Summary of Breakout 3a:
Atmospheric monitoring for quantifying GHG emissions

e.g. atmospheric retrievals of CO$_2$, CH$_4$, halocarbon, NO$_2$, CO, etc, and inverse modelling to derive sources and sinks (i.e. top-down)

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**XCO$_2$: Multi-sensor merged**

**XCO$_2$/OCO-2 & NO$_2$/S5P**

**XCH$_4$: Multi-sensor merged**

**XCH$_4$/S5P**
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Breakout 3a: Atmospheric monitoring for quantifying GHG emissions

Seed questions:

Q1: Identify case studies based on existing work that illustrate how EO can already support the Paris agreement.
   • What has been done already and what can we do already now?

Q2: Are there R&D case studies that may in the next 5-10 years lead to new types of actionable information supporting Paris Agreement goals?
   • What should we do in a follow-on programme?

Q3: How can the CCI community contribute to the first Global Stocktake in 2023? (i.e., ideas for projects in CCI+ Phase 2)
   • What should we do in Phase 2?
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**General recommendations for CCI+ Phase 2 and follow-on programmes:**

**Priority 1:** Fundament of CCI is R&D to develop and/or further improve satellite retrieval algorithms and to use them to generate highest-quality ECV data products as needed for the challenging climate applications. This is the basis for all higher level products / assessments and needs to be the focus of CCI+ Phase 2 and follow-on programmes. **User feedback: Make it better, reduce biases, increase the yield, ... !**

**Priority 2:** Use of the ECV data products (and other information + modelling etc.) for important climate-relevant applications (including Paris, ...)

**Priority 3+:** Other
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*How to contribute via atmospheric GHG observations?:*

**Abstract**

Under the Paris Agreement progress of emission reduction efforts is tracked on the basis of regular updates to national Greenhouse Gas (GHG) inventories, referred to as *bottom-up* estimates. However, only *top-down* atmospheric measurements can provide observation based evidence of emission trends. ...

**How to „Support Paris” via atmospheric observations?**

- **Atmospheric observations** (satellites & other; CO₂ & non-CO₂ GHGs)
- Meteorological information
- Inversion methods (e.g., forward/inverse models)
- A priori information
- GHG emissions and sinks, incl. trends etc.
- Comparisons with (national) inventories
- Providing complementary information (Mechanism?: Via Copernicus? Other?)
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How to contribute via atmospheric GHG observations?:

IPCC Guidelines:


Jansens-Maenhout et al., 2020:

“... The UNFCCC’s Subsidiary Body for Scientific and Technological Advice (UNFCCC-SBSTA, 2017, 2019) as well as the IPCC Task Force on the 2019 Refinement to the 2006 Guidelines (IPCC-TFI, 2019) acknowledged the complementary capability offered by GHGs monitoring through in-situ as well as satellite observations. ...”


• Via inventory verification
• Via providing complementary information
Identify case studies based on existing work that illustrate how EO can already support the Paris agreement.

- So far, for CO₂, most satellite top-down inversion studies focused on terrestrial carbon fluxes assuming that anthropogenic emissions are well known (e.g., Basu et al., 2013; Miller and Michalak, 2020)
- Although existing satellites have not been optimized to obtain information on anthropogenic CO₂ emissions there are first peer-reviewed publications addressing this important aspect. Examples:
  - CO₂ emissions / emission trends for large areas (e.g. Europe, East Asia, ...):
    - Schneising et al., ACP, 2013, using SCIAMACHY XCO₂
    - Reuter et al., Nature Geoscience, 2014, using SCIAMACHY XCO₂ and NO₂
  - CO₂ localized emission sources (power plants, cities, ...):
    - Reuter et al., ACP, 2019, using OCO-2/XCO₂ & S5P/NO₂
  - CO₂ emissions of China during COVID-19 pandemic via S5P/NO₂: Zheng et al., in review, 2020
- Methane: Several studies have been conducted using SCIAMACHY and GOSAT (see, for example, publication list on https://climate.esa.int/en/projects/ghgs/publications/)
  - Especially S5P (but also GHGSat) permits to obtain detailed information on localized CH₄ emission sources (e.g., oil and gas fields). Some initial publications (e.g., Zhang et al., 2020; Schneising et al., 2020) but far from fully exploited.
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Breakout 3a: Seed question 1:

Identify case studies based on existing work that illustrate how EO can already support the Paris agreement.

• The CCI community has facilitated the use of CCI data via the climate and inverse modelling communities (and subsequently impact upon the Paris Agreement) through a variety of mechanisms:
  • Making CCI data available in standard formats, e.g. OBS4MIP: Reuter et al., 2020 – “Ensemble-based satellite-derived carbon dioxide and methane column-averaged dry-air mole fraction data sets (2003–2018) for carbon and climate applications”
  • Building the data into widely used tools, e.g. ESMValTool: Lauer et al., 2017 – “Benchmarking CMIP5 models with a subset of ESA CCI Phase 2 data using the ESMValTool”
  • Using the CCI data to perform our own carbon and climate-relevant research:
    • Reuter et al., 2019 - Towards monitoring localized CO₂ emissions from space: co-located regional CO₂ and NO₂ enhancements observed by the OCO-2 and S5P satellites
    • Reuter et al., 2017 - How much CO₂ is taken up by the European terrestrial biosphere?
    • Gier et al., 2020 - Spatially resolved evaluation of Earth system models with satellite column averaged CO₂
    • Schneising et al., 2020 - Remote sensing of methane leakage from natural gas and petroleum systems revisited
    • Parker et al., 2018 - Evaluating year-to-year anomalies in tropical wetland methane emissions using satellite CH₄ observations
    • Ganesan et al., 2017 - Atmospheric observations show accurate reporting and little growth in India’s methane emissions
    • Gloor et al, 2018 - Tropical land carbon cycle responses to 2015/16 El Niño as recorded by atmospheric greenhouse gas data
    • etc. (see, e.g., https://climate.esa.int/en/projects/ghgs/publications/)
Identify case studies based on existing work that illustrate how EO can already support the Paris agreement.

- (Also) Important:
  - Developing countries
  - Covid-19 related assessments
  - Networks (such as TCCON etc.):
    - Sufficient funding needed
  - Is there a place where info is collected?
  - Publications list on GHG-CCI website: [https://climate.esa.int/en/projects/ghgs/publications/](https://climate.esa.int/en/projects/ghgs/publications/)
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Breakout 3a: Seed question 2:
Are there R&D case studies that may in the next 5-10 years lead to new types of actionable information supporting Paris Agreement goals?

• Derive CO₂ and CH₄ emission information & compare with inventories:
  • Exploitation of existing satellite missions (OCO-2/3, GOSAT-1/2, TanSat, S5P, GHGSat, ...)
    • To obtain Paris relevant emission information
    • To prepare for upcoming passive imaging NIR/SWIR missions (S5, CO2M, ...)
  • Exploitation of upcoming passive (MicroCarb, S5, CO2M, ...) and active (MERLIN) missions stand alone and in combination; possibly also in combination with TIR (IASI, ...)

• MircoCarb will be launched 2021 (TBC)
• S5-A will be launched 2021 (TBC)
  • CH₄ similar as S5P (likely even more data due to “Proxy XCH₄”); CO similar as S5P; covers also CO₂ absorption lines (but currently no XCO₂ product foreseen)
  • MERLIN will be launched 2024/25 (TBC):
    • Dusk/dawn orbit; stand alone and active/passive combination (e.g., MERLIN+IASI), ...; for bias correction of passive XCH₄, ...
  • Proposed TANGO mission (2024, TBC)
• CO2M satellites will be launched in 2026 (TBC):
  • The challenging applications requires R&D on all aspects (not only for CO₂ but also for CH₄, for NO₂ to get info on CO₂, ...)
Breakout 3a: Seed question 2:
Are there R&D case studies that may in the next 5-10 years lead to new types of actionable information supporting Paris Agreement goals?

- Merging different sensors to get consistent CDR:
  - How to do this optimally esp. in the future new high-res satellites (e.g., CO2M)?
  - Existing: GHG-CCI/C3S Level 2 EMMA and Level 3 Obs4MIPS products
  - Aerosol-CCI has developed an approach
  - Several other ongoing activities (eg in Italy)

- Timeliness of data / inventories for GST?
  - Data needed well before GST date(s)

- Observing systems for cities etc.:
  - Satellites + other obs, esp. ground based column networks
  - Needed for stand alone assessments (emissions), cal/val, comparisons concentrations and emissions, ...
Breakout 3a: Seed question 3:

How can the CCI community contribute to the first Global Stocktake in 2023? (i.e., ideas for projects in CCI+ Phase 2)

- Ongoing CCI+ Phase 1 ends in 2022; Phase 2: 2021/22 – 2024/5 (3 years)?
- First GST in 2023 will be based on year 2021 inventories
- Contributions via atmospheric observations:
  - Derive CO₂ and CH₄ emission information & compare with inventories
    - Exploitation of existing satellite missions (OCO-2/3, GOSAT-1/2, TanSat, S5P, GHGSat, MicroCarb, S5, …) to obtain Paris relevant emission information:
      - On CO₂ sources (and sinks) via XCO₂ (possibly also via NO₂, CO)
      - On CH₄ sources via XCH₄
  - Mechanism?: How to get EO data into GST?