GHG Roadmap Status Update

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The CEOS Architecture for Monitoring Atmospheric CO_2 and CH_4 Concentrations

The CEOS Atmospheric Composition Virtual Constellation (AC-VC) white paper defines a global architecture for monitoring atmospheric CO_2 and CH_4 concentrations from instruments on space-based platforms

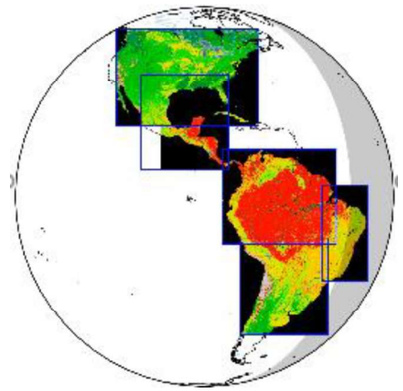
- 166-page document, 88 authors from 47 organizations
- Executive Summary (2 pages)
- Body of report (75 pages)
- Technical Appendices (42 pages)

http://ceos.org/document_management/Virtual_Constellations/ACC/Documents/CEOS_AC-VC_GHG_White_Paper_Publication_Draft2_20181111.pdf

A Candidate Operational CO_2/CH_4 Constellation Architecture

The coverage, resolution, and repeat frequency requirements could be achieved with a constellation that incorporates:

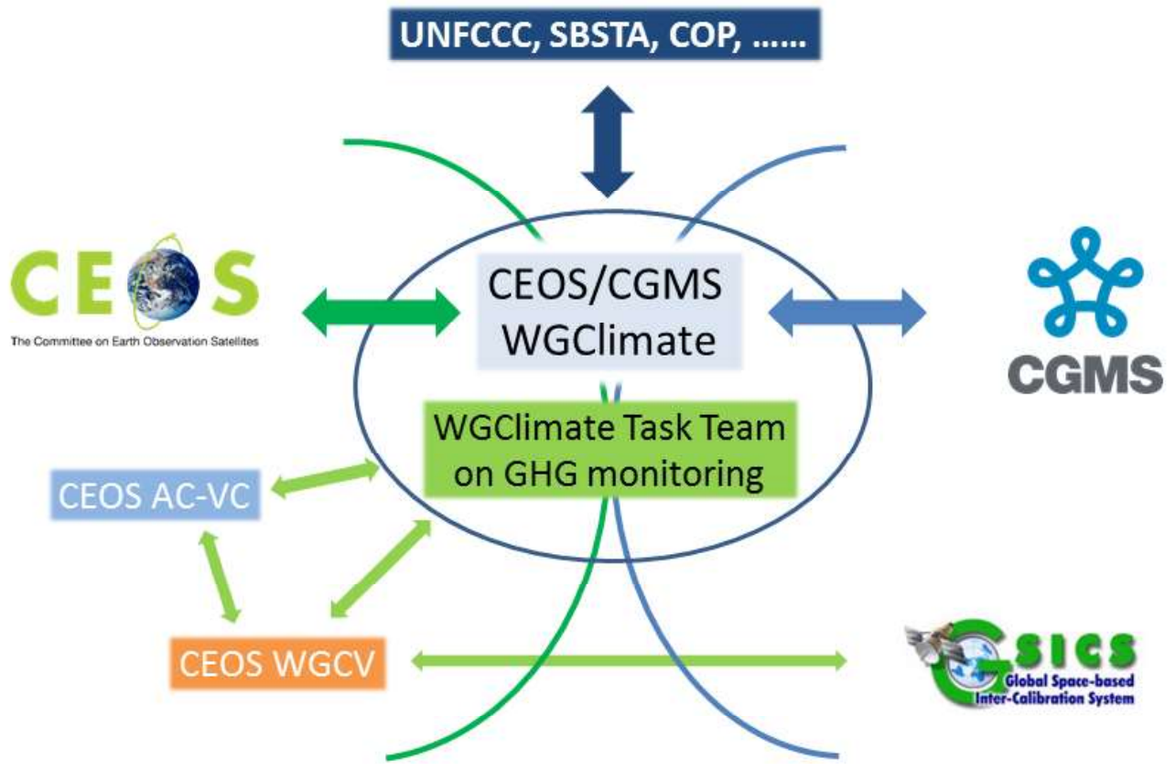
- A constellation of 3 (or more) satellites in LEO with
  - Broad (> 250 km) swaths with a footprint size < 4 km^2
  - Single sounding random error < 0.5 ppm
  - Vanishing small regional scale bias (< 0.1 ppm)
  - Ancillary sensors to identify plumes (CO, satellites NO_2)
- A constellation with 3 (or more) GEO satellites
  - Stationed over Europe/Africa, Americas, and East Asia
  - Diurnally varying processes (e.g. rush hours, photosynthetic uptake)
- Possible augmentations include:
  - Active (lidar) satellites in LEO for night-time/polar night coverage
  - Satellites in HEO for improved high latitude coverage and repeat frequency



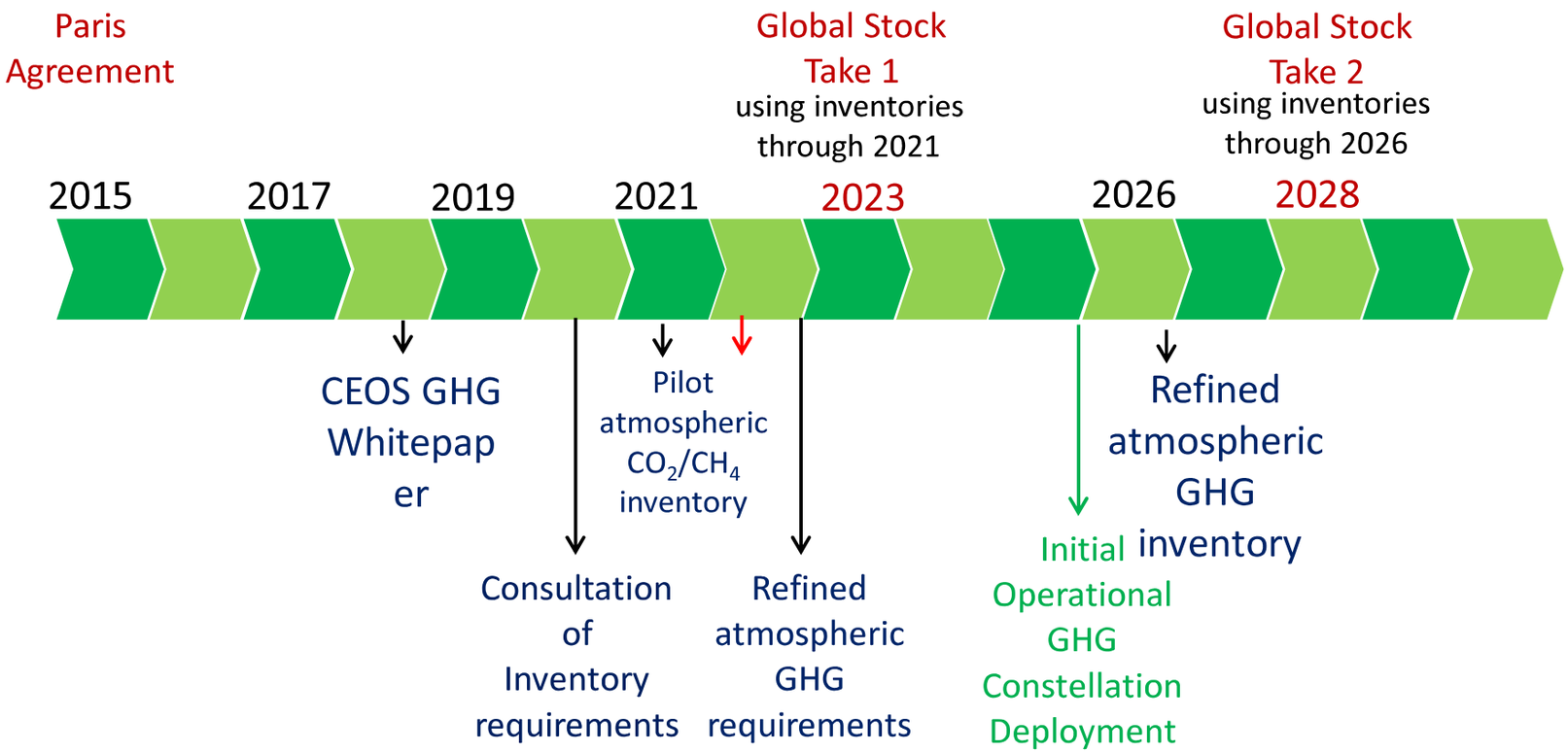
The Greenhouse Gas Roadmap Objectives

- GHG Roadmap Objectives:
  - A prototype end-to-end system that yields estimates of CO_2 and CH_4 fluxes supporting the first global stocktake; and
  - An Initial Operational System for producing future atmospheric CO_2 and CH_4 flux products for use in future Global Stocktakes.
- The roadmap document has established a more rigorous approach to the terminology:
  - *"Pilot phase providing access to targeted products from individual CEOS and CGMS Agency programs to establish appropriate relationships with stakeholders and users (e.g. National Inventory Agencies) to enhance to uptake of Earth Observation based datasets informing the national reporting needs"*.
- The delivery of each system version is accompanied by a requirements refinement process leading to the additional objective:
  - Establishing the end-to-end requirements for a system that delivers atmospheric CO_2 and CH_4 flux products for use in stocktakes (with requirements apportioned to each system version).

Key Players in the GHG Roadmap/Project Plan



GHG Roadmap Timeline



GHG Roadmap Table of Contents

Primary Roles

- **WGClimate GHG Task Team**
  - Create and maintain a roadmap to implement actions proposed in the AC-VC white paper
  - Establish primary user interface to Users (Inventory and Policy) and ensure feedback on prototype products
  - Provide a system engineering overview and track requirements, capabilities, and deliverables
  - Identify additional resource needs and relevant CEOS Agencies to dedicate appropriate resources
- **WGCV ACSG**
  - Identify best practices for prelaunch calibration of CO_2 and CH_4 concentration sensors and facilitate the exchange and harmonization of approaches and reference standards
  - Identify best practices for on-orbit calibration of GHG sensors and disseminate standards including solar, lunar, and surface vicarious validation sites
- **AC-VC GHG Team**
  - Coordinate ongoing agency activities to implement a prototype atmospheric GHG inventory system that incorporates products from a virtual constellation of sensors by 2021
  - Coordinate efforts to trade studies on constellation architecture
  - Coordinate development of a more complete atmospheric GHG inventory for the 2028 Stocktake

Status GHG Task Team Activities

- Mature GHG Roadmap and Project Plan developed specifying deliverables, responsible organizations, schedules and resources
- Establishing interfaces with National Inventory community
  - Worked with the Copernicus H2020 VERIFY Project to organize an atmospheric inventory workshop @ Global Emissions IniAtive (GEIA)
- Establishing interfaces with stakeholders (UNFCCC/SBSTA & GCOS)
  - Support UNFCCC/SBSTA & GCOS at COP-25 & Earth Information Day
- Workshop on synergies and opportunities between GHG and AFOLU Earth Observation communities working in support of UNFCCC

- Engaged Atmospheric GHG Community
  - Presented Roadmap to AC-VC, Jun 2019; workshop @ AGU Dec. 2019
- Progress in Atmospheric Inventory Development
  - ESA/CCI, Copernicus CAMS, OCO-2, NASA CMS and others
- Progress in identification of GHG validation capabilities

Resources Needed from CEOS/CGMS

Three broad categories of resources are envisaged and requested for consideration by Agencies:

1. **Human resources** from CEOS and CGMS members and external experts supported through Agency programmes & grants
   (~ 16 PM/yr)
2. **Support for travel and hosting of workshops** and networking with
   - National inventory community
   - Atmospheric GHG measurement and modelling communities
   - Stakeholders (GCOS, UNFCCC/SBSTA)
3. [On longer-term] Through internal funding mechanisms **support research, development and infrastructure** for priorities identified by GHG Task Team and Roadmap Implementation (*annual updates will be provided to Agencies*)

GHG Roadmap Status and Next Steps

- The Roadmap is a living document, we have a version available for consultation, and will continue to revise/refine it as we start to address the work required (see Annex C)
- We will continue efforts to:
  - establish links to national inventory community to refine needs for atmospheric inventories
  - Enhance links with critical interfaces at GCOS, IPCC and IG3IS following WMO reorganization
  - Foster integration of CGMS Working Groups
  - Prepare for endorsement of the GHG Roadmap/Project Plan at 2020 Plenary

GHG-AFOLU Workshop

- Workshop on synergies and opportunities between GHG and AFOLU Earth Observation communities working in support of UNFCCC
  - [Planned] July 9-10th Varese-Italy together with H2020 CHE-VERIFY General Assembly
  - Start dialogue between the different Earth Observation communities addressing the needs of UNFCCC.
  - In particular, atmospheric GHG monitoring and those addressing aspects of the AFOLU sector (e.g. REDD+).
  - Co-organised, based on an identified gap, both at the European level through discussions in Copernicus as well as at the international level CEOS
- The workshop plans to address:
  - both the "soft" coordination and stakeholder engagement aspects of the interface with the Convention, the UNFCCC Secretariat and,
  - Parties (including through their inventory agencies/compilers) but also more technical aspects of reporting, outputs datasets, formats, avoiding "double-accounting" and the longer-term ambition of using diverse earth observation datasets in the modelling and data integration systems being developed.
- Now postponed till ~2021, but plan to hold teleconferences with main coordination mechanisms and stakeholders in meantime i.e. CEOS/CGMS, GFOI, GEO, UNFCCC Sec, GCOS, GOFC-GOLD etc.

AC-VC Support for the GHG Task Team

David Crisp
(NASA Jet Propulsion Laboratory, California Institute of Technology)

CEOS AC-VC

May 7, 2020

AC-VC Contributions to the WGClimate GHG Task Team

- Work with stakeholders (i.e. UNFCCC, IPCC, GCOS) and users (national inventory community) to define the requirements for space-based atmospheric CO_2 and CH_4 inventories that are used as part of a GHG emission inventory system
- Coordinate CO_2 and CH_4 flux inversion efforts by CEOS agencies to implement a pilot atmospheric GHG inventory in time to support the 2023 Global Stocktake
- Work with WGCV ACSG and GSICS to define best practices and facilitate exchange and harmonization of approaches for instrument cross-calibration
- Coordinate Observation System Simulation experiments (OSSEs) among CEOS agencies to support trade studies on constellation architecture
- Coordinate discussions of auxiliary observations enhancing data quality (e.g., aerosol properties, NO_2 for plume detection)
- Work with WGClimate to identify gaps in space-based GHG sensors
- Refine requirements for space based CO_2 and CH_4 measurements to support a more complete atmospheric GHG inventory for the 2028 Global Stocktake

Interactions with Stakeholder and Science Communities

- **Supported COP-21 Earth Information Day with talks and posters**
  - *Space-based observation for supporting Nationally determined contributions (NDCs), national inventories and the global stocktake*
  - *A constellation architecture for space-based observations of greenhouse gases: measurement approaches, datasets, and models in support of the global stocktake*
  - *Space-based capabilities to deliver climate data records for essential climate variables*
  - *The carbon cycle and the climate: an evolving system?*

- **Hosted a WGClimate Task Team workshop in conjunction with the American Geophysical Union meeting in San Francisco, CA USA**
  - Described GHG Roadmap objectives, deliverables and schedule
  - Solicited inputs and contributions from members of the ground-based and space based measurement communities and the atmospheric GHG flux inversion modeling communities

Progress in Inventory Development

- AC-VC is coordinating agency activities to implement a prototype atmospheric GHG inventory to support the 2023 Global Stocktake
  - New CO_2 and CH_4 Data Sets
    - The OCO-2/ACOS team reprocessed the decade-long GOSAT TANSO-FTS XCO_2 record using the Version 9 ACOS/GOSAT algorithm https://disc.gsfc.nasa.gov/datasets?keywords=acos%20gosat&page=1
    - The OCO-2 team is using an updated retrieval algorithm (Version 10) to reprocess the entire 5.5 year XCO_2 data record with increased accuracy https://disc.gsfc.nasa.gov/datasets?keywords=oco-2%20b10&page=1
    - ESA Climate Change Initiative (CCI) has integrated SCIAMACHY, GOSAT and OCO-2 data to produce a harmonized 18-year-long atmospheric CO_2 and CH_4 climate data record (Reuter et al., AMT, 2020, http://cci.esa.int/ghg)
    - Beginning to integrate S5p TROPOMI CH_4, GOSAT-2 TANSO-FTS-2 CO_2, CH_4, and CO, and OCO-3 CO_2
  - New Flux Inversion Models
    - Copernicus Climate Monitoring System (CAMS) is using GOSAT and OCO-2 XCO_2 estimates and *in situ* data to create global CO_2 flux maps (Chevallier et al., ACP, 2019; https://atmosphere.copernicus.eu/new-high-quality-cams-maps-carbon-dioxide-surface-fluxes-obtained-satellite-observations)
    - OCO-2 Project is conducting a Flux Multi-Model Intercomparison Project (MMIP) to assess the relative roles of these factors on atmospheric flux uncertainties (Crowell et al. ACP, 2019; https://www.esrl.noaa.gov/gmd/ccgg/OCO2/)

GHG Plans for first Virtual AC-VC Annual Meeting

- When: 8 – 12 June, 1300-1500 UTC
- Registration: http://ceos.org/meetings/ac-vc-16-virtual/
- Topics: This year, because of the limited time (2 hours, total), the AC-VC GHG team will focus the discussion on two specific issues:
    1. AC-VC inputs to the CEOS WGClimate GHG Task Team Roadmap and Project Plan (and other efforts supporting the CEOS SIT Carbon and Biomass Initiative); and
    2. Joint efforts among AC-VC themes (GHG, AQ, Aerosols, Ozone) and other CEOS entities to track the impacts of the COVID-19 pandemic using space based measurements (addressing SIT focus on Analysis Ready Data (ARD) and Sustainable Development Goals (SDG))
- These topics will be covered on the first day of the meeting (8 June) to prepare for a broader, interdisciplinary discussion on the final day (12 June) that focuses Analysis Ready Datasets (ARD) for Air Quality (reactive gases, aerosols) and greenhouse gases to support a more rapid response to future high interest events (Australian fires, COVID-19 pandemic, etc.)

GHG Cal/Val roadmap and Case study toward Global Stocktake 2023 and 2028

Akihiko KUZE

(Earth Observation Research Center, Japan Aerospace Exploration Agency)

CEOS WGCV

May 7, 2020

GHG Roadmap
WGCV Action: Sens-3

Define best practices and facilitate exchange and harmonization of approaches for instrument cross-calibration in coordination with CEOS WGCV and GSICS - text from Rec#10: The strategy for cross-calibrating the GOSAT and OCO-2 instruments has employed common standards, including observations of the sun, Moon, and surface vicarious calibration sites, such as Railroad Valley, Nevada, U.S.A. Additional effort by WGCV and GSICS is needed to maintain and improve the quality of these standards to better address the calibration needs of space-based CO2 and CH4 sensors

(1) GOSAT, OCO-2 calibrations are documented and published

Cross-Calibration

Solar reflected light sensors, radiance spectra and column density intercomparison: F. Kataoka, et al., "The Cross-Calibration of Spectral Radiances and Cross-Validation of CO2 Estimates from GOSAT and OCO-2", MDPI Remote Sens., 9, 1158-1179 (2017).

Thermal infrared sensors: F. Kataoka, et al., "Calibration, Level 1 Processing, and Radiometric Validation for TANSO-FTS TIR on GOSAT," IEEE Trans. Geosci. Remote Sensing, 57., 3490-3500 (2019).

Vicarious Calibration

Method, Uncertainty level: A. Kuze et al., "Long term vicarious calibration of GOSAT sensors; techniques for error reduction and new estimates of degradation factors", Trans. Geosci. Remote Sensing, 52, 3991-4004 (2014).

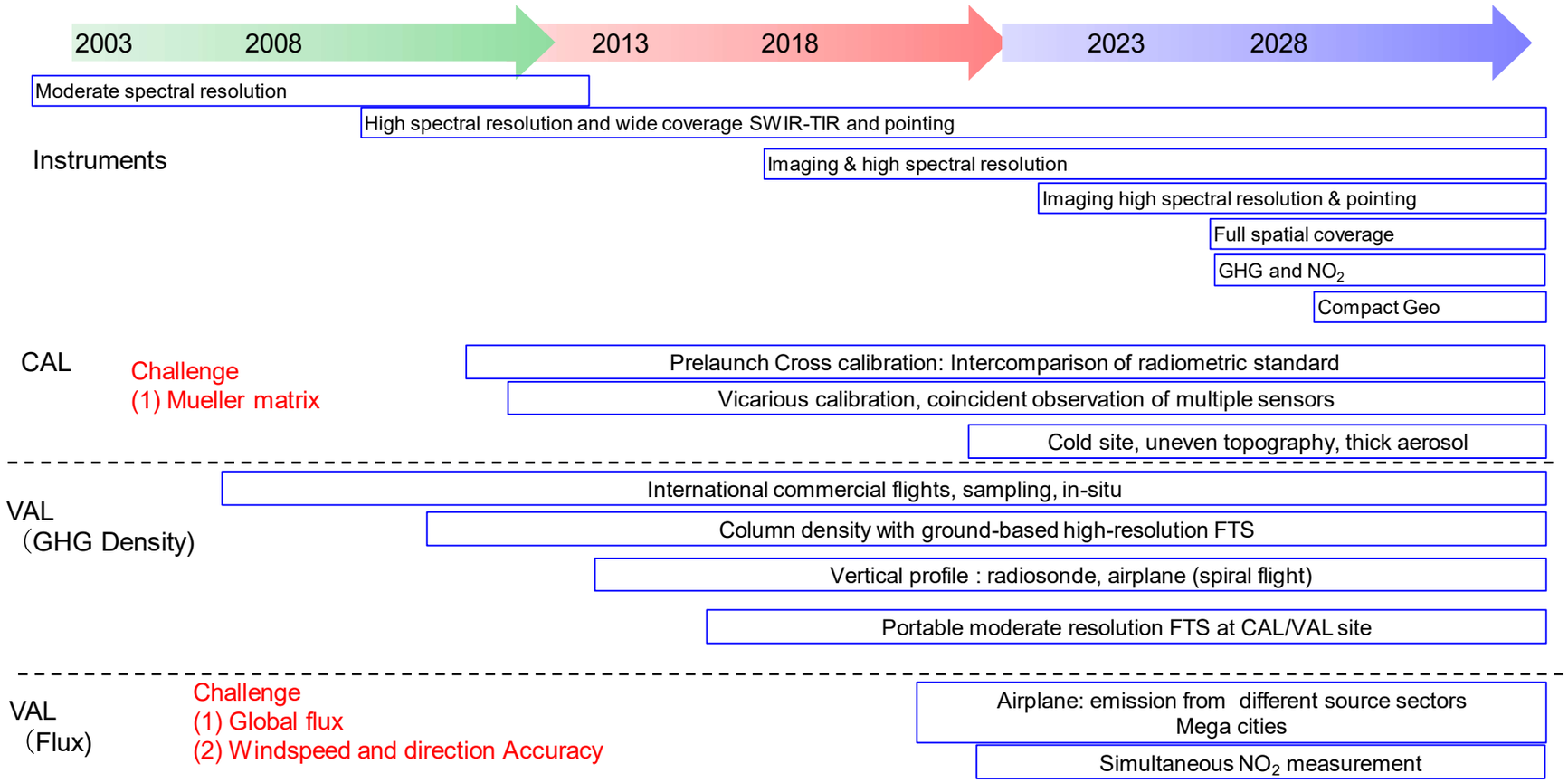
Uncertainty: Bruegge, et al., "Bi-Directional Reflectance Factor Determination of the Railroad Valley Playa". Remote Sens. 11, 2601, (2019)

(2) Intercomparison identified error souses caused by individual instrument and common database. (FTS, grating specific bias, Solar data)

(3) Consistent radiance spectra and retrieved density have demonstrated the effectiveness of GHG observation from space.

(4) Long term cross calibration can correct step change of bias caused by instrument anomaly in orbit.

GHG Cal/Val Roadmap (draft) toward global stocktake 2023 and 2028



Next step
What WGCV can do

- All the satellite data level 1 and Level 2 are free and open.
- However, calibration and validation dataset are not easy to access yet.
- <Already available>
  - Total Carbon Column Observing Network (TCCON)
  - Comprehensive Observation Network for Trace gases by AIrLiner (CONTRAIL)
- <Best practice from OCO-GOSAT collaboration>
  - Cross calibration: from prelaunch to 10-year on orbit
  - Vicarious calibration and validation at CEOS Railroad Valley and other sites
- <Dataset to be prepared by WGCV>
  - GHG vertical profile (Radiosonde, Airplane,) (partial column density improve global flux estimation)
  - Campaign dataset funded by space agencies (intense measurement, forward model validation)

Case study toward Global Stocktake 2023 and 2028 by GOSAT

1. GST 2023: global flux estimation using existing GHG satellites
2. GST 2028 goal: both global and local flux estimations using next generation satellites
3. Case study toward GST2023: local flux index from selected mega cities (5-6) of different region using existing GOSAT data

<Done> Sensitivity study

NIES NICAM XCO_2 simulation

The model can distinguish Emission (ODIAC)

(1) Vegetation (NIES VISIT)

<almost Done> Monthly average for GOSAT and GOSA-2 for selected target cities.

<To do> Information contents from GOSAT data

2 (center, upwind), 3 by 3 or 4 by4 points are enough?

<To do> Megacity Flux Index

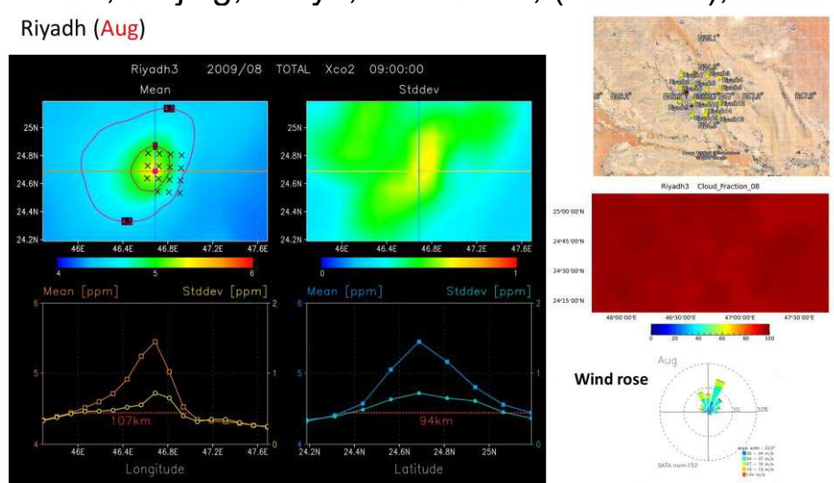
Simply Calculate

$\triangle XCO_2$ × Wind speed at airports such as Riyadh Airport

Select reference and enhanced from GOSAT target points within the local area

<To do > Modify sampling pattern

City-level flux index of Riyadh, New York or LA, Beijing, Tokyo, New Delhi, (Tentative),



Emission from Cities using 2016-2020 GOSAT data NICAM CO_2 model, GOSAT sampling pattern (4 by 4 points per orbit path) wind, clear sky ratio (Riyadh)

Activities status update of CEOS WGCV Atmospheric Composition Subgroup and the CGMS GSICS

and Towards an operational GHG monitoring system

B. Bojkov (WGCV/ACSG), R. Munro (CGMS/GSICS),

R. Lang (WGClimate GHG TT)

WGClimate 12

7 May 2020

Towards an operational GHG monitoring system (i)

- Status at WGClimate 10 Marrakech, Short-term:
  1. Address the WP action CV-18 with respect to CO2, CH4 (and CO, N2O) Level-2 products

  2. Identify the current shortcomings/gaps/sustainability in GHG Cal/Val, and formulate recommendations on the medium- to long-term way forward i.e. specific focus on GHG Fiducial Reference Measurement (FRM)

  3. Prepare a position/way forward paper to close the action CV-18 by mid-2020

Towards an operational GHG monitoring system (ii)

- Status at WGClimate 10 Marrakech, Medium to long term:
  4. Based on the expected outcome of the short-term, address a) improvements/gaps in the (inter-) calibration of sensors (in cooperation with GSICS), b) the level-2 validation infrastructures (GB algorithm inter-comparisons, and geographical/geophysical gaps for FRMs)

  5. Identify long-term validation needs (2025-on) and potential process study needs (e.g. aircraft campaigns to characterise sources, challenging geophysical conditions)

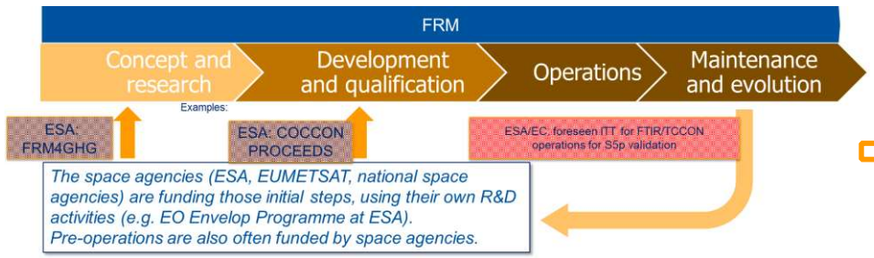
  6. Work towards an operational reporting on the quality of space-borne GHG measurements and the underlying Cal/Val infrastructure

Ground-based network / FRM capacity analysis for GHG Cal/Val

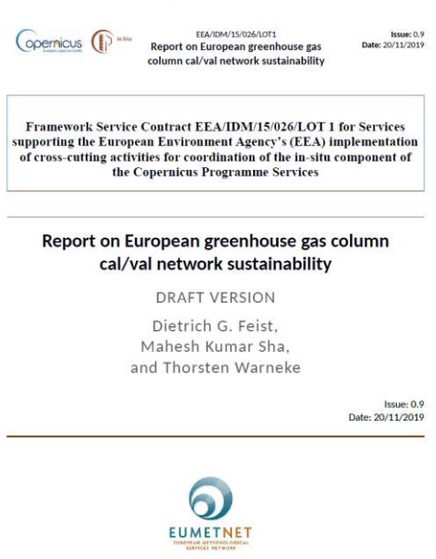
On Activity 2, 4b and 5:

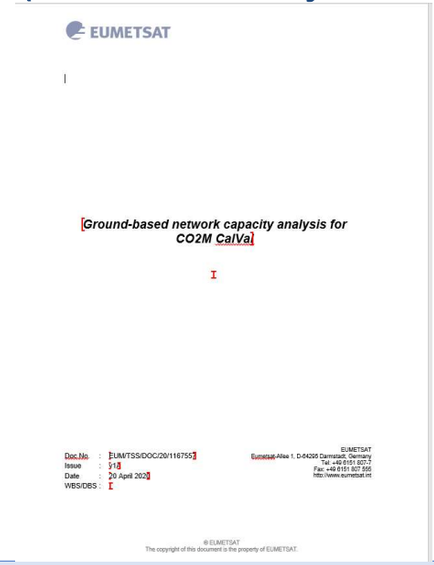
European coordination meeting on GHG FRMs took place in April 2019 at EUMETSAT, focussing on the current status and long-term sustainability of the European Monitoring and Verification Support (MVS) capacity, for identifying the current shortcomings/gaps/sustainability in GHG Cal/Val.

E.g. through a report on European greenhouse gas column Cal/Val network sustainability by EEA, and we are currently putting together a position paper, which is planned for summer (short term objective).



European coordination meeting on GHG FRMs at EUMETSAT April 2019

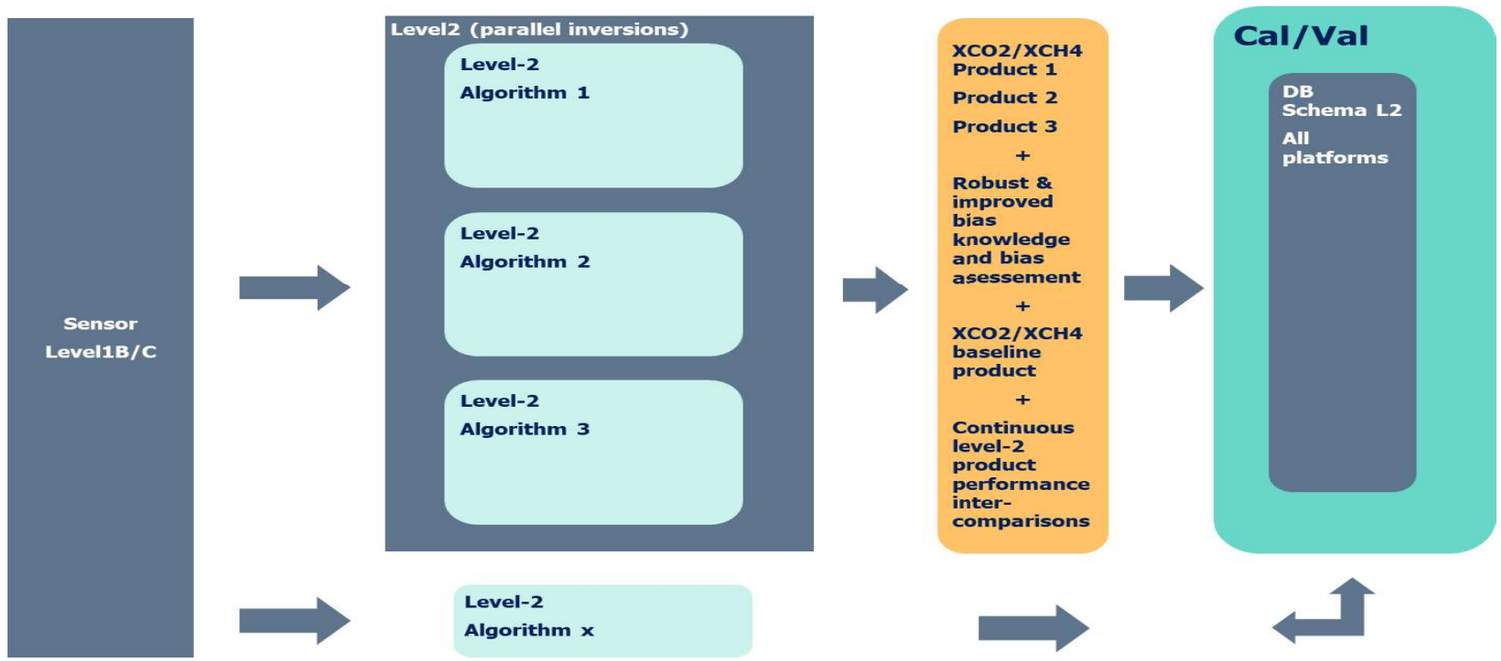




GHG level-2 validation infrastructures and inter-comparisons

On Activity 1, 3 and 6:

Progressing in proposing integrated operational systems and infra-structures for continuous and robust level-2 algorithm inter-comparisons and Cal/Val, in an operational context (and in the context of CO2M – the space component of the European MVS). Short-term objective is to report on initial system engineering results 2020/21 TBC).



NIR/SWIR sensor inter-calibration

On Activity 4a:

GSICS - UVNS spectrometer sub-group inter-calibration related activities, with an activity in the sub-group on S5p / GOSAT inter-calibration currently delayed (as the GSICS meeting was also impacted by Covid-19) and to be restarted again soon (medium term objective).

<u>Outlook for UVNS Spectrometer Sub-Group</u>

Addressing the following aspects for UV – SWIR spectrometers

- On-ground characterization (workshop planned for October 2020)
- Solar calibration
- Lunar calibration
- Inter-calibration
- Polarization
- Development of common methods for use of invariant targets & vicarious calibration sites with homogeneous surface over sufficiently large area.