Expert Meeting on Short-Lived Climate Forcers (SLCF)

Meeting Report

28-31 May 2018, Geneva, Switzerland

Task Force on National Greenhouse Gas Inventories (TFI) /

Working Group I (WGI)

ipcc

INTERGOVERNMENTAL PANEL ON climate change

Task Force on National Greenhouse Gas Inventories (TFI)

WMO UNEP

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Table of Contents

Foreword 4
List of Acronyms and Abbreviations 5
Executive Summary 8
Background 10
a) Relevant IPCC decision, Decision IPCC/XLVI-6. Short-lived Climate Forcers; IPCC-46, 6-10 September 2017, Montreal 10
b) List of SLCF species considered during EM 10
c) Coverage of SLCF in existing non-IPCC guidance 10
d) Meeting objectives 11
A. Introduction 12
B. Conclusions and Recommendations 14
C. Summary of Keynote Presentations 16
D. Reports From Break-Out Groups on Themes 1, 2 and 3 28
E. Annexes 36
Annex 1: Agenda of the meeting 36
Annex 2: Synthesis of responses to the questionnaire 39
Annex 3: Reports from break-out groups – slides of presentations delivered at the plenary on day 4 (1a, 1b, 2a, 2b, 3a, 3b, 3c, 3d) 41
Annex 4: List of participants (in alphabetical order by family name; country by nationality) 63

Foreword

We are pleased to present this report of the Expert Meeting on Short-Lived Climate Forcers which was held on 28-31 May 2018 in Geneva, Switzerland.

Based on the request by some Members, the Intergovernmental Panel on Climate Change (IPCC) decided at its 46th session in September 2017 in Montreal to hold an expert meeting on Short-Lived Climate Forcers (SLCFs) to discuss issues on estimation of emissions and climate effects jointly co-organized by Task Force on National Greenhouse Gas Inventories (TFI) and Working Group I (WGI). An Expert Meeting on Emission Estimation of Aerosols Relevant to Climate Change took place in 2005; the IPCC was of the view that the science had progressed enough since then so that another expert meeting with this topic would be reasonable.

The meeting brought together many scientists and inventory compilers. From 172 experts nominated by IPCC member governments, observer organizations and members of IPCC Bureau as well as the Bureau of IPCC Task Force on National Greenhouse Gas Inventories (TFB), 80 were selected as participants, taking into account regional and gender representation, expertise and experience in this field.

The outcomes of the meeting will be used as a basis for consideration of future work of TFI. Key aspects of future work in this area, including the timing, scope, nature, format, and sequencing of such work on inventory methodology should be considered by the scientific steering committee for this expert meeting and TFB, and be decided by the IPCC Plenary.

The outcomes of the meeting are also expected to feed into the WGI AR6 report, primarily in Chapter 6 (Short-lived climate forcers) but also chapter 7 (The Earth's energy budget, climate feedbacks, and climate sensitivity), and recommendations will be presented to the IPCC Plenary in October 2018 via the expert meeting report. The meeting also highlighted the scientific background of key climate metrics related to short-lived climate forcers which should be considered for coordination across WG reports towards the synthesis report (SYR) of the sixth assessment report (AR6).

We would like to thank all those involved in this meeting, namely, the experts who participated, and the members of TFB and WGI Bureau and their TSUs, for their contribution to make this meeting a success. In particular, we would like to express our sincere gratitude to the Governments of Switzerland and Norway for their financial contribution, and to the World Meteorological Organization (WMO) and IPCC Secretariat for their generous support by hosting this meeting.

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List of Acronyms and Abbreviations

ACCMIP	Atmospheric Chemistry and Climate Model Intercomparison Project
AerChemMIP	Aerosols and Chemistry Model Intercomparison Project
AP	Air Pollutant
AP-42	US EPA Compilation of Air Pollutant Emission Factors
API	Application Programming Interface
AR4	Fourth Assessment Report
AR5	Fifth Assessment Report
AR6	Sixth Assessment Report
BC	Black Carbon
BOG	Break-Out Group
BrC	Brown Carbon
BVOC	Biogenic Volatile Organic Compounds
CCAC	Climate and Clean Air Coalition
CEDS	Community Emissions Data System
CEM	Continuous Emission Monitoring
CH_4	Methane
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CMIP6	Coupled Model Intercomparison Project Phase 6
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COSMOS	Continuous Soot-Monitoring System
EBC	Equivalent Black Carbon
EC	Elemental Carbon
EDGAR	Emission Database for Global Atmospheric Research
EEA	European Environment Agency
EF	Emission Factor
EM	Expert Meeting
EM-SLCF	Expert Meeting on Short-Lived Climate Forcers
EMEP	European Monitoring and Evaluation Programme
ERF	Effective Radiative Forcing
EU	European Union
FAO	Food and Agriculture Organization of the United Nations

GAINS	Greenhouse Gas – Air pollution Interactions and Synergies
GAW	Global Atmospheric Watch
GEIA	Global Emissions InitiAtive
GEOS-Chem	Goddard Earth Observing System Global Chemical Transport Model
GHG	Greenhouse Gas
GTP	Global Temperature change Potential
GWP	Global Warming Potential
HFCs	Hydrofluorocarbons
HTAP	(UNECE) Task Force on Hemispheric Transport of Air Pollution
ICAO	International Civil Aviation Organization
IEA	International Energy Agency
IGES	Institute for Global Environmental Strategies
IIASA	International Institute for Applied Systems Analysis
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Intertropical Convergence Zone
LEAP-IBC	Long-range Energy Alternatives Planning – Integrated Benefits Calculator
LRTAP	Long-range Transboundary Air Pollution
MAAP	Multi-Angle *Absorption* Photometer
MAGICC	Model for the Assessment of Greenhouse Gas Induced Climate Change
N_2O	Nitrous Oxide
NECD	National Emission Ceilings Directive
NF_3	Nitrogen Trifluoride
NH_3	Ammonia
NMVOC	Non-Methane Volatile Organic Compounds
NO_3	Nitrate (ion)
NOx	Nitrogen Oxides
NTCF	Near-Term Climate Forcer
O_3	Ozone
OC	Organic Carbon
OH	Hydroxyl Radical
PFCs	Perfluorocarbons
PM_1	Particulate Matter with aerodynamic diameter ≤ 1 μm (micrometer)
PM_{10}	Particulate Matter with aerodynamic diameter ≤ 10 μm (micrometer)

$PM_{2.5}$	Particulate Matter with aerodynamic diameter ≤ 2.5 μm (micrometer)
PSAP	Particle Soot Absorption Photometer
rBC	Refractory Black Carbon
RCP	Representative Concentration Pathway
RF	Radiative Forcing
RFMIP	Radiative Forcing Model Intercomparison Project
SAP	Scientific Advisory Panel
SAR	Second Assessment Report
SEI	Stockholm Environment Institute
SF_6	Sulphur Hexafluoride
SLCF	Short-Lived Climate Forcers
SLCP	Short-Lived Climate Pollutants
SO_2	Sulphur Dioxide
SO_4	Sulphate (ion)
SSC	Scientific Steering Committee
SYR	Synthesis Report
TAR	Third Assessment Report
TFEIP	(UNECE) Task Force on Emission Inventories and Projections
TFI	Task Force on National Greenhouse Gas Inventories
UNECE	United Nations Economic Commission for Europe
UNEP	UN Environment (United Nations Environment Programme)
UNFCCC	United Nations Framework Convention on Climate Change
US EPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
WGI	Working Group I
WHO	World Health Organization
WMO	World Meteorological Organization

Executive Summary

The IPCC Task Force on National Greenhouse Gas Inventories (TFI) and Working Group I (WGI) held an Expert Meeting on Short-Lived Climate Forcers (SLCF)[1] on 28-31 May 2018 in Geneva, Switzerland, hosted by the World Meteorological Organization (WMO).

SLCF species are gases and particles that affect the climate. They have lifetimes in the atmosphere of a few days to a decade, and many of them are also air pollutants. Human activities contribute to SLCF emissions to the atmosphere. The impacts of SLCF species on climate are complex and depend on multiple factors, for example, where and when they are emitted. Methane is the longest lived SLCF, and is also included under the well mixed GHGs. There has been substantial improvement in scientific understanding of emissions and climate effects of SLCFs since the last Expert Meeting on Emission Estimation of Aerosols Relevant to Climate Change in 2005, and continued improvements since the AR5 WGI report (2013).

The following SLCF species were considered during the Expert Meeting: Black Carbon (BC), Organic Carbon (OC), $PM_{2.5}$, NOx, CO, NMVOC (including BVOC), SO_2 and NH_3. Methane and halogenated compounds were not included, because inventory methodologies for them are already provided in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (*2006 IPCC Guidelines*).

Since AR5, progress has been made in improved definitions of OC and BC, increased understanding of non-combustion aerosol sources, more measurements on aerosol particle sizes, and better model parametrisations of aerosol processes. Some of the remaining uncertainties are expected to be reduced if more information on SLCF emissions from improved inventories is available. More robust emission estimates can manage some of the remaining uncertainties associated with recent and projected SLCF radiative forcing.

Much of the existing work on SLCF inventories is due to the role of these substances in affecting air quality and human health. Improved SLCF emission inventories and methodologies are also necessary to enhance scientific understanding and assessment of their role in climate change as well as to inform climate policy at the national and international levels, particularly through United Nations Framework Convention on Climate Change (UNFCCC). Internationally-agreed, globally applicable methodologies and emission factors for SLCF emission inventories are necessary. In several cases there are current data gaps that limit their application and require further developments. It is desirable to commence work for these inventories, based on existing methodologies such as those in the EMEP/EEA Emission Inventory Guidebook for Air Pollutants (EMEP/EEA Guidebook), recognizing that further discussion is needed on the timing, nature, format, and sequencing of such work. The IPCC can play an important role because of its unique position, and therefore it is considered to be the right organisation to fill gaps in existing methodologies and to develop and disseminate an internationally-agreed, globally applicable methodological guidance based on existing methodologies. This could be achieved in close cooperation and collaboration with other relevant international bodies such as EMEP/EEA, CCAC, Arctic Council, ICAO, IMO.

Some SLCF species are of key importance globally and/or regionally for climate change (e.g., CH_4, NOx, OC, BC and SO_2). Others may become a high-priority over time in terms of mitigation strategies (e.g., NH_3 and VOC). In order to take into account trends and developments, all SLCFs should be considered with more focus on species and sources that are not well covered in existing guidance. It is recognised that OC is not covered in existing guidance due to methodology and data gaps. The current approach to derive BC emissions might need assessment, improvement or new elaboration due to significant challenges in deriving BC from $PM_{2.5}$ and variability in observations.

If the IPCC Plenary decides to engage into further work on SLCF inventories, careful consideration needs to be given to possible issues in consolidating existing inventory methodologies on GHGs and SLCFs, including those in harmonizing methods, aligning source categories, documenting emission factors, and linking to climate

[1] Short-lived climate forcers (SLCF) are also referred to as short-lived climate pollutants (SLCP). They are referred to as near-term climate forcers (NTCF) in the AR5, which are a set of compounds whose impact on climate occurs primarily within the first decade after their emission. This set of compounds includes methane, which is also a well-mixed greenhouse gas, ozone and aerosols, or their precursors, and some halogenated species that are not well-mixed greenhouse gases (Annex 3 Glossary, WGI contribution to AR5).

processes and climate change, and to establishing close cooperation and information exchange with other bodies working with these issues, for example, the UNECE Task Force on Emission Inventories and Projections (TFEIP), which develops the EMEP/EEA Guidebook.

Generally, much of the existing guidance on good practice methodologies/approaches on GHG inventory is applicable to, or can be a good basis for, SLCF inventories at a national level, if a more detailed air pollutant inventory does not exist. For example, the common activity data could be used for fossil fuel combustion, livestock enteric fermentation and manure management source categories, although additional information may be required for SLCF emission estimation. For some emission sources, however, existing inventory methodology does not provide a good basis for SLCF inventory (e.g., combustion of biofuels for cooking and heating, open burning of domestic waste).

Reporting of SLCF and GHG inventories should be in mass units for each individual emitted compound. Some SLCF species (e.g., VOC) comprise multiple different chemical compounds and thus mass-based emissions must be carefully defined. It should be noted that the existing inventory methodology on GHGs (*2006 IPCC Guidelines*) does not require inventory compilers to calculate and report national total emissions in CO_2 equivalent unit. The understanding of emission metrics and how they can be used, particularly in the context of SLCF emissions, has advanced but there is currently no agreed recommendation. The meeting participants concluded that SLCF emissions addressed in this meeting report should not be converted to CO_2 equivalent units in the same way as done based on GWP_{100} in the inventory reporting under the UNFCCC. The meeting agreed that the issue of metrics and how they can be used may be further considered based on new scientific literature for coordination across Working Group reports, particularly those of Working Group I and Working Group III, towards the synthesis report (SYR) of the sixth assessment report (AR6).

Key aspects of future work in this area, including the timing, scope, nature, format, and sequencing of such work on inventory methodology should be considered by the scientific steering committee for this expert meeting and the Bureau of IPCC Task Force on National Greenhouse Gas Inventories (TFB), and be decided by the IPCC Plenary.

Background

a) Relevant IPCC decision, Decision IPCC/XLVI-6. Short-lived Climate Forcers; IPCC-46, 6-10 September 2017, Montreal

“The *Intergovernmental Panel on Climate Change decides,* to approve the proposal for an expert meeting on Short-lived Climate Forcers to discuss issues on estimation of emissions and estimations of climate effects (i.e. Option 2 in the submission).”

Three different options had been proposed to the Panel in the submission SHORT-LIVED CLIMATE FORCERS, Proposal for an IPCC Expert Meeting on Emission Estimation of Short-Lived Climate Forcers, IPCC-XLVI/Doc.7; IPCC-46, 6-10 September 2017, Montreal:

Option 1: Discussion on issues on estimation of emissions (TFI)

Option 2: Discussion on issues on estimation of emissions and estimations of climatic effects (direct and indirect effects on radiative forcing, including implications on clouds) (TFI, WGI)

Option 3: Discussion on issues on estimation of emissions and estimations of climatic effects (direct and indirect effects on radiative forcing, including implications on clouds) as well as non-climate effects including implications on human health, crop yields and ecosystems (TFI and all WGs)

The IPCC approved the Option 2 which was associated with a discussion on issues on estimation of emissions and estimations of climatic effects (direct and indirect effects on radiative forcing, including implications on clouds) combining experts from TFI and WGI.

b) List of SLCF species considered during EM

The following SLCF species were considered during the Expert Meeting:

- Aerosols
  - Black Carbon (BC)
  - Organic Carbon (OC)
  - $PM_{2.5}$
- Precursors (ozone precursors and aerosol precursors)
  - NOx
  - CO
  - NMVOC (including BVOC)
  - SO_2
  - NH_3

Methane and halogenated compounds were not included, because inventory methodologies for them are already provided in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (*2006 IPCC Guidelines*).

c) Coverage of SLCF in existing non-IPCC guidance

Most of the SLCF species listed above (b) are included in existing guidance. The only exception is OC that generally is not accounted for due to methodology and data gaps. In addition, the current approach to derive BC emissions as a fraction of $PM_{2.5}$ or PM_{10} (e.g., in EMEP/EEA Guidebook) might need improvement or elaboration due to significant variability in observed (measured) BC/$PM_{2.5}$ ratios and often the ratio change when an emission reduction technology is applied. Existing guidance does not cover all global sources.

d) Meeting objectives

This expert meeting had the following objectives:

- To review existing methodological work to estimate emissions of SLCF (e.g., studies on measurement methods, methodological guidance developed by other organizations, inventories that were actually produced by some countries) with a view to considering feasibility for the IPCC to develop methodological guidance;
- To consider which species of SLCF should be prioritized in the possible future work to develop inventory methodology, taking account of uncertainties in emission estimates and applicable common metrics as well as the extent to which it will contribute to inform decision making in mitigation policies and measures;
- To consider how the inventory methodology on SLCF would relate to the existing inventory methodology on greenhouse gases (What kind of elements in the existing GHG inventory methodology can or cannot be applied to SLCF?);
- To identify gaps in scientific understanding on estimates of SLCF emissions that need to be filled in by scientific research community;
- To review existing methodological work to quantify the global radiative direct and indirect effects of SLCF, with a focus on new developments since the AR5;
- To identify gaps in scientific understanding on estimates of direct and indirect climate effects of SLCF on radiative forcing, including implications on clouds, that need to be filled in by scientific research community.

This expert meeting required participation of the following experts in order to achieve the objectives mentioned above:

- National greenhouse gas inventory experts who are familiar with TFI work;
- Inventory practitioners who have experiences of developing SLCF emissions inventories;
- Experts representing other relevant organizations/initiatives that are engaged in methodological work on SLCF, e.g., UNECE Task Force on Emission Inventories & Projections (TFEIP), Climate and Clean Air Coalition (CCAC), Arctic Council;
- Experts representing the WGI physical science basis on common metrics such as GWP, GTP provided in AR5;
- Experts representing the WGI physical science basis on near term climate forcers and their precursors (including the evolution of emissions, concentrations, at sectoral/regional and global scale, direct and indirect effects on radiative forcing).

A. Introduction

The primary motivation to organize this expert meeting proposed by the IPCC member countries was the need to better understand source strengths of air pollutants that have climate effects as well as possible gaps in inventory methodology to estimate emissions of such pollutants, and to assess possible IPCC roles in furthering inventory methodologies for these pollutants. Methane and halogenated compounds were not included in the list, because inventory methodologies for them are already provided in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (*2006 IPCC Guidelines*). Inventory methodologies for CO, NOx, NMVOC and SO_2 were not included in the *2006 IPCC Guidelines*, because the IPCC agreed at its 21st Session (November 2003) that development of new methods for them was not necessary as they were addressed under other agreements and conventions, such as the UNECE CLRTAP. The SSC decided to also review the current status of existing inventory methodologies for these SLCFs after 15 years of knowledge developments.

The IPCC assessments have addressed SLCFs in the past, and the AR6 WGI report will feature a chapter dedicated to SLCFs (Chapter 6) and will assess literature on key emissions, observed and reconstructed concentrations and radiative forcing, direct and indirect aerosol forcing, implications of greenhouse gas lifetimes and of different shared socio-economic and emission pathways for radiative forcing, and SLCF connections to air quality and atmospheric composition. This chapter is connected to several other WGI chapters through the assessment of radiative forcing (e.g., Chapter 3 on Human influence on the climate system and Chapter 7 on the Earth's energy budget, climate feedbacks, and climate sensitivity), as well as with the AR6 WGII report through the integrated risk assessment (e.g., SLCFs' role in air quality and the impacts of climate change on human health, natural and managed ecosystems and their services), and the AR6 WGIII report, through the role of SLCFs in scenarios and the potential for, and co-benefits of, SLCF mitigation.

Three key themes were identified to be discussed at the meeting:

Theme 1: Assessment of existing methodological framework, observation of atmospheric concentrations and methods to estimate emissions of SLCF

Theme 2: Assessment of climate impacts of SLCF emissions

Theme 3: Suitability for IPCC to develop inventory methodology for SLCF

Themes 1 and 2 were discussed in parallel in days 1 and 2, two break-out groups (BOGs) per each theme. Theme 3 was discussed in day 3, in four parallel BOGs, taking into account some issues raised by participants in their responses to a questionnaire (see Section F. Annex b) collected in advance of the meeting. The structure of the meeting was as shown in the plan below (figure 1).

Under Theme 1, the following key questions were discussed:

- How accurately can we monitor SLCF sources and emission trends, and link them to atmospheric concentrations?
- On what SLCF species do emission quantification methodologies already exist, and at what scale (regional, national, sub-national, etc)?
- Are they accessible, comprehensive, globally applicable, up-to-date?
- Are new emission measurements by sources and species available?
- What are the most significant knowledge gaps and uncertainties?
- Is it necessary to develop new/improved guidance?
- Is the current knowledge on emissions mature enough to support the development of new/improved guidance?
- What new knowledge is expected to emerge in the coming years?

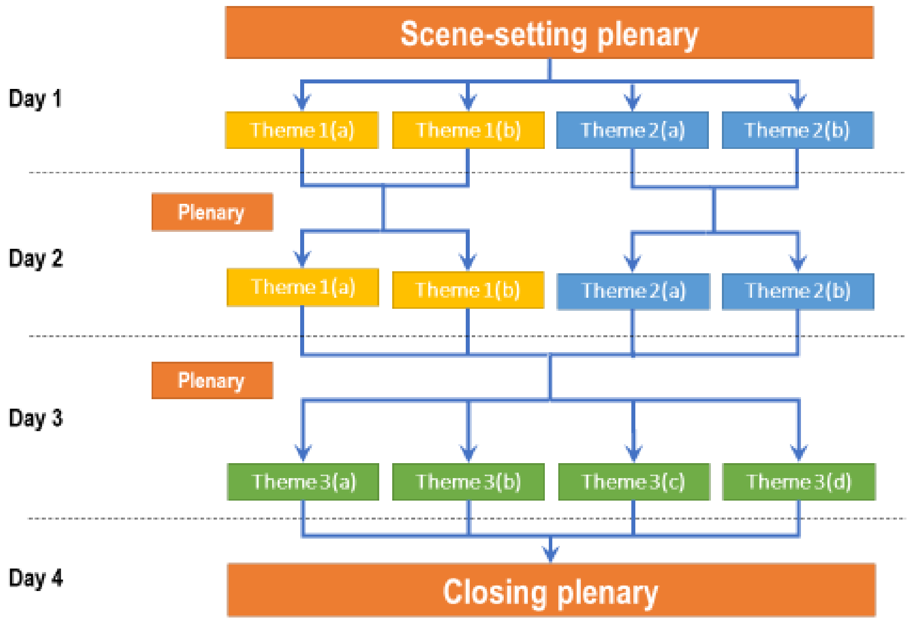


Figure 1: Flow of BOG sessions at the Expert Meeting on SLCF. BOG participants were shuffled within each theme so that both TFI experts and WGI experts participated in each group.

Under Theme 2, the following key questions were discussed:

- What is the current scientific understanding of global radiative forcing (via direct and indirect effects)?
- What emission metrics are available for SLCF?
- What is the current scientific understanding of the local/regional climate effects of SLCFs?
- What are the most significant knowledge gaps and uncertainties?
- What new knowledge is expected to emerge in the coming years?

Under Theme 3, the following key questions were discussed:

- Which species of SLCF (and which sources) should be prioritized in the future work to develop inventory methodologies? [Building on findings from themes 1 and 2]
- Is the IPCC the right organisation to develop the inventory methodologies?
- How will these methodologies on SLCF relate to the existing inventory methodologies on GHG (What kind of elements in the existing GHG inventory methodology can or cannot be applied to SLCF?)

B. Conclusions and Recommendations

On the basis of the reports from BOGs, the following conclusions and recommendations were agreed by the participants of the meeting.

General conclusions/recommendations

- Science on SLCFs has significantly advanced since the IPCC Expert Meeting on Emission Estimation of Aerosols Relevant to Climate Change was held in 2005 with AR5 being a landmark. The importance of SLCFs in the climate system has become clearer, including both positive and negative forcing implications.
- Improved SLCF emission inventories are necessary to enhance scientific understanding and assessment of climate change as well as to inform climate policy at the national and international levels, particularly through UNFCCC. They may also provide co-benefits for air quality management. There are methodologies on SLCF emission inventories developed and used by some organizations and/or by some countries (e.g., the EMEP/EEA Emission Inventory Guidebook); however, they do not cover all existing sources in developing countries and compounds, and as such they are not yet globally applicable.
- Therefore, internationally-agreed, globally applicable methodologies and emission factors for SLCF emission inventories are necessary, although there may be data gaps that limit their application. It is desirable to commence work for that, based on existing methodologies such as those in the EMEP/EEA Guidebook, recognizing that further discussion is needed on the timing, nature, format, and sequencing of such work.
- The IPCC can play an important role because of its unique position, therefore considered to be the right organisation to fill gaps in existing methodologies and to develop and disseminate an internationally agreed, globally applicable methodological guidance based on existing methodologies.
- If the IPCC Plenary decides to engage into further work on SLCF inventories, careful consideration needs to be given to possible issues in consolidating existing inventory methodologies on GHGs and SLCFs, including those in harmonizing methods, aligning source categories, documenting emission factors, and linking to climate processes and climate change, and in establishing close cooperation and information exchange with other bodies working with these issues, for example, the UNECE Task Force on Emission Inventories and Projections (TFEIP), which develops the EMEP/EEA Emission Inventory Guidebook for Air Pollutants.
- It is also important to seek cooperation/collaboration with other relevant international bodies such as CCAC, Arctic Council, ICAO, IMO.

Which species of SLCF should be prioritized in the future work to develop inventory methodology?

- Several different criteria should be considered for prioritization of SLCF species, such as:
    - ✓ Climate impact
    - ✓ Availability and global applicability of existing methodologies
    - ✓ Availability of relevant data such as measurements of emission sources to develop local emission factors
    - ✓ Relevance of mitigation efforts to other benefits (e.g., air quality)
- Prioritization according to these criteria may vary depending on spatial and temporal resolution.
- Taking various criteria into account, all SLCF species discussed at this expert meeting are considered important.

Is the IPCC the right organization to fill gaps and consolidate the inventory guidelines?

- Yes. The IPCC can play an important role because of its unique position.
    - ✓ It is a global organization to which governments from all over the world have already been involved.
    - ✓ It is experienced in developing internationally-agreed, globally applicable inventory methodological guidance.
    - ✓ SLCFs are key in AR6 and climate context.
- Resources required to carry out this work may be a challenge. In order to avoid duplication of work and to efficiently cover gaps, the IPCC should align closely with other relevant bodies such as EMEP/EEA, CCAC, Arctic Council, ICAO, IMO, national agencies, etc.
- Other bodies have different missions with respect to SLCF inventories, and in particular stress the use of them in the context of monitoring and improving air quality and public health. IPCC cooperation with other organizations in future work on consolidating SLCF inventories should recognize the importance of these non-climate goals.

How will inventory methodology on SLCFs relate to existing inventory methodology on GHGs?

- Generally, much of the existing guidance on good practice methodologies/approaches on GHG inventory is applicable to, or can be a good basis for, SLCF inventory at a national level, if an air pollutant (AP) inventory of higher relevance does not exist. For example, for fossil fuel combustion sources, the same activity data should be used to estimate both GHG emissions and SLCF emissions, although additional information may be required for SLCF emission estimation.
- However, it should be noted that there are areas where existing inventory methodology on GHGs does not provide a good basis for SLCF inventory (e.g., combustion of biofuels for cooking and heating, open burning of domestic waste, and mobile sources).
- There are possible issues that need further careful consideration in consolidating inventory methodologies, such as spatial and temporal requirements and aligning source categories.
- Reporting of SLCF inventories and GHGs should be in mass units for each individual emitted compound. The understanding of emission metrics and how they can be used, particularly in the context of SLCF emissions, has advanced but there is currently no agreed recommendation; therefore, the meeting participants concluded that SLCF inventories addressed in this meeting report should not be converted to CO_2 equivalent units in the same way as done based on GWP_{100} in the inventory reporting under the UNFCCC. The meeting agreed that the issue of metrics and how they can be used may be further considered based on new scientific literature for coordination across Working Group reports, particularly those of Working Group I and Working Group III, towards the synthesis report (SYR) of the sixth assessment report (AR6).
- It should be noted that the existing inventory methodology on GHGs (*2006 IPCC Guidelines*) does not require inventory compilers to calculate and report national total emissions in CO_2 equivalent unit. However, for some elements/processes, aggregation of emissions of different gases in CO_2 equivalent units is suggested in the existing methodology (e.g., “Key Category Analysis”).

C. Summary of Keynote Presentations

In this section, only abstracts of the keynote presentations are given. Full presentations can be found in an online archive, which is accessible via the following link:

https://www.ipcc-nggip.iges.or.jp/public/mtdocs/1805_Geneva.html

Presentations on general background

In the opening plenary, four general presentations were delivered by Co-Chairs of TFI and WGI; they were followed by general discussion.

❖ Eduardo Calvo Buendia: Historical background

Presentation on the background to this expert meeting, recognizing that the potentially significant influence of aerosols had led to an expert meeting in 2005. Its objectives were to conduct a preliminary assessment of issues to developing estimates of aerosols and to discuss methodological approaches. Primary focus was black carbon and organic carbon. It was concluded that it was not yet possible to reliably produce emission estimates and the real differences in characteristics between countries. Work, including more cooperation between WGI and TFI, was needed to reduce uncertainties.

Understanding of aerosol radiative forcing (RF) advanced through AR4 and AR5, however, aerosols are still the largest sources of uncertainty to total RF with approx. -0.27 Wm^{-2}.

❖ Valérie Masson-Delmotte: Overview of AR6 products

With three Special Reports and a renewal of the guidelines for national greenhouse gas inventories being delivered in addition to the three working group reports and the Synthesis Report, AR6 is the busiest IPCC assessment cycle to date. Despite this expert meeting being primarily focused on the SLCF communities from WGI and the TFI, additional linkages exist between SLCFs and WGII and WGIII. Some of the key SLCF topics being assessed within these other AR6 reports are described below.

- Special Report on 1.5°C: Chapter 2 focuses on the mitigation pathways compatible with 1.5°C in the context of sustainable development and will assess constraints on, and uncertainties in, global greenhouse gas emissions consistent with warming of 1.5°C, considering short lived and other climate drivers and taking into account uncertainty in climate sensitivity.
- Special Report on Land: Chapter 2 on Land-Climate Interactions looks at terrestrial GHG fluxes in natural and managed ecosystems; biophysical and non-GHG feedbacks and forcings on climate. Chapter 3 on desertification includes assessments on aerosols and dust.
- Working Group 2: WGII features sectoral and regional risk assessment, including the implications of SLCFs. Additionally, Chapter 6 on Cities, settlements and key infrastructure will include SLCFs through air quality.
- Working Group 3: Chapter 3 on mitigation pathways compatible with long-term goals will assess modelled emission pathways compatible with the Paris Agreement, including the long-term temperature goal, and higher warming levels, taking into account CO_2, non-CO_2 and short-lived climate forcers (including peaking, rates of change, balancing sources and sinks, and cumulative emissions).

❖ Kiyoto Tanabe: Overview of IPCC Guidelines for National Greenhouse Gas Inventories, including on-going work on 2019 Refinement

A national greenhouse gas inventory is a compilation of estimates of anthropogenic emissions and removals of greenhouse gases on a national scale on an annual basis. It provides a fundamental basis for scientific understanding of climate change as well as for making and implementing climate policies and measures. Therefore, all the Parties to the United Nations Framework Convention on Climate Change (UNFCCC), including its Kyoto Protocol and Paris Agreement, are obliged to produce and publish their national greenhouse gas inventories in accordance with the internationally-agreed methodologies provided by the IPCC's Task Force on National Greenhouse Gas Inventories (TFI).

The IPCC Guidelines for National Greenhouse Gas Inventories have been updated and revised several times since the initial version published in 1995, taking into account advancement of scientific knowledge and technologies relating to greenhouse gas emissions and removals. The latest comprehensive one is the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. It assists countries in producing inventories that are accurate in the sense of being neither over- nor underestimates so far as can be judged, and in which uncertainties are reduced as far as possible. It provides methodology to estimate emissions and removals of greenhouse gases such as CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, NF_3 and other halogenated gases, but does not provide methodology for the short-lived climate forcers except for CH_4 and HFCs. For precursors (NOx, NMVOC, CO, SO_2, …), estimation methodology is not provided but links to information on methods used under other agreements and conventions are provided.

The IPCC TFI is now working to refine the *2006 IPCC Guidelines* to provide an updated and sound scientific basis for supporting the preparation and continuous improvement of national greenhouse gas inventories. The new Methodology Report titled "*2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories"* will be completed in May 2019.

- Zhai Panmao: Guidance on the key themes and expected outcomes

Presentation on the scope and structure of the meeting. This included the expected meeting outcomes, which are expected to feed into the WGI AR6 report, primarily in Chapter 6 (Short-lived climate forcers) but also chapter 7 (The Earth's energy budget, climate feedbacks, and climate sensitivity), amongst others, and recommendations will be presented to the IPCC Plenary in October 2018 via the expert meeting report.

Presentations on issues relating to key questions

Introduction of new scientific findings from recent literature since AR5 about SLCF emissions and their climate effects

- Olivier Boucher: AR5: main findings & knowledge gaps on Short-Lived Climate Forcers and their Radiative Forcing

Short-lived climate forcers (SLCFs) encompass a range of chemical species, some gaseous, some in particulate form, that are responsible for a radiative forcing of climate change. SLCFs are often co-emitted, and their emissions could decrease in the future, either because of air quality policies, or as a by-product of mitigating greenhouse gas emissions. The IPCC AR5 provides estimates of their radiative forcings, either atmospheric species by atmospheric species, or emitted species by emitted species (the difference arising because of their chemical transformation in the atmosphere). The radiative forcings by SLCF can be positive or negative, depending on the species, and are characterized by large uncertainties. Black carbon is an interesting SLCF because it is regionally important and offers some synergy between air quality and climate policies (see, e.g., INDC from Mexico), but its climatic importance has been revised downwards since IPCC AR5. Aviation-induced cloudiness and aerosol-cloud interactions from maritime shipping emissions are another two examples of SLCFs that need attention. In particular the new limit for sulphur in fuels, that should be effective in 2020 according to International Maritime Organization regulations, may result in 7-fold decrease in SO_2 emissions and an unmasking (warming) effect of up to 0.15 Wm^{-2} (back-of-the-envelope calculation based on the Malavelle et al. (2017) study with a factor of two enhancement because of the spatio-temporal distribution of the emissions over the ocean). In conclusion SLCFs offer in principle some climate mitigation opportunities but i) only few SLCFs have warming effects, ii) SLCFs may not be so easy to mitigate as other species are often co-emitted, and iii) uncertainties are large. There may be trade-offs between air quality and climate policies. In any case monitoring of the radiative and climate effects by SLCFs is needed and detailed knowledge of SLCFs emissions and their evolution in time is paramount to monitor climate change and progress towards the goals of the Paris Agreement.

- Bjørn Hallvard Samset: Recent findings on the effects of aerosols on the climate

Anthropogenic aerosols, here taken as the key subset sulphate (SO_4), black carbon (BC) and organic carbon (OC), currently act to reduce global mean surface temperatures by at least 0.5°C. Their regional impacts vary significantly, with a spatial pattern that is different to greenhouse gases, and the influence of each aerosol type on temperature, clouds and precipitation is quite different.

Sulphate aerosol, formed in the atmosphere from emissions of SO_2, is the main particulate driver of global cooling. The main recent developments are in the aerosol-cloud interactions, where cloud whitening is becoming better constrained while impacts on cloud lifetime now appear less important. Recently, Chinese emissions of SO_2 have been strongly reduced. The local and global climate impacts of this change are not yet known.

Black carbon aerosol (BC), stemming from incomplete combustion, has a weaker impact on surface temperatures than previously thought. The main reason is that BC heats the atmosphere at high altitudes, causing both clouds, circulation and precipitation to adjust to its presence. The time BC remains in the atmosphere after emission is now also thought to be lower than previously believed. The effects of BC emissions on global and regional precipitation is an active topic of research.

Organic carbon aerosol (OC), from biomass and other burning, is thought to moderately cool the surface. However, both the emissions and climate impacts of OC aerosol are poorly known, compared to BC and SO_4. Recent studies have focused on brown carbon (BrC), a component of OC that acts more like BC, but the full impact of BrC on the total climate effect of aerosols is still not well quantified.

In addition to causing a net global cooling, anthropogenic aerosols likely affect both global and regional precipitation patterns, primarily through lowering surface temperatures through the Northern Hemisphere. This has been linked to changes in the ITCZ, and in regional monsoon patterns. Mediterranean and South African drying patterns have also been linked to local aerosol emissions.

It is clear that present and future air quality measures that reduce anthropogenic aerosol emissions will also affect both temperatures, and mean and extreme precipitation. This impact is however still not fully constrained by climate science.

- Keith P. Shine: Emission metrics for SLCFs

Climate emission metrics provide an “exchange rate” which allow the climate impact of emissions of a mix of species to be placed on a CO_2-equivalent (CO_2-e) scale. The Kyoto Protocol, and many NDCs, use the 100-year Global Warming Potential (GWP_{100}) for this purpose; GWP_{100} measures the time-integrated radiative forcing due to a pulse emission relative to emission of the same mass of CO_2. It is only one of many possible metric choices and although it is widely-used, there is no compelling reason to indicate it is the best choice, particularly in the context of climate policy with a long-term temperature goal. Metric choice impacts on the perceived importance of SLCF emissions, and metric values change between IPCC reports, as understanding develops. It was emphasized that for SLCFs, the metric values depend on where a species is emitted, primarily because of local differences in atmospheric chemistry processes. This poses a policy challenge not faced when applying metrics to longer-lived greenhouse gases. Recent work (doi: 10.1038/s41612-018-0026-8) seeks to reconcile the climate impact of SLCFs and long-lived greenhouse gases in the context of a temperature target, especially for ambitious mitigation when emissions are falling, and when the application of GWP_{100} can be shown to yield misleading results. A new usage of GWP, labelled GWP^*, equates sustained changes in SLCF emission with one-off emissions of CO_2. Although there would be challenges in implementing the GWP^*, it was demonstrated that it is better suited to monitoring progress towards a temperature target than the GWP.

- Detlev Helmig: Impacts of atmospheric chemistry on the lifetimes of SLCF

Short-lived climate forcers that are ozone pre-cursors such as NOx, CO, NMVOCs (incl. BVOC) as well as SO_2 and NH_3 have atmospheric lifetimes that can vary from hours to months depending on their atmospheric sinks. These lifetimes vary with temperature, seasons, and across different geographical locations.

The hydroxyl radical (OH), a highly reactive and difficult to monitor compound, is the dominant sink of short-lived climate forcers, but other sinks include dry and wet deposition, reactions with other species such as Cl, O_3, NO_3, photolysis, uptake or conversion to aerosols, amongst others.

OH is created by ozone, water vapour and sunlight. Atmospheric concentrations can vary by orders of magnitude depending on season, elevation, atmospheric water vapour concentration, and geographical location. This affects the lifetimes of SLCFs. As a result, SLCF lifetimes of most SLCF gases are shorter during the summer, and longer during the wintertime, with atmospheric destruction ceasing completely during the winter in the Polar Regions. For CO, for example, the atmospheric lifetime can range from as low as 0-1 months to up to 120 months. Ethane, the longest-lived non-methane hydrocarbon, has a similar OH rate constant as CO, though the temperature dependencies of these rate constants are different, causing the ratio of the CO/ethane lifetime to change by a factor of 2-3 throughout the year. Ethane is mostly emitted from anthropogenic fossil fuel sources with little seasonal variation, which makes ethane a valuable tracer for fossil fuel emissions and seasonal and latitudinal oxidation changes. Coordinated global atmospheric monitoring of ethane under the umbrella of the World Meteorological Organization (WMO) Global Atmospheric Watch (GAW) (Schultz, 2015) over the past 12 years and new air and ice core retrievals, have resulted in much improved characterization of ethane (and other VOC) seasonal atmospheric concentrations and trends, oxidation, emission inventories, and historic and modern emission dependencies and changes (Aydin, 2011, Helmig, 2014, Tzompa-Sosa, 2017, Helmig, 2016, Nicewonger, 2016).

The strong seasonality of the VOC oxidation and the increase of the seasonality with latitude are a strong determinant in the photochemical production rate and resulting concentrations of surface ozone. In the presence of NOx, higher rates of VOC oxidation during the summer can lead to elevated surface ozone. This increased production, however, is in part compensated by lower NOx lifetimes (from oxidation by OH) and shorter ozone lifetime (from photolysis, oxidation, and uptake by plants), causing surface ozone behaviour to be very sensitive to local conditions of NOx and VOC.

Introduction of existing inventory methodologies or experiences in estimating emissions of SLCF

- Kristina Saarinen: EMEP/EEA Emission Inventory Guidebook

The EMEP/EEA Emission Inventory Guidebook provides technical guidance and default emission factors to national emission inventories under the United Nations' Economic Council for Europe's Convention on Long Range Transboundary Air Pollution (UNECE CLRTAP) and the European Union's National Emission Ceilings' Directive (EU NECD). The EMEP/EEA Guidebook is published by the European Environment Agency (EEA).

The UNECE Task Force on Emission Inventories and Projections (TFEIP) is responsible for the technical contents of the Guidebook chapters and which are developed by dedicated sector specific Expert Panels. The Guidebook is updated every 3-4 years to reflect the latest scientific findings and knowledge. The users are recommended to refer to the latest version of the Guidebook, currently September 2016 version with amendments up to 2017, while the next version is foreseen in 2019. Updates to previous versions are available on a log file on the website https://www.eea.europa.eu/publications/emep-eea-guidebook-2016. The translation of the Guidebook into Russian will be finalized during summer 2018.

The scope of the EMEP/EEA Guidebook is the UNECE/EEA countries, while many emission factors are from international literature. The methods in the Guidebook, however, do not cover certain sources relevant in developing countries such as cooking. The TFEIP is currently focusing the work on other pollutants than BC, and wishes to continue the good cooperation in referencing between the *2006 IPCC Guidelines* and the EMEP/EEA Guidebook to avoid overlaps but rather to align between the IPCC and EMEP/EEA guidance. Fine particulate matter ($PM_{2.5}$) emission inventories are obligatory to be reported under the UNECE CLRTAP and the EU NECD since the year 2000, while black carbon (BC) emission inventories (since 2000) are voluntary, but reported by almost all Parties.

❖ Valentin Foltescu, Harry Vallack, Zbigniew Klimont: Estimating emissions of Black Carbon and other SLCFs within CCAC activities

The presentation given by experts representing the Climate and Clean Air Coalition's (CCAC) Scientific Advisory Panel (SAP) and Secretariat highlighted key Coalition activities linked to emission inventories of SLCF and communicated CCAC observations with respect to SLCF emission inventory guidance.

CCAC has been relying in its activities on emission inventories prepared with the Long-range Energy Alternatives Planning - Integrated Benefits Calculator (LEAP-IBC) and the Greenhouse gas–Air pollution Interactions and Synergies (GAINS) model.

Within the SNAP initiative (Supporting National Action and Planning) on Short-lived Climate Pollutants (SLCP) of the CCAC, many countries are producing emission inventories (for both SLCF and long-lived greenhouse gases (GHG) using the LEAP-IBC tool. The tool has been developed by the Stockholm Environment Institute (SEI) in collaboration with the US EPA and the University of Colorado. The model pathway of the tool was described, starting with emissions estimates, and linking these through global atmospheric chemical transport model (GEOS-Chem Adjoint) coefficients to derive ambient concentrations of fine particulate matter ($PM_{2.5}$) and ozone, and the resultant impacts on human health and crops in the target country as well as global climate. LEAP-IBC is now available for use in over 90 countries, mainly in Latin America and the Caribbean, Africa and Asia. Where relevant, the tool uses default emission factors from the EMEP/EEA Guidebook and IPCC Guidelines, which are then supplemented by factors from the peer-reviewed literature for those technologies and pollutants not well covered by these official sources. However, what would really be helpful is for an official body such as the IPCC to take on the development of comprehensive methods to help meet the growing demand from countries around the world (including the CCAC member countries) for authoritative guidance on estimating SLCP-relevant emissions.

The other tool widely used in support of CCAC activities is the GAINS model developed by the International Institute for Applied Systems Analysis (IIASA). GAINS is available online (gains.iiasa.ac.at), has a global coverage, and includes all key air pollutants (including black carbon) as well as Kyoto GHGs. Emission estimation methodology considers explicit assumptions about implementation of emission control measures and their impact on co-emitted species for which emission factors rely largely on peer-reviewed studies. For several countries and regions, the model development and application has benefited from bilateral contacts and collaboration with local experts. An example comparison of GAINS and EU countries' national submissions to the LRTAP convention for black carbon shows good agreement for the trend but GAINS estimates higher emissions for residential combustion sector, especially for countries that rely on the simple Tier I methods from the EEA guidebook. Recently, the GAINS model estimates have been used in development of the new set of emissions for the CMIP6 experiments and the model is the central tool for the development of new black carbon scenarios within the new EU funded activity addressing black carbon knowledge gaps and policy support focusing on Arctic Council and observer countries.

The presentation of CCAC concluded that: 1) There is a large expressed demand from non-UNECE countries to develop emission inventories for additional SLCF beyond those covered by the Kyoto or Montreal Protocols; 2) A comprehensive methodology and a database of default emission factors for the additional SLCF for all sectors, that has global coverage, with regional differentiation where appropriate, is currently lacking; 3) A large pool of data and information on emissions is already available. It can be scrutinized, bundled and incorporated into a comprehensive emission inventory guidance; 4) There is valuable experience in using existing UNECE-LRTAP black carbon guidelines that can serve the development of globally applicable guidelines for black carbon and co-emissions; 5) Climate analyses such as those underlying IPCC Assessments or UNEP Gap Report include all SLCFs but for emissions they rely on expert estimates.

The position of the CCAC SAP and Secretariat related to the benefits of having authoritative guidance from the IPCC on the SLCF was communicated at the Expert Meeting as follows:

1. Integration and the internal consistency between GHG emission inventories and non-GHG emission inventories, within and across the various assessments (including IPCC's).

2. Comparability in terms of the emissions inputs into the various climate models used to inform policies.

3. Consistency of climate mitigation strategies at global to local levels, and across sectors.

4. Consistency in providing uncertainty estimates for calculating emissions relevant to mitigation of climate change and air pollution.

5. Ability to monitor and evaluate progress in reducing emissions of those SLCF not covered by the Kyoto or Montreal Protocols.

6. Ability to more reliably estimate wider benefits (health, food security, etc) by a harmonized approach for all emissions leading to formation of particulate matter and ozone.

7. Ability of countries to estimate emissions of BC and co-emitted substances according to authoritative global methodology and include black carbon emission reduction measures in the National Determined Contributions (NDC).

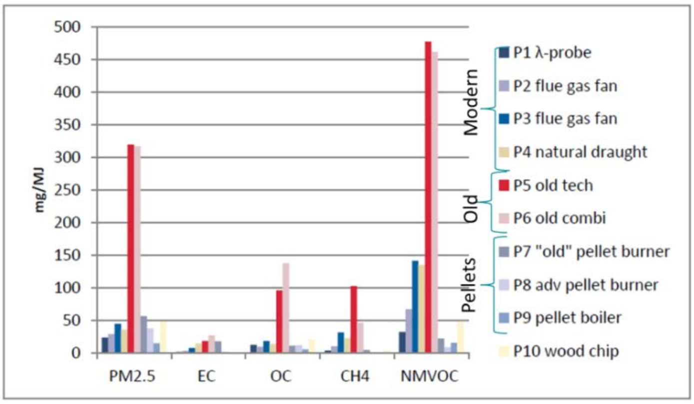
8. Transparency of national estimates, including potential future updates and recalculations based on revised/updated guidelines.

9. Ability for countries to transparently assess the multiple benefits of their emissions control strategies for public health, food security and other related sustainable development goals.

- Karin Kindbom: Emission estimates on a national scale - experiences of Nordic countries

Residential wood combustion is a major source of $PM_{2.5}$ and BC in the Nordic countries (Denmark, Finland, Norway and Sweden). Emissions are estimated by multiplying activity data (amount of fuel combusted) with appropriate emission factors. Uncertainties in emission estimates arise both from emission factors and activity data.

A Nordic measurement program has provided SLCP and $PM_{2.5}$ emission factors for several types of residential wood combustion technologies (stoves and boilers), both for standard combustion conditions and at bad user behavior (inefficient combustion conditions). Results show that older technologies generally result in higher emission levels than modern (*see figure*), that bad user behavior can increase emission levels significantly, that BC and $PM_{2.5}$ emissions do not correlate (no "fixed" share BC/$PM_{2.5}$), and that BC is the pollutant least affected by "bad combustion conditions".



Emission factors from measurements. Modern and older wood boilers, and pellets technologies, standard combustion conditions (Kindbom *et al*, Emission factors for SLCP emissions from residential wood combustion in the Nordic countries, TN2017:570). http://norden.diva-portal.org/smash/record.jsf?pid=diva2:1174670

Activity data needed to estimate emissions include 1) the combustion technologies used, 2) the fuel consumption for each technology, and 3) the user behavior (share of "bad combustion"). Activity data collection is challenging and the Nordic countries use information from regular or intermittent surveys, in some countries in combination with modelling based on energy demand (fuel consumption) and expected lifetimes of equipment (combustion technologies). It is not uncommon with insufficient information from the surveys, and expert judgement and assumptions are an integral part of activity data. Information on user behavior can for example be based on dedicated studies and/or interviews with chimney sweepers, in combination with expert assumptions.

- Emission inventories of residential wood combustion are sensitive to combustion technology and user behavior.
- It is important to take user behavior into account in emission factors.
- Activity data collection is challenging and information from different sources needs to be combined, using expert judgement.

❖ Laura Elena Dawidowski: Ammonia emissions from agriculture sector in Argentina

A recently developed NH_3 emission inventory for the agriculture sector in Argentina is presented. The time series 2000–2012 of NH_3 emissions were estimated at national and spatially disaggregated levels. Agriculture is one a key economic sectors in Argentina and the main NH_3 emitter. In recent decades, significant changes occurred in agricultural activities under the increase in prices and competitiveness of some grains. These include the displacement of livestock farming to other lands pushed by the preference of cultivating more profitable crops on these lands, and the intensification of livestock farming through an increasing number of feedlot systems.

The Tier 2 EMEP/EEA methodology was applied to estimate emissions using activity data with high resolution in terms of (i) manure management livestock, (ii) fertilizer type and (iii) waste burning of agriculture crops. Ammonia emissions from these activities were assigned to the districts in the Argentinean territory from which the emissions originate.

The spatiotemporal resolution of the key activity data allowed identifying the sensitivity of the estimated emissions to three main drivers: (i) expansion of croplands associated with increased rainfall in certain regions of the country, (ii) dominance of soybean cultivation, competing for lands with N-fertilized crops such as wheat, corn and sunflower and (iii) changes in the dynamics of livestock farming including the relocation of cattle in lower performance areas and the increasing implementation of feedlot systems

The inventory is an important tool for the study of the role of this SLCF on air quality and climate and points out to the importance of spatial and temporal disaggregation of SLCF emission estimates and the application of the EMEP/EEA methodology by a developing country. Nevertheless, there is room for improvement of the emission estimates, regarding obtaining local emission factors, refining temporal resolution by considering seasonal and monthly patterns in agricultural practices and climate conditions, particularly ambient air temperature and refining spatial disaggregation beyond district level by using land use information on fertilizer application and manure disposal practices on specific areas within each district.

❖ Steven J. Smith: Links between global-scale emission estimates and national emission inventories

This talk discusses current practices and future possibilities for linking national emission inventories with global emission datasets. There are three general approaches to date: no linkage (EDGAR), mosaic of gridded emissions data (EDGAR-HTAPv2), and mosaic of sectoral emissions data (RCP, EDGAR-HTAP_V1, CEDS). Barriers to connecting country-level inventories to global datasets include heterogeneous data formats, inconsistent definitions, a general lack of fuel- and sector-level data and associated activity data, and limited or no uncertainty analysis. The appropriate level of harmonization between country and global inventories depends on the application. For many applications gaps and inconsistencies in country level data need to be filled and biases, where known, in some country level data addressed. The use and analysis of emissions data would be improved through the development of common data formats and definitions, the use of modern data sharing tools such as APIs (Application Programming Interface) and consistent use of observations to evaluate the robustness of inventory estimates.

Presentation on WGI AR6 outline

❖ William Drew Collins & Hong Liao: Chapter 6 of WGI AR6: Intention at the scoping meeting and the outline

In addition to the chapter dedicated to SLCFs (Chapter 6) in the AR6 Working Group 1 (WGI) report, they will also be assessed in broader contexts across multiple chapters in the WGI report and other IPCC AR6 products. For example, within the WGIII-topics such as the assessment of carbon budgets compatible with climate targets, land surface aspects (including land management and climate feedbacks), SLCF climate and air quality effects and their mitigation potential, and GHG removal and solar radiation management. Several chapters within WGI will also assess SLCFs-related literature, where necessary. This includes: the natural and anthropogenic forcings of SLCFs in Chapter 2 (Changing state of the climate system); natural variability versus anthropogenically-forced change in Chapter 3 (Human influence on the climate system); radiative forcing of and responses to SLCFs, and the Earth's energy budget, climate feedbacks, and climate sensitivity in Chapter 4 (Future Global Climate); and cloud-aerosol processes in Chapter 8 (Water cycle changes).

Within WGI Chapter 6, the following topics were identified at the scoping meeting and approved by the IPCC Plenary to be assessed:

- Key emissions of SLCFs, including primary and precursor emissions, and past, present and future emissions (both natural and anthropogenic). Technological, socio-economic, and environmental factors governing emission trends can be covered, as well as the implications for the shared socio-economic pathway (SSP) scenarios.
- Observed and reconstructed concentrations and radiative forcing: This includes current and historical concentrations and implied radiative forcing of SLCF gases. For most SLCFs and precursors there are limited observations in time and space. The chapter will assess reconstructed analyses of the spatial and temporal variability. Past SLCF radiative forcing supports estimating climate sensitivity from historical records (coordinated with Chapter 7).
- Direct and indirect aerosol forcing: Aerosol-radiation interactions and aerosol-cloud interactions are still major sources of uncertainty in the estimate of the net radiative forcing. Current understanding of these uncertainties will be addressed in depth. New methods combining satellite observations and models will also be important.
- Implications for greenhouse gas lifetimes: SLCF emissions affect the oxidation capacity of the atmosphere and in turn affects the lifetime of key GHGs (e.g., CH_4, HFCs, and HCFCs). Models yield different simulations of oxidation capacity changes due to complexity of photochemistry etc., which affects the relationship of GHG concentrations to primary emission changes and indirect chemical effects (links with Chapters 2 and 7).
- Implications of different shared socio-economic and emission pathways (SSPs): These emissions determine future SLCF concentrations and radiative forcing and they include projected population, urbanisation, etc., with implications for risks from air pollution (connections to WGII and WGIII).
- Connections to air quality and atmospheric composition: Local and episodic changes in SLCFs are important since they contribute to air pollution, which affects health and agricultural yields at local to regional scales. Different scenarios and climate feedbacks alter the lifecycles of short-lived climate forcers and hence air quality.

Presentations on Preliminary consideration on possible issues in harmonizing existing inventory methodologies on GHG and those on SLCF – Views on specific potential issues

- ❖ <u>Lin Huang</u>: The issue of harmonizing the methodologies for emission inventories of GHGs with those of SLCFs

In harmonizing the methodologies for emission inventories of GHGs with those of SLCFs (e.g., BC), there are two major common approaches, i.e.

1) "bottom up" national report via statistical technique to sum of <u>activities*emission factors</u> (EFs) &

2) "top-down" inverse technique via using atmospheric measurements in conjunction with lagrangian particle dispersion model to constrain/estimate the emission inventories.

The challenges for "bottom up" report on SLCFs are obtaining consistent EF values, which depends on many unpredictable factors. Although not applicable to every region/country, it is still possible to use the "top-down" approach in the areas/regions where high quality (i.e., traceable and robust) atmospheric measurements are available. In this presentation, we are going to focus on the perspective of BC measurements.

Due to the complexity of its characteristics, including composition, morphology, volatility solubility and light absorption, BC measurements are methodology dependent, i.e., different methodology emphasizing on measuring its different characteristics, mainly on volatility (or thermal refractory) and light absorption. There is no single methodology which is able to justifiably claim to provide the best suitable measurements of BC via measuring all aspects of BC. In addition, all the characteristics of BC are changing in real atmospheric aerosols, forming continuous spectrum in all the properties (e.g., optical & thermal properties) and there is no one to one relationship between the properties. Therefore, this leads to difficulties in harmonizing BC mass measurements via different methodologies.

To evaluate the impacts of BC on direct radiative forcing, the measurements of BC mass as well as its optical properties are required. To assess the effectiveness of mitigation policies in BC emission and to estimate the uncertainty of BC emission inventory induced in climate forcing, measuring BC mass, including atmospheric concentration, is critical, playing a key role in binding BC emission inventory to the corresponding climate impacts.

In fact, long-term trends (of annual means over decadal scale) of BC mass measurements reflect mainly on the changes in BC emissions over the areas influencing the measurement sites, while the influencing atmospheric BC concentrations by meteorological transport are dominant on shorter time scales (e.g., synoptic or seasonal scales). This has been supported by the comparison results between the observed tends in atmospheric BC mass over Canada and the trends in historical emission data prepared for CMIP6 over the region of North America. The trends of BC observed at eastern Canada sites (e.g., Toronto and Egbert, ON) were dominated by anthropogenic emission changes, whereas that the seasonal pattern and inter-annual variability observed at western Canada sites (e.g., ETL, SK) were influenced to a large degree by biomass burning events. The decreasing trends (2006-2015) in eastern Canada would imply beneficial effects from clean air policies both in the US (Clean Air Act) and Canada (Clean Air Regulatory Agenda). However, there are inconsistencies in seasonal patterns between the observations in eastern Canada and the regional emissions inventories in North America. That raises questions and suggests constraining/constructing the seasonal profile of BC emissions in North America via observations.

Take home messages are:

- It is possible to use “top-down” approach to constrain BC emissions or emission trends.
- Long-term traceable and robust atmospheric BC measurements are required for “top-down” approach.
- To determine real trends in atmospheric BC, a traceable (through a primary approach) and stable standard is required to ensure consistent atmospheric BC measurements over decadal time. Unfortunately, a <u>universally accepted standard of BC is not currently available in the community</u>.

It is known that those widely adopted methodologies of BC measurements are based on one or more characteristics of BC, e.g., elemental carbon (EC) by thermal or thermal-optical method based on refractory/volatility, equivalent BC (EBC) by Aethalometer/PSAP/MAAP/COSMOS on light absorption, and refractory BC (rBC) by SP2 on volatility. To ensure the consistency of measurements by individual method over decadal time and the consistent differences between the methods during the same period to constrain the emission trends in regional scales, establishing suitable BC reference standards is strongly recommended. Hope the Expert Meeting becomes a vehicle of effort moving this forward.

❖ <u>William Irving</u>: Considerations for future IPCC inventory work on SLCF (black carbon example)

As the IPCC Task Force on Inventories begins its consideration of possible future work on methodologies for short-lived climate forcers, it is important to look at aspects of the policy context, source category considerations, and the current use of methodological tiers. Historically, through its development and subsequent revision and refinement of the Guidelines, the IPCC emphasized the importance of complete, consistent, comparable, transparent and accurate estimates of annual national totals and trends for the well-mixed greenhouse gases. The emphasis on national totals for the well-mixed GHGs is consistent with Articles 4 and 12 of the United Nations Framework Convention on Climate Change (UNFCCC) in which Parties agreed that development and reporting of national inventories is an essential element of international cooperation to address climate change.

For short-lived climate forcers that are not well-mixed in the atmosphere, the radiative forcing impacts may depend on the timing and location of where they are emitted. Additionally, other non-climate impacts on human health, environment, and agriculture – and policies to address these impacts - may also depend on the timing and location of emissions. Both factors suggest that optimally any further IPCC work in this area should consider whether more spatial and temporal resolution is needs for SLCFs than is currently reflected in the IPCC Guidelines, and additionally consider the implications in terms of time, resource and expertise needed for methodological development and subsequent use by governments.

The IPCC might also consider a "cross-walk" of categories that are important sources of well-mixed GHGs as reflected in current guidance, with categories that are important sources of various SLCFs. Using black carbon as an example, the largest sources for many developed countries are: transportation, and open biomass burning & wildfires. For developing countries, the largest sources of black carbon are typically: open biomass burning, residential energy use, transportation, and various manufacturing processes (e.g., brick kilns). In the case of black carbon, the IPCC might consider focusing on these categories, and in particular assessing whether or not there are similar needs for activity data and other parameters.

Finally, a short survey of existing methods for well-mixed GHGs and for black carbon show that there are similar approaches at the "Tier 2" level when estimating both non-CO_2 emissions and black carbon emissions from wild fires and from transportation. Countries using the IPCC Tier 2 approach for non-CO_2 emissions from these categories could also have a straight-forward opportunity to estimate black carbon at the same time. Such a survey and identification of efficiencies could be part of future IPCC targeted approach to further work on SLCF methods, and represent an alternative or a supplement to a full methodological work programme. The current IPCC approaches for CO_2 from fossil fuel consumption and for carbon stock changes are based on mass-balance techniques, and may have less relevance to estimating emissions from many SLCFs.

- Antti-Ilari Partanen: Aerosol forcing in different categories of models

In climate science, climate effects of aerosols are modelled in large variety of models with different level of detail, time and spatial resolution. While the global aerosol-climate models with explicit aerosol microphysics and aerosol-cloud interactions represent our best understanding of the global climate effects of aerosols, their computational cost makes them unfeasible for many applications. Therefore, full earth system models and especially reduced complexity climate models use simplified description of aerosol processes.

Although the results of simpler models can to some degree be tuned to match those of more comprehensive models, there are some significant differences. In Figure 1, I show the global mean aerosol forcing in different models. It is noteworthy that although the historical aerosol forcing in MAGICC model (data from RCP database, https://tntcat.iiasa.ac.at/RcpDb/dsd?Action=htmlpage&page=welcome#) corresponds well to the range of ACCMIP ensemble (Shindell et al., 2013), the year-2100 aerosol forcing is significantly stronger than that of the ACCMIP ensemble.

For CMIP5 simulations, the problem has been that the forcings haven't been quantified. Therefore, some studies that analyse CMIP5 data, use aerosol forcings from the RCP database (e.g., Matthews and Zickfeld, 2017), and these forcings are not consistent with the CMIP5 models. In CMIP6, there are separate model experiments to diagnose forcings in climate models. However, the model versions used in this Radiative Forcing Model Intercomparison Project (RFMIP) may not exactly match those of other experiments in CMIP6.

Moreover, there is a wealth of integrated assessment model studies that are using some version of MAGICC. Some of these studies can be very influential when we assess the role of aerosols or other SLCFs. Therefore, also their results and conclusions should be critically evaluated when reviewing climate effects of SLCFs instead of focusing only on state-of-the-art global climate models.

- Michael J. Prather: A perspective on the requirements for Emission Inventories of Short-Lived Climate Forcers needed to assess human role and to project SLCFs

The key question to ask is whether the atmospheric science community can accurately simulate the causal chain going from emission of SLCFs to calculating production and loss of climate relevant species (photochemistry), to calculating the change in composition (transport and scavenging), to deriving the radiative forcing. We have been working on these problems for more than 2 decades.

- 1994: CH_4 chemical feedback through short-lived OH species results in longer perturbation time scales, this increase of 1.4x gets into SAR with multi-model assessment.
- 1999: SLCFs a key part of the IPCC SR Aviation
- 2001: NOx and CO driven changes to CH_4 and O_3, dependent on location of emissions. These now have "indirect GWPs" in TAR and AR4. We learn that NOx emissions in marine boundary layer have dominant cooling effect through CH_4 reductions.
- 2010: Chemical feedbacks link CH_4 and N_2O, reducing N_2O GWP by 5% because of accompanying CH_4 loss (barely noted in AR5).
- 2013: RF based on SLCF species emitted is now standard assessment in AR5, can be done by sector emissions.
- 2015: Air quality and climate becoming more quantitative and multi-model

Overall, the community has established the ability to follow the path:

- Emission ► Production/Loss ► Abundance/Burden ► RF

By nature SLCFs are heterogeneous in the atmosphere, responding to emissions and photochemical heterogeneities. Essential characteristics of an emission inventory: high resolution (not just by country, not just by decade), traceable so as to revise with new understanding, consistent across co-emitted species.

- ❖ Luis Gerardo Ruiz Suárez: Emissions Trends and Key Sources of Short-lived Climate Pollutants Using Top-down/Technology Based Methodologies in Mexico

In Mexico national emission inventories of SLCF (Black carbon (BC), organic carbon (OC) and VOC) have been estimated by several approaches. The Fifth National Communication (5NC) (SEMARNAT 2012) reported black carbon emission trends for 1990-2010 as an annex to the National Greenhouse Gas Emissions Inventory. This inventory was latter updated to include organic carbon and VOC (MCE2 and INECC 2016). A central goal to the team in charge of that inventory, was to show that black and organic carbon emissions could be estimated at the same tier level as Kyoto GHG emissions with small additional burden to the national GHG emissions system and following same good practice guidance (IPCC-NGGIP 2000).

The 1990-2010 GHG emission trends reported in the Fifth National Communication were estimated as follows: Energy sector emissions were estimated by sectoral end-use of energy at national level with subsector resolution provided by the National Energy Balance (NEB) (SENER 2011). To estimate BC and OC from this sector a technology based approach was followed (Bond et al. 2004). Care was taken to account for bad emitters in all diesel internal combustion emissions by sector. Agriculture and LULUCF emissions were estimated using 1996 IPCC Guidelines and (IPCC-NGGIP 1997). Waste emissions were estimated following 2006 IPCC Guidelines (IPCC 2006).

In all cases the Excel notebooks were used with appended calculation blocks or spreadsheets as follows: Whenever in the GHG calculations carbon monoxide was reported, a link to the activity data of that sectoral source was made. The BC or OC emission factor of the combustion process that better represented that sectoral source was chosen from Bond (2004) or a literature search. If not emission factor was found, $PM_{2.5}$ and BC or OC partition ratios to $PM_{2.5}$ were used. National emission factors were used when available. For waste emissions by 2006 Guidelines, activity data for combustion CO_2 emissions were used as indirect GHG emissions are not estimated by that guidelines. Following good practice, reported combustion GHG activity data uncertainties were also taken and assigned to BC and OC emissions. Pasting the block (only for the energy sector) or spreadsheet (for all other sectors) into any given year of the installed software made the calculation.

The time series shown in the Power Point Presentation are the result of this approach. The more task consuming work was the choosing and justification of the used emission factors.

By government decision, since 2012 the emissions inventory community has been working towards a unified climate change and air pollution emissions inventory. For a country of the size and diversity as Mexico that implies a bottom-up emissions inventory. The current emission inventory is a combination of Tier 2 and Tier 3 approaches and make the emissions estimates reported in the First Biennial Update Report to the UNFCCC, as well as the emissions inventory to be reported in the Sixth National Communication. In the comparison between the 5NC and 6NC for 2010, totals are quite similar but differences between sector vary noticeably. The choice of emission factors in key sectors explains the differences. For the implications on mitigation policy, these inconsistences need further work.

Additional presentation

- Richard Mason, Tesh Rao, Rob Pinder: US EPA Perspective on Black Carbon Emissions

The United States Environmental Protection Agency (US EPA) generates inventories of black carbon (BC) and organic carbon (OC) emissions for all anthropogenic sources as part of the public release of the National Emissions Inventory (NEI). The BC and OC emissions are based on NEI $PM_{2.5}$ emissions by application of speciation factors. US EPA estimates that approximately 7-8% of total global BC is from the US. These speciation factors are based primarily on elemental carbon (EC) profiles using thermal optical reflectance methods, where EC estimates are used to represent BC. These BC and OC speciation factors are applied to annual $PM_{2.5}$ estimates, with factors specific to each process-specific source classification codes (SCC); however, factors used for on-road mobile sources are also dependent on meteorological conditions. The SPECIATE database is the repository for the BC factors and most SPECIATE profiles are derived from literature or other credible source testing programs. The resulting BC estimates are reported to many agencies including the UN Economic Commission for Europe (UNECE), Convention on Long-range Transboundary Air Pollution (CLRTAP) and the 2012 Black Carbon Report to Congress. The key sectors for BC emissions include wild and prescribed fires, nonroad mobile diesel equipment, on-road diesel engines, with smaller but locally-significant contributions from open burning, residential wood combustion, agricultural field burning, and numerous other source types. US EPA is working on obtaining improved $PM_{2.5}$ estimates for many of these source categories and seeking updated emission factors of both BC and OC for these sources as well.

D. Reports From Break-Out Groups on Themes 1, 2 and 3

The parallel BOGs of each theme discussed the same key questions of that theme, and each BOG prepared its report that was presented at the final plenary. All reports from BOGs can be found in Annex 3. There was a lot of convergence among the BOGs of each theme.

Theme 1: Assessment of existing methodological framework, observation of atmospheric concentrations and methods to estimate emissions of SLCF

Discussion in break-out groups under Theme 1

Overall, existing methodological frameworks for all SLCF species are being considered and are at different levels of scientific maturity. Experts recognised that the existing IPCC inventory guidelines provide methodological guidance on GHG inventory at a national level on an annual basis. However, SLCF emission estimates may need to be provided at a more disaggregated level both spatially and temporally because the effects of SLCF on climate often depend on the location and regime of their emissions. This means more detailed emission data would be required for SLCFs compared to GHGs. In particular, for aerosol emissions, it would be very important to have higher resolution spatial data than only emissions per country. In addition, the annual cycle of emissions might also have a role in their climate effects.

Atmospheric concentration measurements, in conjunction with modelling techniques, were recognised by experts as a powerful technique for verification of estimates of both emissions and emission trends at different scales. This verification approach includes among others the use of ratios of two or more species, multivariate statistical models and dispersion models and requires long-term robust and traceable atmospheric measurements, which are not always available in every region/country. Experts noted that the *2006 IPCC Guidelines* include a discussion on the use of atmospheric concentrations for the verification of GHG emission inventories and that further work on this subject has been undertaken under the *2019 Refinement to the 2006 IPCC Guidelines*.

Use of receptor chemical speciation models can help to link emission inventories with ambient concentrations by identifying ground emission sources. However, SLCF inventories should not be based on atmospheric concentration measurements alone. For example, the accuracy of EFs back calculated from concentrations is difficult to assess because (i) the individual emission sources are often not thoroughly identified, (ii) it is difficult to separate individual sources via ambient measurements at regional scales and (iii) there is lack of appropriate reconciliation methods. In countries with large area, spatial mapping of SLCF emissions is needed, which could include regional inverse modelling or other methods to resolve local/city or regional level emissions. Much progress has been made in recent years in using satellite observations for estimating emissions of SLCFs (e.g., NOx), because of both improved spatial resolution and quality of the data and improved inversion techniques.

Substantial uncertainties associated with emissions of short-lived species were identified as a barrier for accurate assessment of the radiative forcing of SLCFs. Non-combustion SLCFs emissions are the biggest source of uncertainty (agricultural ammonia, refineries etc.). In the case of BC and OC, additional difficulties exist. They are associated with the fact that these atmospheric components are operationally defined and the reported concentrations in the sources and/or the atmosphere depend on the analytical technique used for determinations. Experts recognized that lacking universally accepted standards is the largest challenge for the BC and OC measurement community, particularly on long-term observations. It is recommended to have international collaborative effort to establish such standards for ensuring stable and consistent BC and OC measurements over decadal time scale and across different analytical techniques. The main problem is how to asses SLCF emissions without having sufficient surface monitoring data. In this regard, the Global Atmosphere Watch (GAW) Programme can be considered as one of the sources of data about SLCF measurements (http://www.wmo.int/pages/prog/arep/gaw/gaw_home_en.html). A number of experts pointed out that it is not relevant to compare the EF measurements of SLCFs between different regions due to geographically specific identities. Nevertheless, in some regions there are plenty of measurements. For example, good continuous measurement data for BC and CO are available in western Japan, suitable for checking region-specific emission ratios from China, Korea, and Japan, individually.

During the discussion, the experts addressed estimation methods provided in the guidance material by, European Environment Agency and the US EPA. The EMEP/EEA Guidebook (https://www.eea.europa.eu/publications/emep-eea-guidebook-2016) and US EPA: AP-42: Compilation of Air Pollutant Emission Factors (https://www3.epa.gov/ttn/chief/ap42/ch14/index.html) provide comprehensive methodologies for estimation of human-induced SLCF emissions. In addition, experts noted that EMEP/EEA is updated every 3-4 years and AP-42 - every year to take into account recent scientific developments. Moreover, the GHG emission source categories in the EMEP/EEA Guidebook have been harmonised with IPCC categories and in most cases (e.g., fuel combustion, livestock) activity data for estimation of GHG and SLCF emissions are common as well, although additional information is often needed for estimating SLCF emissions such as equipment age structure, emission control application and control effectiveness. While EMEP/EEA covers not only EFs for modern technologies but also for some old technologies (at least earlier versions of EMEP Guidebook), it is not always known if these EFs are applicable to all the varied technologies and operational practices currently in place around the globe.

Experts identified the following issues in the use of outlined regional guidelines such as EMEP/EEA Guidebook on a global scale:

- The EMEP/EEA Guidebook provides technical guidance to estimate national emissions under the UNECE CLRTAP and the EU NECD (though higher tier methods can be applied globally, these may entail large errors when applied for SLCF emissions).
- Difficulties with choice (or availability) of suitable emission factors (EFs) for SLCFs (particularly BC) applicable to each country/region/condition and prioritized sectors. For example, some EFs in EMEP/EEA and AP-42 may not be applicable for other regions because they may not be representative of national and/or local conditions.
- Difference in coverage or classification. The existing methodologies on SLCFs do not cover all categories within the IPCC sectors, and vice versa, there are SLCF source categories which are not included in any of the IPCC sectors. Classification of, and/or terminology on, emission sources of SLCF may not be the same or consistent between the two.
- Emissions of BC are estimated on a fractional basis of the emissions of $PM_{2.5}$ (or PM_{10}). While the EMEP/EEA guidebook includes methodologies for all sources of $PM_{2.5}$ for which air quality standards have been established, methodologies to estimate BC emissions do not cover all sources because the reporting of emissions of this aerosol is optional. Existing methodological framework for BC might not be appropriate because for certain sources it has been identified that BC and $PM_{2.5}$ emissions do not correlate, which may be attributable to the fact that BC is more abundant in finer aerosol size fractions, e.g., PM_1.
- For some SLCFs, there is a lack of data (both activity data and EFs) or comprehensive and regionally applicable methodology: Organic Carbon, OC emissions can be derived based on correlation with EC, for example (co-pollutants). Primary OC:EC ratio can be estimated using the range of markers for primary and secondary processes provided by the VOC data. For example, most of the BC EFs in the US EPA methodology result from the speciation profiles of elemental carbon (EC), which are based on the determination of the content of EC using thermal optical reflectance, which also provides the content of OC in the analysed samples.
- Natural sources may need to be considered for SLCF emissions (e.g., in terms of total climate impact and of how they affect anthropogenic sources) while the existing GHG inventory methodology focuses on anthropogenic emissions. EMEP/EEA Guidebook and AP-42 provide methods and EFs for some natural sources (e.g., forest fires, lightening, and volcanoes) but data are rather scarce. In addition, models and satellite data can be used as a relevant data sources (e.g., for wild fires area burned, sand storms). One particular challenge is lack of consistent approach on treatment of wildfires in managed ecosystems (natural vs anthropogenic).
- Gaps on activity data and EFs for the following sources: (i) combustion of biofuels for transportation, cooking and heating, (ii) open-burning of waste and agricultural residues, (iii) traditional coke and charcoal production, (iv) brick kilns, (v) kerosene lamps, (vi) flaring, (vii) residential coal burning and (viii) non-combustion process emissions (SO_2, NMVOC). Also there is not sufficient information regarding BVOC emissions from agricultural silage.
- Lack of activity data on aviation and shipping (particularly lack of historical data for the trend analysis).

- Methodology for combustion in petroleum engines exists and is applicable if sufficient data exist but it is difficult to derive representative EFs for off-road transport.
- Inclusion of residential wood combustion means that technology-specific activity data on biomass fuel consumption would need to be collected, which is not part of the current GHG-inventories.

New emission measurements by sources and species (e.g., in China, US etc.) and guidance for co-pollutants are available and should be taken into account in development of new internationally agreed and globally applicable methodology.

As it is known, IPCC default EFs for CO_2 from fossil fuel combustion already account for the immediate oxidation of CH_4, CO and NMVOCs emissions. IPCC default carbon content or CO_2 emission factors assume that except the small fraction of carbon remaining as un-oxidized solids, for example soot or ash, all carbon in the fuel is oxidized to CO_2 in the combustion process (double-counting of emissions should be avoided).

Experts noted availability of new literature on sources that are not covered in the existing guidance, for example SLCF emissions from kerosene lamps (Lam et al., 2012), gas flaring (Conrad and Johnson, 2017; Weyant at al., 2016) and brick kilns (Christian et al., 2010; Ortinez Alvarez et al, 2018). Brown carbon aerosol (emitted mainly from biomass combustion) was outside the main scope of the meeting; however, increasing interest of the scientific community in brown carbon is observed.

In general, it is expected that better characterization of emission sources would be available. More specifically, improvements are expected in (i) the characterization of fugitive emissions, venting and flaring, (ii) EFs for biofuel combustion, (iii) on-road testing of vehicular emissions, (iv) the characterization of super emitters, and (v) the speciation of BC/OC. Improvements in monitoring and sensors are also expected, these include (i) improved remote sensing data (useful for verification of emission inventories), (ii) wider use of continuous emission monitoring (CEM) for large emission sources, (iii) widespread use of mobile sensors (CO, CH_4 and NMVOC), and (iv) high time resolution measurements of CO, NOx, and NMVOC at ground based supersites and on aircraft.

Lack or incomplete activity data for several sources can lead to high uncertainty in emission estimates. Other causes of uncertainty include inadequate representation of technology shares and/or practices. The differences between real world emissions and those determined under emission tests should also be taken into account when assessing uncertainty. Uncertainty can be reduced by using “Bottom-up” approach based on robust data and methodology in combination with “Top-down” technique (e.g., inverse modelling for verification).

Summary of discussion in break-out groups under Theme 1

- Overall, existing methodological frameworks for all SLCF species are at different levels of scientific maturity.
- The scientific community has developed methods on how to link monitoring data to emission sources (e.g., network measurement and monitoring, remote sensing, satellite and receptor models) at local and regional scales. However, uncertainty is high and EFs applicable for the entire region are not available. Depending on the design of the monitoring system and local conditions, it can be difficult to identify the individual sources from the ambient measurements.
- Comprehensive, although not complete, methodologies on SLCFs exist in the AP-42 and EMEP/EEA Guidebook for national emission inventories. EMEP/EEA and IPCC guidelines are harmonised in terms of methodologies for GHG emission estimates, while US EPA guidance is not necessarily harmonised with IPCC categorisation and may go beyond the IPCC structure.
- Extensive literature review should be conducted to cover all the available science in this field.
- The most significant knowledge gap is the lack of data and methodology on OC. Existing methods and emissions factors are not covering all sources and need further development and improvement.
- It is necessary to develop new guidance for estimation of SLCF emissions that will refer to existing methodologies (e.g., EMEP/EEA Guidebook) and address data gaps identified.
- The current knowledge is mostly mature enough to develop new/improved guidance. However, maturity of knowledge depends on species and sources. The characterization of these emissions is an active area of research as technologies and practices are rapidly changing. There are still knowledge gaps (e.g., lack of data for some sources, challenges with BC methodology etc.). Lack of activity data can lead to high uncertainty and new guidance will be required for activity data. Tier 1 emission factors for SLCFs for all

sources considered should be provided. Because of the role of technologies and practices in the emissions of SLCFs, it is likely that Tier 1 EFs would need to be disaggregated according to these parameters in different regions worldwide.

Theme 2: Assessment of climate impacts of SLCF emissions

Discussion in break-out groups under Theme 2

Overall, there has been substantial improvement in scientific understanding of the climate effects of SLCF emissions since the last Expert Meeting on Aerosols in 2005. The meeting concluded with several recommendations to improve scientific understanding of aerosol climate impacts. Since the 2005 expert meeting, knowledge on all topics has been advanced. These included improved definitions of organic carbon (OC) and black carbon (BC), increased understanding of non-combustion aerosol sources, more measurements on aerosol particle sizes, and better model parametrisations of aerosol processes. Some of the remaining uncertainties can be further reduced if researchers have better information on SLCF emissions from improved inventories generated by governments. More robust emission estimates can manage some of the remaining uncertainties associated with recent and projected SLCF radiative forcing if methodology guidelines are developed.

Theme 2 break-out groups (BOGs) structured discussions around five main questions, as summarized below. The presentations of the outcomes of each BOG are provided in Annex c.

1. What is the current scientific understanding of global radiative forcing (via direct and indirect effects)?

Scientific understanding of (direct and indirect) aerosol radiative forcing effects has increased since AR5. There have been improvements in understanding of the direct RF effects of all species considered in this expert meeting and the concept of Effective Radiative Forcing (ERF), which relates emission more directly to climate responses than RF, has been broadly adopted. The global direct RF of sulphate, BC, nitrogen oxides and carbon monoxide are relatively constrained but there is less robust understanding for OC and NH_3. Since AR5 WGI report, while some models indicate a lower global direct RF effect of BC, other models and observationally-constrained analyses suggest the opposite. The ERF of BC, which more closely captures observed effects of BC and co-emissions on climate, is generally found to be lower than its direct RF. Some measurements indicate gaps in modelling of processes, showing that the net RF (direct and ERF) of BC is still uncertain.

Although the (E)RFs are better understood and quantified, changes in atmospheric levels and the climate responses of SLCFs is an area of larger uncertainty. New knowledge on temperature and precipitation responses to aerosol emissions in general and BC and brown carbon specifically, has improved our scientific understanding. Knowledge on tropospheric ozone and its climate impacts has increased but further improvements can be achieved by additional understanding of temporal and spatial patterns of emissions of ozone precursors. The indirect effects of aerosols remain associated with large uncertainties.

Since AR5, there has been a growing literature basis on SLCF emissions from aviation and shipping and their climate impacts, including modelling studies of the climate effect of NOx. The current understanding of total effects of shipping and aviation is limited by uncertainties related to clouds-aerosols interactions. Recent studies have provided estimates of the impact of shipping emissions in the Arctic. The increased availability and use of GPS data allow for more accurate emission estimates, although it is more difficult to consistently apply these methods over time to estimate trends.

2. What emission metrics are available for SLCF?

Emission metrics attempt to represent the climate effects of a unit emission of a species. They can be used to make comparisons of the strengths of climate effects between species, typically using CO_2 as a reference. The most used metrics are the Global Warming Potential (GWP), which compares the effect on the energy balance of the climate system, and Global Temperature-change Potential (GTP), which compares the effects on surface temperature change. Participants stressed the usefulness of various metrics for different purposes (e.g., inventory assessments, impact ranking, mitigation) and highlighted the importance of ensuring consistency between the metric and its use. In light of the long term goal of the Paris Agreement, metrics are important in relating emission trends and mitigation strategies to global temperature targets. Participants discussed a new usage of GWP which could be more relevant to the Paris targets. This is denoted GWP* and compares the effects of changing the *rate* of SLCF emissions with respect to cumulative emissions of CO_2. The issue of metrics and how they can be used may be further considered and addressed in the WGI contribution to the AR6.

3. What is the current scientific understanding of the local/regional climate effects of SLCFs?

SLCFs climate impacts are largely restricted to the hemisphere where they are emitted. The level of uncertainty increases at regional scales. Modelling studies have attributed some large-scale regional climate changes to SLCFs, in particular aerosols. Global and regional climate implications and impacts can be different depending on the SLCF species and the location of the emission.

The scientific understanding of the regional importance of SLCF emissions has been assessed through model intercomparison projects, such as the Hemispheric Transport of Air Pollution (HTAP) and the Atmospheric Chemistry and Climate Model Intercomparison Project (ACCMIP). The associated level of confidence depends on the modelling tools available (idealized and parameterized), the robustness of attribution of effects to individual SLCFs and the confidence associated with projections of SLCF mitigation and its effects.

Sources of uncertainties arise from assumptions of linearity in the scaling up of local emission perturbations, and from the challenges associated with the detection of a forced signal against the background noise of regional natural climate variability. Modelling methods (e.g., tagging) can be used to follow emission pathways and improve this detection. The level of scientific understanding of the regional effects is better for SO_2 than for BC due to uncertainties associated with BC vertical distribution, lifetime, and interactions within the atmosphere. Region specific studies are emerging for many SLCFs, for instance for the Arctic climate effects of BC.

Participants discussed several specific regional climate impacts from SLCFs during the Theme 2 break-out groups. Examples of regional climatic changes that can be (partly) attributed to changes in SLCFs include:

- Weakening of the Asian Monsoon
- Drying of the Mediterranean region
- Southward shift of the Intertropical Convergence Zone
- Slowing of the hydrological cycle in the Northern Hemisphere
- Arctic warming
- Precipitation changes
- Changes in Amazonian climate

In some cases the cooling by aerosols is believed to be the dominant driver of these changes. Cooling by aerosols, for instance, explains the weakening of the Asian Monsoon and the southward shift of the ITCZ. It also tends to slow down the hydrological cycle in the Northern Hemisphere. Transport of BC and ozone to high latitudes contributes to the warming of the Arctic. Biomass burning aerosols are believed to be an important driver for the Amazonian region. In general, there are large variations in the level of understanding of the role of SLCFs in forcing such regional climate changes. For instance, precipitation changes due to changes in the energy balance of the atmosphere, as a result of changes in aerosol emissions, are well understood, while changes due to rapid adjustments are more uncertain.

4. What are the most significant knowledge gaps and uncertainties?

Despite advancements in scientific understanding, many knowledge gaps and uncertainties persist or have been identified. The imbalance of literature across regions highlights geographical knowledge gaps, namely in Africa, South America, and Australasia. Model perturbation studies can help examine the effects of SLCFs in these understudied regions, but improved observational networks are necessary to reduce knowledge gaps.

Indirect RF effects from SLCFs are more uncertain than direct effects. The climate impact of some SLCFs is less understood than of others, namely VOCs (particularly BVOCs), OC and brown carbon. The development of methodologies for inventories for these species would thus help to constrain the total RF of these precursors, as well as an improved scientific understanding of the effects of other species such as ozone and methane.

Other particular areas of uncertainty that were discussed in the theme 2 BOGs were:

- The three-dimensional and temporal distribution of absorbing species and their speciation
- Model processes from emissions to concentrations and radiative effects to temperature and precipitation changes
- Downscaling global simulations to regional and urban scales
- The local / regional variability of physical and chemical climate conditions (amplified compared to global scale) creates uncertainty in the modelling of the regional responses to SLCF emissions
- Detection and attribution of climate response from individual SLCFs due to signal to noise (isolation of effects from individual SLCFs, e.g., precipitation and extreme events)
- Spatial and temporal changes in atmospheric oxidative capacity
- The total RF of ozone and its contribution to climate change
- Uncertainties in calculating forcing from aerosol emissions and aerosol precursors (chemistry and aerosol-cloud interactions)
- Feedbacks from changes in climate (temperature and water vapour) on chemistry and aerosols, e.g., NOx, BVOCs/SOA
- Impacts of SLCFs on carbon cycle, ecosystems, and snow
- The secondary indirect effect of aerosols on clouds and its representation in models

5. What new knowledge is expected to emerge in the coming years?

Over the AR6 cycle, advances in both observational evidence and modelling studies can be expected to improve scientific understanding further. The topics discussed in the expert meeting included:

- Observational advances in satellite, ground based, airborne measurements
- Emission estimates from new inverse modelling techniques
- Model Intercomparison Projects (MIPs) looking at the climate response to SLCF, for example, AerChemMIP to guide the assessment of regional forcing and climate response
- Continued efforts on characterizing Arctic response to SLCFs
- New advances on understanding effects of SLCFs on precipitation
- Advances in understanding impacts of SLCFs on carbon cycle
- City and region-level simulations, and ultimate connections to global simulations
- Better characterization of brown carbon, secondary organic aerosol (SOA), organic aerosol and some of their regional climate responses
- Greater understanding of aerosol-cloud interactions
- New findings on natural SLCF emissions

Theme 3: Suitability for IPCC to develop inventory methodology for SLCF

Discussion in break-out groups under Theme 3

Four BOGs discussed several issues around three questions that were proposed for the Theme 3:

- Which species of SLCF (and which sources) should be prioritized in the future work to develop inventory methodologies? [Building on findings from themes 1 and 2]
- Is the IPCC the right organisation to develop the inventory methodologies?

– How will these methodologies on SLCF relate to the existing inventory methodologies on GHG? (What kind of elements in the existing GHG inventory methodology can or cannot be applied to SLCF?)

Under the first question, two communities, IPCC TFI and IPCC WGI, discussed sources and species. It was difficult to decide on the concept of prioritization of gases, because all of them are considered to be important. Experts did some attempts to categorize gases in terms of impacts on climate, availability and applicability of methods and data, co-benefits from mitigation policies and measures (e.g., air quality, health impacts). Some participants highlighted that if prioritisation was done, it should be done in a systematic way, for example starting from sources where there is no regional data or information on activity data and emission factors, taking into account that IPCC deals with annual inventories.

There was a general agreement that all the addressed species are relevant. Emission estimates of $PM_{2.5}$, which is not a climate agent as such, are also needed in currently existing methodologies for estimation of BC/OC. Speciation of NMVOC is also important. As for categories, some of them were developed within Theme 2. Experts agreed that the main sources of interest are related to biofuel/biomass combustion in various applications, coal and coke transformation and combustion including traditional charcoal production, and others. The comprehensive list of categories is difficult to produce during the meeting and it requires a careful consideration. The idea of *Not Re-Doing* things was recognized in relationship to existing IPCC guidelines. The participants highlighted the results of AR5 impact assessment and trends for SLCFs. They also considered other issues including: availability of data and methods, knowledge gaps, feasibility to develop guidance, spatial and temporal resolution, ongoing research, mitigation efforts, co-benefits.

Regarding the second question, participants identified several organizations that deal with SLCFs. The organisations include: ICAO, IMO, WHO, FAO, CCAC, UNEP, Arctic Council, IEA, UNECE, US and other national EPAs, EMEP/EEA, GEIA, etc. Experts discussed the differences in mandates of the various organisations that have established methodologies for estimating SLCFs, for example UNECE/CLRTAP whose focus is on air pollutants. During the course of discussions, it emerged that the IPCC may play an important role given its experience on providing guidance on GHG inventories. However, some participants also highlighted that there is a need to separate air quality and climate change impacts or at least have an integrated approach. Experts discussed the mandate and experience of IPCC, a link to the climate, existing IPCC Guidelines, gaps and priorities, a role of IPCC and other organizations on international, regional and national scale, capability of IPCC TFI to deliver comprehensive guidelines, benefits of producing such guidelines, etc.

Under the third question, the experts pointed out that there are existing methodologies like EMEP/EEA and US EPA and they can be used as the starting point, though SLCFs require more specificity in technologies and practices, so a broader and more versatile set of emission factors would be needed in order for these to be applicable for all regions/countries. The experts discussed existing methodologies and their level of development to different species and sources (gaps with BC, OC, NH_3, VOC), availability of activity data, the challenges in developing countries both in relation to collecting activity data and emission factor suitability and availability, concepts of IPCC Tier 1 approach, Key category analysis and Uncertainty, reporting in mass units, etc.

Summary of discussion in break-out groups under Theme 3

- Some SLCF species are of key importance at this stage (e.g., OC, BC and SO_2), others may become a high-priority over time (e.g., NH_3). Therefore, all SLCFs should be considered to reflect trends and developments with more focus on species and sources that are not well covered in existing guidance.
- IPCC has relevant experience and resources to develop guidance for national SLCF inventories. In case of new guidance development, IPCC should closely collaborate with relevant international bodies (EMEP, ICAO, IMO, FAO etc.) and national EPAs.
- The main challenge in the development of SLCF methodology is to derive regionally differentiated applicable EFs, within consistent, well-documented framework.
- The following potential challenges in harmonization of SLCF and GHG inventory methodologies can be recognized:
    a) Positive correlations between data on multiple SLCF species can be considered as a constraint for implementation of Tier 1 uncertainty analysis (Tier 1 provides more accurate results with

either independent or fully correlated values). Some techniques can be used to reduce influence of correlations, for example, data can be aggregated to an appropriate level (Section 3.2.2.4, Chapter 3 in Volume 1 of the *2006 IPCC Guidelines*). Tier 2 Monte Carlo is dealing with correlations but cannot be used by many countries due to lack of resources. Submission of uncertainty estimates for new sources might be a challenge as well.

b) Temporal and spatial variability of SLCFs.

c) Inclusion of residential wood combustion means that technology specific activity data on biomass fuel consumption would need to be collected, which is not part of the current GHG inventory methodologies.

d) IPCC Guidelines neither prescribe the choice of metrics nor require estimation and reporting national total emissions in units of CO_2-equivalent (CO_2-eq) emissions. IPCC Guidelines suggest to aggregate GHGs in CO_2-eq for key category and uncertainty analysis. Current metrics make it difficult to develop a comprehensive prioritization scheme that includes both GHGs and SLCFs. This also means that it may be difficult to integrate the two inventories, e.g., with regards to calculation of "national total emissions". The issue of metrics and how they can be used may be further considered based on new scientific literature for coordination across Working Group reports, particularly those of Working Group I and Working Group III, towards the synthesis report (SYR) of the sixth assessment report (AR6).

E. Annexes

Annex 1: Agenda of the meeting

IPCC Expert Meeting on Short-Lived Climate Forcers

Geneva, Switzerland, 28 – 31 May 2018

Draft Agenda (as of 29 May)

Day 1: Monday, 28 May

9:00 - 9:30	Registration
Opening Plenary Session for Scene-setting	
9:30 - 9:40	Welcome Address (Abdalah Mokssit, Secretary of the IPCC) Adoption of agenda
9:40 - 10:40	Presentations on general background ➢ Background of this expert meeting: Relevant IPCC decisions and history of relevant discussion (Eduardo Calvo Buendia) ➢ Overview of planned IPCC products during AR6 cycle and their relevance to this expert meeting (Valerie Masson-Delmotte) ➢ Overview of IPCC Guidelines for National Greenhouse Gas Inventories, including on-going work on 2019 Refinement (Kiyoto Tanabe) ➢ Guidance to the participants on the key themes and expected outcomes of this expert meeting (Panmao Zhai) Q & A (20 min)
10:40 - 11:00	*Coffee break*
11:00 - 13:00	Presentations on issues relating to key questions ➢ Introduction of new scientific findings from recent literature since AR5 about SLCF emissions and their climate effects • AR5: main findings & knowledge gaps on SLCFs and Radiative Forcing (Olivier Boucher) • AEROCOM: Recent findings on effects of aerosols on climate (Bjørn Hallvard Samset) • Emission metrics for SLCFs (Keith P. Shine) • Impacts of atmospheric chemistry on the lifetimes of SLCF (Detlev Helmig) Q & A (20 min) ➢ Introduction of existing inventory methodologies or experiences in estimating emissions of SLCF • EMEP/EEA Emission Inventory Guidebook (Kristina Saarinen) • Estimating emissions of Black Carbon and other SLCFs within CCAC activities (Valentin Foltescu, Harry Vallack, Zbigniew Klimont) Q & A (10 min)
13:00 - 14:15	*Lunch break*
14:15 - 15:10	Presentations on issues relating to key questions (continuation)

	➢ Introduction of existing inventory methodologies or experiences in estimating emissions of SLCF (continuation) • Emission estimates on a national scale – experiences of Nordic countries (Karin Kindbom) • Ammonia emissions from the agriculture sector in Argentina (Laura Elena Dawidowski) • Links between global-scale emission estimates and national emission inventories (Steven J. Smith) Q & A (10 min)
15:10 – 15:20	Introduction to BOG Session 1
15:20 - 15:40	*Coffee break*
Break-out Group (BOG) Session 1	
15:40 – 18:20	➢ 2 parallel BOGs on Theme 1 (Assessment of existing methodological framework, observation of atmospheric concentrations and methods to estimate emissions of SLCF) ➢ 2 parallel BOGs on Theme 2 (Assessment of climate impacts of SLCF emissions)
18:30 - 19:30	*Reception*

Day 2: Tuesday, 29 May

Plenary Session	
09:30 - 10:00	Presentation on WGI AR6 outline ➢ Chapter 6 of WGI AR6: Intention at the scoping meeting and the outline (William Drew Collins & Hong Liao)
10:00 – 11:15	Continuation of BOG Session 1
11:15 - 11:30	*Coffee Break*
11:30 – 12:00	Brief report from BOG Session 1 ➢ Report from each of 4 BOGs (5 min each) Q & A and discussion (10 min)
BOG Session 2	
12:00 – 13:00	Taking outcomes of BOG Session 1 and Plenary discussion into account, BOGs will continue discussion. ➢ 2 parallel BOGs on Theme 1 (Assessment of existing methodological framework, observation of atmospheric concentrations and methods to estimate emissions of SLCF) ➢ 2 parallel BOGs on Theme 2 (Assessment of climate impacts of SLCF emissions)
13:00 - 14:30	*Lunch break*
14:30 - 16:00	Continuation of BOG Session 2
16:00 - 16:30	*Coffee break*
16:30 - 17:50	Report from BOG Session 2 ➢ Report from each of 4 BOGs (10 min each) Q & A and discussion (30 min)

Day 3: Wednesday, 30 May

Plenary Session	
09:30 - 10:40	Preliminary consideration on possible issues in harmonizing existing inventory methodologies on GHG and those on SLCF ➢ Introduction of results of preliminary survey on potential issues (SSC member) ➢ Views on specific potential issues (Lin Huang) ➢ Views on specific potential issues (William Irving) ➢ Views on specific potential issues (Antti-Ilari Partanen)
10:40 - 11:00	*Coffee break*
11:00 - 11:50	➢ Views on specific potential issues (Michael John Prather) ➢ Views on specific potential issues (Luis Gerardo Ruiz Suárez) Q & A and discussion (30 min)
11:50 - 12:00	Introduction to BOG Session 3
BOG Session 3	
12:00 – 13:00	Taking outcomes of BOG Session 2 and Plenary discussion into account, BOGs will consider Theme 3 (Suitability for IPCC to develop inventory methodology for SLCF) ➢ 4 parallel BOGs on Theme 3
13:00 - 14:30	*Lunch break*
14:30 – 16:00	Continuation of BOG Session 3
16:00 - 16:30	*Coffee break*
16:30 - 17:50	Continuation of BOG Session 3

Day 4: Thursday, 31 May

Closing Plenary Session	
9:30 - 11:00	Report from BOG Session 3 ➢ Report from each of 4 BOGs (10 min each) Q & A and discussion (50 min)
11:00 - 11:20	*Coffee break*
11:20 - 12:30	Discussion and conclusion
12:30	*End of the meeting*

Annex 2: Synthesis of responses to the questionnaire

The questionnaire shown below was distributed to the participants in advance of the meeting.

Expert Meeting on Short-Lived Climate Forcers (SLCF)

Request for input to the meeting

1. If you have any material relevant to the themes and key questions of this meeting (see the paper "Scope and Key Themes", please share it with the TFI Technical Support Unit by e-mail to nggip-meetings@iges.or.jp.

2. Please share your view on possible issues in harmonizing existing inventory methodologies on greenhouse gases and those on SLCFs. What kind of difficulties are envisaged if we try to integrate short-lived climate forcers in the current national greenhouse gas inventory?

3. Please share your view on the usefulness of a compilation of scientifically documented emission factors for SLCFs".

4. Please share your view on any other questions/issues that are relevant to this meeting, if any.

Please fill in the boxes above, and send this paper back to TFI Technical Support Unit (nggip-meetings@iges.or.jp) by Monday, 7 May.

Responses from the participants were collected and synthesized by the scientific steering committee, based on which possible issues in consolidating existing inventory methodologies on GHGs and SLCFs were presented at the meeting on Day 3 before the discussion on Theme 3 started.

Possible issues in consolidating existing inventory methodologies on GHGs and SLCFs (From responses to questionnaire)

- Harmonizing methods
- Aligning categories
- Links with climate processes
- Other considerations

Considerations: harmonizing methods

- Most commented upon issue: unique and perhaps more complex methodological requirements of SLCFs;
- The existing IPCC inventory guidelines provide methodological guidance on GHG inventory at a national level on an annual basis. However, it is important for SLCF emission estimates to be provided at a more disaggregated level both spatially and temporally;
- Technologies (including for control), practices, fuel characteristics are very influential in SLCF emissions;
- Larger uncertainties in some SLCF emission factors;
- Co-emissions impact the mitigation effect of reducing emissions from particular sources of SLCFs;
- Same basic methods: AD x EFs = emissions;
- Need to compile scientific literature on Emission Factors (EFs);
- Do not duplicate existing guidance, complement it.

Considerations: aligning categories / terminology

- Pollutant classification of, and/or terminology on, emission sources may not be the same or consistent between the two.
- Useful first steps:
    - Mapping emission categories or sectors in GHG and Air Pollutants
    - Identifying categories with common activity data
- No perfect match between GHG and Air Pollutant categories

Challenges of complex atmospheric processes involving SLCFs

- Lack of common metrics such as GWPs for SLCFs will make it quite difficult to integrate inventories in the calculation of "national total emissions" and key category analysis.
- Impact of SLCF emissions on climate is time- and location-sensitive.

Other considerations

- Natural sources can have disproportionately large effects on climate, yet are not included in IPCC inventory methods.
- On-going definitional issues (BC vs EC) and inconsistent measurements methods
- Unique health impacts of SLCF emissions
- Challenges in collecting activity data
- Potential benefit of internally consistent approaches
- Improved analysis of mitigation potential
- Enhanced comparability of streamlined methodological Framework

Practical difficulties for inventory compilers

- Increased work loads
- Activity data: in some cases the same as for GHGs (e.g., fuel combustion) but not always
- Institutional challenges (harmonizing methods between two different programs)
    - May lead to increased reporting requirements;
    - May increase the capacity-building needs.

Annex 3: Reports from break-out groups – slides of presentations delivered at the plenary on day 4 (1a, 1b, 2a, 2b, 3a, 3b, 3c, 3d)

Disclaimer: The reports compiled in this annex are as they were presented, without any editing.

Break-out group 1a

(BOG1) Session-1 (May 28, 2018)

Question 1

How accurately can we monitor SLCF sources and emission trends and link them to atmospheric concentrations:

Different interpretations of Question 1

- Check how well monitoring emission measurements can be linked to atmospheric concentrations
- Verify emission inventory by field measurement
- Suggest to link emission to atmospheric concentrations by optimizing emission factor prediction, measurement and calculations
- How well can we calculate atmospheric concentrations from the estimated emissions

- **How accurately can air monitoring data be linked to sources and emission trends?**

(BOG 1) Summary

	Black Carbon	Organic Carbon	PM2.5	NOx	CO	NMVOC	SO_2	NH_3
How accurately can ambient air monitoring data (incl remotely sensed data) be linked to SLCF sources and emission trends	• Scientific community has developed methods on how to link monitoring data to emission sources (e.g. network measurement and monitoring, remote sensing, satellite and receptor models) at the Local, regional scales. • However uncertainty is larger for short lived species. • Linking air monitoring to emission data works best at the local or regional scale. • Receptor chemical speciation models can be used for identifying ground emission sources • Depending on the design of the monitoring system, it can be difficult to identify the individual sources from the ambient measurements.							

(BOG 1) Summary

	Black Carbon	Organic Carbon	PM2.5	NOx	CO	NMVOC	SO_2	NH_3
On what SLCF species do emission quantification methodologies already exist and at what scale	• Comprehensive methodologies exist in the EMEP/EEA guidebook for national emission inventories. Also available are guidance developed by the US and China. Overall there are comprehensive methodological framework, however, emission factors applicable to the entire region are missing • OC is generally missing from the guidance • There are needs to develop EFs for developing countries especially for old industries like coal burning, kerosene lamps, brick kilns and open waste burning and indoor and outdoor biomass burning • The issue of large natural sources that affect air quality and public health like VOCs from vegetation and dust from sand storms. Collaboration would be needed to fill these gaps and minimize overlap.							

Session 2 of BOG 1(a) Summary

	Black Carbon	Organic Carbon	PM2.5	NOx	CO	NMVOC	SO_2	NH_3
What are the most significant knowledge gaps and uncertainties ?	• Sources: Residential cooking, open burning of; • OC: methods and emission factors are not covering all sources and needs further development and improvement; • **Activity data** mostly missing in developing countries (sources of data and additional studies – guidance on local work to develop activity data); • Other sources: gas flaring, brick kilns, burning of agricultural residues, charcoal making; • AP 42 – possible source of data • BC estimation methodologies for the transport sector exists and are generally applicable but we are missing representative emissions factors • Challenges with methodologies for Off-road and super-emitters (mal-function)							

(BOG 2) Summary

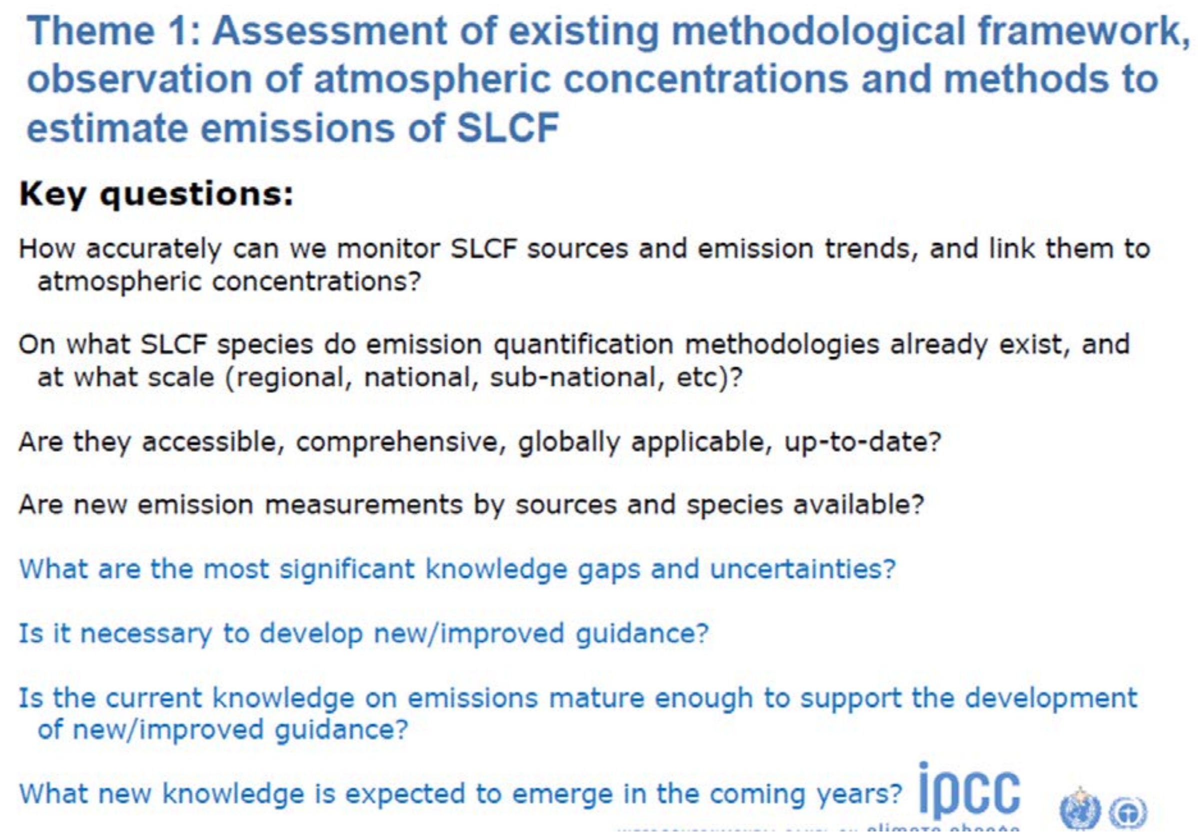
	Black Carbon	Organic Carbon	PM2.5	NOx	CO	NMVOC	SO_2	NH_3
Is it necessary to develop new?	• We need good practice guidance to guide the process for estimation of SLCF emissions; • Methodological guidance on how to deal with super-emitters and other sources that are not generally part of the national statistics including suggesting emission factors; • See gaps in slide 1							

(BOG 2) Summary

	Black Carbon	Organic Carbon	PM2.5	NOx	CO	NMVOC	SO_2	NH_3
Is the current knowledge on emissions mature enough to support the development of new/improved guidance?	(Yes/partially –except for specific sources not covered well enough – see slide 1)							

(BOG 2) Summary

	Black Carbon	Organic Carbon	PM2.5	NOx	CO	NMVOC	SO_2	NH_3
What new knowledge is expected to emerge in the coming years?	• Examples: Kerosene lamps (Lam et al, 2012) Gas flaring (Conraa Johnson 2017, Weyant et al, 2016, Beikc klins (Chrsitina, Ortinez Alvarez 2'18							



Q1. What are the most significant knowledge gaps and uncertainties?

Sources/categories - SLCF: AD and EFs

- Liquid biofuels for transportation
- Traditional coal-coke production
- Biofuel cooking
- Biofuel heating
- Coal heating
- Open waste burning
- Brick kilns
- Kerosene lamps
- Flaring
- Agricultural silage – BVOC
- Non-combustion process emissions (e.g. refineries SO2)
- Agricultural waste burning on fields (AD)

Uncertainties

- Lack of AD can lead to high uncertainties
- Technology shares
- behavoir/practices
- Testing versus in practice

Q2. Is it necessary to develop new/improved guidance?

The answer is yes

- **New guidance to address knowledge gaps**
- **Revise guidance to make it globally applicable for existing methodologies**

➢ **For example one approach is to follow a harmonised approach consistent with the EMEP/EEA guidance**
➢ **New guidance will be required for AD**
➢ **Provide tier 1 EFs for all categories**

Q3. Is the current knowledge on emissions mature enough to support the development of new/improved guidance?

➢ **Yes active area of research**
➢ **Yes but knowledge rapidly changing**
➢ **The maturiy of knowledge depends on species and sources**
➢ **Useful to have a body assessing and distributing new information as it is generated**

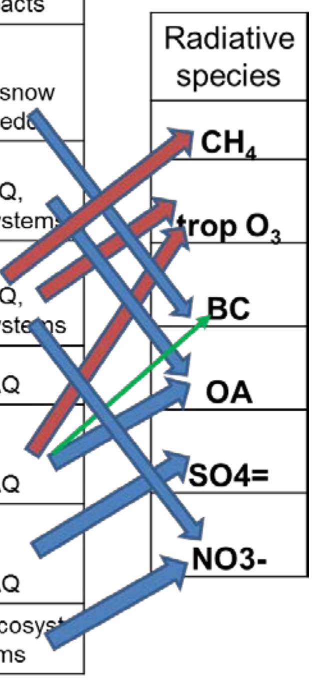
Q4. What new knowledge is expected to emerge in the coming years?

- **Improve remote sensing data**
- **Improve EF for solid biofuel burning**
- **On road testing of transportation**
- **Improve the speciation of BC/OC**
- **Wider use of CEM for large sources?**
- **Better characterisation of super emitters?**
- **Improved characterisation of fugitive emissions, flaring**
- **Widespread mobile sensors (CH4, VOC, CO)**

Break-out group 2a

Table 1a. Scientific Understanding of how SLCFs drive Climate Change

SLCF species	Emissions: confidence re global uniformity & quality	Chemistry and processes: confidence	Impacts on radiative species	Other environmental impacts
BC	Yes, Q poor, questionable speciation, size distribution, PI background difficult, meteorology.	Low: chemical aging & coating.	**BC**	AQ, snow albedo
OC	**Low**: poorly documented, speciation & size, initial oxidative state.	Low: chemical aging	**OA** (=POA&SOA), **BC**	AQ, ecosystems
NOx	Medium: lack space & time resolution	High: but resolution critical. Medium: for NO3-	**O3, CH4, NO3-, OA**	AQ, ecosystems
CO	High (FF) Medium (BB& BF)	High: kinetics, OH	**CH4, O3**	AQ
NMVOC	Medium: speciation	Medium: oxidation and condensation	**CH4, O3, OA, (SO4, NO3)**	AQ
SO2	High (primarily FF)	High: oxidation, deposition	**SO4, OA, NO3, BC coating**	AQ
NH3	Low: agricultural sources	Medium-High: kinetics	**NO3-**	AQ, ecosystems



Break Group 2b??: Scientific Understanding of how SLCFs drive Climate Change
Yassaa, Samset, Prather reporting – morning 28 May rev 30 May

Table 1b. Scientific Understanding of how SLCFs drive Climate Change (cont'd)

Radiative species	Production and loss from SLCFs	Transport & final concentration	Direct Radiative Effect given concentration	Aerosol-cloud interactions	other adjustments, feedbacks	RF 2010-2100 across RCPs
CH_4	High Confidence	Very High	Very High		High	0.48 -> 0.27/1.08
trop O_3	Medium	Medium	High		Medium	0.40 -> 0.17/0.60
BC	High: total, Low: mixing state	Low	Medium, given mixing state	Medium	Medium: model formulation, cloudinteraction	-1.1 -> -0.6/-0.5 or to -0.12 **needs checking**
OA	Medium: POA good, secondary production low	Low confidence	Medium: composition, secondary prod, optics	Medium; high altitude transport	Medium; brown carbon rapid adjustment	
SO4=	Medium; secondary production	Medium: scavenging	Medium; hygroscopic growth, radiative transfer	Low; cloud albedo / lifetime	N/A	
NO3-	Low: depends on NH3, SO4=, small scales	Medium: scavenging	Medium; hygroscopicity, radiative transfer	Low; cld albedo & lifetime	N/A	
CO_2	Very High	Very High	Very High		High	1.80 -> 2.22 (RCP2.6)

Break-out group 2b

Break Group 2b: Scientific Understanding of how SLCFs drive Climate Change

SLCF species	Emissions: global uniformity, quality	Chemistry and processes	Impacts on radiative species	Other environmental impacts
BC	Yes, Q poor, questionable speciation,size distribution, PI background difficult, meteorology.	Low, Aging & coating.	BC	AQ, snow albedo
OC	**Low**: poorly documented, speciation & size weak, lack initial oxidative state.	Low, aging	OA (=POA&SOA), BC	AQ, ecosystems
NOx	Medium to high, lack space & time resolution	High, but resolution critical. Medium, NO3	O3, CH4, NO3-,OA	AQ, ecosystems
CO	High (FF), Medium (BB& BF)	High	CH4, O3	AQ
NMVOC	Medium, speciation	Medium, oxidation and condensations	CH4, O3, OA, (SO4,NO3)	AQ
SO2	High (primarily FF)	High. oxidation, deposition	SO4, BC coating,OA , NO3	AQ
NH3	Low, agric sources	Medium high	NO3	AQ,ecosystems

Radiative species
CH_4
trop O_3
BC
OA
SO4=
NO3-

Radiative species	Production and loss from SLCFs	Transport & final concentrati on	Direct Radiative effect of concentration	Aerosol-cloud interacti ons	other adjustments, feedbacks	RF changes across RCPs
CH_4	High Confidence	VH Confidence	VH		VH	
trop O_3						
BC	High: total, Weak: mixing state	Low Conf	Medium, given mixing state	Medium	Medium:,diffe rent model formulation, interaction with clouds.	
OA						
SO4=						
NO3-						

Report from BOG 2b, Session 2

Leads: Bill Collins and Jan Fuglestvedt

Rapporteur: Twan van Noije

What is the current scientific understanding of how SLCFs affect climate of locate/regional scales (differently from CO2)?

- We are now able to make some definite conclusions on some limited aspects
- Regional aerosol signal obscured by natural variability
- Some large-scale regional climate change has been attributed by global modelling to SLCFs:
  - Asian aerosol cooling and weakening of Asian Monsoon
  - Mediterranean drying (aerosols)
  - Shift in ITCZ
  - Slowing of hydrological cycle in NH (aerosol cooling)
  - Contribution to Arctic climate change; impacts from BC/ozone transport uncertain
  - Precipitation response explained by energy balance well understood
  - Effect of biomass burning aerosol in Amazonia observed

What are the most significant knowledge gaps and uncertainties?

- Uncertainties in calculating forcing from emissions (chemistry and aerosol-cloud interactions); response to precursors not well known, just to O3, CH4, aerosols
- Rapid adjustments vs. slow response to warming/cooling
- Role of SLCFs on precipitation and extreme events; we cannot separate signature of global warming from specific contributions from SLCFs
- Feedbacks from changes in climate (temperature and water vapour) on chemistry and aerosols, e.g. LNOx, BVOCs/SOA
- Impacts of regional SLCF emissions (compared to global emissions) on regional climate
- Impacts of SLCFs on carbon cycle, ecosystems, and snow

What new knowledge is expected to emerge in the coming years?

- New satellite instruments, surface measurements and inverse modelling techniques
- Longer observational data sets to link climate changes to regional trends in SLCFs

<u>Break-out group 3a</u>

Theme 3: Suitability for IPCC to develop inventory methodology for SLCF - BOG 3a

Facilitators: Eduardo Calvo & Maria Kanakidou
Rapporteur: Rita Van Dingenen

- Q1 Which species of SLCF (and which sources) should be prioritised in the future work to develop inventory methodologies?

Which species of SLCF (and which sources) should be prioritised in the future work to develop inventory methodologies?

SLCF	Methodology (non globally applicable)	Climate impact	Ability to project climate	Climate change certainty (cummulative)	Research	Education/ Capacity building	Mitigation effort/climate negociations
NOx	***	*	***	**	*	***	*
CO	***	*	***	***	**	***	*
NMVOC	* (speciation)	+	*	*	**	***	*
SO_2	***	gl ** reg ***	** (ACI)	**	*	***	-
BVOC	models	*?	* (ACI)	*	***	***	-
NH_3	*** (Agriculture)	*	*	*	***	***	-
PM2.5	** sectors missing	-	-	-	-	*	-
BC	** (emep definition)	gl * reg **	**	*	**	***	***
OC	* (emep definition)	gl * reg *	*	*	***	***	-

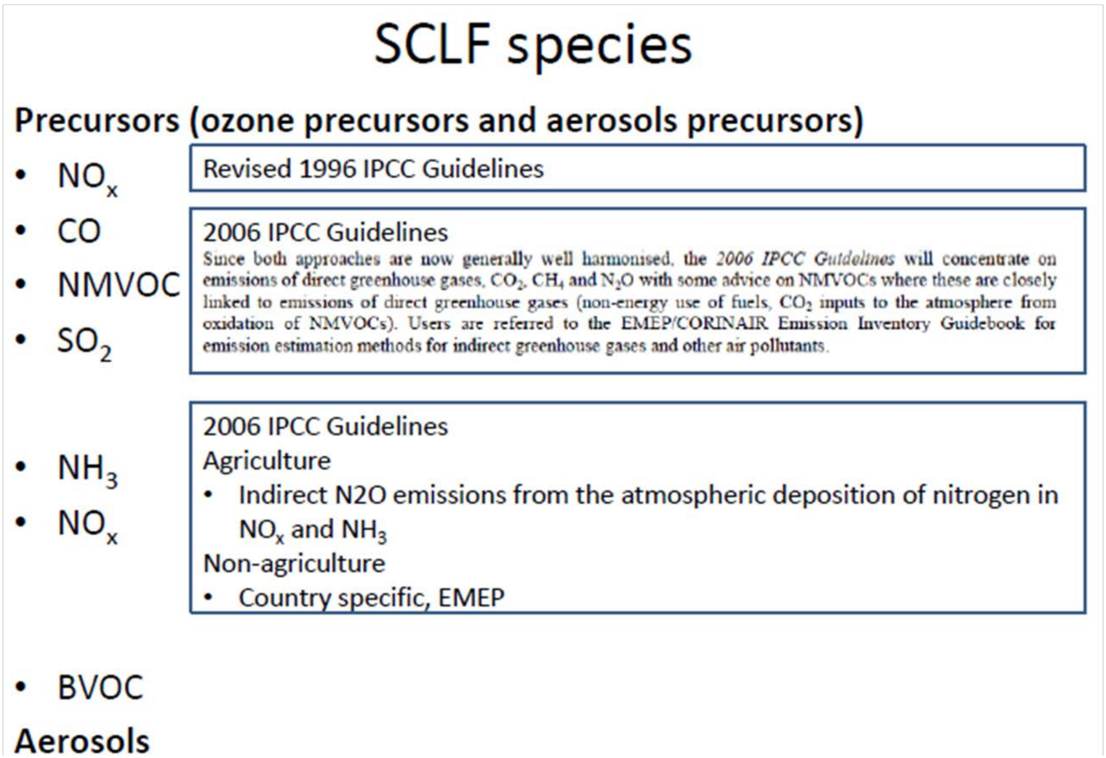
Which species of SLCF (and which sources) should be prioritised in the future work to develop inventory methodologies?

SLCF	Methodology (non globally applicable)	Climate impact	Ability to project climate	Climate change certainty (cummulative)	Research	Education/ Capacity building	Mitigation effort/climate negociations
1-NOx	***	*	***	**	*	***	*
1-CO	***	*	***	***	**	***	*
NMVOC	* (speciation)	+	*	*	**	***	*
2-SO_2	***	gl ** reg ***	** (ACI)	**	*	***	-
5-BVOC	models	*?	* (ACI)	*	***	***	-
4- NH_3	*** (Agriculture)	*	*	*	***	***	-
PM2.5	** sectors missing	-	-	-	-	*	-
3- BC	** (emep definition)	gl * reg **	**	*	**	***	***
3- OC	* (emep definition)	gl * reg *	*	*	***	***	-

- Compounds for which methodologies exist, relevant impact for global CC (O3 precursors)
  - NOx
  - CO
  - NMVOC (need for speciation)
- Compounds with regional climate relevance
  - SO2
  - BC + OC: more research needed to go from current inventories to CC impact, both from inventory (AD, EF) and atmosph. process point of view – BC already used in some countries in NDCs
  - NH3 (agriculture sector)
- Compounds where research can strongly contribute
  - BVOC (O3, SOA): natural with anthrop. component (AFOLU) → field of scientific interest
- PM2.5: low priority because not speciated, but is (currently) part of BC & OC methodology

- Note: Capacity building important for all species
- No global methodology
- Need for regional EF and AD (issues: super emitters, vehicle population)

➢ Q2 Is the IPCC the right organisation to fill gaps and consolidate the inventory guidelines ?



- Q2 Is the IPCC the right organisation to fill gaps and consolidate the inventory guidelines ?

Yes
Why IPCC: <u>global</u> organization to which governments have already commitments

- Making use of available structures (e.g. AFOLU for NH3, BVOC) and comprehensive methodologies (EMEP/EEA, US, China)
- ‘Old’ IPCC methodologies for some SLCFs need upgrading/updating
- Consolidate and fill gaps – e.g. region-specific EF

Is the IPCC the right organization?

- Existing comprehensive methodologies EMEP/EEA, US, China
- Structures
- ‘IPCC could focus on products that facilitate countries preparing GHG and SLCF inventories’

- Need for
- ...
- Methodological guidance on how to deal with super-emitters and other sources that are not generally part of the national statistics including suggesting emission factors;

➤Q3: How will the methodologies on SLCF relate to the existing inventory methodologies on GHG?

TABLE 7.1
LINK BETWEEN THE IPCC CATEGORIES AND THE CORRESPONDING METHODOLOGY CHAPTERS IN EMEP/CORINAIR GUIDEBOOK [1]

Reporting category				Source Sector	EMEP/CORINAIR Inventory Guidebook Chapter	NO_x	CO	NM-VOC	SO_x
IPCC category		CRF	NFR			Relevance of emissions from the category (see codes above the table)			
1 ENERGY									
1A1 Energy Industries	1A1a	1A1a	1A1a	Main Activity Electricity and Heat Production	B111 and B112	A	A	A	A
	1A1b	1A1b	1A1b	Petroleum Refining	B132 and B136	A	A	A	A
	1A1c	1A1c	1A1c	Manufacture of Solid Fuels and Other Energy Industries	B142, B146 and B152	A	A	A	A
1A2 Manufacturing Industries and Construction	1A2a	1A2a	1A2a	Iron and Steel	B111, B112, B323, B324, B325, B331, B332, B333	A	A	A	A
	1A2b	1A2b	1A2b	Non-ferrous Metals	B336, B337, B338, B339, B3310, B3322, B3323	A	A	A	A
	1A2c	1A2c	1A2c	Chemicals	B111 and B112	A	A	A	A
	1A2d	1A2d	1A2d	Pulp, Paper and Print	B3321	A	A	A	A
	1A2e	1A2e	1A2e	Food Processing, Beverages and Tobacco	B111 and B112	A	A	A	A
	1A2f	1A2f	1A2f	Non-Metallic Minerals	B3311, B3312, B3313, B3314, B3318, B3319, B3320, B3323	A	A	A	A
	1A2g			Transport Equipment	B111 and B112	A	A	A	A
	1A2h			Machinery	B111 and B112	A	A	A	A
	1A2i			Mining and Quarrying	B111 and B112	A	A	A	A
	1A2j			Wood and Wood Products	B111 and B112	A	A	A	A
	1A2k			Construction	B111 and B112	A	A	A	A
	1A2l			Textile and Leather	B111 and B112	A	A	A	A
	1A2m			Non-specified Industry	B111 and B112	A	A	A	A

Q1. What are the most significant knowledge gaps and uncertainties?

Sources/categories - SLCF: AD and EFs

- Liquid biofuels for transportation
- Traditional coal-coke production
- Biofuel cooking
- Biofuel heating
- Coal heating
- Open waste burning
- Brick kilns
- Kerosene lamps
- Flaring
- Agricultural silage – BVOC
- Non-combustion process emissions (e.g. refineries SO2)
- Agricultural waste burning on fields (AD)

Uncertainties

- Lack of AD can lead to high uncertainties
- Technology shares
- behavoir/practices
- Testing versus in practice

➢ Q3: How will the methodologies on SLCF relate to the existing inventory methodologies on GHG?

- Main task: to obtain regional-specific EF for global inventories
- Add substances (BC, OC, NH3)
- BVOC from modeling (biogenic under anthropogenic perturbation)

To explore according to the needs:

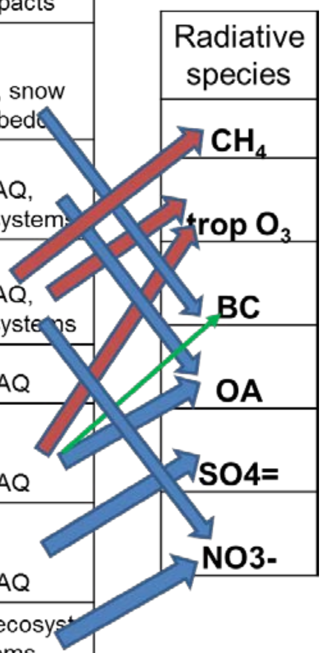
- Good practice guidance report with gradual implementation
- Supplement like done for Kyoto 2013
- Separate work as for wetlands report (introduce new categories)
- Or combination of above

Table 1b. Scientific Understanding of how SLCFs drive Climate Change (cont'd)

Radiative species	Production and loss from SLCFs	Transport & final concentration	Direct Radiative Effect given concentration	Aerosol-cloud interactions	other adjustments, feedbacks	RF 2010-2100 across RCPs
CH_4	High Confidence	Very High	Very High		High	0.48 -> 0.27/1.08
trop O_3	Medium	Medium	High		Medium	0.40 -> 0.17/0.60
BC	High: total, Low: mixing state	Low	Medium, given mixing state	Medium	Medium: model formulation, cloudinteraction	-1.1 -> -0.6/-0.5 or to -0.12 **needs checking**
OA	Medium: POA good, secondary production low	Low confidence	Medium: composition, secondary prod, optics	Medium; high altitude transport	Medium; brown carbon rapid adjustment	
SO4=	Medium; secondary production	Medium: scavenging	Medium; hygroscopic growth, radiative transfer	Low; cloud albedo / lifetime	N/A	
NO3-	Low: depends on NH3, SO4=, small scales	Medium: scavenging	Medium; hygroscopicity, radiative transfer	Low; cld albedo & lifetime	N/A	

Table 1a. Scientific Understanding of how SLCFs drive Climate Change

SLCF species	Emissions: confidence re global uniformity & quality	Chemistry and processes: confidence	Impacts on radiative species	Other environmental impacts
BC	Yes, Q poor, questionable speciation,size distribution, PI background difficult, meteorology.	Low: chemical aging & coating.	**BC**	AQ, snow albedo
OC	**Low**: poorly documented, speciation & size, initial oxidative state.	Low: chemical aging	**OA** (=POA&SOA), **BC**	AQ, ecosystem
NOx	Medium: lack space & time resolution	High: but resolution critical. Medium: for NO3-	**O3, CH4, NO3-,OA**	AQ, ecosystems
CO	High (FF) Medium (BB& BF)	High: kinetics, OH	**CH4, O3**	AQ
NMVOC	Medium: speciation	Medium: oxidation and condensation	**CH4, O3, OA, (SO4,NO3)**	AQ
SO2	High (primarily FF)	High: oxidation, deposition	**SO4, OA, NO3, BC coating**	AQ
NH3	Low: agricultural sources	Medium-High: kinetics	**NO3-**	AQ,ecosystems



Break Group 2b??: Scientific Understanding of how SLCFs drive Climate Change

Yassaa, Samset, Prather reporting – morning 28 May

Q2. Is it necessary to develop new/improved guidance?

The answer is yes

- New guidance to address knowledge gaps
- Revise guidance to make it globally applicable for existing methodologies

➢ For example one approach is to follow a harmonised approach consistent with the EMEP/EEA guidance
➢ New guidance will be required for AD
➢ Provide tier 1 EFs for all categories

Possible issues in harmonizing existing methodologies on GHGs & those of SLCFs

- Differences in
  - required spatial/temporal resolution (higher resolution is needed for SLCFs than GHG)
  - in coverage and classification of emission sources (natural sources may be important)
  - level of uncertainty for emission estimates
- Lack of common metrics for SLCFs make be a pb
- Unavailability of data particularly on SLCFs
- Practical difficulties for inventory compilers
- Increase reporting requirements, man power needs, etc

Which species of SLCF (and which sources) should be prioritised in the future work to develop inventory methodologies?

SLCF	Priority/ sector
BC	
OC	
PM2.5	
NOx	
CO	
NMVOC (+BVOC)	
SO_2	
NH_3	

- Maturity of knowledge depends on species
- Missing activity data and emission factors
- OC is generally missing from guidance
- BC/OC but not much interest on PM2.5
- Old industries & waste burning emissions; cook stoves
- Aviation/shipping
- there are existing national and regional inventories – how comparability on global scale can be increased ?
- NMVOC speciation
- NH3 - agriculture
- High spatial and temporal resolution (diurnal cycle for NOx) – vertical distribution
- Co-emissions are important / basis for mitigation options/ info needed on sectoral basis
- Avoid CO2-eq inventories

<u>Break-out group 3b</u>

Species	Climate impacts	Air quality, health and other benefits	Feasibility on current guidelines	Level of source characterization	Local measurement availability (ambient)
BC	G+, R++	R+, N+	G-, R0, N0	N--	N--
OC	G+, R++	R++, N++	G-, R--, N--	N-	N--
SO2	G++, R++	R++, N++	G+, R+, N+	R+, N+	R+, N+
NOx	G++, R++	R++, N++	G+, R+, N+	R+, N+	R+, N+
CO	G+, R+	R+, N+	G+, R+, N+	R0, N0	R+, N+
NH3	G0, R0	R+, N+	G+, R+, N+	R--, N--	R-, N-
PM2.5		R++, N++	G+, R+, N+	R-, N-	R0, N0
VOCs	G0, R0	R+, N+	G0, R0, N0	R--, N--	R-, N-

G=Global; R=Regional; N=National.
++ means High impact; +=significant impact; 0=variable ; - equal moderate uncertainty; and -- equals high uncertainty.
Feasibility of developing emission inventories using available guidance.
Level of source characterization: relates to source emissions.
Local measurement availability refers to measurements that are available today.
Climate impacts quantified in terms of radiative forcing.

Species	Existing methodologies for greenhouse gases (IPCC+EMEP)	Additional info on new methodology	Primary sources are on the inventories	Level of confidence on Emission Factors
BC	YES-	Needs definition, measurement methods, missing sources	No	Very low
OC	No+	Needs definition, measurement methods, missing sources	No	Very low
SO2	YES		YES-	Medium-high
NOx	YES		YES	Medium-high
CO	YES	Missing sources	YES-	Medium
NH3	YES-		YES	Very low
PM2.5	YES	Missing sources	No+	Low
VOCs	YES	Missing sources	No+	Very Low

First column: **Yes** means IPCC guidelines with EMEP extensions are applicable. YES- for black carbon means that the inventory is based on available methodology for PM2.5. For OC, No+ means that there is no sistematic methodology available. OC data is included in the EMEP BC anexes.
Third column: It explicit if the specie is covered or not in current inventory methodologies.

Break-out group 3c

Theme 3: Suitability for IPCC to expand inventory methodology for SLCF

Key questions:

- Which species of SLCF (and which sources) should be prioritised in the future work for inventory methodologies? [Building on findings from themes 1 and 2, e.g. gaps identified]
- Is the IPCC the right organisation to fill gaps and consolidate the inventory guidelines?
- How will the methodologies on SLCF relate to the existing inventory methodologies on GHG (e.g. good practice)?

Q1. Which species of SLCF (and which sources) should be prioritised in the future work for inventory methodologies? [Building on findings from themes 1 and 2, e.g. gaps identified]

- **All SLCFs are important for estimating impact on climate change (see Table 1)**
- **Existing guidance (EMEP/EEA and US EPA) cover most SLCFs, but not OC**
- **Existing guidance (EMEP/EEA and US EPA) cover most sources, but there are gaps (see Table 2)**
  - **Especially for EFs for technologies in developing countries**
  - **List of gaps is not complete**
  - **PM2.5 is included in the table, because BC and OC estimates depends on it**
- **Potential work for IPCC should prioritize the gaps, but not duplicate existing guidance**

Emitted species	Impact on climate	Required besides emitted mass
SOx	**High** Enhance scattering via sulfate aerosol Cloud effects Indirectly via chemistry (e.g. nitrate formation)	
BC	**Moderate to high** Enhance absorption Cloud effects Snow, albedo	Size of sub-micron particles, radiative properties, particle density, state of mixing
OC	**Moderate to high** OA predominantly scattering Cloud effects ecosystems	Size of sub-micron particles, radiative properties, particle density, AO/OC ratios
NOx / CO / NMVOC	**Moderate to high** Modify radiation via ozone & methane Indirectly via additional chemical effects Ecosystems NMVOCs produce secondary OA	Speciation of NMVOCs
NH3	**Small but growing** Enhance scattering via nitrate aerosol Cloud effects	

Q1. Which species of SLCF (and which sources) should be prioritised in the future work for inventory methodologies? [Building on findings from themes 1 and 2, e.g. gaps identified]

GAP SOURCES	CO	NOX	SO2	NMVOC	NH3	PM 2.5	BC	OC
IPCC/EMEP/EEA/US EPA								
Liquid biofuels for transportation								
Traditional coal-coke production (incl. charcoal)								
Biofuel cooking								
Biofuel heating								
Coal heating								
Open waste burning								
Brick kilns								
Kerosene lamps								
Flaring								
Agricultural waste burning on fields								
Copper smelters								
OTHERS (!) – TBD								

Q2. Is the IPCC the right organisation to fill gaps and consolidate the inventory guidelines?

IPCC has a mandate to convey scientific and technical understanding of the impact of all climate forcers on climate, and to assess mitigation options for these

IPCC role in filling the gaps in developing guidance for SLCFs should be important because IPCC is expereinced in developing globally applicable inventory guidance

Existing guidance developed by regional and national of other institutions (EMEP/EEA and US EPA) are developed for other purposes and will be relevant to consolidated global guidance

Q3. How will the methodologies on SLCF relate to the existing inventory methodologies on GHG (e.g. good practice)?

Same methods and *good practice* apply, but SLCFs methods have specific requirements, e.g. information on technologies and practices

***Key categories analysis* only at species level**

Break-out group 3d

BOG 3d

Chairs: Valerie Masson-Delmotte; Paulo Cornejo

Rapporteur: Bjørn H. Samset

1) Which species of SLCF should be prioritized?

- **We need them all...** (Sorry, no priorities.) Both warming and cooling. (But do we perhaps need to focus on species not presently included in IPCC guidelines. Aerosols in particular; OC + BC (PM2.5), SO2; but also O3 precursors; NH3-)
- Some species are of key importance today, other may be more relevant in the future. Hence we need them all, to cover trends and developments.
- Largest methodology gaps on OC
- Note: Our focus is on methodology gaps, not science gaps. Also, we have not considered human health. Hence, it is a partial view.
- Main challenge is to provide regionally differentiated applicable EFs, within consistent, well documented framework
- Verification with concentration measurements? Difficult, should be pursued, but this should not be a showstopper.
- Can we generalize EF? Need to focus on sectors that are missing from existing methodologies. Brick kilns, residensial biomass burning, OC. (See list from BOG2)
- Take advantage of work to harmonize categories between IPCC and EMEP (and other)
- We note that natural emission sources are also key for understainding the total climate impact of SLCFs. While not part of national inventories, better knowledge should be pursued. Wildfires represent one particular challenge. Where do we place emissions from managed ecosystems?

2) Is the IPCC the suitable organization?

- SLCFs are key in AR6 and climate change context; both to reduce uncertainty, and in importance for stabilizing climate change
- **If not the IPCC, who?** Other organizations may struggle to get funding, though the IPCC also has challenges here.
- To cover gaps, should align closely with relevant bodies such as
  - ICAO on aviation; IMO for shipping; WHO; FAO; CCAC; UNEP; IEA; LRTAP; regional EPAs; EMEP/EEA; GEIA; etc.
- Is being a «one stop shop» for emission information beyond the capabilities of the TFI? Building methodology and capability is massive undertaking. New sources, new tools, …
- New paradigm? Would build on existing methodology and experience, but methods need to be extended to new countries and sources.
- Is «approval» what is requested? Is it possible?
- Knowledge gaps on EF will need to be filled by someone else

3) How will methodologies on SLCF relate to existing GHG inventory methods?

- **Existing methodologies can be used as a first step.** Most activity data can be re-used, put data providers in contact. Key differences is the increased complexity of SLCF; requires broader set of EFs and special cases.
- A key challenge for developing countries is to collect activity data
- Tier 1 IPCC method represents a starting point where nothing country specific exists.
- First order of business is to get national totals, as is the current IPCC approach. Temporal and spatial variability is crucial information for scientific purposes, public health and public policy, but can be added later.
- We are discussing guidance for countries/sectors that are not presently making SLCF inventories. Hence they need to be directed towards non-experts, and be comprehensive and user friendly.
- The relationship between SLCF and existing methodologies is weakest in some cases where the IPCC approach is a mass balance; best where multiple species can be estimated using the same methodology. Note that Tier 1 methods count all carbon – including e.g. BC, CO – as CO_2. Risk of double counting.
- Uncertainty analysis is a key factor in emission estimation, but very challenging. IPCC guidance for uncertainty estimates for EF exists, but e.g. dealing with correlations is a particular obstacle for SLCFs. May not be able to submit uncertainty estimates for new sources.
- Reporting of SLCF inventories should be mass units, consistent with GHG and precursors. We observe that CO_2e is often calculated by countries, but metric choice is not part of IPCC guidelines. Choice of metric becomes more critical the shorter the lifetime, and hence more contentious.

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