in Rio de Janeiro "Brazilian Climate Forum" and organized by Ecofys. 19 Participants attended the meeting and two experts joined the discussion part time by telephone conferencing (see Annex B).

2. ISSUES

2.1 ISSUES DISCUSSED IN SCC MEETING

The scientific coordination committee (SCC) met on Sunday evening (10 April) to discuss the agenda of the workshop, on Monday at lunch time (11 April) to discuss possible future work, and on Tuesday evening (12 April) to discuss the chairmanship.

Michael Prather had announced that he would resign from his duties as chairman of the scientific coordination committee of the MATCH group by end of July 2005 due to his new position at the US state department for the following 12 months. The members of the SCC present agreed that Joyce Penner and Jan Fuglestedt should co-chair the SCC. Both candidates accepted the task. Niklas Höhne informed all SCC members not present at the meeting, which had no objections.

2.2 INVOLVEMENT OF OTHER ORGANIZATIONS

As for the previous expert meetings, Ecofys has invited interested organization to attend the meeting and has sent an announcement of the meeting, including the invitation via Climate-L. One journalist from Brazil, writing for the Brazilian Climate Forum, attended most of the meeting.

2.3 SCOPE OF MEETING AND DISCUSSION

2.3.1 Day 1, 11th April 2005

The meeting was opened by *Michael Prather*, the recent Chairman of the scientific coordination committee of the MATCH group. Michael Prather expressed his thanks on behalf of the experts to IVIG (COPPE/UFRJ) hosting this meeting.

This opening was followed by an introductory note of Luiz Pinguelli Rosa, the chairman of the Brazilian Climate Forum, welcoming the participants to this meeting and inviting them for fruitful discussions.

The fifth meeting provided substantial discussion of the paper #2, and also discussed a way forward until November 2005, which will be the end of the financial support to the MATCH that is currently provided by UK, DEFRA.

Niklas Höhne introduced all participants to the **history of MATCH** and listed agreements made last expert meeting in Cologne 2004 including timelines. He stressed that due to delays related to the paper #2, the meeting had to be postponed from December 2004 to April 2005. He also mentioned that it seems unrealistic today to complete and submit paper#3 and #4 until December 2005 due to delays with paper #2. The way forward including possible paper#3 and #4 were discussed on Day 2 in greater detail.

Next, *Michel den Elzen* presented a **summary of paper #1**: "Analysing countries' contribution to climate change: Scientific uncertainties and methodological choices". The main results of paper #1 are:

- The analysis undertaken provides the comprehensive summary so far to date.

- The analysis does not provide a full formal assessment of the uncertainty range, but a qualitative evaluation of the influence of different policy-related and scientific choices.
- The influence of scientific choices is notable. Therefore research is ongoing and will be continued in paper #2 and #3.
- However, the current work suggests, that the impact of policy choices, such as time horizon of emissions, climate change indicator and greenhouse-gas mix is larger than the impact of scientific uncertainties.
- The impact of uncertainties on the *relative* contributions is smaller than the impact of uncertainties on the *absolute* changes in temperature.
- Pressing research needs include historical emission datasets (e.g. there are substantial differences in emission estimates between datasets, in particular for emissions from land-use change and forestry).

Paper #1 was submitted in mid October for peer review to Environmental and Science and Policy. No review comments were received since its submission. The authors hope that comments will be provided at the end of April or in early May 2005, so that the necessary revisions can be completed before July 2005 and the paper finally can be published.

Michael Prather introduced an **outline of and work in progress on paper #2 (see Annex C)**. There are a number of lead and co-authors that confirmed their willingness to contribute to the paper. It was noted, that the authors currently on the authors list but not contributing to the paper would not be included in the final paper #2.

Michael Prather presented the draft outline of paper # 2 that resulted from the Exeter meeting and which the lead authors (Michael Prather, Jason Lowe and Joyce Penner) had prepared in September 2004 (see Annex C) and then fine-tuned in February 2005. However, it was stressed that the outline could change during this meeting depending on discussions.

Presentations on the content of the sub-chapters of paper #2 were continued in the afternoon (see Chapter 3 for detailed discussion on paper #2).

In the late afternoon, three **breakout groups** were formed and the following issues discussed until end of day 1:

- Breakout group 1: "CO2 emissions including LUCF, uncertainties, closure"
- Breakout group 2: "CH4, N2O, Tropospheric ozone"
- Breakout group 3: "Aerosols, black carbon".

It was agreed that Atúl Jain would present the outcomes of discussion on CO2 (Group 1), Promode Kant would present discussion points on LUCF (Group 1), Jan Fuglestvedt would present the outcomes of breakout group 2 and Joyce Penner of breakout group 3 on day 2.

The day was closed with a joint dinner at the venue.

2.3.2 Day 2, 12 April 2005

Day 2 started with a discussion on the **way forward beyond paper #2**. Due to difficulties with telephone conferencing with Ben Matthews, Belgium *Niklas Höhne* began to introduce a memo (see Annex F) developed by Ben Matthews and reviewed by Niklas Höhne. Participants were reminded that:

- Paper #3 was meant to be a formal assessment of uncertainties to be done e.g. with Monte Carlo Analysis.
- Paper #4 should take into account all insights experts got by then and should basically represent an update of paper #1 with updates and revisions.
- The original plan was to finish all papers by end of 2005, deadline December 2005, which seems not any more realistic.

As *Ben Matthews* was connected to the discussion, he further discussed the memo and ideas. Originally it was thought to do a probabilistic analysis in paper #3, but looking at the results of paper #1, he noted that it would not be promising. Therefore a new idea was raised for paper #3 as follows:

- I MATCH would provide a simple tool that can be used to perform these calculations and have the methodological parameters selected by the user.
- II It will essentially consist of plots/matrices similar to those that Jesper Gunderman first presented at the Berlin Meeting.
- III A simple excel tool could use these plots as a basis to let a user to perform his own calculations.

Ben Matthews noted that Ian Enting would be interested to take a role on this paper, describing uncertainties in response functions. Cathy Trudinger is interested, too, but would not take a leading role.

In the discussion, many participants voiced that:

- a) it is very difficult for policy makers to understand the models and possibly also the proposed plots,
- b) they are concerned about whether it could be done and in what time frame since some key potential authors would not be able to commit considerable time to the paper,
- c) it may be difficult to tackle the uncertainty issue, and
- d) developing a tool is going beyond what the MATCH group should do and in addition would be politically sensitive. A counter argument, that policy makers would put more resources into work if they see the application, was put forward. It was also stressed that this group cannot develop tools for policy makers without institutional support, individuals can do, but this group is not the place unless SBSTA is changing the mandate of the group.

Due to the complexity of the future work it was proposed to split the two elements of the paper and

- to undertake uncertainty analysis (bands), and propagating the uncertainties and
- to develop the tool

or to only consider a revision of paper #1. It was finally agreed that a draft outline of paper #3 will be developed by Ben Matthew and Niklas Höhne and be presented at the next expert meeting in October 2005.

At the meeting **capacity building** and the **funding situation** for developing country experts were discussed. *Niklas Höhne* mentioned that in the last expert meeting three experts from developing countries were supported with travel and subsistence costs while at the present meeting 4 experts were funded. There is further money for additional 12 experts trips available in the fund provided through the UK, German and Norwegian government. It was asked whether the remaining funds could also be

used for other issues such as supporting the dissemination of work done. Ecofys mentioned that any diversion from the agreed funding arrangements with the UK, German and Norwegian government would need to be agreed by the funding governments first. Ecofys will put forward this issue to the sponsors.

On capacity building issues it was further stressed that to date already two examples exist where young researchers from developing countries joined research team in Annex I countries: e.g. Guoquan HU, China in New Zealand, Christiano Pires de Campos, Brazil in Belgium, we should further continue this process. Further, it was pointed out from present developing country experts that it does not help to only support travel for developing country expert. Instead, through the MATCH process new funds could be identified to support model building and its performance through young developing country experts.

The MATCH group could possibly seek further funding to support the following items:

- 1) an interaction with groups in the developing world who run models;
- 2) the arrangement of visits of developing country scientists on a short term, to undertake modelling process and exercise;
- 3) organisation of a workshops in climate modelling activities (e.g. organisation of a workshop in Africa on climate modelling, request participation from scientists in this group);
- 4) involvement of scientists from existing labs in Annex I countries and their invitation for lectures to relevant groups.

It was noted that there are some funds available in Africa. The group could also look at foundations supporting some of the above-mentioned aspects. It was further noted that it would be helpful if the SCC could issue recommendation letters for scientists in developing countries if specific funding organizations would require this.

In the late morning and afternoon the **results for the breakout group discussions** were presented (see Chapter 3 for further details).

Guoquan HU from China held an **additional scientific presentation** presenting results from his model runs with a simple climate model. Guoquan HU, China has done model runs during an exchange visit in New Zealand at NIWA (National Institute of Water & Atmospheric Research).

In the later afternoon **the new outline of paper #2** (see Annex D) was presented based on discussion. Timelines were agreed (Due: all sections 2&3 end of June, to Jason Lowe for section 4, and zero order draft by mid August) and present authors confirmed their contributions to the sections (see Annex D).

3. DISCUSSION OF PAPER #2

Based on the draft outline worked out as result of the Exeter meeting held in September 2004 (see Annex C) lead authors and co-authors have started working on the content. The following **presentations and document discussions** were given at the meeting featuring the concepts and anticipated content of the various sub-chapters. Speakers are highlighted in *italics*.

Atsushi Kurosawa / Fabian Wagner: Uncertainties for CO₂ emissions: In the paper, data after 1970 will be compared with databases e.g. IEA. As reminder it was mentioned that Fabian Wagner volunteered to collect different data sets.

Christiano Pires de Campos reported on uncertainty issues for LUCF CO₂. The speaker handed out a document addressing the issue. He also mentioned that

uncertainties cannot yet be assessed. To overcome this barrier it was suggested to identify which of the presented curves (per selected country) shown have systematic problems and why these problems exist.

Atúl Jain, Jan Fuglestedt: Closure uncertainty for CO₂. On this chapter the following plan was proposed:

1. Introduction: using different sets of emissions (fossil emissions, and LU emissions (using the activity level e.g. area changes etc.) these are input data to model (2)
2. Run a coupled climate carbon cycle model
3. Compare the different results

The anticipated use of datasets was discussed (e.g. for fossil fuel: Marland (CDIAC) and Hyde, for land cover changes for cropland and abandonment (three sets of data); for land cover changes for pasture land (two sets of data, Houghton, Hyde). Input data other than activity data will be precipitation and temperature. Different results from simulations were presented.

The presentation concluded that one group would discuss CO₂ uncertainties, where LUCF is a part. Authors from the presented participants include: Atúl Jain, Atsushi Kurosawa, Christiano Pires de Campos, Promode Kant.

Jan Fuglestedt held the presentation on closure uncertainties for CH₄, N₂O and tropospheric ozone (which is driven by emissions of the precursors NO_x, VOC, CO and CH₄). Due to lack of an observational historical record of ozone, a different approach must be used for O₃ as compared to gases such as methane and nitrous oxide. One option is to scale ozone history by the use of fossil fuels. On the global forcing the effect is moderate. A next step for this chapter is to update observational data for CH₄ and N₂O, to find tropospheric O₃ history from model studies in the literature. A band for the historical development can be developed for trop O₃ and compared with the calculations using different assumptions about emissions and lifetimes.

Joyce Penner: Carbonaceous aerosols, sulphur aerosols & indirect effects: It was stressed that data for carbonaceous aerosols are available from biofuels, fossil fuels and open biomass burning (data sets using satellite information, starting in 1979). It remains unclear how to put in uncertainties before 1979. It was mentioned that there might be some overlap in emissions estimated. For fossil fuel aerosols the bottom-up methods are used. For the further references, the authors could look at a paper recently published by Bond. Rough estimates according to various technologies before 1950 is very poor and represents another source for estimating the uncertainties. For the bio fuels, reasonable estimates are available also for past time periods. For the section on sulphur aerosols a new author needs to be identified. There are neither historical data nor observations available. On the indirect effects Natasha Andronova will provide some estimates and can summarise work that has been done so far.

In the afternoon *Jason Lowe* presented by telephone the limits on the climate change indices (Chapter 3, see Annex C). The aim of this part of the paper is to propagate source of uncertainty (from uncertainties and bottom-up calculations) into temperature change record and to compare with the observed range of temperature changes. It will start with the temperature change record and perform an inverse calculation to estimate the range of forcing compatible with the observed temperature dataset. Then a comparison between these forcings and observations and the uncertainty plume from the bottom-up calculations will be done. For these calculations a simple model such as the MAGICC model can be used.

Jason Lowe also presented results prepared by Sarah Raper on inverse calculation and estimating forcings for three different values of the climate sensitivity. Some major difficulties to resolve include: a) how to remove the internal and external variability from temperature records (try to resolve in May) and b) unravelling forcing from inverse calculations.

Jason Lowe and Sarah Raper will work out a procedure in May how to do the calculations. Intermediate results should be available in end June.

Niklas Höhne presented the sub-chapter on fluorinated gases, which includes source and closure uncertainties. On SF₆, there are large differences in what countries report and what other estimates provide (e.g. EDGAR dataset or estimates based on measurements in the atmosphere). It could be caused by Non-Annex I or reporting to little amounts for Annex I countries. In the discussion it was mentioned that CFCs should also be covered, but national attribution would not necessarily be needed.

The following presentations were held on Day 2 and information provided as **result of the breakout group discussions on Day 1**:

Atsushi Kurosawa: Source uncertainties (fossil fuel CO₂, CH₄, N₂O) including discussion on level of uncertainties for combustions activity data. Next steps are to define common emission database dimensions, identify regional and country level uncertainties, to assess UNFCCC reported data reports form parties. Since no uncertainties for earlier time periods are available the authors cannot address historic uncertainties.

Promode Kant: Uncertainty in LUCF emissions: The causes of uncertainties are mainly: data uncertainties, methodological uncertainties, scientific uncertainties. In addition calibration issues bring considerable uncertainties. Promode Kant noted that the content presented does not represent a consensus of the breakout group on CO₂ and LUCF emissions. As a way forward it was presented that for uncertainty reductions and assessment the group should using data with lower range of uncertainty as tested by other researchers, by comparison model results with field observations. An overall uncertainty assessment could be done by combination of multiple databases and multiple C-cycle models. There was no consensus yet in the group whether the anticipated final product should be a qualitative or a quantitative assessment. During discussion it was noted that the authors cannot use non-peer reviewed data, and that developing a new approach might take long time to justify. It was also mentioned that LUC and forestry could be a separate paper on its own in the future.

Atul Jain: Coupled Terrestrial-Ocean Carbon Cycle – ISAM Model results. This model is using data that is already published: two datasets for fossil data using CDIAC and Hyde. It performs separate simulations to see the differences of datasets on concentration level, (fossil, for cropland and pastureland). There was also a combined simulation done for pastureland and cropland. It was observed that when combining the HYDE (cropland and pasture land) data with CDIAC data for fossil fuel emissions you get the best approximation for observed concentration data. Regarding the closure issue it is relevant differentiating between sources versus sinks. The presenter hopes to be able to bring the uncertainty issues together and show the different profiles based on the different datasets.

Jan Fulgrestvedt: Approach to tackle N₂O and CH₄ and tropospheric ozone in paper #2. A more detailed outline of the relevant chapters was presented (see Annex D). Since the lifetime of methane is controlled by several factors (NO_x, CO, VOC, and methane itself) the focus on lifetime and change in lifetime will be important.

Joyce Penner: Aerosols and uncertainty assessments, sulphur and indirect effect of aerosols. POM (Particulate organics matter), BC (black carbon) from OV (open vegetation), BF (bio fuel burning) and FF (fossil fuel burning) will be assessed. OV uncertainties are calculated by top-down approach, since a projection back in time (anytime before 1979) is difficult. The uncertainty factor could be up to 2. To reconfirm the uncertainty factor the authors on the aerosol chapter should get information from the CO2 group (end of May 2005 at the latest). For BF: uncertainty also increases by the factor 2 for early time series. Sulphur aerosol uncertainty factors and indirect effects from aerosols were also discussed. The end product of the chapter will include a) emissions with uncertainty range, and b) ranges in forcing (direct and indirect), thus two types of uncertainties are covered.

4. WAY FORWARD & WORK PLAN

Until the next MATCH expert meeting (tentatively scheduled for October 2005) the following work items were agreed to be undertaken:

- Paper #1, "Analysing countries' contribution to climate change: Scientific choices and methodological issues": To collect comments from reviewers and publish as soon as possible. (Michel, Jan, Niklas, whereas Michel will take the lead in informing the other authors)
- Paper #2, "Attributing a fraction of climate change to a nation's historical emissions: closure and scientific uncertainty". To advance the draft, full draft at October meeting, ready for submission in November 2005 (Michael, Joyce, Jason). Submit draft of paper #2 to e.g. Journal of Geophysical Research, Journal on Climate, Climate Dynamics, Climatic Change.
- For paper #3, "Formal assessment of uncertainties and clarification of parameter space to be covered / use of response plots" to write detailed outline for October meeting (Ben Mathews, Niklas Höhne)
- For paper #4, to prepared an update of paper #1 "Repeating elements and attribution calculations discussed in paper #1 by including the outputs from paper #2 and paper #3" (Michel, Jan, Niklas, as necessary)
- To sketch a paper on possible future work (Michel, Niklas). It would include four elements
 - Continuation of present situation (scientific papers on contributions to climate change)
 - Development of a tool, so that any user can do the calculations selecting input emission data and making the policy choices
 - Considering the application of the contribution results (e.g. burden sharing or contributions to adaptation fund). Michel agreed to contact some people who work on burden sharing using the Brazilian proposal (approx. 6 groups) whether they are interested in a joint paper.
 - Broadening the scope of the work to consider also other future commitment regime designs.

In December 2005, when the MATCH group will report back to SBSTA, it is anticipated to report

- Final paper #1
- Submitted draft of paper #2

- Possible work for paper #3 (outline)
- Possible future work of MATCH

The following shows the schedule as agreed in the meeting.

	2005											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UNFCCC meetings												
MATCH meetings												
Paper #1				inal iscu sion								
Paper #2				raft						ull raft		ubm sion
Paper #3										utlin		
Paper #4/ update #1										Decisi on if neces sary		
Paper on future work										raft		rese tatio

Rachel Warren, representing DEFRA, mentioned that the next expert meeting could also be used to expose some policy makers to material the group is going to present in SBSTA meeting, so that the group can get some feedback before SBSTA meeting.

As potential meeting places for the next meeting the UK, the USA (Michigan), and Canada were mentioned. A possible time could be between 3 and 7 October 2005. An earlier meeting e.g. 26 to 28 September 2005 would interfere with IPCC meetings and carbon cycle meeting in Bolder, where some experts and authors of paper #2 would not be available.

ANNEX A: AGENDA**AGENDA****AD HOC GROUP FOR THE MODELLING AND ASSESSMENT OF CONTRIBUTIONS OF CLIMATE CHANGE (MATCH)**

**11-12 APRIL 2005, RIO DE JANEIRO, BRAZIL
VERSION 10 APRIL 2005**

Monday, 11 April 2005

9.30 – 11.00	Chair: Michael Prather	- Luiz Pinguelli Rosa: Welcome - Niklas Höhne: Quick review of timelines (SBSTA), tasks, goals - of MATCH, review of our project list & long-term work plan	1.5
10.00 – 11.00	Chair: Michael Prather	- Michael Prather: News from the Scientific Coordinating Committee - Michel den Elzen: Main results of paper #1: "Analysing countries' contribution to climate change: uncertainties and methodological issues"	
11:00	COFFEE BREAK		30'
11.30 – 13.00	Chair: Michael Prather	- Michael Prather: Introduction to the draft paper #2: "Attributing a fraction of climate change to a nation's historical emissions: closure and scientific uncertainty" - Atsushi Kurosawa: Source uncertainty fossil CO2 - Christiano Campos de Pires: Source uncertainty forestry CO2 - Atúl Jain: Closure uncertainty CO2 - Atsushi Kurosawa: Source uncertainty CH4, N2O - Jan Fuglestedt: Closure uncertainty CH4, N2O - Niklas Höhne: Source and closure uncertainty fluorinated gases - Joyce Penner: Sulphate, organic carbon black carbon, indirect aerosols	1.5
13.00	Lunch		1h
14.00 – 15.30	Chair: Joyce Penner	Jason Lowe (by phone, tentative): Limits on the climate change indices	1.5
15:30	COFFEE BREAK		30'
16:00 – 17:30	Group chairs	Discussion of the draft paper #2 in small groups - Breakout group 1 "CO2 and LUC CO2 emissions, uncertainties, closure" - Breakout group 2: "CH4, N2O, Tropospheric ozone" - Breakout group 3: "Aerosols, black carbon"	1.5
17:30	END		
19:30	DINNER		

Tuesday, 12 April 2005

9.00 - 11.00	Chair: Niklas Höhne	Organization of future work Ben Mathews (by phone): Presentation of possible work plan	2h
11:00	COFFEE BREAK		30'
11:30 - 13.00	Chair: Michel den Elzen	Revised detailed outline for Paper #2 and discussion of chapters - Atsushi Kurosawa: CO2 & CH4 emissions (fossil fuel & industry/agriculture) - Promode Kant: LUC CO2 Emissions - Atúl Jain: CO2 Closure	1.5
13:00	LUNCH		1:0
14:00 - 14:40	Chair: Michel den Elzen	Continued discussion on chapters of paper #2 - Jan Fuglestvedt: CH4, N2O Closure - Joyce Penner: Aerosols	40'
14:40 - 15:15	Chair: Michel den Elzen	- Michael Prather: Further discussion of section 4, assignments, close up paper #2	45'
15:15	COFFEE BREAK		30'
15:45 - 16:00	Chair: Michael Prather	Model presentation and wrap up - Guoquan HU: New Model Results - Niklas Höhne: Review of work plan until next meeting	15'
16:00	CLOSING THE MEETING		

ANNEX B: PARTICIPANTS OF EXPERT MEETING

The following experts attended the expert meeting:

- Atsushi Kurosawa, Japan
- Atul Jain, USA
- Ben Matthews, Belgium (by telephone on 12 April 2005 during morning session)
- Christiano Pires de Campos, Brazil
- Guoquan HU, China
- Jan Fuglestedt, Norway
- Jason Lowe, UK (by telephone on 11 April during afternoon session)
- José Domingos Gonzalez Miguez, Brazil
- Joyce Penner, USA
- Luiz Gylvan Meira Filho, Brazil
- Luiz Pinguelli Rosa, Brazil
- Maria Silvia Muylaert de Araujo, Brazil
- Mauro Meirelles O Santos, Brazil
- Michael Prather, USA
- Michel den Elzen, Netherlands
- Natasha Andronova, USA
- Niklas Höhne, Germany
- Promode Kant, India
- Rachel Warren, UK
- Simone Ullrich, Germany
- Stephen W. Wood, New Zealand
- Wandera Ogana, Kenia

ANNEX C: OUTLINE PAPER #2, VERSION 4 FEB 2005

Version 4. February 2005

Attributing a fraction of climate change to a nation's historical emissions: closure and scientific uncertainty

Authors:

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 Atsushi Kurosawa <kurosawa@iae.or.jp> - National greenhouse gas inventories
 Fabian Wagner <wagnerf@iiasa.ac.at> - National greenhouse gas inventories
 Murari Lal <lal_m@usp.ac.fj> - Non-Annex I national greenhouse gas inventories
 John van Aardenne <john.van-aardenne@jrc.it> - EDGAR emissions
 Christiano Pires de Campos <campos@ivig.coppe.ufrj.br> - historical LULUCF emissions
 Niklas Höhne <N.Hoehne@ecofys.de> - coordination, GHG inventories

Timing

4 Feb	Höhne, Lowe, Penner, Prather: transmit detailed outline and tasks to co-authors
11 Feb	All Authors: confirm tasks and timeline
1 Apr	Results from authors to all authors, first-draft assembled
4 April	first-order draft assembled and sent to MATCH group (Höhne)
11-12 April	MATCH meeting in Rio, discussion/presentation of paper

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1. Introduction

[1] The ability to attribute climate change and related damage to specific actions, such as the emission of greenhouse gases, requires a thorough scientific evaluation not only of the uncertainty in the magnitude of those defined emissions but also in possible systematic errors whereby natural or anthropogenic emissions have been miscounted. This paper combines the propagation of errors in accountable emissions with closure calculations to estimate possible biases, such as over/under-counting greenhouse gas emissions, or other radiative forcings, that might be country specific. This study originates from an expert group hosted by the UNFCCC Secretariat to study the Brazil proposal. The first paper from this group (den Elzen et al) evaluated the errors associated with propagating different balances and histories of emissions through the non-linear climate system, investigated different mathematical approaches and their self-consistency, and showed how different geophysical indices could alter the attribution of relative climate change. This second paper examines the scientific uncertainty associated with attributable emissions.

[2] The Brazil Proposal (FCCC/AGBM/1997/MISC.1/Add.3), contemporary with the negotiations on the Kyoto Protocol, planned to use the relative climate change or damage due to a nation's historical emissions as an index for targeted reductions in

greenhouse gas emissions. During the scientific evaluation of the Brazil Proposal, it became clear that – in addition to the mathematical and methodological issues (see den Elzen et al paper) – an approach based solely on ratioing the reported accumulated emissions of the Kyoto gases from Annex I countries has some potential, hidden biases. Simply put, there is a closure problem: our best models do not always match the observed climate system changes, including the greenhouse gas abundances; and thus uncertainties implied in this mismatch of absolute changes must be transferred to uncertainty of relative changes. Without some level of confidence that (i) all known emissions of greenhouse gases (anthropogenic and natural) can explain the historical record of atmospheric abundance and (ii) this observed history of greenhouse gases plus other radiative forcings (e.g., solar, volcanoes, and especially anthropogenic aerosols) can explain the observed climate changes over the 20th century, there are possible errors in the national emissions that may be country specific, even within Annex I. This paper examines the level of closure in items (i) and (ii) above insofar as it points out the magnitude of unspecified sources or sinks for greenhouse gases and aerosols. It compares these with uncertainties derived from bottom-up national inventories such as EDGAR-HYDE. We then follow the propagation of both measures of scientific uncertainty as in the first paper (den Elzen et al.) to two simple indices of climate change, the global mean surface temperature (T_{surf}) and the sea-level rise due to oceanic heat uptake (O_{cn}).

[3] The scientific evaluation of the Brazil Proposal was instigated by Brazil (May 1999) with subsequent UNFCCC expert meetings organized under SBSTA in Bonn (May 2001, FCCC/SBSTA/2001/INF.2), and in Bracknell (Sep 2002, FCCC/SBSTA/2002/INF.14). The UNFCCC withdrew support for the process, agreed it should be continued by the scientific community, and requested a progress report at SBSTA meetings 20 (Jun 2004) and 23 (Nov 2005) (FCCC/SBSTA/2002/L.24). The third expert meeting in Berlin (Sep 2003) was held on the initiative of the governments of UK, Brazil and Germany. This now ad hoc group renamed the project MATCH (loosely from Modeling and Assessment of Contributions of Climate Change) and was supported by UK funding of administrative support and an executive secretary at Ecofys (Köln). The MATCH group, with only scientists present, met again in Köln (May 2004) to review the preparation of scientific papers and prepare for the first presentation to SBSTA (Jun 2004).

2. Limits to uncertainties in emissions

Step I. Define plausible upper/lower limits to uncertainties in primary emission of GreenHouse Agents (GHA = gases and aerosols that act directly and/or indirectly) that could reflect systematic errors in national emissions of such agents.

Two approaches will be used:

1) Source Uncertainties. Using bottom-up inventories (e.g., EDGAR-HYDE, NGGI) we derive uncertainties in nation-specific and in total GHA emissions. This is somewhat subjective and based on expert judgment, but will include historical national emissions for some Annex I countries.

Prepare a common emission dataset to be used later in step II. (Kurosawa (lead), Wagner) with emissions and uncertainty ranges.

2) Closure Uncertainties. Only for the greenhouse gases (Kyoto and Montreal plus ozone), do we have observed abundances (approximate for ozone) that can be compared with our best forward atmospheric chemistry/C-cycle models calculating abundance from emissions. (Although these observations are only approximate for ozone.) Hence, a disparity in predicting abundances from total 'known' emissions

can be mapped onto a possible systematic error in emissions. This closure uncertainty applies only to total emissions and represents a fundamental scientific uncertainty in our understanding. It needs to be compared with the source uncertainty and then we need to make an 'expert judgment' as to how this might be attributable to the sector/national inventories -- a difficult task.

2.1 CO₂ and the carbon cycle

2.1.1. Source uncertainty

Fossil CO₂

Kurosawa (lead), Wagner, Lal (Non-Annex-I), van Aardenne

Uncertainty of bottom up national inventories: Marland, IEA, EDGAR, and national emission inventories

- Bottom up uncertainty per country for *some* countries.
- Bottom up uncertainty for the global total

LUCF CO₂

van Aardenne (lead), Pires de Campos

Uncertainty of bottom up national inventories: EDGAR, Houghton, IVIG

- Bottom up uncertainty per country for *some* countries.
- Bottom up uncertainty for the global total

2.1.2 Closure uncertainty

Jain (lead), Fuglestedt,

For mean atmospheric CO₂ we can use a single reconstruction for the past millennium (Francy, Etheridge, ...). We will use one or more C-cycle model from paper #1, and hope to include at least one complex, multi-dimensional C-cycle models with climate feedbacks (e.g., interactive vegetation, such as the 3+ models in C4MIP). We will run the different emissions options with one or more 'standard' models to provide an 'envelope' of results for CO₂ abundance (which is unlikely to match the observed history). (This avoids the problem of models tuning their choice in emissions to match observations.) Try to add ¹³CO₂ hisotrical record as additional test.

2.2 CH₄, NO_x, CO, VOC, and O₃, (OH implied)

2.2.1 Source uncertainty

Kurosawa, Wagner (lead), Lal (non-Annex-I), van Aardenne

Uncertainty of bottom up national inventories for CH₄ (only) EDGAR, USEPA, others?

- Bottom up uncertainty per country for *some* countries.
- Bottom up uncertainty for the global total

Uncertainty in emissions inventories for NO_x, CO , VOC?

2.2.2 Closure uncertainty

Prather (Lead), Fuglestedt

1B. CH₄. We have only one emission model (? EDGAR), but the calculation of CH₄ abundance involves some atmospheric chemistry complexities. Will need to assume a parallel scenario for NO_x, CO, VOC emissions (EDGAR+natural??). Have different models do their best, plus perform a separate set with one model assuming CH₄ budget lifetime fixed (8.4 yr), some CH₄ feedback (TAR/WGI/Ch.4); using history of NO_x, CO, VOC.

Do we have natural CH₄ emissions history? ¹³CH₄ historical record provides test? (ice core, emissions?)

1C. trop O₃. Have participating models (or IPCC/AR4 model results) calculate tropospheric O₃ increases (and related RF) for attributable emissions (CH₄, NO_x, CO, VOC) and compare with a range of published trop O₃ RF histories: TAR/WGI/Ch.6 (fig 6.8); TAR/WGI/Ch.4 back projection (w/EDGAR); Mickley et al; Wang?; Portman and Solomon; Berntsen et al., 2000; Oltmans free trop O₃ 25 yrs; Staehelin historical record, others? The only comparison with observed trop O₃ that I would use is the recent (not the connect dots with 1900 obs. at a few stations?). ?Attribution to individual / regional emissions of CH₄, NO_x, CO, VOC (non-additive issues here) ?

2.3 N₂O

2.3.1 Source uncertainty

Kurosawa, Wagner (lead), Lal (NAI), van Aardenne

Uncertainty of bottom up national inventories for N₂O(only) EDGAR, USEPA, others?

- Bottom up uncertainty per country for *some* countries.
- Bottom up uncertainty for the global total

2.3.2 Closure uncertainty

Fuglestvedt (lead)

2.4 Fluorinated greenhouse gases

2.4.1 Source uncertainty

Höhne (lead), Kurosawa, Wagner

National greenhouse gas inventories

2.4.2 Closure uncertainty

Höhne (lead)

Comparison with atmospheric measurements

2.5 Sulfate

2.5.1 Source uncertainty

Penner (lead), currently looking for additional authors

We have at least 3 reconstructions of industrial SO₂ emissions.

2.5.2 Closure uncertainty

Penner (lead)

There are different values for direct RF from these emissions (depends on lifetime, size distribution, etc). Use TAR Ch.5 models to show spread in direct RF for one SO₂ emission history, use the 'average' TAR model plus one of the integrated assessment models to show spread in direct RF for different emission histories. [?Observations compared as per TAR Ch.5, ?total optical depth, ?].

2.6 Organic and black carbon from fossil and bio fuel combustion

2.6.1 Source uncertainty

Penner (lead), currently looking for additional authors

Alternative emissions history from Novkaov (ffuel) + Ito (bfuel), and Bond (ff+bfuel).

2.6.2 Closure uncertainty

Penner (lead)

Propagate through range of TAR/Ch.5 models (assume linear). Observations compared as per TAR.

2.7. Indirect aerosols

Penner (lead)

Can we define an RF history for indirect effects? It will be essential for part 3. Can the D&A studies be used to infer total indirect? vs. bottom-up methodologies.

3. Limits on the climate change indices

Step II. Define plausible upper/lower limits on the climate change indices (Tsrf = global mean surface temperature, Ocn = sea level indices such as ocean heat uptake) that cannot be explained by propagating the currently accounted-for GHA. This indicates possible systematic errors in climate-change calculations that might impact the national accountability.

3.1. Source Uncertainties (forward calculation)

Raper (lead), Lowe, Fuglestedt

1) Source Uncertainties (forward calculation).

First phase until the meeting: Take historical observed concentrations of GHAs and run the simple climate model to obtain temperature increase.

Second phase: we use the bottom-up inventories of emissions driving the non-observed GHA -- specifically aerosols and possibly tropospheric ozone. We propagate the source uncertainty in these non-observed GHA into climate indices, using the observed total (not national) forcing from greenhouse gases. The uncertainty in national attribution of these indices combines the source uncertainties from the non-observed GHA with the uncertainty in the attributable fraction of the observed greenhouse gases from Goal I.

3.2 Closure Uncertainties (inverse calculation)

Lowe (Lead), Stott, Raper

2) Closure Uncertainties (inverse calculation). The closure calculation here is matching the observed global mean surface temperature record, using the observed GHA (greenhouse gases) and fitting a history of the non-observed GHA (primarily aerosols). We can use the 'beta fits' derived in the attribution study from 3 different GCMs (Stott) to infer the history of non-observed GHA radiative forcing. The MAGIC model using the different fits to GCMs from the TAR (Raper) would have to be run in an inversion/fitting mode to derive this also. Given the history and uncertainty range in aerosol RF, we need to invert to derive aerosol emissions, compare with the source uncertainties, and possibly attribute to sector/national emissions.

Schematically, the closure emission and uncertainties are based on these two steps

- I. Greenhouse gas observed abundances ==> GHGas Emissions
- II. Tsrf (?& Ocn) ==> total RF - natural RF
 - GHGas RF ==> Aerosols (?& LU change) RF
 ==> Aerosol Emissions

ANNEX D: APPROACH FOR N₂O AND CH₄

Point b) for N₂O

Use EDGAR emission data

Calculate C(t) using best estimate for lifetime.

Compare with observed concentrations and use this as a constraint.

Test effect of assumed uncertainty in lifetime /emissions for this evaluation to achieve an emission "band"

Calculate difference in **emissions** from difference in **conc** ($\Delta\text{ppbv} \rightarrow \Delta\text{Tg/yr}$) and adjust emissions to be consistent with observed concentration.

Compare deviation in emission ($\bar{\delta}_{\text{mod}}$) with range from Kurosawa's part.

Use this for evaluation of the quality of the inventories and possible systematic error in emissions:

- missing sources?
- Underestimates / overestimates of source strengths

The history of the deviation may give important info about where the errors are. Gives us qualitative assessment of the level of understanding of the gas budget. But applies only to **total global emissions** (natural + anthropogenic) and represents a fundamental scientific uncertainty in our understanding.

Discuss whether this/these errors could be within Annex I, RoW or natural sources, if we can. Short.

Are the errors confined to some specific sectors? This overlaps with a).

If so, this may affect the national emissions differently and thus the attribution calculations. Use expert judgements.

Point b) for CH₄

Same as for N₂O, but the importance of lifetime estimate and formulation is more important since loss of methane is controlled by OH which is a function of NO_x, CO, VOC and CH₄ itself.

Use assumptions about lifetime/adjustment time:

- constant (best estimate) lifetime (too simple, but may be useful to show the effect of this assumption)
- TAR formulation $d\text{OH} = f(\text{CH}_4, e\text{-NO}_x, e\text{-CO}, e\text{-VOC})$
- Any new formulations?

These results are not taken further in the calculations but will be used as input to the discussion and conclusion:

- level of understanding the budgets and the significance of this for the 'big picture'; i.e. how well can we model the changes in global climate and how may this affect the attribution calculations.

Modeling development trop O₃ forcing:

O3 different from CH4/N2O sections since we're **not** trying to attribute O3 changes to nations. This assessment is more a part of the assessment of our general understanding and says something about our ability to model man made climate change.

1) Critical review and choose a history for trop O3 (DU or RF) or a set of histories from the literature. Obtain a band for RF-tropO3.

2) SCM: Model the development in RF trop O3 based on EDGAR emissions of CH4, NOx, CO and VOC with various assumptions about lifetime/adjustment time of CH4 (constant, TAR)

TAR gives tropO3 as function of e-NOx, e-CO, e-VOC and level of CH4. Thus, assumptions about methane chemistry affect O3.

We expect a large range from the literature. But if everyone gets approx the same answer: Use uncertainty in emissions of O3 precursors (e.g. +/- x% for NOx) to calculate a band of trop O3 RF.

Also test effect of uncertainty in current RF-O3 since history is calculated based on this estimate.

Focus on WHEN RF-O3 kicks in.

ANNEX E: OUTLINE PAPER #2, VERSION 8

MATCH paper #2

Version 8 – outline only 11 April 2005 (MJP)

Attributing a fraction of climate change to a nation's historical emissions: closure and scientific uncertainty

1. Introduction (1 pp, Prather, Lowe, Penner)

(DUE: all sections 2&3 end of JUNE, to Jason for 4, zeroth draft by mid August)

2. Long-lived Greenhouse Gases:

Uncertainties in Annex-I emissions from inventories &
Possible global bias in reconciling emissions-to-abundances

For these long-lived components of Radiative Forcing (RF) we can use the observed atmospheric record (whole air, firn air, and ice cores) to define the RF history. Thus, our questions here are separated into the "attribution" one (what are Annex-I emissions?) and the overall "closure" one (is there a systematic bias between emissions, models, and observed abundances?).

2.1. CO₂ (5-6 pp, Jain, Kurosawa, Wagner, Campos, Kant, ...)

(a) Annex-I emissions by country (*fossil-fuel+cement & LUCF*):

NGGI reporting w/uncertainties (1990--),
pre-NGGI (18??-1990) period from other inventories – with uncertainties
Comparison with annex-I data from other global inventories
(e.g., EDGAR, Houghton, ...)

(b) Possible bias / lack of understanding of global CO₂ emissions

Global emissions for *fossil-fuel & LUCF* (full period, bottom-up w/uncertainty)
+ C-cycle model (with uncertainty ranges?)
=> Global mean atmospheric abundance
Difference with observed abundance
=> missing / over-estimated emissions

(c) Discuss possible biases & uncertainties, whether they might affect attribution in part (a)

Product: Annex-I CO₂ emissions history with bottom-up uncertainty plus added possible bias or systematic errors (semi-quantitative, not necessarily Annex-I) due to closure errors of the global CO₂ budget. History of total RF from CO₂.

2.2. CH₄ (2 pp, Fuglesvedt, Kurosawa, Wagner, Prather,...)

(a) Annex-I emissions by country:

NGGI reporting w/uncertainties (1990--), including fossil-fuel, agricult, etc.
pre-NGGI (1890-1990) period from other inventories – with uncertainties

comparison with annex-I data from other global inventories (e.g., EDGAR)

- (b) Possible bias / lack of understanding of global CH₄ emissions
 Global emissions (full period, bottom-up with uncertainty)
 + Atmospheric chemistry model (with uncertainty ranges?)
 => Global mean atmospheric abundance
 Difference with observed abundance
 => missing / over-estimated emissions
- (c) Discuss possible biases & uncertainties,
 whether they might affect attribution in part (a)

Product: Annex-I CH₄ emissions history with bottom-up uncertainty plus added possible bias or systematic errors (semi-quantitative) due to closure errors of the global CH₄ budget. History of total abundance/RF from CH₄.

2.3. N₂O (1 pp, Fuglestedt, as above...)

- (a) Annex-I emissions by country:
 NGGI reporting w/uncertainties (1990--), including fossil-fuel, agricult, etc.
 pre-NGGI (18??-1990) period from other inventories – with uncertainties
 comparison with annex-I data from other global inventories (e.g., EDGAR)
- (b) Possible bias / lack of understanding of global N₂O emissions
 Global emissions (bottom-up with uncertainty)
 + Atmospheric chemistry model (with small lifetime uncertainty)
 => Global mean atmospheric abundance
 Difference with observed abundance
 => missing / over-estimated emissions
- (c) Discuss possible biases & uncertainties,
 whether they might affect attribution in part (a)

Product: Annex-I N₂O emissions history with bottom-up uncertainty plus added possible bias or systematic errors (semi-quantitative) due to closure errors of the global N₂O budget. History of total abundance/RF from N₂O.

2.4. SF₆, PFCs, HFCs (1 p, Hoehne, Kurosawa, Wagner...)

- (a) Annex-I emissions by country:
 NGGI reporting (1990--) & pre-NGGI (1800-1990) period (?not important)
 Uncertainties are probably not important here, limited to total observed.
- (b) Possible bias / lack of understanding of global F-gas emissions
 Atmospheric abundance history => global emissions
- (c) Discuss possible biases & uncertainties,
 whether they might affect attribution in part (a)

Product: Annex-I F-gas (SF₆, PFCs, HFCs) emissions history with simple uncertainties from bottom-up or from global closure of atmospheric budgets. History of total abundance/RF from F-gases (SF₆, PFCs, HFCs).

2.5. CFCs and HCFCs (not attributable) (0.5 p, Hoehne, ...)

These gases are an important source of current RF, but are not going to be nationally attributable => just compile observed history for RF calculations.

Product: History of total abundance/RF from CFCs and HCFCs.

3. Short-lived Greenhouse Agents & other forcings:

**RF history and uncertainty for aerosols & tropospheric O₃
RF history of "other", natural forcings(?)**

For these short-lived components of RF we have no well documented history. There are brief periods of global-scale observations that help constrain the history (e.g., recent satellite observations of absorbing aerosols, trends in free-tropospheric ozone), there are several modeling studies, but no unambiguous history. Thus, we need to construct an RF history based on precursor emissions or surrogate emissions, one THAT includes an uncertainty range.

3.1. Sulfate Aerosols (5 pp, Penner, Andronova, Bond?, van Ardenne? ...)

3.2. Organic Carbon and Black Carbon Aerosols

(a) Define historical OC/BC/SO₂ emissions (?regional), uncertainty from alternative emission scenarios.

(b) Map emissions to abundances to RF direct (with uncertainty)

Product: History of direct total RF from BC/OC - sulfate aerosols, including an uncertainty range or band.

3.3. Total Aerosol Indirect Effect

Product: History of total indirect RF from OC/BC+sulfate aerosols, including an uncertainty range or band.

3.4. Tropospheric O₃ (1 p, Fuglestedt, Prather, ...)

(a) Critical review of tropospheric ozone history from published models and observations. Look at TAR also.

Product: History of total abundance/RF from tropospheric O₃, including an uncertainty range or band.

3.4. Other / Natural Forcings (Lowe, Andronova, ...)

Do we want to quickly summarize here an RF range for solar and volcanic? And for LUCF-albedo change?

Product: History of total RF from total solar irradiance changes, volcanoes, Inad-use albedo changes (cooling).

4. RF and Climate Change (6 pp, Lowe, Raper, Stott, ...)

This section examines the possible errors/uncertainties in going from greenhouse gas abundances and other specified RFs to climate change. A failure/discrepancy in climate models to reproduce the last 150 years of climate change (i.e., global mean surface T and patterns, mean sea level rise) could be due to either (i) a failure of the model to simulate climate feedbacks (e.g., water & clouds) OR (ii) a possible error in the RF history. In either case, significant discrepancy reduces overall confidence in attributing climate change, even relative climate change. In case (ii), however, there are several errors that might significantly alter the relative attribution: e.g., non-linear additivity effects of different greenhouse agents, incorrect calculation of RF from abundance, missing gases (unlikely).

4.1. Mapping Abundances to RF

4.2. Reconciling RF with climate change record (forward and reverse)

4.3. Forward models of Annex-I emissions/RF to climate indices (which ones?)

4.4. Spatial patterns and attribution from the 3 GCM runs

Product: ? Confidence that the relative RF histories are a correct measure of the relative climate change. Estimate possible errors/systematic bias in RF.

ANNEX F: WAY FORWARD AFTER PAPER #2

Possible MATCH workplan Draft for discussion 7 April 2005

By B. Mathews and N. Höhne

At the last meeting the MATCH group agreed that in total four scientific peer reviewed papers could be produced before the end of 2005 the deadline for reporting MATCH progress to SBSTA 23.

Paper #1, "Analysing countries' contribution to climate change: Scientific choices and methodological issues" is submitted and under review.

Paper #2, "Attributing a fraction of climate change to a nation's historical emissions: closure and scientific uncertainty" is available in draft form and is to be discussed at this meeting.

At the last meeting we agreed to have paper #3 and paper #4. The report stated:

- For paper #3 "Formal assessment of uncertainties and clarification of parameter space to be covered", Ben Mathews, Ian Enting and Cathy Trudinger could have a leading role in drafting an outline of this paper until the next meeting. Additional potential co-authors will be approached following the fourth expert meeting."
- For paper #4 "Repeating elements and attribution calculations discussed in paper #1 by including the outputs from paper #2 and paper #3", Niklas Höhne agreed to take the lead and will be supported by Ben Mathews in drafting an outline of the paper until the next meeting. In addition some of the experts involved in paper 1 should also contribute to paper 4. Further details will be discussed during the next months.

Already during the discussions on paper #1 we found that a doing a probabilistic assessment of the uncertainties due to the scientific parameters of the climate model would result in only small changes to the **relative** attribution compared to the influence of other methodological choices such as the starting year and the inclusion of certain gases.

Therefore a new paper #3 is proposed:

- IV We would provide a simple tool that can be used to perform these calculations and have the methodological parameters select by the user.
- V It will essentially consist of plots/matrices similar to those that Jesper Gunderman first presented at the Berlin Meeting (figure 1).
- VI A simple excel tool could use these plots as a basis to let a user perform his own calculations.

Figure 1 was originally shown in Jesper Gunderman (DEA-CCAT)'s submission to ACCC in 2002. The concept behind such a plot/matrix was suggested by Gylvan Meira-Filho to Jesper (and myself) when we met in Geneva (IPCC) in April 2002. DEA-CCAT's submission to ACCC (which was accompanied by extensive documentation and examples in Mathcad) showed plots like this for concentration, forcing, temperature and sealevel, for CO₂, N₂O and CH₄, and also the difference between 3 attribution methodologies.

Note that the z-axis (colors) shows the temperature change per [ton] emissions.

Essentially such plots show a stack of pulse-response functions, one for each year (each of which similar to the curves generated by Niklas for Match Paper1).

The advantage of this approach, is that it encapsulates the more-complex but less-sensitive part of the model in a simple plot/matrix, while leaving the user to choose the emissions and indicators (including the time-intervals). Note that the uncertainties regarding historical emissions from land-use-change, to which the relative attribution is more sensitive, and which are not so quickly resolveable, are external to such a matrix, and can be explored using it.

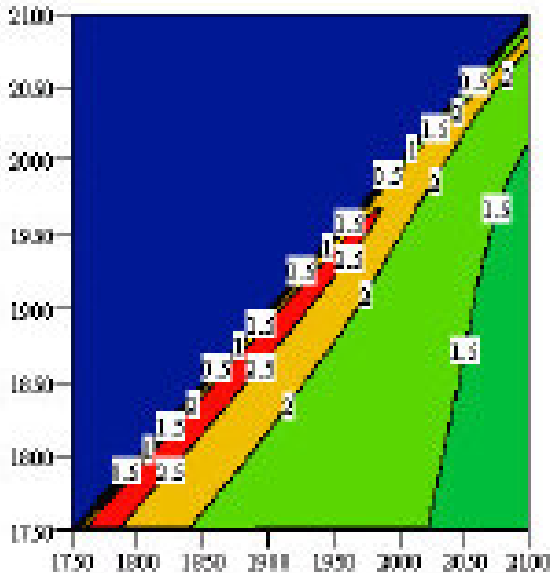


Figure 1: Example plot

Rather than using the 2002 results, the proposed paper would show matrices calculated using more complex models, building on MATCH papers 1 and 2 (see also note below regarding probabilistic assessment).

Some scientists may fear that this concept makes the relative attribution calculation appear too simple. However it is postulated that providing end-users with such a matrix, calculated using a relatively complex model (combined with a probabilistic exploration of parameter space), would lead to more accurate results than providing them with an over-simplistic model.

We would calculate the effect of an amount of gas emitted in a year (y-axis) on temperature rise or radiative forcing in another year (x-axis). Proposed change: change the x-axis to the time *difference* (years) between emissions and impacts. This would remove the empty triangles (top left of plot), and also make it easier to see changes due to nonlinearities and feedbacks (in the absence of which, the contours would become parallel to y-axis).

These pictures could be generated for several parameters. Plots would be shown for each (attributable) gas, and for each indicator (concentration, forcing, temperature, sea-level).

Regarding model parameters, there are infinite potential combinations that might be shown. However the results of paper 1 suggest that the overall effect of model uncertainties (such as climate sensitivity, biogeochemical feedbacks etc.) on the **relative** attribution is rather small, although their effect on the absolute indicators (such as temperature change) is large. Therefore it is proposed to *normalise* the

plot/matrix to ensure it can only be used for relative attribution, and also to make a probabilistic assessment to summarise the range due to uncertain model parameters.

Normalisation (and relation to GWP):

The plots/matrices could be normalised by dividing by the indicator-change for one gas and year combination (e.g. divide by the temperature change in 2050 due to 1ton of CO₂ emitted in 1990). A better variant might be to divide by the integral of the indicator from 2000 to 2100 (still for a pulse of CO₂ emitted in 1990): in this latter case, we would have something similar to the GWP: indeed if the relative radiative forcing (calculated this way) for another gas were integrated over the same interval, the sum should be exactly equal to its GWP. Thus effectively this matrix would provide a more generalised variant of GWP, which not only allows the user to choose the indicator and time-period for integration, but also takes into account the effect of changing the year of emissions. Such a matrix could also be useful for other applications -for example in comparing projects, or generating cost-effective multi-gas mitigation scenarios etc.

It is anticipated that in the normalised (relative) matrix many model uncertainties will cancel (because each pulse is affected similarly), hence it may be reasonable to propose that a single plot (per gas/indicator pair) would be sufficient for many applications. However to test and demonstrate this, it is proposed to make a probabilistic assessment covering the parameter space, from which the maximum ranges and standard deviations could be derived as well as the means. Probabilities may be assigned to parameter sets according to the correspondence of predictions with historical measurements. Such methodology has already been incorporated into JCM for analysis of stabilisation under uncertainty, although this should be updated to take into account several recent papers on probabilistic approaches.

In principle, we could also provide plots for different attribution methods (timeslice, normalised marginal) – but again it is anticipated that the difference will be small (see Gunderman analysis, and Match paper1) . One advantage of the timeslice method is that the x-axis of the plot/matrix can be extended independently of the future scenario (although if the y-axis is also extended into the future, it remains scenario-dependent). Calculating the matrix using the timeslice method may be computationally intensive, but once that is done it would be easy for anybody to apply the result for different emissions datasets.

Possible timing:

	2005											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UNFCCC meetings												
MATCH meetings												
Paper #1				final discussion								
Paper #2				draft							submission	
Paper #3											...	

Considering that Papers 1 and 2 have taken longer than anticipated, it may seem ambitious to finish a third paper this year. On the other hand, once I have finished the new structure of JCM5 (end May?), we could apply this to make such plots/matrices relatively quickly, providing results for discussion at the autumn Match meeting.