GCOS Atmosphere Breakout: Summary

Breakout of Session 6: Evolving Requirements I - GCOS

Chair: Simon Pinnock (ESA); Rapporteur: Michael Buchwitz (Univ. Bremen, GHG)

ECV atmosphere projects (names of input providers): GHG (Michael Buchwitz), Ozone (Daan Hubert), Aerosols (Thomas Popp), Water vapour (Marc Schröder), Clouds (Martin Stengel), Precursors supporting aerosols and O3 ECVs (CO, HCHO, SO2, NO2) (Folkert Boersma, Michel Van Roozendael)

Seed questions:

1. What are the major challenges posed by the evolution in your respective domain in the GCOS updated implementation plan by comparison to 2016 in terms of

- Threshold, breakthrough and goal
- Uncertainty characterization
- Additional variables per ECV

2. How could you address these challenges in future projects and/or CLIMATE-SPACE?

3. How could you contribute to the six implementation themes (page 20-70)?

GCOS Atmosphere Breakout: Summary for Plenary

- Initial inputs collected before the splinter -> slides with detailed (but preliminary) answers to each seed question
- **Q1: Major challenges to meet new GCOS requirements:**
  - Depends on ECV
    - Several new products, several new requirements; can be very challenging and some cannot be met
    - E.g. GHG:
      - New products (XCO2, XCH4), new applications (Paris), new requirements (essentially for future missions such as CO2M);
        - new requirements cannot be met by existing sensors
        - for Phase 2 relevant requirements are those listed in the GHG-CCI URD (cited by GCOS 2022); key challenge remains the one on systematic errors (specified in out URD but not by GCOS (uncertainty)
    - E.g. Aerosols: Several new products, some are possible, others not
    - E.g. Clouds and WV: TBD if certain requirements (e.g., new water path requirements and vertical resolution) can be met
    - E.g. Precursors: Significant R&D needs identified
    - E.g. ozone: Even verification of compliance not possible for certain requirements (uncertainty, stability)
- **Q2: Inputs for CLIMATE-SPACE to address GCOS needs:**
  - Several items identified, e.g., R&D for new applications (Paris, …), new sensors, algo improvements, refining uncertainties (random, systematic, correlations), …
- **Q3: Contributions to 6 GCOS themes A-F & related actions:**
  - Initial list provided referring per ECV to listed GCOS IP actions

Themes and issues in the IP2022

A: ENSURING SUSTAINABILITY

- Ensure long-term support for in situ networks
- Address gaps is satellite observations likely to occur in near future – prepare follow-on plans

B: FILLING DATA GAPS

- Development of reference networks: in situ and satellite
- Implement GBON
- Global reporting of hydrological observations,
- Implement trace gas and aerosol, ocean biological, biogeochemical, CO_2 and N_2O observations
- Improve estimates of latent and sensible heat fluxes and wind

C: IMPROVING DATA QUALITY, AVAILABILITY AND UTILITY, INCLUDING REPROCESSING

- Develop standards and best practices
- Improvements to satellite and in situ products
- New and improved reanalysis products

D: MANAGING DATA

- Define governance and requirements of data centre
- Ensure in situ data centres exist for all ECV
- Improve discovery and access
- Data rescue

E: ENGAGING WITH COUNTRIES

- Improve regional and national engagement in GCOS
- Enhance support for national climate observations

F: OTHER EMERGING NEEDS

- Higher resolution real time data
- Improvements in urban, polar, coastal regions and EEZ
- Develop operational Global GHG Monitoring System

Source: Plenary presentation of Han Dolman

IP2022 Actions with relevance for monitoring missions

Theme A: Ensuring Sustainability

Action A2: Address gaps in satellite observations likely to occur in the near future

Action A3: Prepare follow-on plans for critical satellite missions

Action B1: Development of reference networks (in situ and satellite Fiducial Reference Measurement (FRM) programmes)

Action B3: New Earth observing satellite missions to fill gaps in the observing systems

Action B5: Implementing global hydrological networks

Action B6: Expand and build a fully integrated global ocean observing system

Action B7: Augmenting ship-based hydrography and fixed-point observations with biological and biogeochemical parameters

Action B9: Improve estimates of latent and sensible heat fluxes and wind stress

Action B10: Identify gaps in the climate observing system to monitor the global energy, water and carbon cycles

Theme B: Filling Data Gaps

Source: Plenary presentation of Han Dolman

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1. What are the major challenges posed by the evolution in your respective domain in the GCOS updated implementation plan by comparison to 2016 in terms of

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- **GHG: Feedback on new 2022 ECV products and requirements:**
  - **New ECV GHG products** = "Our" column-averaged products **XCO2 & XCH4**; note that all dedicated CO2 and CH4 sensors (GOSAT, OCO-2, S5P, CO2M, …) are optimized for XCO2 and/or XCH4
  - **New applications:** Past (2016) requirements were for the application "**regional sources & sinks**" but now (2022) this has been extended to address also **Paris**-related applications requiring higher spatial resolution etc. to resolve emission plumes; key document listed are EC docs for "fossil fuel CO2 emissions monitoring" (Blue & Red reports, …)
  - **New requirements:** Requirements are essentially **for future missions.** The T (= minimum) requirement for XCO2 is now essentially CO2M (launched 2026); the G (= maximum) requirement is 1 km / 1 hour (= constellation of geostationary imagers). Similar for XCH4: The T requirement for uncertainty (random error) is 10 ppb (1-sigma) referring to S5P although S5P uncertainty is around 15 ppb; G is 0.3 km / 1 hour (but few 10 m needed to pinpoint leaks in infrastructure etc.; therefore unclear why this is G meaning "better performance not needed"). A (or even "the") key requirement is missing: the one on systematic errors or biases.
  - **Phase 2 implications:** The 2022 requirements are essentially for future sensors and cannot be met for the GHG ECV products generated from existing sensors in Phase 2 (2022-2024). In Phase 2 we focus on meeting the **GHG CRG requirements (see GHG URD)**; in parallel, we plan to start working also with new high-res satellites (PRISMA, EnMAP, …) and we are working since years for future satellites (esp. **CO2M**) via other projects

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Seed question 1: … continued …

AEROSOL

- requirements for **resolution** (G, B, T) reflect the discussions well which we had in the community
- requirements for **uncertainties** (G, B, T) reflect the discussions well which we had in the community

- **remaining challenges** to meet high accuracy targets for AOD and in particular absorbing AOD / SSA (POLDER)

- additional variables:

    - **extinction profile in the troposphere**: can be retrieved from lidar, IASI (dust); not for total AOD from passive instruments
    - **size distribution**: can be inverted from polarimeters

    - **number cloud condensation nuclei**: not possible from satellite; proxys: FM-AOD or AOD*ANG
    - **chemical composition**: some interpretation of optical properties (combination of instruments or instruments with highest information content) can be used to infer aerosol types

GCOS Atmosphere Breakout: Summary

Seed question 1: … continued …

Water vapour:

- The **uncertainty requirements** are highly challenging. Additionally it will be hardly possible to validate the uncertainty estimates globally and at all levels with similar (high) confidence.
- For **stratospheric water vapour** it is highly challenging to provide a product with decent sampling as function of longitude and latitude due to the sampling nature of limb sounders.
- For the **UTLS** the requirement on vertical resolution can hardly be met.
- WV_cci covers the ECV
  - Integrated Water Vapour,
  - Water Vapour Mixing Ratio in the Upper Troposphere and Lower Stratosphere, and
  - Water Vapour Mixing Ratio in the Middle and Upper Stratosphere.
- Other ECVs around atmospheric water vapour are not addressed within WV_cci.

GCOS Atmosphere Breakout: Summary

Seed question 1: … continued …

Precursors ECV:

Major challenges for ECV Precursors to meaningfully address the GCOS 2022 requirements:

(a) Uncertainty should be distinguished in **random and systematic** component

(b) **Better a priori information** needed on surface reflectivity, a priori vertical distributions of trace gases, clouds, and aerosols to meet requirements

(c) Improve understanding of **geostationary** ECV Precursor retrieval needs and associated uncertainties

(d) Address **new challenges for stratospheric NO2 and SO2 requirements** from GCOS 2022 - additional instrumentation and dedicated retrieval algorithms.

(e) For **additional variables NH3 and glyoxal** (missing from GCOS-245 but listed in GCOS-244), new prototype requirements are being defined within the ECV Precursor project.

GCOS Atmosphere Breakout: Summary

Seed question 1: … continued …

Clouds

- Cloud variables:
  - The goal requirement for **temporal resolution** is now 1h. GCOS 2016 had 3h as target requirement.
  - **Cloud water path requirements** are now split into liquid water path and ice water path and expressed in absolute values instead of relative ones. It is still TBD if it is a challenge (or not) to meet the these new water path requirements
  - There are yet no requirements for ice particle effective radius. In addition, Cloud Droplet Number Concentration (CDNC), which is of crucial importance for many aerosol-cloud interaction studies, is still not listed as variable.
- Surface/Earth radiation budget:
  - The goal requirement for **temporal resolution** is now 1h. GCOS 2016 had 1month as target requirement.
  - B and T requirements for spatial resolution are now 10 and 50km. GCOS 2016 had 100km as target requirement, which is threshold now.
  - B and G requirements for uncertainty are now 0.5 and 0.2 Wm-2. GCOS 2016 had 1Wm-2 as target requirement, which is threshold now.

- Meeting the G and B **stability requirements** for all cloud and radiation variables remain to be a challenge.

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Seed question 1: … continued …

Ozone:

- Verifying the threshold requirement of 3%/decade **stability for the stratospheric profile** is realistic right now, but this will very likely be impossible once current limb sensors (e.g., Aura MLS) are decommissioned over the next three years.
- Verifying compliance with the threshold requirement on **uncertainty** (10%, 2σ) **and stability** (3%/decade) is not feasible for the **tropospheric and UT/LS O3 profile** variables, due to poorly characterised co-location mismatch uncertainties (different air parcels probed by satellite and reference data) and due to the quality/availability of reference data.
- **New variables** for O3 are the tropospheric & stratospheric column. These can be provided, however, **various definitions** of the tropospheric top level are in use and that GCOS does not specify one choice.
- GCOS sets requirements for horizontal resolution, but it remains **unclear whether products must be latitudinally and longitudinally resolved**. If so, there is a trade-off between either meeting the threshold requirement on horizontal resolution or on vertical resolution for profile variables.
- The threshold of 30 days for **timeliness is unrealistic** for research-grade Climate Data Records.

GCOS Atmosphere Breakout: Summary

2. How could you address these challenges in future projects and/or CLIMATE-SPACE?

- **GHG:**
  - Team members are involved in CO2M and related ongoing projects focusing on, for example, requirements analysis, performance assessments and retrieval algorithm development for operational data processing**; recommendation:** CLIMATE-SPACE should provide significant & continuous resources for **R&D to generate highest quality atmospheric CO2 and CH4 ECV products (implies iterative analysis/algo improvements/re-processing cycles)** as needed for the challenging "Paris applications" (to get reliable "hot spot" emissions but also regional-scale CO2 and CH4 fluxes)

- **WV:**
  - Assess uncertainties as function of dependent variables
  - Consider to use improved a-priori information

- **Precursors:**
  - Refining the breakdown of **uncertainties** (systematic, random, error correlation scales)
  - Including new sensors (**limb, geostationary**)
  - Including better a priori information in retrievals - **more and more dedicated R&D** is needed to make the step towards compliance with GCOS 2022 requirement.

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Seed question 2: … continued …

- **Aerosols:**
  - **Further R&D to improve current products**
    - AOD: reduce SLSTR bias + FM-AOD bias all DV instruments
    - Improve absorbing AOD / SSA (POLDER, 3MI)
    - Bring IASI / Dust AOD back into the project – dust change is major uncertainty in modelling
    - Bring stratospheric extinction record back into the project - significant contribution to aerosol forcing

  - **Respond to new variables**
    - **extinction profile in the troposphere**: improve IASI profiles for dust (MAPIR algorithm); exploit EarthCare
    - **size distribution**: invert with GRASP from POLDER, 3MI
    - **number cloud condensation nuclei**: demonstrate us as proxy: FM-AOD or AI=AOD*ANG
    - **chemical composition**: demonstrate interpretation of optical properties (combination of instruments or instruments with highest information content such as MISR or POLDER, EarthCare) to infer aerosol types

GCOS Atmosphere Breakout: Summary

Seed question 2: … continued …

Clouds

- Meeting a 1h **temporal resolution** G requirement is only feasible with GEO-ring data. This is possible with the current and future advanced GEO-imagers in space but would come at the cost of data record length as the advanced imagers (we need spectral information of at least SEVIRI for a decent set of cloud and radiation properties) as geo-ring are only available from 2018 onwards.

- To meet the **stability requirements** when using AVHRR data will likely require intercalibration of IR channels which does not exist yet.

GCOS Atmosphere Breakout: Summary

Seed question 2: … continued …

Ozone:

- Perform R&D to better quantify the uncertainties due to co-location mismatch in validation analyses. This will improve constraints on measurement uncertainty (& stability) and lead to a more robust user compliance analysis for tropospheric and UT/LS ozone.
- Perform R&D to identify for what products a harmonisation of the tropospheric column definition is technically feasible and, for the other products, develop tools / documentation so users can recompute the tropospheric column for their particular application based on existing data.
- Requirements at high risk of not being met in the coming years due to the expected loss of observing capabilities (Aura MLS, but also OSIRIS and ACE-FTS)
    - Threshold stability (3%/decade) of current vertically resolved ozone products can only be sustained and verified with at least three limb instruments in orbit.
    - Provision of adequate longitudinally-resolved profile products is only possible with densely sampling sensors in orbit. Once Aura MLS is decommissioned, our ability to maintain the quality and coverage of the lat-lon-resolved profile products will be strongly reduced.
- In order to (sustain our ability to) meet GCOS requirements for ECV products, the needs of CLIMATE-SPACE should be considered more prominently in ESA's programme for new EO missions, and CLIMATE-SPACE scientists should be invited to Mission Advisory Groups
    - We highly recommend launching a limb-emission sensor in the IR or MW domain (e.g., EE11 CAIRT) that combines dense sampling capability (horizontal, day/night) with the ability to retrieve multiple trace gases. An IR or MW limb sensor will reduce the risk of systematic uncertainties in common with current and planned UV-Vis limb-scattering sensors (e.g., ALTIUS, OMPS-LP).
    - Furthermore, if limb-viewing sensors are flown in (loose) formation with nadir-viewing ozone sensors the resolution of tropospheric ozone products can be maintained/improved and their uncertainty reduced.

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3. How could you contribute to the six implementation themes (page 20-70)?

- **GHG:**
  - Several, in particular: **B3** (new EO; here: carbon related), B4 (surface/in-situ (GHG related)), **B10** (gaps carbon cycle), **C2** (improved processing), **F5** (operational GHG monitoring system – **needs R&D**; note: GHG-CCI team members involved in CO2M (requirements, algorithms, …) etc.)

- **AEROSOL** – details to be worked out / choice from above (see Q1)
  - MAIN:
    - **C2**. General improvements to satellite data processing methods
  - Contribute to:
    - **C4**: New and improved reanalysis products
  - Further:
    - **B10**. Identify gaps in the climate observing system to monitor the global energy, water and carbon cycles
    - **C1**. Develop monitoring standards, guidance and best practices for each ECV
    - **D3**. Improving discovery and access to data and metadata in Global Data Centres

GCOS Atmosphere Breakout: Summary

Seed question 3: … continued …

WV:

- Promote need for **limb sounding mission**
- Continue working on **uncertainty** estimation
- Provide **higher resolution products**
- Focus on **polar regions**

Precursors:

- Extending surface reference measurements for ECV Precursors via various initiatives (action **B1**)
- Usage of existing programs (IAGOS) helps address the need for a global aircraft climatology of atmospheric composition vertical profiles (action **B4**).
- Testing uncertainty assessment, QA and validation of ancillary data (profiles, reflectivity, …).
- Aspiring consistent retrieval approaches for NO2, glyoxal, HCHO, and SO2.

Clouds:

- Improve uncertainty quantification of satellite retrievals. (Action **C2**)
- Improve satellite observations of Atmospheric ECVs at the very highest latitudes (Action **F2**)
- Identify gaps in the climate observing system to monitor the global energy, water and carbon cycles (Action **B10**)

GCOS Atmosphere Breakout: Summary

Seed question 3: … continued …

Ozone:

A2. Address gaps in satellite observations likely to occur in the near future
Project scientists can contribute to establishing the need for new limb-sounding missions capable of measuring several ECV species in the Upper Troposphere/Lower Stratosphere (UTLS) and stratosphere, during day and night. We can help define mission requirements that ensure GCOS requirements on ECV products.
B1. Development of reference networks (in situ and satellite Fiducial Reference Measurement (FRM) programs)
Identify requirements for the ozone FRM programs (e.g., spatial sampling, temporal sampling, accuracy) for proper ECV product quality assessment.
B3: New Earth observing satellite missions to fill gaps in the observing systems
Identify requirements on new satellite missions in order to preserve continuity of current O3 ECV products and to ensure their data quality.
C1. Develop monitoring standards, guidance and best practices for each ECV
C2. General improvements to satellite data processing methods
Improve uncertainty quantification of satellite measurements and their validation. Reprocess full satellite data records after improvements to calibration and retrieval algorithms. Provide gridded ECV products. Ensure harmonisation and quality of ancillary data used to generate satellite products.
C4. New and improved reanalysis products
Inform reanalysis centres of the release of new/updated ECV products and their uncertainty characterisation.
F4. Improve climate monitoring in urban areas
Develop tropospheric ozone column products that resolve (almost) the urban scale (few kms). The limb observing system faces degraded sampling capability in the coming years, which will limit our ability to resolve the urban scale. Additional limb sensors are therefore a prerequisite to develop such urban-scale tropospheric ozone products.