UNIVERSITIES SPACE RESEARCH ASSOCIATION
7178 Columbia Gateway Drive • Columbia, MD 21046
410-730-2656 • 410-730-3496 (fax) • www.usra.edu

Date: 3 March 2023

Input to the first Global Stocktake (GST): A satellite-based, highly spatially resolved gridded greenhouse gas (GHG) emission inventory product in support of national emission reporting and climate mitigation monitoring

Universities Space Research Association (USRA), an admitted observer Non-Government Organization (NGO), is pleased to submit an input regarding the type of information for the Global Stocktake (GST) to the third meeting of the Technical Dialogue (TD1.3) to be held at the 56th sessions of subsidiary bodies (SB56). The proposed information outlined below should serve as key data to address the mitigation guiding questions for the technical assessment.

Summary

- USRA with its science and research sponsors and collaborators have developed and maintained a satellite-based highly spatial resolved carbon dioxide (CO_2) emissions inventory data product ODIAC (Open-source Data Inventory for Anthropogenic CO_2).
- ODIAC spatially and temporally distributes country level fossil fuel CO_2 emission estimates on a global 1x1km grid on a monthly basis using satellite-observations and geospatial information.
- The data product is freely available in data formats readily usable for various science applications including atmospheric simulations and inverse flux estimations.
- ODIAC has been extensively used and examined in science applications using the atmospheric data from various platforms (surface, aircrafts and satellites) at key policy relevant scales (global, regional and local).
- ODIAC serves as a “bridge” between the emission reporting and science-based assessment by sharing country level emission information into science analysis in support of the mitigation technical assessment in GST as well as QA/QC and verification of reported emissions.

ODIAC and its modeling approach

In order to address the mitigation guiding questions, the technical assessment in GST should accurately reflect the current and past status of global greenhouse gas (GHG) emissions and the resulting atmospheric concentrations (e.g. Weir *et al* 2022). One of the challenges in using the reported national emission inventories (NEI) for the technical assessment is the lack of completeness of the emission information. For example, emissions in NEI are reported at country levels on an annual basis. NEI often do not provide critical subnational emission information beyond the country scale, such as subnational emission sources and their spatial extents and temporal patterns of emissions. Such subnational information is crucial when emissions are incorporated into science analyses. More fundamentally, Parties have been reporting NEIs in different frequencies (e.g. Annex-I vs. non-Annex I countries) and calculation methods/approaches (e.g. key emission sector, emission factor, and calculations with different tier) and thus it is challenging to complete a global coverage (both spatially and temporally) with consistency.

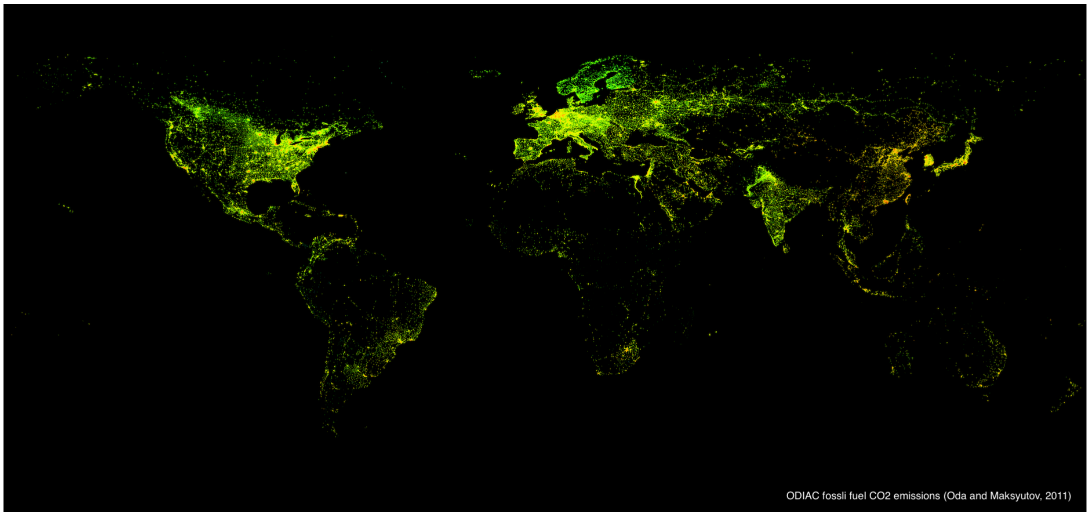

Figure 1. ODIAC global emissions at a 1x1km resolution. Country level emissions are distributed using point source information and satellite observation of nighttime lights. Figure 1 only indicates emissions over land regions while the ODIAC product also include other non-land emissions, such as marine bunker and aviation emissions (see Figure 2).

At the Universities Space Research Association (USRA), we develop value-added science products to support climate and environmental sciences. ODIAC (Open-source Data Inventory for Anthropogenic CO_2) is a global highly spatially resolved gridded emission inventory of country level fossil fuel CO_2 emissions (Oda and Maksyutov 2011, Oda *et al* 2018, see Table 1 for a brief technical summary). ODIAC distributes country level emissions to subnational levels using geospatial information, such as point source information and satellite observations of nighttime lights (NTL) (see Figure 1). Satellite observations of NTL enable us to pinpoint the source regions and their dynamic temporal and spatial changes. ODIAC is based on the global consistent "reference approach (see Marland and Rotty 1984)" based emission estimates by Gilfillan and Marland (2021). As noted in the IPCC guidelines (e.g. IPCC 2006), the reference approach is often used for evaluation of "sectoral approach" based calculations, and the estimates for energy sector CO_2 (mostly from fossil fuel combustion) from two approaches should match well. The emission estimates are annually updated based on the latest United Nation's energy statistical data. The estimates also include emissions from cement production and gas flares as well as emissions from marine bunkers and aviation that are not part of the national emissions under the current emission reporting convention (see in Figure 2). Thus, ODIAC should represent the current and past status of fossil fuel CO_2 (~ energy related CO_2) emissions and the emission values are provided in a gridded form to be ready for science applications. The product is freely available from the website hosted by Japan's National Institute for Environmental Studies (https://db.cger.nies.go.jp/dataset/ODIAC/).

Proven utilities through science applications

While the emission modeling approach is rather simple, ODIAC has been extensively examined (e.g. Oda *et al* 2019, Wang *et al* 2021) and its uniquely added science utility has been proven through various science applications. Notably, ODIAC has been successfully used for the global flux inversion calculations implemented under Japan's Greenhouse gas Observing SATellite (GOSAT) project (e.g. Maksyutov *et al* 2013) and NASA's Orbiting Carbon Observatory (OCO) mission (e.g. Byrne *et al* 2022) as well as other inversions using ground-based observations. In

Table 1. A summary of the ODIAC inventory product. The complete details of the ODIAC approach and data product can be found in elsewhere (Oda and Maksyutov, 2011, Oda et al. 2018). The data product is available from https://db.cger.nies.go.jp/dataset/ODIAC/.

		Note
Spatial coverage and resolution	Global 1km and 1degree	Global 1km only indicates land
Temporal resolution	Monthly	See also temporal modeling approach
Value	CO_2	CO_2 from fossil fuel combustion, gas flaring, cement production, aviation and marine bunker
Emissions estimates	Fuel-based/reference approach	Based on UN data.
Spatial modeling approach	Direct and proxy mapping approach	Satellite-observed nightlight for non-point sources and database for point sources
Temporal modeling approach	Fuel consumption approach	Extendable to hourly scale using scaling factor approach

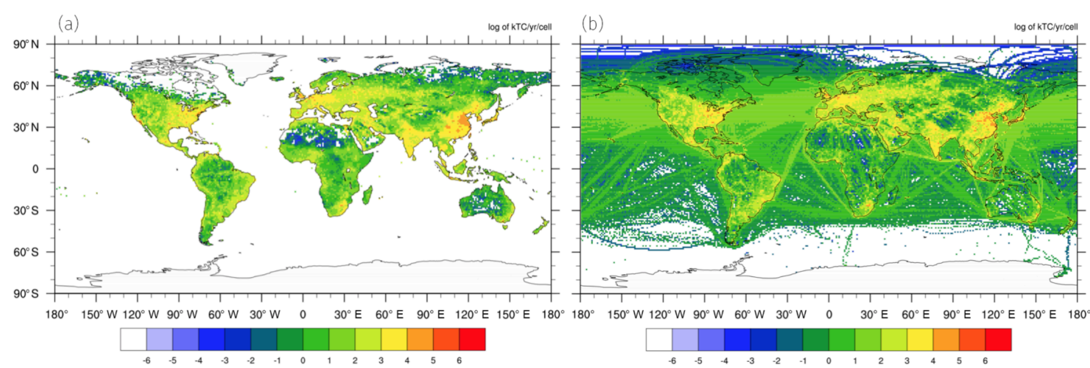

Figure 2. ODIAC global emissions aggregated to a 1x1degree (approx. 110km at equator) resolution. Adopted from Oda et al (2018). The aggregated resolution version of ODIAC inventory product has been often used by global simulation applications, such as Maksyutov et al (2013) and Byrne et al (2022). The ODIAC high-resolution emission product completes the global coverage including bunker emissions (marine bunker and aviation) that are not part of national emissions under the current emission reporting convention (see the difference from the CO2 map w/o bunker emissions). Thus, ODIAC can serve as an input for the evaluation of the collective emission mitigations.

those applications, ODIAC served as a prior emission to prescribe fossil fuel CO_2 emissions in order to estimate natural sources and sinks. Due to the high resolution emission field, in addition to the global applications, ODIAC has been often used for cutting-edge emission analyses for cities (e.g. Lauvaux *et al* 2020) and localized sources (e.g. Hakkarinen *et al* 2023) as well as satellite CO_2 data evaluation (e.g. Kiel *et al* 2022), especially at many locations where locally reported emissions are not available. While limited to certain areas, the proven ODIAC emission modeling approach has also been applied to newer satellite data, such as NASA's improved NTL product (see Figure 3).

It is important to emphasize that ODIAC was primarily designed to serve for carbon analyses using atmospheric data. The utility of ODIAC as an emission data product has been uniquely evaluated using atmospheric CO_2 data and confirmed by the improvement in the model reproducibility of atmospheric CO_2 (Oda *et al* 2021). This is critically important for gridded

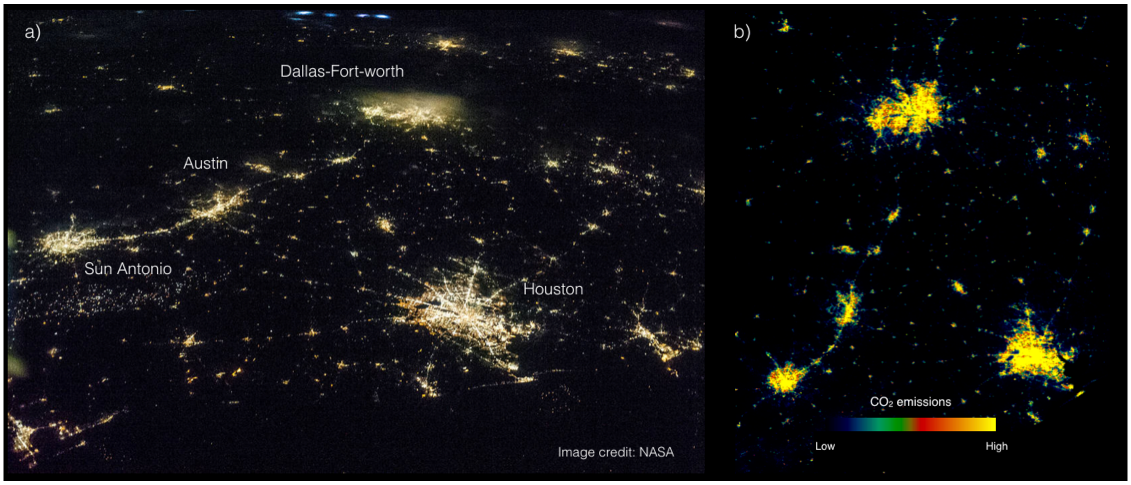

Figure 3. ODIAC approach with new NTL data. An emission map for Texas cities (right) is compared to an image taken from the International Space Station (left). Fine within-city spatial structures are depicted using the new NTL data. Adopted from Oda et al (2021).

emissions used in technical assessments including QA/QC and verification of NEI (as noted in IPCC 2019) as potential biases due to the emission modeling would impact the results.

Expected contributions to the GST

Ideally, evaluation of our global collective mitigation progress, which should address the mitigation guiding questions, should be carried out based on the GHG emission information reported as NEIs. However, as discussed earlier, several technical challenges prevent us from doing so. Below, the challenges identified and our ODIAC approaches to them are briefly summarized:

- Global coverage – In ODIAC, global emissions (country emissions plus bunker emission) are achieved with consistent up-to-date emission estimates.
- Temporal coverage – ODIAC provides multiple-year, consistent gridded emissions. Emissions also include seasonality to provide monthly level emissions. The month emissions can be further extended weekly, daily and hourly using an established scaling factor approach (see Nassar *et al* 2010).
- Spatial resolution – ODIAC provides a global 1x1km high-resolution field that should resolve the key emission sources to be considered at different policy relevant scales (global, provide/states, urban/cities and facilities).
- Timely and updated information - ODIAC takes up-to-date emission estimates and regularly updates the underlying emission information in the same/similar manner as NEIs.

ODIAC has already been used in product developments using NASA's OCO CO_2 data in support of the GST technical assessment, such as:

- OCO-assimilated global CO_2 model field (level 3) https://disc.gsfc.nasa.gov/datasets/OCO2_GEOS_L3CO2_DAY_10r/summary
- Flux inversions for evaluating NEIs as published by Bryne et al (2022)

In addition, ODIAC can particularly contribute to the GST technical assessment contributing

QA/QC and verification of NEIs, especially using atmospheric data as noted in IPCC (2019), as:

- Direct (emission-emission) comparison or comparison to atmospheric data via modeling
- Analysis of identifying key target sectors for NEI compilation, especially for the country and region parties who have less experience in emission compilation

USRA contact point

Dr. Tomohiro Oda - USRA COP delegation lead
Universities Space Research Association
425 3rd Street SW, Suite 950, Washington, D.C. 20024 U.S.A.
Tel: +1 410-730-2656
Email: USRA-UNFCCC@usra.edu

References

Byrne et al (2022) National CO_2 budgets (2015–2020) inferred from atmospheric CO_2 observations in support of the Global Stocktake *Earth Syst. Sci. Data Discuss*. doi.org/10.5194/essd-2022-213

Hakkarainen et al (2023) Building a bridge: characterizing major anthropogenic point sources in the South African Highveld region using OCO-3 carbon dioxide snapshot area maps and Sentinel-5P/TROPOMI nitrogen dioxide columns *Environ. Res. Lett.* **18** 035003 doi.org/10.1088/1748-9326/acb837

Gilfillan and Marland (2021) CDIAC-FF: global and national CO_2 emissions from fossil fuel combustion and cement manufacture: 1751–2017 *Earth Syst. Sci. Data* **13** 1667–1680 doi.org/10.5194/essd-13-1667-2021

Lauvaux et al (2020) Policy-Relevant Assessment of Urban CO_2 Emissions *Environ. Sci. Technol*. **54** 10237–10245 doi.org/10.1021/acs.est.0c00343

Oda and Maksyutov (2011) A very high-resolution (1 km×1 km) global fossil fuel CO_2 emission inventory derived using a point source database and satellite observations of nighttime lights *Atmos. Chem. Phys.* **11** 543–556 doi.org/10.5194/acp-11-543-2011

IPCC (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories Prepared by the National Greenhouse Gas Inventories Programme ed H S Eggleston et al (Hayama: the Institute for Global Environmental Strategies (IGES))

IPCC (2019) 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories ed C Buendia et al (Switzerland: IPCC)

Maksyutov et al 2013 Regional CO_2 flux estimates for 2009–2010 based on GOSAT and ground-based CO_2 observations, *Atmos. Chem. Phys*. **13** 9351–9373 doi.org/10.5194/acp-13-9351-2013

Marland and Rotty (1984) Carbon dioxide emissions from fossil fuels: a procedure for estimation and results for 1950–1982 *Tellus B* **36** 232-261 doi:10.1111/j.1600-0889.1984.tb00245.x

Nassar et al (2013) Improving the temporal and spatial distribution of CO_2 emissions from global fossil fuel emission data sets *J. Geophys. Res. Atmos*. **118** 917-933

Oda et al (2018) The Open-source Data Inventory for Anthropogenic CO_2, version 2016 (ODIAC2016): a global monthly fossil fuel CO_2 gridded emissions data product for tracer transport simulations and surface flux inversions *Earth Syst. Sci. Data* **10** 87-107 doi:10.5194/essd-10-87-2018

Oda et al (2019) Errors and uncertainties in a gridded carbon dioxide emission inventory *Mitig. Adapt. Strateg. Glob. Chang.* **24** 1007–1050 doi:10.1007/s11027-019-09877-2

Oda et al (2021) US Cities in the Dark. In Urban Remote Sensing, X. Yang (Ed.). doi.org/10.1002/9781119625865.ch16

Kiel et al (2021) Urban-focused satellite CO_2 observations from the Orbiting Carbon Observatory-3: A first look at the Los Angeles megacity *Remote Sens. Environ*. **258** 112314 doi.org/10.1016/j.rse.2021.112314

Wang et al (2020) The impacts of fossil fuel emission uncertainties and accounting for 3-D chemical CO_2 production on inverse natural carbon flux estimates from satellite and in situ data *Environ. Res. Lett*. **15** 085002 doi:10.1088/1748-9326/ab9795

Weir et al (2022) Assessing progress toward the Paris Climate Agreement from space. Environ. Res. Lett., 17 111002 doi:10.1088/1748-9326/ac998c