Meeting Scope: In order to make informed comparisons between top-down estimates and use of those estimates for science and policy needs, we need a common framework for reporting estimates, their uncertainties (or covariances), and ancillary data indicating data sensitivity and potential biases (e.g. DOFS, surface attributes). An analog for this effort is the harmonization by the satellite community for reporting Level 2 composition products. We also need to review protocols for evaluating emissions with independent data sets (e.g. aircraft data, point release). Formal error attribution, their evaluation with independent data, and corresponding product definition, will provide increased transparency and trust in the use of these data by the science community and policy agencies. Concerns about how emissions are reported were raised during the CEOS ACVC meeting May 2022 with the outcome being a proposed workshop on characterizing and reporting emissions estimates which was subsequently held July 3rd at CNES HQ in Paris during the week of IWGGMS.

Our use cases for this workshop include 1) top-down inversions that might inform inventories from the regional to the global scale (e.g. the Global Stock-take) to 2) the facility scale such as being reported by high-resolution plume-mapping instruments.

Top Level Concerns / Recommendations

1) **Reporting top-down emissions and uncertainties from satellite data**: CO_2 and CH_4 fluxes and uncertainties are being reported at different spatio-temporal scales by different centers and science activities (e.g. European CAMS and World Emissions Project, USA GHG Center, Japanese NIES) and these are all different than that required, for example, by WMO for its needs. CEOS should enable collaboration between groups to harmonize how top-down estimates and their uncertainties are reported. Ideally algorithms / products (e.g. covariances, mapping matrices) are provided to intercompare results and project from one resolution to another.
2) **Transparency of New Space GHG measurements**: Intellectual property (IPR) concerns may limit the transparency of New Space GHG measurements (i.e. the traceability of reported concentrations and emissions to observed radiances). CEOS should support transparency of New Space measurements of GHG emissions, if they are to be used for science and policy. These efforts include (where possible given IPR concerns) generation of ATBD's from L1 (radiances) through L2 (concentrations) to L4 (emissions), documentation and evaluation of their VVUQ process for each product, documentation of their product definition, and evaluation of their data or science readiness levels (see Appendix). The documentation and provenance of similar New Space measurements can then be evaluated against the public missions. CEOS can utilize the joint ESA / NASA efforts to develop these evaluation requirements of New Space measurements (e.g. EDAP Earth Observation Mission Quality Assessment Framework)
3) **Use of Public and New Space GHG measurements for Science and Policy**: CEOS should continue to support efforts by IMEO (International Methane Emissions Observatory) to develop requirements for how Public and New Space GHG measurements are to be used for science and Policy.

4) **Contribution to Global Stock-take:** The data latency and coverage of satellite observations allows for yearly contribution of satellite based top-down emissions to support the Global Stock-take satellite data. These top-down results could be used to identify potential errors in bottom-up inventories.

Outline of Document:

1) Summary of Presentations
2) Emergent Themes, Concerns, and Recommendations
   a. Quantifying, evaluating, and reporting top-down CO_2 and CH_4 emissions and uncertainties
   b. Emissions from high resolution plume mapping instruments
   c. Products from reporting centers
3) Appendices
   a. Presentation Notes
   b. References
   c. NASA Data / validation readiness levels
   d. ESA Science Readiness Levels
   e. Cited figures from presentations

1.) Summary of Each Session

The agenda was organized into the following categories:

- Overview of error characterization
- Intercomparing estimates and source attribution
- Assessment of errors affecting emissions using high-resolution "plume mapping" measurements
- Current products from reporting centers (e.g. CAMS, WMO, GHG Center, IMEO)

Each session was followed by an extensive Q/A to identify emergent themes, issues, and recommendations. Concerns and recommendations were also generated during post-meeting discussions.

2.a Quantifying, evaluating, and reporting top-down CO_2 and CH_4 emissions and uncertainties

Background: Discussions on top-down inversions centered around wwo different approaches for arriving at an estimate and characterizing uertainty:
Empirical Approaches: These leverage multi-model comparisons and ensembles of individual models to holistically assess model errors (such as transport), smoothing errors (arising from prior uncertainties and data sensitivity), and data uncertainties (Figure 1).
Analytic Approaches: Currently applied primarily to methane emissions, analytic methods offer explicit calculation of posterior covariance. This results in robust smoothing error characterization through the quantification of an "averaging kernel" matrix, akin to satellite-

derived atmospheric composition products. This analytical approach can enhance source attribution and comparison reliability (Figures 2 and 3), as well as show where the inversion has information, but demands higher computational resources. This approach doesn't directly calculate transport model error but can incorporate this error via empirical evaluations. In the CEOS global stock-take contribution, empirical methods assessed CO_2 flux uncertainties (Byrne et al. 2023), while an analytic approach estimated methane emissions (Worden et al. 2022).

Challenges and Emerging Themes:

- **Underestimated Uncertainties:** CO_2 flux uncertainties could be underestimated by up to 50%, as indicated by aircraft data comparisons (Figure 4).
- **Representation Complexity:** Products' complexity in terms of large state vectors and covariances can challenge usability for both the scientific community and the public. Strong correlations between state vector elements and nuances in data quality assessment and sensitivity might lead to misleading conclusions (Figure 3)
- **Systematic Errors:** Systemic errors within data can yield spurious outcomes. For example a recent paper in PNAS, using TROPOMI data, claimed that temperature changes of a geologic feature resulted in increased methane (Frotzheim *et al*. 2021) whereas Barré et al. (2021) had already shown this was an albedo driven artefact, also later confirmed by Lorente *et al*. 2023.
- **Contribution to Global Stock-take:** The data latency and coverage of satellite observations allows for yearly contribution to the Global Stock-take using these data. Many countries do not have the capability to provide frequent emissions estimates (e.g. Brazil stopped reporting emissions in 2015) and satellites can fill this gap.

Recommendations:

- CO_2 and CH_4 estimates should aim to provide the products needed to quantify uncertainties and project from one space to another (e.g.5x4 degrees to 1x1 degrees) as many emissions are reported on different grid cells. For the analytic inversions demonstrated for CH_4 fluxes, this is accomplished by providing the priors, prior covariances, and posterior covariances which allows one to project between state vectors while quantifying uncertainty and information content (Worden et al. 2021; 2023).
- **Data Maturity:** Including a data maturity level and/or science readiness level (e.g., Appendix A.c as an example) helps demonstrate independent data-based uncertainty assessment and first-principles uncertainty calculations.
- **Inclusion of Inputs:** Products should provide the inputs (e.g. priors and prior covariances) used for generating CO_2 and/or CH_4 emission estimates.
- **Ancillary Information:** Products should provide ancillary information such as the information content (e.g., DOFS) and potential systematic errors/confounding factors at each reported grid cell to ensuring robustness of results.
- **Mapping Matrices and Covariances:** Including mapping matrices and covariances enhances intercomparison and interoperability of different reported products.

- **Transport and Chemistry Impact:** Ongoing assessments are necessary to understand the influence of model transport and chemistry on CH_4 and CO_2 flux estimates.
- **ATBDs:** Products generation and provenance should be transparent through provided Algorithm Theoretical Basis Documents (ATBDs).

2.b Emissions from high spatial resolution plume mapping instruments

Background: Emissions originating from plume mapping instruments offer an innovative approach to spatially resolve methane and carbon dioxide concentrations tied to specific sources like oil wells and landfills. By bolstering transparency, collaboration, validation, calibration, and data utilization, the potential of this technology can be fully harnessed for both scientific investigation and policy formulation. **Advantages of Plume Mapping Instruments:** Plume mapping instruments, in contrast to top-down methods using total column data, enable the identification of enhanced greenhouse gas concentrations linked to individual facilities through high-resolution measurements of atmospheric concentration at spatial scales of 10's of meters. Presently, these instruments can quantify the "large emitters", which make up approximately 5-10% of total methane emissions from fossil fuels and waste (Figure 5). Ongoing developments like Carbon Mapper and MethaneSat may enhance their capacity further. Notably, plume mapping offers direct validation potential through comparisons of estimated emissions with those from point release experiments.

Challenges: Primary uncertainties lie in knowledge of wind fields and surface albedo variations. Albedo variations can confound emissions quantification, particularly when they overlap with gas-enhanced regions. Consequently, a "human in the loop" approach, utilizing auxiliary data like visible imagery and wind direction, corroborates facility-related concentrations. An additional concern arises from intellectual property limitations, impeding transparency in emissions quantification by New Space entities. Finally, different approaches for quantifying emissions (e.g. Jacob *et al*. 2022) can yield different results that are outside estimated uncertainties (Figure 6).

Addressing Limitations:

- **Transparency Enhancement:** To bolster public trust in plume mapping data, especially from publicly funded missions, CEOS should enforce transparency in product reporting and provenance. Providing Algorithm Theoretical Basis Documents (ATBDs) from L1 to L4 and ensuring traceability back to L1 data will promote accountability, essential for data distributed by private "NewSpace" companies.

- **Collaborative Validation:** Continuous collaboration with Earthnet Data Assessment Pilot (EDAP) and International Methane Emissions Observatory (IMEO) is crucial in order to evaluate and update data evaluation and provenance.

- **Emissions Validation:** CEOS should evaluate its role in supporting validation experiments from, enhancing the credibility of plume mapping emissions estimates (See Figure 7 as example).

- **Calibration Sites:** CEOS' support in establishing and maintaining L1 radiance calibration sites, serving spectrometers like EMIT and other wide field spectrometers such as GOSAT, OCO 2/3, TROPOMI, and CO2M, will enhance the accuracy of emissions quantification.

- **Data Utilization:** Encouraging dual application of plume mapping data in the public space—scientific inquiry into the global methane budget and informed decision-making—will optimize its utility.

2.c Products from reporting centers

Background: Different centers and scientific groups are taking on the crucial task of quantifying CH_4 and CO_2 emissions using atmospheric data, across various spatio-temporal scales. These efforts are pivotal in supporting global initiatives like the Paris Agreement, the Global Methane Pledge, and carbon markets, while also aiding scientific research and remediation strategies. The July 3rd CEOS workshop on “reporting emissions and uncertainties based on satellite data”, convened representatives from several key centers, including the World Meteorological Organization (WMO), the International Methane Emissions Observatory (IMEO), the Copernicus Atmospheric Monitoring Service (CAMS, Figure 8), the USA Greenhouse Gas Center (Figure 9), the World Emission Project (Figure 10), and the GOSAT project. Among these, WMO and IMEO are stakeholders for CAMS, the USA Greenhouse Gas Center, and the World Emission Project, as outputs from these emerging centers offer support to their respective reporting initiatives.

Challenges and Concerns: A concern that immediately became apparent during the Q/A session was that the emissions reported by each center had different spatio-temporal gridding. This could challenge the use of these emissions for use by WMO which required reported products at a spatial resolution of 1 degree and a temporal resolution of 1 month, preferably with source identification.

Recommendations:

- Different groups and centers employing atmospheric composition data for flux estimation (referred to as top-down approaches) should provide the tools needed to intercompare products. For the analytic, top-down methane fluxes shown in the meeting, this was accomplished by providing the a priori and prior covariances and posterior covariances from the inversion as these are what is required to quantify uncertainty when projecting from one space to another.

- CEOS should facilitate coordination among the different groups and centers reporting top-down based emissions, supported by groups such as the Greenhouse Gas task team , EDAP, IMEO, and WMO, to establish latency and reporting standards that cater to both scientific and policy needs. This coordination should uphold the unique internal requirements of each center. To ensure data quality, CEOS should also encourage centers to share common ancillary information that bolsters the accuracy of reported emissions.
- Recognizing the diverse purposes of emission estimates (e.g. science, policy, carbon markets and remediation), centers are encouraged to provide multiple levels of reported emissions that support different end-users. This acknowledges that emission product definitions used for scientific inquiries might substantially differ from those catering to carbon markets or policy formulation. ATBD's should be generated for each product, describing how they can be traced back to the original set of atmospheric measurements and subsequent projection of these measurements to emissions at different scales.

3. Appendices

3.a Notes from presentations

1) Lars Peters / WMO: WMO intends to consolidate monthly CO_2 and CH_4 fluxes at 1 degree resolution from global partners for use by 1) parties to the Paris agreement, 2) regional agencies, 3) carbon markets, 4) science community, 5 IPCC. Uncertainties from flux ensemble suggested (pros / cons on this approach for uncertainty calculation from other presentations)
2) Wang / Maksyutov: Discussed regional estimates for methane for SE Asia. Uncertainties produced from flux ensembles
3) Maksyutov: Presented on Level 4 fluxes using GOSAT data: 1 degree resolution is relevant and in part driven by historical setups (TRANSCOM, CDIAC) but mapping to smaller countries is problematic. Bayesian approach to calculating uncertainties
4) Maasakkers: Presented on joint use of TROPOMI and GHGSAT to quantify large emitters (~10 tons / hour!). Spatial allocation errors in gridded prior inventories can bias inversion results. Tracking groups of point sources over time is essential to assess statistics and any remediation efforts or the opposite. Land imagers provide important context (i.e. wellhead location, potential biases from albedo variations) for emissions. Additional quality checks on TROPOMI emissions required.
5) McKeever: Presented on GHGSAT emissions validation and uncertainties. Controlled releases are an excellent tool to validate 1) detection limit, 2) quantification accuracy, 3) Full retrievals chain is included in this (any retrieval biases at the column level propagate through to the estimated source rate). Locally measured wind helps accuracy vs GEOS (we've seen this directly in aircraft data). However, there are limitations with these data including 1) difficulty to build up large sample size for satellite case, 2) Difficult to get full range of terrain classes seen in standard operations, 3) Detection limit is primarily applicable to the case where we have prior knowledge of emitter location, i.e. human quality check plus prior data influence actual detection limit. 4) Emitters with *a priori* unknown position are harder – higher limit in practice, hard to quantify

6) Engelen: CAMS reports monthly emissions for CO_2, CH_4, and N_2O using a combination ground and satellite data. ATBD equivalent documents are available on CAMS website. Gridded estimates for CO_2 are at ~2x4 degrees and for CH_4 at ~2x3 degrees and for each month. Unclear how uncertainties are generated. Information content (e.g. posterior covariance / Averaging kernel not calculated). See docs at: https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-global-greenhouse-gas-inversion?tab=overview

7) Chevallier: Gave presentation on overview of inversion problem and calculation of uncertainties. For CO_2 there is skepticism about posterior uncertainty calculation as prior uncertainties are not well understood. Averaging kernel matrix not usually calculated for CO_2 for either cost regions or lack of trust in posterior covariance.

8) Suto: Described lower tropospheric products for CH_4 and CO_2 that are based on combining near IR and Thermal wavelengths. Initial results show promise in quantifying CH_4 and CO_2 emissions as compared to inventories and super emitters.

9) Nesser: Demonstrated utility of Analytic inversion for characterizing information content of methane emissions. Calculation of posterior covariance and averaging kernel matrix critical for calculating emissions by sector, for sensitivity studies that do not require an additional inversion, and for information content analysis.

10) Worden: Analytic inversion and corresponding information content analysis using averaging kernel demonstrated where emissions have information and where they do not by directly comparing posterior emissions estimate by sector for methane to a gridded inventory that had accounted for choice of prior and spatial resolution (via the averaging kernel matrix). The Nesser and Worden studies demonstrate that quantifying posterior covariance is possible for methane and is demonstrably important for identifying where the emissions estimates have and do not have information. They also show how to directly compare satellite based emissions to other products using these error characterization products. Demonstrated that smoothing error (or null-space error) is likely the largest source of uncertainty for global top-down inversions using current observations.

11) Combley / Kavvada: Presented on the USA GHGCenter deliverables 1) Bottom-up CH_4 inventories for N. America, 2) Global natural fluxes for CO_2 and CH_4, and 3) Facility scale CO_2 and CH_4 emissions using high-resolution imaging spectrometers (e.g. EMIT)

12) Bowman: Presented on uncertainties of CO_2 fluxes based on OCO2/3. Current uncertainties calculated through model ensembles: While this approach implicitly accounts for model transport uncertainty (one of the largest sources of errors) it does not allow for error attribution or information content analysis to determine where top-down inversion has information

13) Gaubert / H. Worden: Discussed top-down inversion approach for CO using full-chemistry. Showed the importance of boundary conditions and chemistry on CO inversions. As CH_4 top-down inversions have similar chemistry/transport constraints it is likely that these same concerns affect CH_4 top down inversions.

14) Gouder: Presented on operational algorithm for upcoming TANGO missions which is intended to quantify emissions of CO_2, CH_4, and NO_2 at the facility scale.

15) Delavois: Presented on the ESA World emission project, a two year project to quantify CH_4 and CO_2 emissions from local to global using data from OCO2/3, GOSAT, and TROPOMI. Could be used as input to the WMO program

16) Liu: presented on using aircraft observations to evaluate posterior uncertainties for CO_2 flux calculations. Showed that CO_2 fluxes uncertainties are typically underestimated. Suggested underestimation in CO_2 flux errors using multi-model approach could be due to low diversity in transport models used in the different models.

17) Nelson: Showed comparison of CO_2 emissions from a set of powerplants using PRISMA (a high-resolution plume mapper) and OCO2/3 (high spectral resolution, lower spatial resolution). Demonstrated that it was challenging to reduce uncertainty of emissions to below 30% using either observational approach even with ~100 samples

18) Randles: Presented on the UNEP/Global Methane Hub which is intended to provide, open, reliable, and actionable information to those that can reduce methane emissions. Discussed five working groups that formed from IMEO meeting (e.g. observability, use-cases, data integration, cal/val/testing, and IMEO roadmap)

3.b References:

Byrne, B., Baker, D. F., Basu, S., Bertolacci, M., Bowman, K. W., Carroll, D., Chatterjee, A., Chevallier, F., Ciais, P., Cressie, N., Crisp, D., Crowell, S., Deng, F., Deng, Z., Deutscher, N. M., Dubey, M. K., Feng, S., García, O. E., Griffith, D. W. T., Herkommer, B., Hu, L., Jacobson, A. R., Janardanan, R., Jeong, S., Johnson, M. S., Jones, D. B. A., Kivi, R., Liu, J., Liu, Z., Maksyutov, S., Miller, J. B., Miller, S. M., Morino, I., Notholt, J., Oda, T., O'Dell, C. W., Oh, Y.-S., Ohyama, H., Patra, P. K., Peiro, H., Petri, C., Philip, S., Pollard, D. F., Poulter, B., Remaud, M., Schuh, A., Sha, M. K., Shiomi, K., Strong, K., Sweeney, C., Té, Y., Tian, H., Velazco, V. A., Vrekoussis, M., Warneke, T., Worden, J. R., Wunch, D., Yao, Y., Yun, J., Zammit-Mangion, A., and Zeng, N.: National CO2 budgets (2015–2020) inferred from atmospheric CO2 observations in support of the global stocktake, Earth Syst Sci Data, 15, 963–1004, https://doi.org/10.5194/essd-15-963-2023, 2023.

Froitzheim, N., Majka, J., and Zastrozhnov, D.: Methane release from carbonate rock formations in the Siberian permafrost area during and after the 2020 heat wave, Proc. Natl. Acad. Sci., 118, e2107632118, https://doi.org/10.1073/pnas.2107632118, 2021.

Jacob, D. J., Varon, D. J., Cusworth, D. H., Dennison, P. E., Frankenberg, C., Gautam, R., Guanter, L., Kelley, J., McKeever, J., Ott, L. E., Poulter, B., Qu, Z., Thorpe, A. K., Worden, J. R., and Duren, R. M.: Quantifying methane emissions from the global scale down to point sources using satellite observations of atmospheric methane, Atmos Chem Phys, 22, 9617–9646, https://doi.org/10.5194/acp-22-9617-2022, 2022.

Lorente, A., Borsdorff, T., Martinez-Velarte, M. C., and Landgraf, J.: Accounting for surface reflectance spectral features in TROPOMI methane retrievals, Atmos. Meas. Tech., 16, 1597–1608, https://doi.org/10.5194/amt-16-1597-2023, 2023.

Worden, J. R., Pandey, S., Zhang, Y., Cusworth, D. H., Qu, Z., Bloom, A. A., Ma, S., Maasakkers, J. D., Byrne, B., Duren, R., Crisp, D., Gordon, D., and Jacob, D. J.: Verifying Methane Inventories and Trends With Atmospheric Methane Data, AGU Adv., 4, https://doi.org/10.1029/2023av000871, 2023.

3.c NASA Data Maturity Levels

See web page at : https://science.nasa.gov/earth-science/earth-science-data/data-maturity-levels

Description

Beta

Products intended to enable users to gain familiarity with the parameters and the data formats.

Provisional

Product was defined to facilitate data exploration and process studies that do not require rigorous validation. These data are partially validated and improvements are continuing; quality may not be optimal since validation and quality assurance are ongoing.

Validated

Products are high quality data that have been fully validated and quality checked, and that are deemed suitable for systematic studies such as climate change, as well as for shorter term, process studies. These are publication quality data with well-defined uncertainties, but they are also subject to continuing validation, quality assurance, and further improvements in subsequent versions. Users are expected to be familiar with quality summaries of all data before publication of results; when in doubt, contact the appropriate instrument team.

- **Stage 1 Validation:** Product accuracy is estimated using a small number of independent measurements obtained from selected locations and time periods and ground-truth/field program efforts.
- **Stage 2 Validation:** Product accuracy is estimated over a significant set of locations and time periods by comparison with reference in situ or other suitable reference data. Spatial and temporal consistency of the product and with similar products has been evaluated over globally representative locations and time periods. Results are published in the peer-reviewed literature.
- **Stage 3 Validation:** Product accuracy has been assessed. Uncertainties in the product and its associated structure are well quantified from comparison with reference in situ or other suitable reference data. Uncertainties are characterized in a statistically robust way over multiple locations and time periods representing global conditions. Spatial and temporal consistency of the product and with similar products has been evaluated over globally representative locations and periods. Results are published in the peer-reviewed literature.
- **Stage 4 Validation:** Validation results for stage 3 are systematically updated when new product versions are released and as the time-series expands.

3.d ESA Science Readiness Levels

Another approach for evaluating data sets is through the Science Readiness Levels. These are taken from the European Space Agencies document: https://eopro.esa.int/wp-content/uploads/2020/05/Science_Readiness_Levels-SRL_Handbook_v1.1_issued_external.pdf

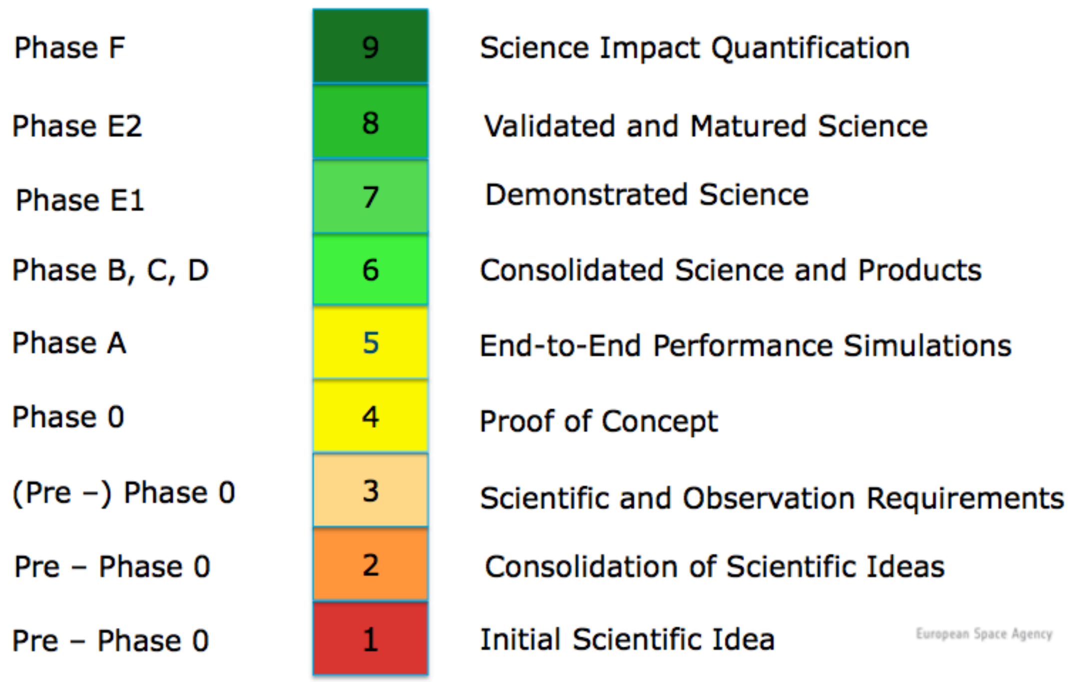
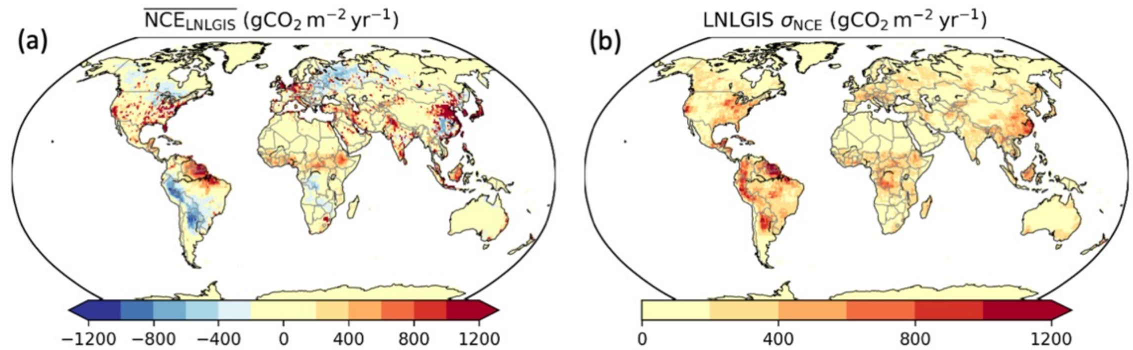


Figure 3.1 provides a high-level illustration of the SRL scale in the context of the progression from basic research to matured science in (operational) applications in relation to the Phases of an EO mission.

3.e Figures
(see below)

Current practice: ensemble approaches

- The OCO-2 Model Intercomparison Project (OCO-2 MIP) circumvents some of these issues:
  - Implicitly incorporates transport uncertainty
  - Incorporates FF uncertainty
  - Incorporates sensitivity to inverse model configuration
    - Not really an uncertainty
  - Formal uncertainty estimates are possible but not currently included.
  - Model democracy is actively debated (Cressie et al, 2022)



$$\sigma_{\mathrm{NCE}} = \frac{\mathrm{IQR(NCE)}}{1.35}$$

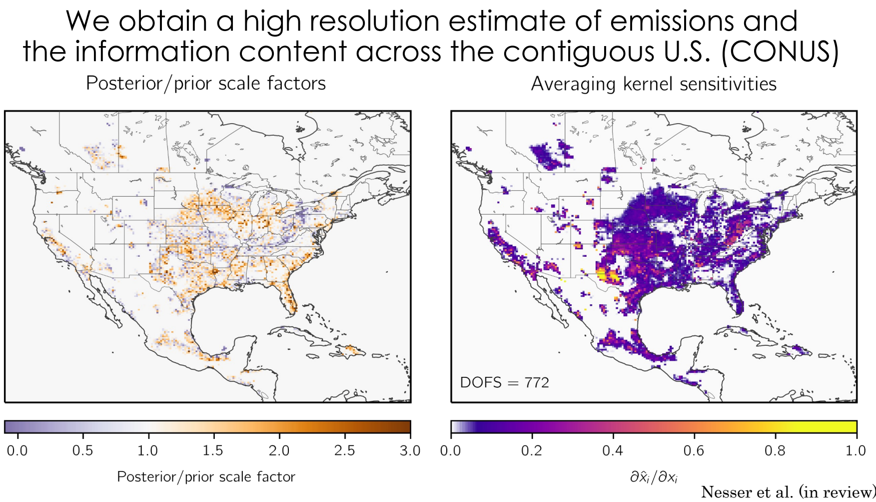
Net carbon exchange (NCE)

$$\sigma^2_{NBE} = \sigma^2_{NCE} + \sigma^2_{FF}$$

Net biome exchange (NBE)

Figure 1: Slide from Chevallier presentation

jpl.nasa.gov



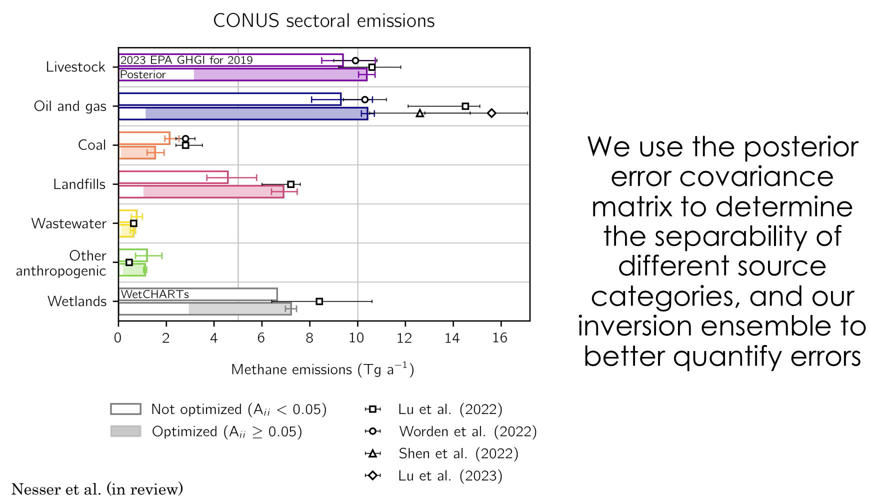
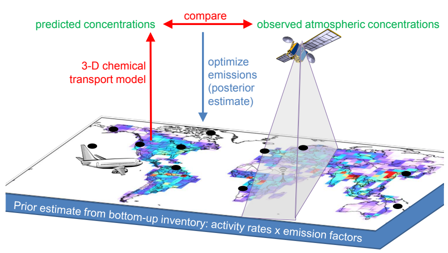


Figure 2: Slides from Nesser presentation

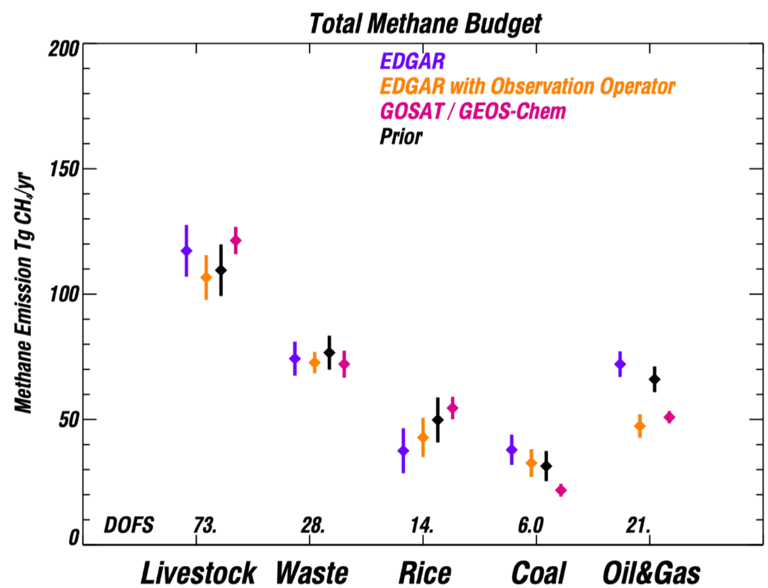
We can use GOSAT data, the GEOS-Chem model, and this OE approach to quantify emissions and trends, information content (uncertainties reduction, spatial and sectoral resolution and then compare to an independent inventory

Bayesian Approach accounts for choices in our inversion, uncertainties, and resolution

$$\hat{\mathbf{z}}_i = \mathbf{z}_A + \mathbf{A}(\mathbf{z}_i - \mathbf{z}_A)$$
$$\hat{\mathbf{z}} - \hat{\mathbf{z}}_i = \mathbf{A}\boldsymbol{\delta}_i + \mathbf{G}\mathbf{n} + \boldsymbol{\delta}_\mathbf{m}$$
$$E||\hat{\mathbf{z}} - \hat{\mathbf{z}}_i|| = \mathbf{A}\mathbf{S}_\mathbf{i}\mathbf{A}^\mathbf{T} + \mathbf{S}_\mathbf{n} + \mathbf{S}_\mathbf{m}$$



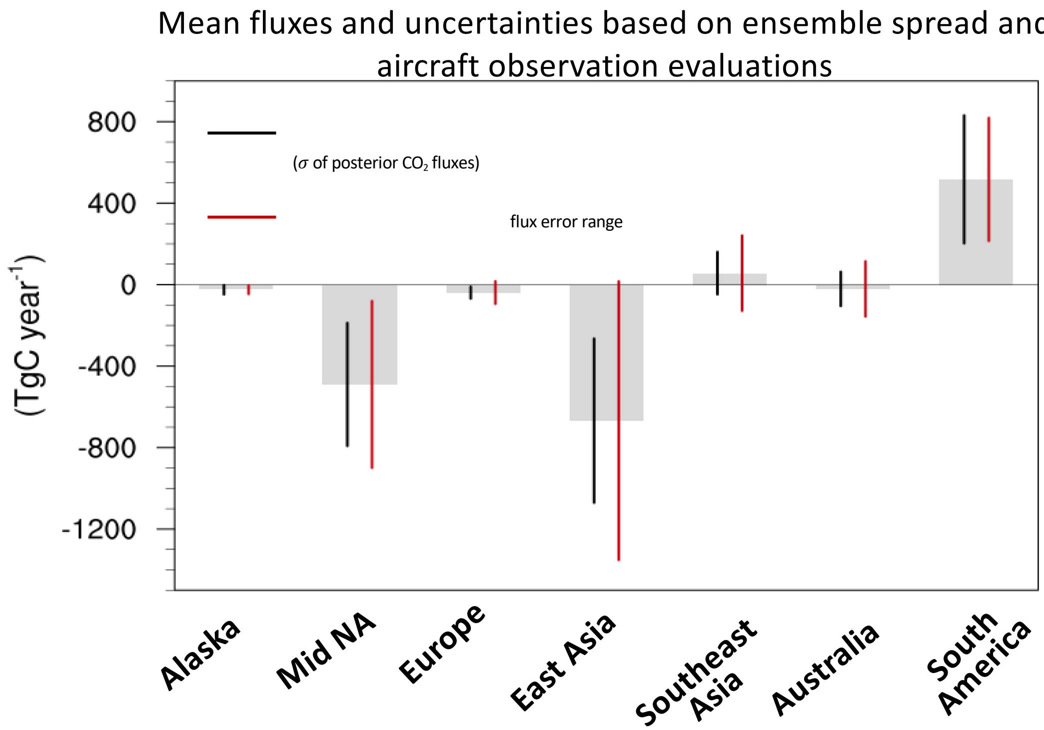
Zhang et al. (ACP) 2021
Worden et al. (AGU Advances in review)

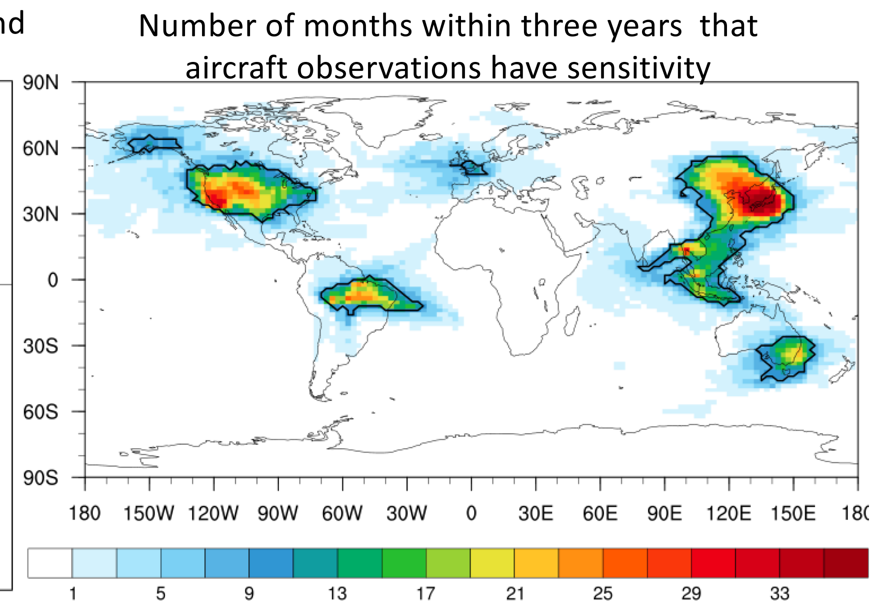


- EDGAR 6.0 emissions are consistent with satellite for the waste, oil / gas sectors, inconsistent for all other sectors.
- This observing system (GOSAT) does not have the sensitivity to falsify the larger emissions posited by EDGAR for oil and gas
- Largest sensitivity of GOSAT estimate to livestock emissions (DOFS ~ 73)

Figure 3: Slides from Worden presentation

Up to ~50% underestimation of posterior flux errors in regional mean fluxes from OCO-2 MIP





- Underestimation of posterior flux errors by ensemble spread in OCO-2 MIP could be attributed to: 1) fossil fuel uncertainties that have not been accounted for; 2) less diversity in the transport models

Figure 4: Slide from Liu presentation

Yun et al., 2023, to be submitted to ACPD

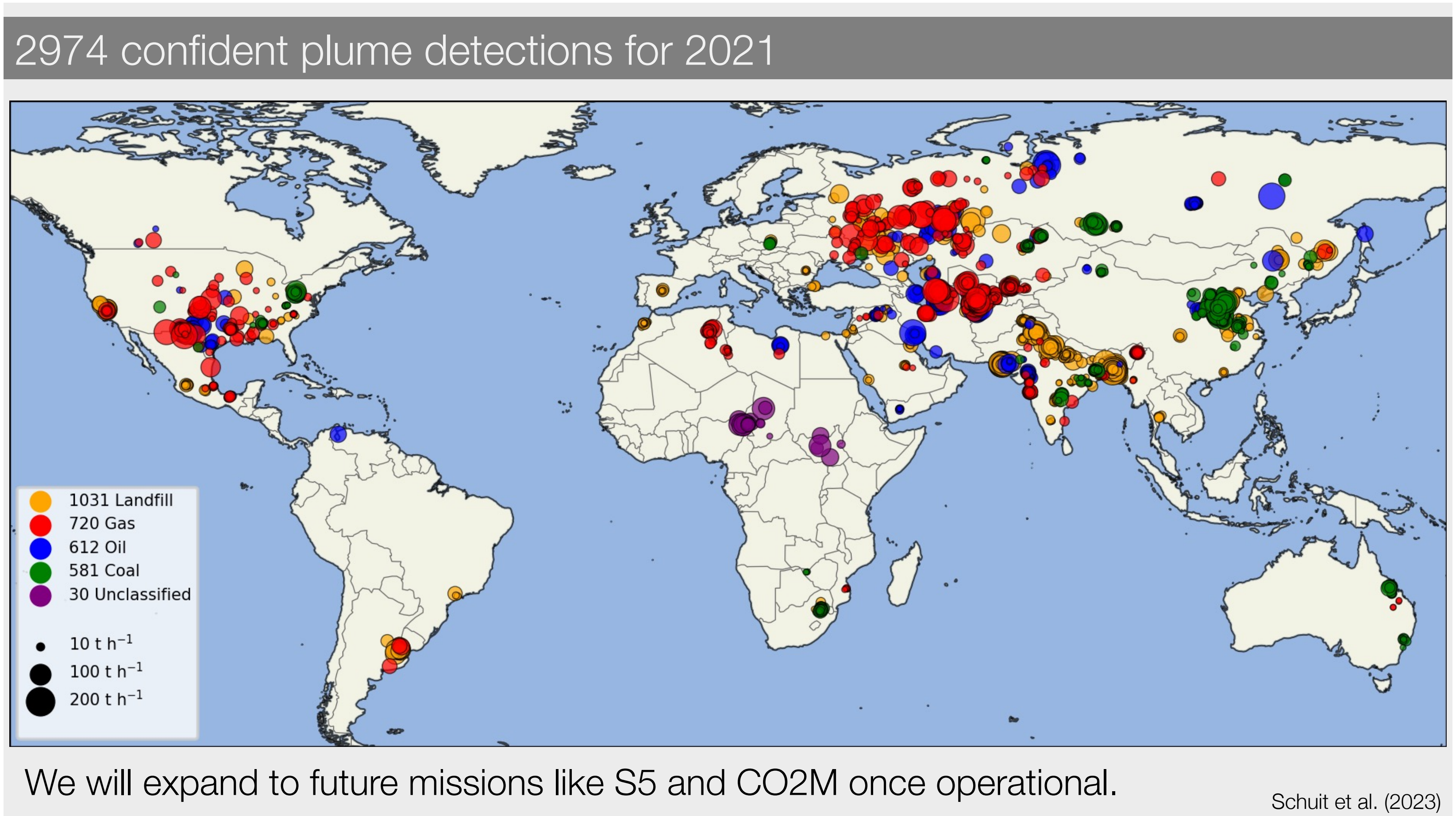


Figure 5: Slide from Maasakkers presentation

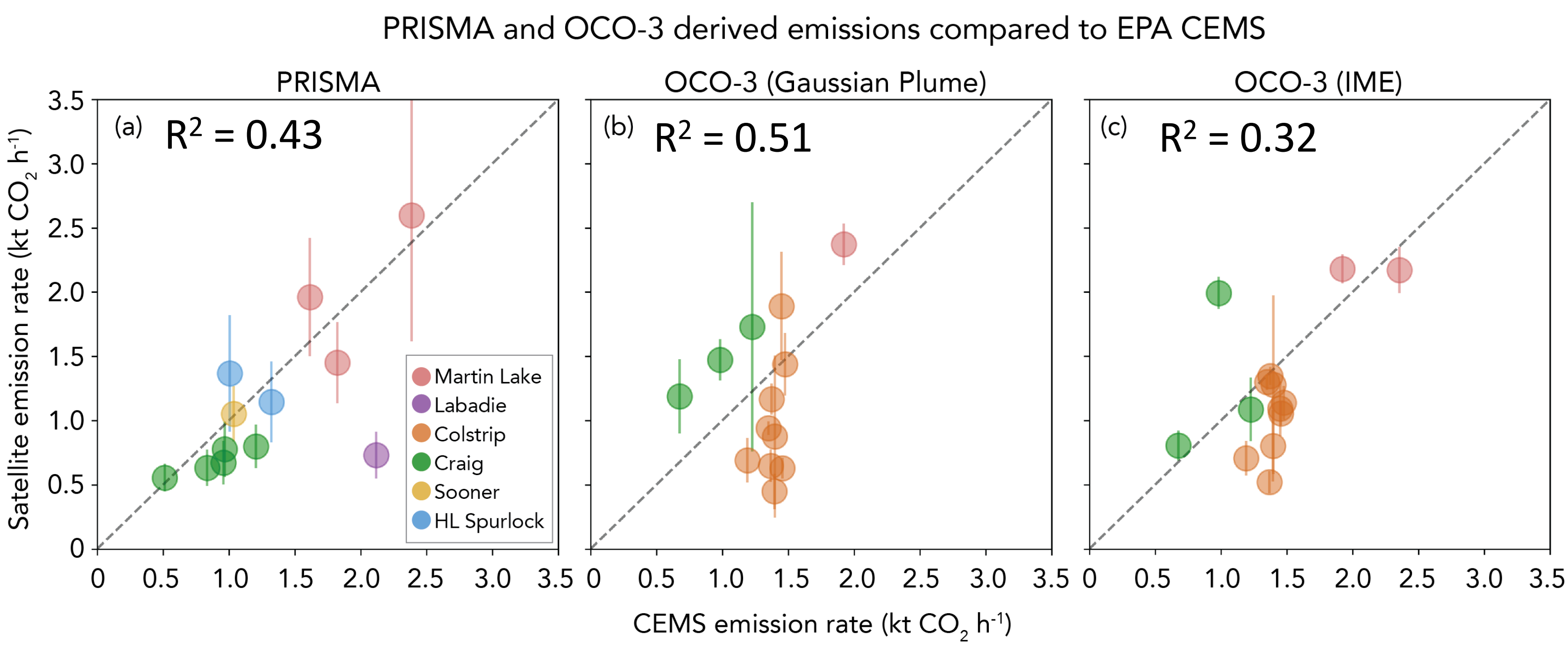
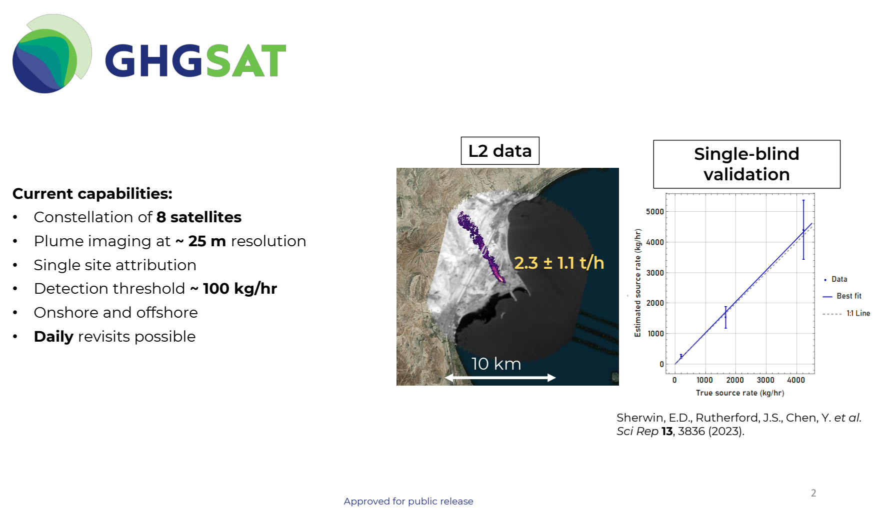


Figure 6: Slide from Nelson presentation



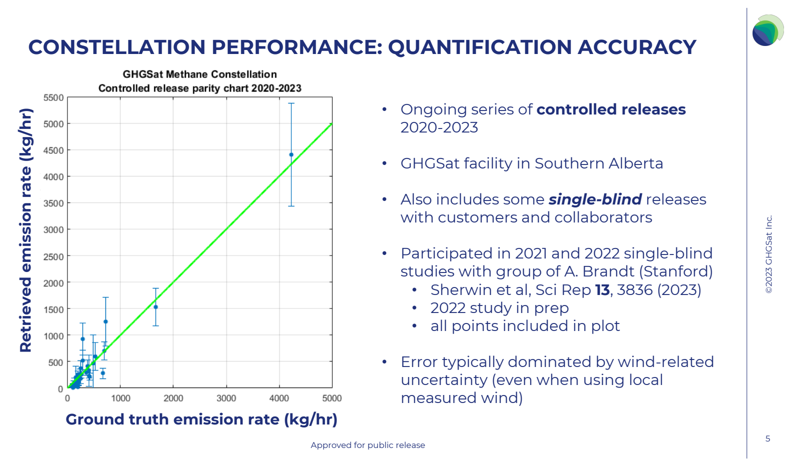


Figure 7: Slide from McKeever presentation

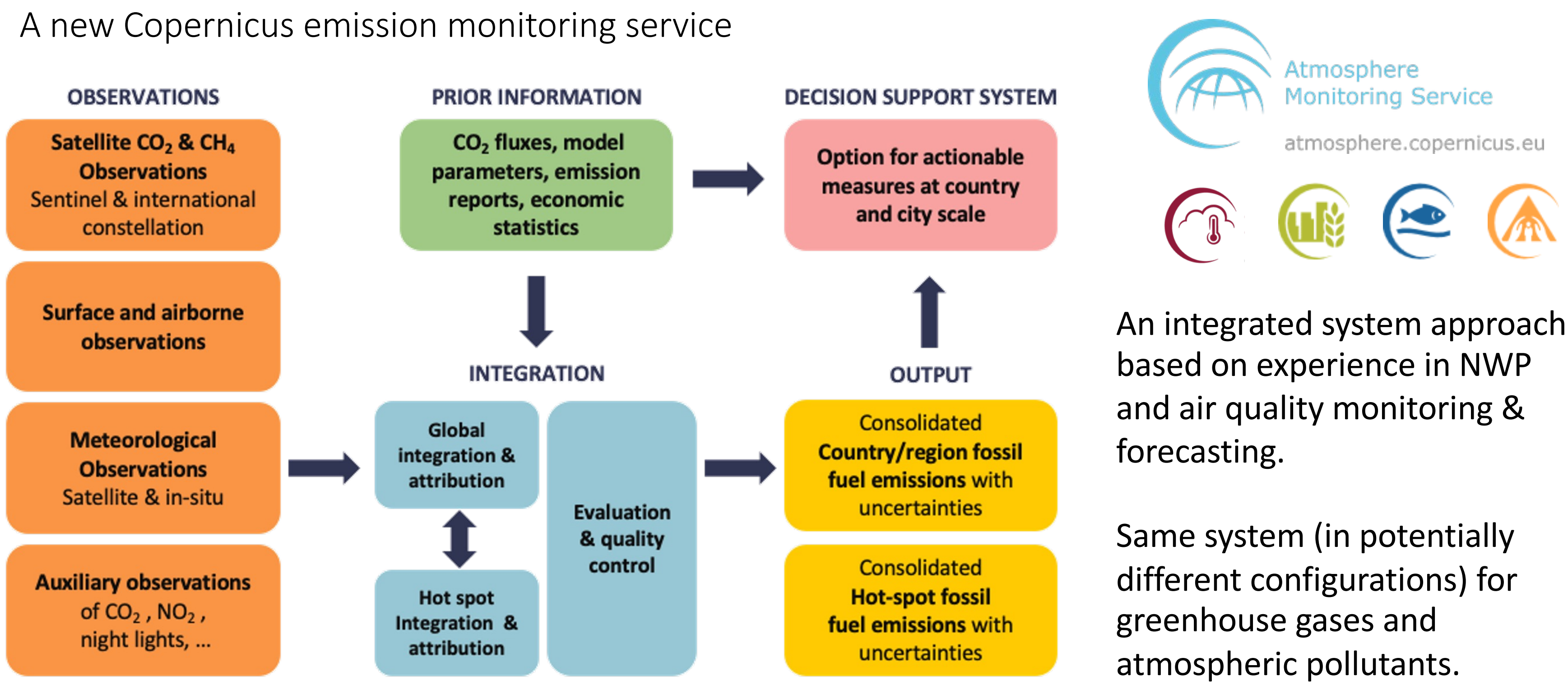


Figure 8: Slide from Engelen presentation

Figure 9: Slide from Delavois presentation

The World Emission project

WorldEmission

World Emission is an enhanced global anthropogenic **emission inventories platform** demonstrator, developing greenhouse gases (GHG) and air pollutants top-down emissions estimates based on satellite data.

Started in March 2022, 2 years project

	Local	Regional	Global
CO_2	X	X	
CH_4	X	X	X
NH_3	X	X	X
SO_2	X		X
NO_x	X	X	X
CO		X	X
CH_3OH (methanol)	X		X
C_2H_2 (acetylene)	X		
C_2H_4 (ethylene)	X		
CHOCHO (glyoxal)			X
HCHO (formaldehyde)			X

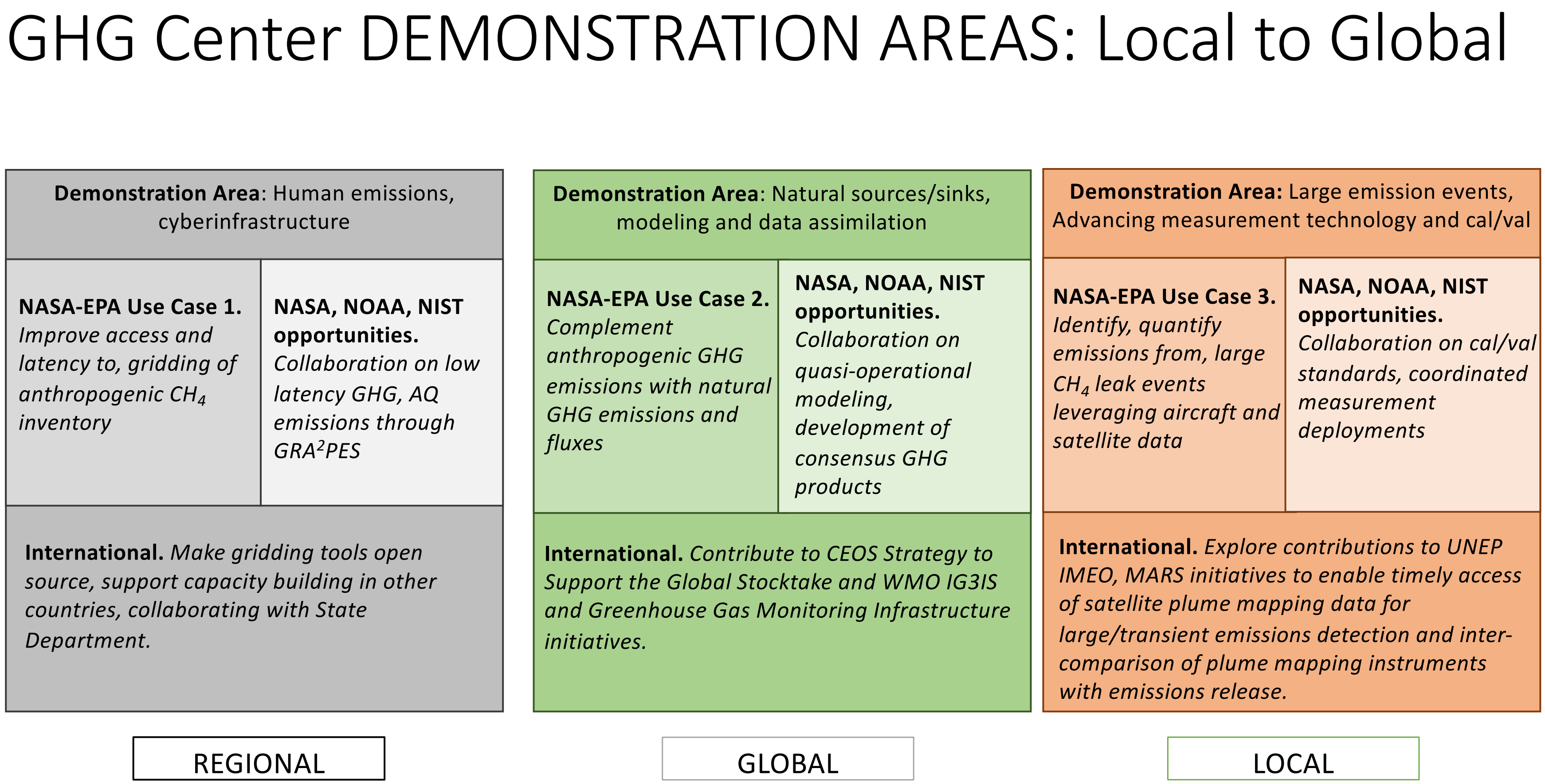


Figure 10: Slide from Kavvada presentation