Committee on Earth Observation Satellites

Report from the CEOS Global Stocktake Study Team

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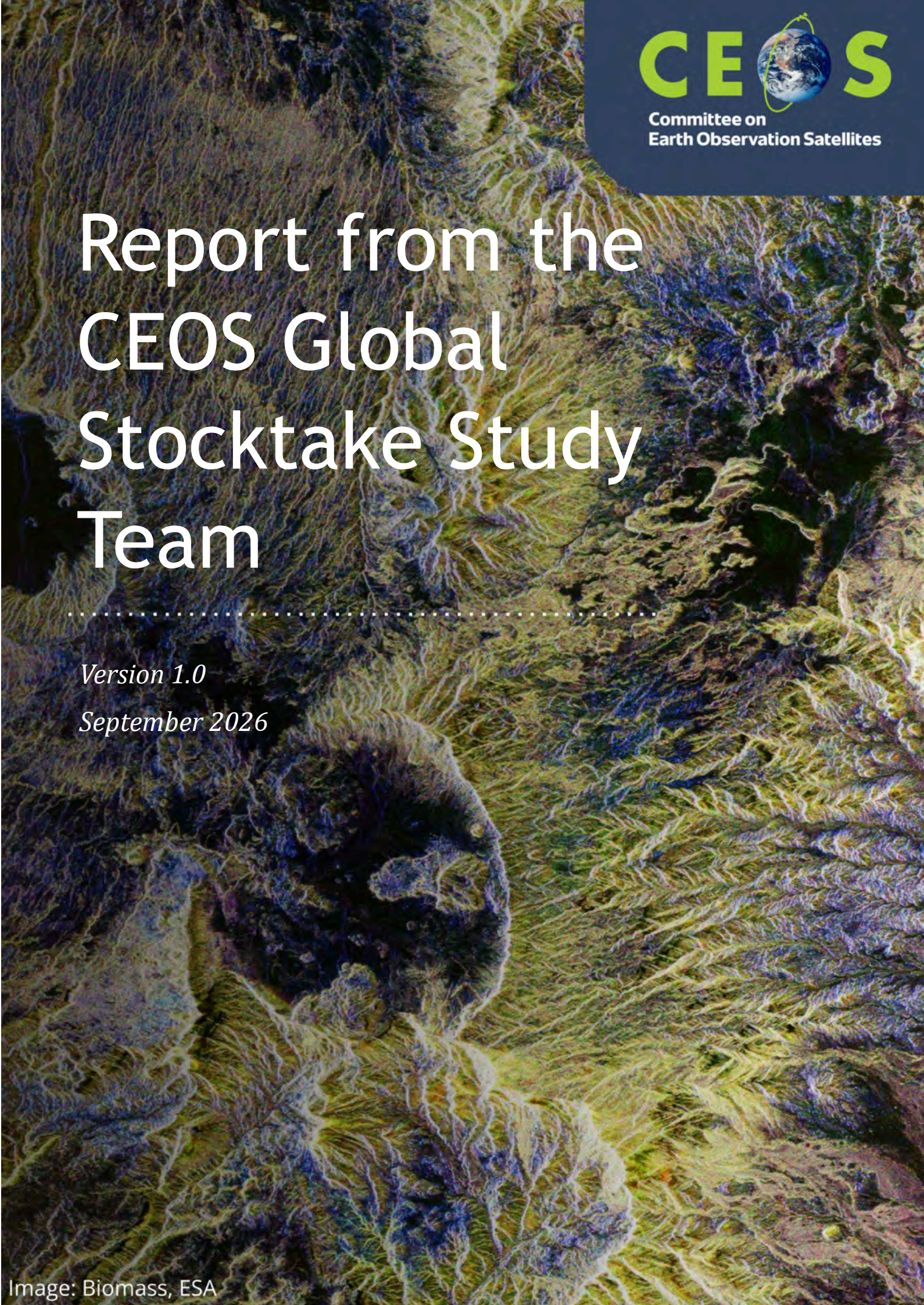


Image: Biomass, ESA

This report from the CEOS Global Stocktake Study Team is the product of a group of experts convened through the Committee on Earth Observation Satellites (CEOS). The document was acknowledged by CEOS Principals in September, 2026, who recognise the quality of the work, and encourage CEOS Members and Associates to consider the recommendations made by this document.

Cover page image: Desert structure in Chad imaged by ESA's Biomass mission. Read more: https://www.esa.int/ESA_Multimedia/Images/2025/06/Desert_structure_in_Chad

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Executive Summary

Systematic, space-based observations of the Earth provide the scientific foundation for tracking climate change on regional to global scales. CEOS Agencies are now using these data to address the needs of a broad range of stakeholders in the science, policy, and regulatory communities. This document provides an assessment by the GST Study Team, led by the JAXA 2024-2025 SIT Chair, on how CEOS Agencies can elect to exploit this information to support the Paris Agreement (PA) and its Global Stocktakes (GSTs). More generally, the actions recommended here could improve access to space-based Earth observations and foster their use to mitigate the impacts of climate change and improve climate resilience.

The PA seeks to strengthen the global response to the threat of climate change by mitigating global temperature changes (mitigation) and by enhancing the ability of societies to adapt to climate change (adaptation). Recognizing that developing nations do not have the means to implement these changes, the PA calls for augmenting their means to meet these objectives (means of implementation). Its mitigation goals encourage rapid reductions in greenhouse gas (GHG) emissions to limit global average temperature increases to less than 2 °C. Adaptation efforts focus on reducing the exposure and vulnerability of societies to climate hazards by increasing their adaptive capacity and reducing GHG emissions without threatening food production. The means of implementation actions redirect finance flows, transfer technology and build capacity to promote reduced GHG emissions and climate resilient development. Progress toward these goals is assessed at five-year intervals through GSTs.

CEOS efforts to support the first GST in 2023 focused primarily on the delivery of national-scale budgets of carbon dioxide (CO_2) and methane (CH_4) emissions and removals derived from global, space-based observations. Here, we recommend that CEOS maintain, but expand these efforts to better support the development of more complete and accurate GHG inventories by the Parties to the PA. In addition, CEOS should work with its partners to monitor emissions from the largest CO_2 and CH_4 sources to assess the impacts of climate policies on their emissions.

To foster the use of these products in the GSTs, these space-based GHG products should be developed in collaboration with the national greenhouse gas inventory community and the Intergovernmental Panel on Climate Change (IPCC). CEOS should also coordinate ongoing efforts by its agencies and work closely with its partners to provide capacity building for this user community to better explain the information content of the space-based products and their utility in managing GHG emissions and removals.

Space-based products spanning a broad range of Essential Climate Variables (ECV) are needed to support the adaptation goals of the PA, because climate change will affect different regions and societies in different ways. Different types of information are needed to increase adaptive capacity, strengthen resilience, reduce vulnerability to climate change, and contribute to sustainable development.

To enhance the impact of space-based products and services supporting adaptation, CEOS must foster more interactive collaborations with both its partners and stakeholders to develop and deliver products that are both more fit for purpose and timely. For example, CEOS should work closely with the United Nations Framework Convention on Climate Change (UNFCCC) and the Parties to the PA to develop ECV-based products that more directly address the development of National Adaptation

Plans (NAPs) support the Global Goal on Adaptation (GGA) and facilitate their use in climate change attribution. CEOS should also promote two-way capacity building to foster community engagement across the globe to better assess and address regionally varying climate threats, vulnerabilities and information needs. Initial actions include improving the discoverability of adaptation-relevant CEOS Climate Data Records, mapping of amenable EO products to GGA indicators, supporting the NAP development and assessment process, and showcasing adaptation use cases.

CEOS can support the means of implementation objectives of the PA by providing space-spaced observations that facilitate identifying and managing emerging climate-related risks and vulnerabilities. These products could also provide a transparent way to monitor the progress of investments intended to mitigate the impacts of climate change. Historically, CEOS has not attempted to coordinate the development or delivery of space-based products or services addressing climate finance and means of implementation. However, some CEOS entities, individual agencies and partners have engaged more directly with key stakeholders serving these needs, providing insights into the types of use cases that CEOS might address in the future.

Initial CEOS efforts to address the means of implementation goals of the PA might include working with partners to co-develop space-based products that could be used for assessing rapidly-evolving climate risks such as coastal flooding, wildfire, flash droughts, or other climate-related threats to food or water security. They might include co-developing space-based products for climate impact assessments, or for rapidly assessing the areal extent loss and damage associated with severe weather or other climate extremes. To make a significant contribution to these goals, CEOS must begin a more active dialogue with the UNFCCC, the climate finance community and the Parties to the PA to ensure that the products, tools and services are fit for purpose.

To support the diverse range of mitigation, adaptation and means of implementation objectives of the PA within the context of a best-efforts organization, CEOS will have to fully exploit available synergies among the products, tools and services it delivers to meet these needs. In addition, the GST support activities by CEOS entities must be carefully coordinated to maximize their benefits within the time constraints imposed by the PA and the resource constraints of CEOS agencies. Some activities may have to be prioritized while others can be introduced as resources become available. Finally, to gain additional recognition for its contributions to the PA and its GSTs and to support effective climate action by the science, policy, regulatory and commercial sectors, CEOS should regularly publish citable peer-reviewed consensus reports documenting the use of space-based EO products for these applications. These reports could then be included in the IPCC assessment reports, which form the scientific basis for the GSTs.

1. Introduction

In 2015, Parties to the United Nations Framework Convention on Climate Change (UNFCCC) met at the 21st annual Conference of Parties (COP21) and signed the Paris Agreement (PA)[1]. This Agreement establishes a framework designed to strengthen the global response to the growing threat of climate change, while encouraging sustainable development and reducing poverty. Key elements of this framework include efforts to mitigate future increases in global average temperatures (mitigation), improve resilience and reduce vulnerability to climate change (adaptation), and mobilize the resources needed to meet these goals (means of implementation).

Recognizing that greenhouse gas (GHG) emissions from fossil fuel use, land use change and other human activities are the primary cause of climate change, the PA mandates that its Parties undertake rapid reductions in these emissions, based on the best available science. To manage these reductions, each Party is required to prepare and report its planned nationally determined contributions (NDCs) to the global response to climate change at five-year intervals. In addition, the PA establishes an Enhanced Transparency Framework (ETR) that requires all Parties to compile and report inventories of anthropogenic GHG emissions by sources and removals by sinks in biennial transparency reports (BTRs). It also requires that Parties take stock of the implementation of the Paris Agreement to assess collective progress towards the goals of the PA. These stocktakes were to be executed at five-year intervals. The first Global Stocktake (GST) was executed in 2023.

Systematic, space-based observations of the Earth's land surface, ocean and atmosphere, provide a key source of information on the climate and its response to human activities. These observations are therefore critical for assessing the growing threat of climate change and for assessing collective progress toward the goals of the PA. For example, satellite observations of atmospheric and surface temperature are critical for monitoring their trends on regional to global scales. Similarly, space-based observations of atmospheric carbon dioxide (CO_2) and methane (CH_4) concentrations can be analysed to track trends in the net emissions and removals of the key GHGs on these scales. Observations of land cover, above-ground biomass and disturbances (e.g., deforestation, fires, droughts, and floods) can provide direct support for the development of bottom-up emissions inventories for agriculture, forestry and other land use (AFOLU). These data therefore support the mitigation goals of the PA.

Other space-based Earth observations (EO) support the adaptation goals of the PA. Observations of land and ocean productivity provide critical information on food security on regional scales over the globe. Near-real-time space-based meteorological observations also provide the data needed for early warnings of severe weather (e.g., hurricanes, heavy precipitation, heat waves) limiting loss and damage and vulnerability to climate change. These data can be combined with space-based observations of sea

[1] https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

level rise, land and sea ice cover, wildfire extent to assess evolving risks imposed by a rapidly changing climate.

Recognizing the potential value of space-based observations for supporting the PA and its GSTs, the Committee on Earth Observation Satellites (CEOS) developed and endorsed the first issue of the *CEOS Strategy to Support the Global Stocktake of the UNFCCC Paris Agreement*[2] in 2021. That document summarizes the objectives, scope, schedule, and (evolving) modalities of the PA and its GSTs. It then identifies areas where CEOS might coordinate ongoing and future efforts among its member agencies to support the GSTs. Given the PA's strong emphasis on GHG emissions and the ongoing efforts being conducted to support the CEOS-CGMS GHG Roadmap[3], the initial issue of the GHG Strategy focused primarily on the mitigation objectives of the PA for the first GST. Potential contributions to the adaptation and means of implementation goals of PA were also explored, but no specific products, tools, or services were defined.

Here, the *CEOS Strategy to Support the Global Stocktake of the UNFCCC Paris Agreement* has been updated by the Study Team to:

- Identify emerging opportunities where space-based products could support climate action in the context of the PA and its GSTs;
- Define examples of use cases, products, tools and services that could be co-developed through cooperative activities with partners and stakeholders;
- Incorporate the Lessons Learned from participation in the first GST;
- Accommodate changing landscape of partners and stakeholders participating in the GSTs;
- Define interfaces among CEOS entities (SIT, Working Groups, Virtual Constellations, Ad Hoc Groups) and between these CEOS entities and critical stakeholders in the policy (COP Delegates, UNFCCC), national GHG inventory (NGHGI) and international scientific communities (e.g., Intergovernmental Panel on Climate Change, Global Carbon Project); and
- Summarize the timelines and reporting schedules needed to support the GSTs.

Section 2 provides additional background on the PA and its GSTs and summarizes the lessons learned from CEOS participation in the first GST. Section 3 identifies areas where space-based observations and products could support the mitigation objectives of the GSTs. Sections 4 and 5 describe opportunities to support the adaptation and means of implementation objectives of the GSTs. Section 6 summarizes the coordination among CEOS entities (Strategic Implementation Team, Working Groups, Virtual Constellations, and Ad Hoc Teams) needed to support these efforts. The conclusions and way forward are documented in Section 7. Contributing authors, acronyms and near-term action items are listed in the Annexes.

[2] https://ceos.org/observations/documents/GST_Strategy_Paper_V3.1.pdf
[3] https://ceos.org/observations/documents/CEOS_CGMS_GHG_Constellation_Roadmap_V2.3_cleaned.pdf

2. Background

2.1. The Paris Agreement and its Global Stocktakes

To strengthen the global response to the threat of climate change while encouraging sustainable development and reducing poverty, Article 2 of the Paris Agreement defines three primary goals:

- **Mitigation:** *"Holding the increase in global average temperature to well below 2 °C above pre-industrial levels and to pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels;"*
- **Adaptation:** *"Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production;"* and
- **Means of Implementation:** *"Making finance flows consistent with a pathway towards low GHG emissions and climate resilient development."*

The first two of these goals directly target the human activities driving climate change and their potential negative impacts on people, their livelihoods and ecosystems. The third goal acknowledges that finance, technology transfer, and capacity building are needed to support effective climate action by developing countries, which are often particularly vulnerable to the adverse effects of climate change.

To achieve these goals, Article 4 of the PA specifies that each Party shall:

- *"aim to reach global peaking of greenhouse gas emissions as soon as possible, …in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century";*
- *"prepare, communicate and maintain successive nationally determined contributions that it intends to achieve" ;*
- *"communicate a nationally determined contribution every five years ..."; and*
- *"formulate and communicate long-term low greenhouse gas emission development strategies, … taking into account their common but differentiated responsibilities and respective capabilities, in the light of different national circumstances."*

In addition, Article 4 requires that each nationally determined contribution (NDC) represent a progressive reduction in anthropogenic emissions compared with the previous one and reflect the "*highest possible ambition*" of the country, accommodating their common but differentiated responsibilities and respective capabilities. Article 14 also invites Parties to report "*adaptation actions and/or economic diversification plans can contribute to mitigation outcomes*" as part of their NDCs. For developed countries, information on finance, technology transfer and capacity building is also required.

Article 5 describes mitigation actions specifically targeting critical sinks, such as forests. In particular, Parties are encouraged "*... to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases … including forests*" and to take actions including:

- *"policy approaches and positive incentives for … reducing emissions from deforestation and forest degradation, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries;" and*
- *"joint mitigation and adaptation approaches for the integral and sustainable management of forests, while reaffirming the importance of incentivizing, as appropriate, non-carbon benefits associated with such approaches."*

While Articles 4 and 5 focus primarily on mitigation, Article 7 focuses on adaptation, requiring each Party to:

- *"establish the global goal on adaptation of enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change … contributing to sustainable development and ensuring an adequate adaptation response";*
- "*recognize that the current need for adaptation is significant and that greater levels of mitigation can reduce the need for additional adaptation efforts, and that greater adaptation needs can involve greater adaptation costs*";
- *"acknowledge that adaptation action … should be based on and guided by the best available science and, as appropriate, traditional knowledge, knowledge of indigenous peoples and local knowledge systems";*
- "*recognize the importance of support for and international cooperation on adaptation efforts and the importance of taking into account the needs of developing country Parties, especially those that are particularly vulnerable to the adverse effects of climate change*";
- "*submit and update periodically an adaptation communication, ... including a national adaptation plan"*

The final bullet requires all Parties to develop and submit National Adaptation Plans (NAPs), which assess vulnerabilities, identify and prioritize adaptation options, implement those options, and track progress on those efforts.

In subsequent COPs, a framework for the Global Goal on Adaptation (GGA) was developed, comprising eleven global targets based around sectors and the adaptation policy cycle. The seven theme or sectoral targets are (i) Water, (ii) Food & Agriculture, (iii) Health, (iv) Ecosystems and Biodiversity, (v) Infrastructure and Human Settlements, (vi) Poverty eradication, and (vii) Cultural heritage. Four other targets refer to the policy cycle: (i) Impact, Vulnerability and Risk Assessment, (ii) Planning, (iii) Implementation, (iv) Monitoring and Evaluation. The GGA targets a 2030 timeframe and adaptation indicators are being developed to track progress towards the GGA framework. These are expected to be adopted at COP 30 (November 2025).

Article 10 of the PA highlights the importance of technology for the implementation of mitigation and adaptation actions under the Agreement and establishes a technology framework "*facilitating enhanced action on technology development and transfer in order to support the implementation of this Agreement*." Key themes of this framework include (i) innovation and implementation of technologies supporting mitigation and adaptation; (ii) capacity building to develop, strengthen and enhance Parties' capabilities to take effective climate action; (iii) collaboration and engagement with stakeholders; and (iv) financial support.

To build mutual trust and to promote a flexible, but effective approach for mitigation and adaptation actions, Article 13 of PA builds on the reporting and review processes under the Convention and introduces an Enhanced Transparency Framework (ETF). The Framework is to be implemented in a facilitative, non-intrusive, non-punitive manner, respectful of national sovereignty, and that avoids placing undue burden on Parties. The overall ETF process is described in a UNFCCC Reference Manual[4]. Article 13 specifies the types of information that each Party must provide, including:

(a) "A national inventory report of anthropogenic emissions by sources and removals by sinks of greenhouse gases, prepared using good practice methodologies accepted by the Intergovernmental Panel on Climate Change and agreed upon by the Conference of the Parties serving; and
(b) Information necessary to track progress made in implementing and achieving its nationally determined contribution under Article 4"

Progress of individual Parties toward their NDCs is reported through the ETF, mainly through submission of Biennial Transparency Reports (BTRs), the first of which were due by end 2024. All Parties, with some exceptions for the most vulnerable countries in Small Island Developing States (SIDS) and Least Developed Countries (LDCs), must submit GHG inventories essentially via the BTRs. Industrialized (Annex 1) countries still report on GHG inventories every year.[5]

Article 14 of the PA defines the Global Stocktakes, which requires parties to the PA to:

- *"take stock of the implementation of the Paris Agreement to assess collective progress towards achieving the purpose of this Agreement and its long-term goals (referred to as the "global stocktake")";*
- *"...considering mitigation, adaptation and means of implementation and support, and in the light of equity and the best available science"*
- *"undertake its first global stocktake in 2023 and every five years thereafter...."; and*
- *"The outcome of the global stocktake shall inform Parties in updating and enhancing, in a nationally determined manner, actions and support in accordance*

[4] https://unfccc.int/sites/default/files/resource/v2_ETFreferencemanual.pdf?download
[5] https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/reporting-requirements

with the relevant provisions of this Agreement as well as in enhancing international cooperation for climate action"

The GSTs therefore provide the primary mechanism for periodically assessing global, collective, progress toward the goals of the PA. They include comprehensive reviews of mitigation, adaptation and the means of implementation, considering equity and employing the best available science. The specific modalities of the GSTs are defined in UNFCCC Decision 19/CMA.1[6]. Notably, this document states that *"the global stocktake will be a Party-driven process conducted in a transparent manner and with the participation of non-Party stakeholders."*

2.2. Lessons Learned from Participation in the First Global Stocktake

CEOS and its 34 member agencies play critical roles in the collection, analysis and distribution of space-based, systematic Earth observations (EO) supporting scientific research as well as policy and regulatory applications. Recognizing that these observations could contribute to the Paris Agreement's Enhanced Transparency Framework and represent "best available science" for tracking the drivers and impacts of climate change on regional to global scales, CEOS quickly resolved to support the PA and its GSTs. With encouragement from the UNFCCC Secretariat and the Subsidiary Body for Scientific and Technological Advice (SBSTA), CEOS made three key contributions to the first GST.

1. In collaboration with its partners at the World Meteorological Organization (WMO), Global Climate Observing System (GCOS) and the Group on Earth Observations (GEO), CEOS responded to the SBSTA's Call for inputs from UN agencies and other international organizations, supportive of the UNFCCC process and submitted the report, titled The Role of Systematic Earth Observations in the Global Stocktake.[7] This report identifies opportunities where systematic Earth observations could support the mitigation, adaptation, means of implementation, and other cross cutting objectives of the PA and its GSTs. It also strengthened and refocused partnerships (GCOS, WMO, GEO, and UNFCCC), identifying space-based measurements supporting the PA.
2. Following the first issue of the CEOS-CGMS GHG Roadmap and the initial release of the CEOS GST Strategy, the CEOS Atmospheric Composition Virtual Constellation (AC-VC) and the Joint CEOS-CGMS Working Group on Climate (WGClimate) Greenhouse Gas Task Team (GHG TT) developed and delivered pilot, top-down national-scale CO_2 and CH_4 budgets to the UNFCCC.[8,9] CO_2 and CH_4 were selected for this application because these two GHG gases account for

[6] https://unfccc.int/sites/default/files/resource/CMA2018_03a02E.pdf?download
[7] https://www4.unfccc.int/sites/SubmissionsStaging/Documents/202203012343---SO-in-GST-2022-final.pdf
[8] Byrne, et al. National CO_2 budgets (2015–2020) inferred from atmospheric CO_2 observations in support of the global stocktake. Earth System Science Data, 2023. https://essd.copernicus.org/articles/15/963/2023/
[9] Worden et al., Verifying Methane Inventories and Trends with Atmospheric Methane Data, AGU Advances, (2023) https://doi.org/10.1029/2023AV000871

more than 80% of the observed global warming. In addition, recent advances in space-based observations of CO_2 and CH_4 by CEOS missions were beginning to provide unique information about their atmospheric concentrations and fluxes on regional to global scales. These top-down budgets were intended to support the development of National GHG inventories (NGHGI), contribute to the quality assessments and quality control (QA/QC) of these inventories and to provide a transparent way to assess collective progress toward mitigation goals of the PA.[10]

3. CEOS and its member agencies and partners supported Earth Information Day (EID) and other activities at the COPs to advertise and promote the use of these space-based products and to identify other opportunities to support the GSTs.

These contributions received positive recognition at EID and at the COPs leading up to the first GST. They also yielded key insights into the current state of the art in space-based GHG monitoring capabilities. In particular, they provided key new insights into CO_2 and CH_4 emissions and removals by the land biosphere associated with human activities and climate change. They also provide a critical baseline for quantifying collective progress toward GHG emissions reductions targets on regional scales, especially across the developing world.

This experience also clearly revealed limitations of the first-generation space-based GHG products. In particular, while existing measurements provided a useful constraint on net CO_2 and CH_4 emissions from middle sized and larger nations, they do not have the spatial resolution needed to quantify net emissions from smaller nations. In addition, while these pilot GHG products provided a useful, integrated constraint on the net emission and removals, they did not clearly attribute emissions to specific sectors or categories that must be documented in the Common reporting format (CRF) tables mandated by the UNFCCC National Inventory Reports. In addition, there were no established protocols for comparing or reconciling the space-based top-down GHG products with the bottom-up national inventories submitted to the UNFCCC by the NGHGI community.

In spite of their potential utility, few national inventory compilers adopted these satellite-based products to support inventory development or QA/QC for the first GST. This limited acceptance was initially attributed primarily to four factors:

- While the guidelines for compiling national inventories from the Intergovernmental Panel on Climate Change (IPCC) Taskforce on Inventories (TFI) encourage the use of top-down GHG budgets for inventory QA/QC, Parties have not agreed to mandate their use;
- Most national inventory compilers and policymakers are not familiar with the information content or uncertainties of top-down atmospheric GHG budgets;
- No internationally accepted protocols exist for comparing and reconciling top-down GHG budgets with bottom-up national inventories or using these products to assess progress toward their NDCs; and

[10] https://ceos.org/gst/ghg.html

- The COVID-19 pandemic limited opportunities for capacity building and hindered efforts to enlist "champions" for space-based GHG products among the national inventory and other stakeholders.

Some members of the policy and NHGHI communities also expressed concerns about the accuracy, transparency or sustainability of the space-based GHG products. Others simply noted that they did not have time or resources to consider a new class of data products in their inventory development process.

Recognizing these limitations, CEOS and CGMS commissioned WGClimate to produce a formal report, titled *Lessons Learned and Recommendations from Space Agencies' Support for the First Global Stocktake*.[11] That report documented lessons and recommendations for GHG flux datasets, stakeholder engagement, and communication. It recommends that CEOS work with the IPCC and its TFI to define protocols for reconciling bottom-up national GHG inventories with top-down GHG budgets and develop a more comprehensive and transparent way to document uncertainties. It also recommends the development of atmospheric inverse models with higher spatial resolution to resolve net emissions from smaller countries. To improve the sustainability of these products, the report recommends a transition from research-oriented science missions to sustained operational systems. To improve stakeholder engagement and communications, they recommend that CEOS and CGMS establish broader and more continuous interactions with the UNFCCC and members of the national inventory and policy communities. This includes:

- Building stronger relationships with COP Delegates, leveraging CEOS and CGMS Member Countries at key UNFCCC events;
- Identifying "champions" in the inventory and policy communities who can communicate the value of space-based products in the development and QA/QC of national GHG inventories and empowering these champions to present this information at EID and throughout the COPs;
- Creating a tiger team to coordinate CEOS-CGMS efforts with the UNFCCC at EID and throughout the COPs;
- Leveraging the partnership with WMO for communication at the COPs;
- Forming partnerships to develop transparent, purpose-built GHG products;
- Engage in 2-way capacity building to communicate the information content of space-based GHG products for inventory development and assessment; and
- Working with IPCC and its TFI to identify standard tools and protocols for using space-based GHG and AFOLU products for QA/QC of inventories and for evaluating collective progress toward the mitigation goals of the Paris Agreement

Responses to these lessons and recommendations have been incorporated into this updated *CEOS GST Strategy*.

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11 https://ceos.org/document_management/Meetings/SIT/SIT-40/Documents/4.3_Lessons%20Learned%20Report_03272025.pdf

3. CEOS Support for Mitigation

3.1. Introduction and Policy Context

Recognizing that GHG emissions are the leading cause of anthropogenic climate change, the Paris Agreement's mitigation efforts focus primarily on promoting rapid reductions in GHG emissions and the preservation and enhancement of natural GHG sinks in the land biosphere and ocean. Given this focus, CEOS support for the GSTs initially highlighted the potential role of global space-based observations for monitoring GHG sources and sinks.

The carbon cycle science community and the regulatory community have developed three different approaches to track GHG emissions and removals:

1. **Top-down budgets** derived from atmospheric inversions informed by assimilating GHG measurements from in-situ monitoring networks and satellites into atmospheric transport models;
2. **Bottom-up inventories** based on bookkeeping or process-based models constrained with space-based Earth observations of natural and anthropogenic GHG sources and sinks; and
3. **Bottom-up inventories** derived by combining activity statistics with emission factors, based on empirical or process-based modelling.

The first approach was used by CEOS to compile the national-scale GHG budgets presented to the UNFCCC to support the first GST. The first and second approaches are now being combined to produce the annual, global GHG budgets compiled by the Global Carbon Project[12]. Most National GHG Inventories (NGHGIs) follow the 3rd approach, with different levels of detail, as required by IPCC Guidelines.

To promote transparency and align emissions reporting with real-world conditions, the IPCC encourages Parties to verify reported emissions against independent measurements, such as comparisons with independently compiled inventory databases or with atmospheric GHG measurements interpreted by atmospheric inversion models. However, verification of bottom-up NGHGIs against scientific results derived from atmospheric measurements or bottom-up methods, is not mandatory. In spite of this, a few countries (e.g., Switzerland, the United Kingdom, Aotearoa / New Zealand, and Australia) have added inversions as a consistency check of their national reports.

Space based estimates of CO_2 and CH_4 have dramatically improved our understanding of the abundance and distribution of these two critical GHGs across the globe and their changes over time. Remote sensing observations of reflected sunlight are now being analysed to yield spatially- and temporally-resolved estimates of the column-averaged dry air mole fractions[13] of CO_2 and CH_4. These data are being combined with surface and airborne measurements of these GHGs and analysed with atmospheric inverse models to quantify net fluxes (the net impact of emissions and removals) of both gases at spatial

[12] Global Carbon Budget 2024; https://doi.org/10.5194/essd-17-965-2025
[13] Dry air mole fraction is a measure of the concentration of a trace gas, such as CO_2 or CH_4.

scales spanning large urban areas to the globe. This information is critical for identifying and tracking the natural and anthropogenic processes controlling the growth rates of these gases and predicting their impacts on the climate.

Top-down estimates of CO_2 and CH_4 fluxes now provide a critical new resource for tracking GHG emissions, removals and their trends. They complement the bottom-up national GHG inventories that form the basis of the BTRs and NDCs by providing an integrated constraint on the net effects of all processes that emit or remove these gases from the atmosphere. The bottom-up inventories will continue to provide the most detailed and actionable information about the emissions from critical categories and sectors, such as fossil fuel in the Energy sector, where the activities and emission factors are well known. In principle, these data can be combined with the top-down GHG budgets to assess the fraction of net emissions and removals that is captured by NGHGIs.

Space-based Earth observations are also providing valuable input to bottom-up inventories of GHG emissions and removals from the land biosphere. Agriculture, forestry and other land use (AFOLU[14]) is the second largest source of anthropogenic CO_2, after fossil fuel use, and the largest source of anthropogenic CH_4 emissions. The land biosphere is also a critical sink, removing almost 30% of the anthropogenic CO_2 emitted each year over the past decade. However, both AFOLU emissions and the efficiency of the land carbon sink vary substantially across the globe and from year to year. High-spatial resolution, global, space-based measurements are being analysed and harmonized to yield much better constraints on activity data for forests and crops, providing critical insight into land carbon stock changes associated with land use and land use change. Space-based observations can also improve the quantification of emission factors that are used by national inventory compilers to develop their bottom-up inventories. This information is of particular value across the developing world, where AFOLU is often the primary source of GHG emissions and nations have less capacity to develop detailed bottom-up inventories.

Recognizing the critical need for a better understanding of the carbon cycle and its response to continuing human activity and climate change, CEOS developed comprehensive roadmaps to support the development of both top-down budgets and bottom-up inventories of emissions and removals of GHGs. The CEOS-CGMS GHG Roadmap[15], which was initially endorsed in 2020, and then updated in 2024, coordinates ongoing efforts focused on the development of top-down budgets of CO_2 and CH_4 to support the mitigation goals of the PA and its GSTs. The CEOS AFOLU Roadmap[16], endorsed in 2023, coordinates the development of bottom-up inventories of GHG stocks and fluxes from the land biosphere to support the GSTs. More recently, members of the CEOS ocean carbon community initiated an effort to develop a CEOS

[14] Also called Land Use, Land Use Change and Forestry (LULUCF) by the UNFCCC.
[15] https://ceos.org/document_management/Publications/Publications-and-Key-Documents/Atmosphere/CEOS_CGMS_GHG_Roadmap_Issue_2_V1.0_FINAL.pdf
[16] https://ceos.org/observations/documents/CEOS_AFOLU_roadmap_FINAL_V1.0.pdf

Aquatic Carbon Roadmap, exploring the use of these space-based ocean carbon products to support the mitigation and adaptation goals of the PA and its GSTs.

To exploit synergies across the GHG, AFOLU, and Aquatic Carbon Roadmaps, the updated GHG Roadmap proposes a series of use cases that might be explored to coordinate these efforts. These use cases included:

- Can the GHG, AFOLU, and Aquatic Carbon teams collaborate with the NGHGI community [and IPCC-TFI] to define protocols and best practices for combining and reconciling top-down and bottom-up products for inventory development and assessment?
- Can space-based measurements of AFOLU be combined with space-based estimates of GHG fluxes to produce a more complete and accurate description of emission and removals of GHGs from the land sector?
- Can space-based activity observations be combined with space-based GHG estimates to provide more realistic, regional-scale constraints on emission factors associated with land use change and disturbance that could be used in bottom-up inventories?
- Can soil carbon fluxes be estimated accurately as a residual from AFOLU activity and atmospheric GHG observations?
- Can space-based observations of CO_2, sea surface temperature, winds, salinity and ocean colour be combined with available *in situ* observations of ocean pCO_2 and dissolved carbon to create ocean carbon models that better exploit available *in situ* data to estimate air-sea fluxes?
- Can we reduce the uncertainties on the transport of carbon among land ecosystems, ocean and atmospheric reservoirs? How is this carbon flux changing due to human activity and climate change?

More recently, the joint CEOS - GGMS WGClimate compiled the lessons learned from CEOS - CGMS participation in the first GST.[11] That document lists a series of recommendations to improve the impact of space-based products for the GSTs. The first reinforces the need to reconcile GHG fluxes derived from top-down budgets and bottom-up inventories and to develop more complete and transparent ways to express uncertainties in the reconciled products. The second supports the development of atmospheric inverse models with greater spatial resolution to better exploit the spatial resolution of existing and planned space-based observations and to deliver products that resolve net GHG emissions and removals from smaller countries. Greater coordination among the AC-VC, GHG TT and AFOLU teams would clearly facilitate the implementation of these recommendations. The GHG Roadmap and the Lessons Learned document also encourage greater engagement with stakeholders and partners in the policy, regulatory and science communities (see Section 2.2).

To more effectively address these goals, this section describes a series of activities that could be pursued by CEOS in close collaboration with its partners and stakeholders on a best-efforts basis to support the GSTs. Each activity includes the development or refinement of space-based data products, tools and services that directly addresses

specific inputs identified in the IPCC guidelines or the other deliverables to the UNFCCC. They also describe communications and capacity building activities needed to foster the use of these space-based products to support the GSTs.

3.2. Create Transparent, Global Top-down Budgets for CO_2 and CH_4

Top-down CO_2 and CH_4 budgets provide the most complete, observation-based estimates of the net emissions and removals of GHGs at regional to global scales. These products could provide a scientific basis for evaluating the completeness of bottom-up national inventories and for identifying sub-national regions or specific emission sectors that would benefit from more research. They could also be used by the UNFCCC to assess collective progress toward the primary mitigation goals of the PA. Finally, they could be used by Parties to justify increases in their level of ambition in the mitigation actions described in their NDCs.

The pilot top-down CO_2 and CH_4 products delivered to support the first GST provide a useful baseline for the net emissions of these two gases on regional scales, but were not widely used to compile or assess inventories. Improvements that would foster their use and improve their impact include:

- Co-development of products and tools with partners and stakeholders to better meet specific requirements of the PA and its GSTs.
- Increased spatial resolution of the gridded products to support comparisons with bottom-up emissions inventories for smaller nations;
- A more transparent and accessible description of the information content and uncertainties in the gridded and national-scale CO_2 and CH_4 budgets;
- Internet-based tools that facilitate access to space-based top-down GHG budgets and allow comparisons of these products to the results reported in specific emission sectors (e.g. Energy or AFOLU) in bottom-up NGHGIs; and
- Two-way communications and capacity building to inform users of the information content and uncertainties in these products, and to train users in their application in the context of the GSTs.

The 2024 CEOS GHG Roadmap describes an updated plan for developing global, gridded maps of CO_2 and CH_4 concentrations and both gridded and national-scale, top-down CO_2 and CH_4 flux budgets to support the GSTs. The GHG TT proposes to work with partners across CEOS and across the scientific community to develop and deliver these products, along with their uncertainties to the UNFCCC. Initially, the spatial resolution and data latency of these products will be limited by the spatial sampling and repeat frequencies of the first-generation GHG missions. However, as the next generation of space-based sensors comes on line with increased spatial resolution, coverage and repeat frequency, the goal is to deliver top-down GHG products that meet the spatial resolution and latency targets adopted by the World Meteorological Organization Global Greenhouse Gas Watch (WMO G3W). This requires the delivery of gridded GHG concentration and flux budgets at a spatial resolution of 1° x 1° or finer at monthly intervals.

Recommendation: The CEOS GHG-TT should work with its partners in the AC-VC and AFOLU teams and within the scientific community to create global, gridded GHG concentration maps and top-down flux budgets, with uncertainties, at a spatial resolution of 1° x 1° or finer at monthly intervals.

3.2.1. Key CEOS Entities

The CEOS GHG Roadmap identifies the following key CEOS entities whose efforts must be coordinated to meet these objectives:

- **GHG TT** - Leading the CEOS-CGMS GHG efforts and serving as the primary interface to the UNFCCC;
- **AFOLU Team** - Supporting the GHG TT with information about carbon stocks and fluxes from the land biosphere and the current state of the art for land carbon measurements and models (used as priors in the flux inversions);
- **AC-VC** - Supporting the GHG TT by tracking space-based GHG measurement capabilities, improvements in GHG retrieval and flux inversion algorithms and ongoing developments of CO_2 and CH_4 concentrations and flux products;
- **Working Group on Calibration and Validation (WGCV)** - Supporting the GHG TT with updates on GHG sensor calibration and data product validation capabilities and opportunities;
- **Working Group on Capacity Building and Data Democracy (WGCapD)** - Supporting the GHG TT with the development of communications and training activities to build awareness of the availability and information content of top-down GHG budgets and to build the skills needed to apply these products for development and evaluation of inventories and for assessments of collective progress toward the goals of the PA.
- **System Engineering Office (SEO)** - Supports CEOS with digital infrastructure and communications through web-based tools. This support may be critical for fostering the use of EO GHG products by the policy and NGHGI communities.

3.2.2. Key External Partners

To foster broader use of these products, the GHG TT has resolved to establish broader and more continuous interactions with members of the national inventory and policy communities. Key partners in the international science community include:

- **WMO G3W** - acting as the principal customer for the gridded, top-down CO_2 and CH_4 concentration and flux products and serving as the primary distribution mechanism for disseminating these products across the WMO community;
- **WMO Integrated Global Greenhouse Gas Information System (IG3IS)** - Providing CO_2 and CH_4 concentrations from ground-based and airborne GHG measurements and insight into emissions from large urban areas;
- **Global Carbon Project (GCP) Regional Carbon Cycle Assessment and Processes (RECCAP)** - Annual estimates of CO_2 and CH_4 emissions and removals from fossil fuel use, land use change and the oceans derived using bottom-up and top-down methods by a global network of carbon cycle scientists.

- **IPCC-TFI and UNFCCC** - Defining and socializing requirements for top-down CO_2 and CH_4 concentration and flux products and methods for their use in development and evaluation of inventories and for assessments of collective progress toward the goals of the PA.

The GHG TT plans to include stakeholders who could benefit from these products, tools and activities in their formulation, and development, to the extent practical. The primary stakeholders for these products include:

- **UNFCCC and its Bodies**: This includes the COP, Subsidiary Body for Scientific and Technological Advice (SBSTA), and Subsidiary Body for Implementation (SBI), responsible for implementing the PA and its GSTs and assessing collective progress toward the top-level goals of the PA;
- **Parties to the Paris Agreement**: COP delegates and members of their inventory development agencies, responsible for delivering bottom-up GHG inventories supporting the PA's transparency framework;
- **Sub-National Stakeholders:** Organizations such as C40 Cities, Global Covenant of Mayors, Governor's Climate and Forest Task Force (GCF), that focus on climate mitigation and climate resilience and often play key roles in climate finance;
- **The Scientific Assessment Community:** Organizations, including the IPCC, WMO, GCP, and national regulatory agencies that compile and release annual to semi-decadal climate assessments; and
- **Non-Governmental Organizations (NGOs):** Organizations, such as the Environmental Defence Fund (EDF), Natural Resources Defence Council (NRDC), and Rainforest Alliance, Climate Action Network, who promote sustainable practices, based on the best available science.

3.2.3. Timelines and Reporting Requirements

While these top-down GHG concentration and flux products will eventually be produced at monthly intervals, they should be compiled and documented at yearly, or at most biennial intervals, to support BTR and NDC development and assessment and to facilitate efforts by Parties to track progress toward their NDCs. At the same frequency, the GHG TT should work with the AC-VC and AFOLU teams to produce at least one citable, peer-reviewed scientific publication describing the top-down GHG budgets.

Capacity building activities (webinars, workshops) should be conducted at annual to biennial intervals to support these activities. A key opportunity to communicate these scientific products to relevant audiences is the annual EID and other activities throughout the COPs. CEOS and its partners should work with the UNFCCC to fully exploit these opportunities. All CEOS entities listed above should report their progress and plans as part of their regular reports to the CEOS Strategic Implementation Team (SIT) and at the annual, spring SIT meeting and the fall Technical Workshop as required.

3.3. Reconciling Scientific Bottom-up Inventories and Top-down Budgets

The national-scale, top-down GHG budgets described in the previous subsection provide a useful, integrated constraint on net emission and removals. However, they often do not resolve the specific sectors or facilities responsible for these emissions and therefore provide limited guidance of emissions management. To derive this information, the top-down budgets must be combined with bottom-up inventories, which document emissions and removals from known GHG sources and sinks.

As noted in the introduction to this section, the NGHGI and scientific communities have developed different methods for compiling these bottom-up inventories. The NGHGI community typically estimates emissions and removals of GHGs by combining activity data (e.g. the number tons of coal burned or the number of mega-Watts of electricity generated) with emission factors (e.g., number of tons of CO_2 released when a ton of coal is burned or a mega-Watt of electricity is produced). This approach can yield accurate results for estimating fossil fuel emissions from the Energy sector, where the activity is easily quantified and emission factors are well known. It is much less reliable for estimating emissions associated with AFOLU, where activities and emission factors are much more challenging to accurately quantify. The AFOLU inventories developed by the NGHGI are incomplete by design, specifically omitting emissions or removals of GHGs from "unmanaged land" or from the ocean.

To address these limitations, the scientific community has adopted a complementary approach that uses bookkeeping methods, which track land carbon stocks, and/or Dynamic Global Vegetation Models (DGVMs), informed by space-based measurements, to estimate carbon emissions and removals from the land biosphere.[12] Ongoing efforts by the CEOS AFOLU team are supporting these efforts with improved, harmonized above ground biomass (AGB) maps. Similarly, ocean carbon fluxes are estimated by combining measurements of ocean acidity or CO_2 partial pressure (pCO_2) collected by ships, buoys or autonomous vehicles, with space-based observations of ocean colour and meteorological parameters (winds, sea surface temperatures) in empirical models or Global Ocean Biogeochemical Models (GOBMs). These methods are being used by the carbon cycle science community to produce global, gridded scientific GHG emissions inventories that distinguish CO_2 and CH_4 emissions and removals by sector (e.g., Energy, Industry, AFOLU, Waste), along with their uncertainties, at a spatial resolution as high as 1° x 1° at monthly to annual intervals.

In principle, these bottom-up, gridded scientific inventories provide independent information on emissions and removals of GHGs. Also, because they distinguish emissions by sector, they should provide a means to assess the quality and completeness of country-scale inventories produced by the NGHGI community. These comparisons should be much easier to interpret than comparisons with top-down budgets described in the previous section. A key challenge to this approach is that inventories derived using these methods are themselves prone to large uncertainties in:

(i) the spatial distribution of surface GHG fluxes over some regions or countries due to model structural differences, parameter values and model input data;

(ii) the land-use, land-cover change and management input datasets used to estimate corresponding fluxes by bookkeeping models and Dynamic Global Vegetation Models are sometimes inaccurate, incomplete, or out of date; and

(iii) the attribution of fluxes to human vs. natural processes, or to managed vs. unmanaged lands is often ambiguous.

In part due to these issues, bottom-up scientific inventories developed by different groups often yield results that disagree substantially, introducing confusion and eroding confidence in their value for QA/QC of the statistical inventories compiled by the NGHGI community. Another factor that impairs the utility of bottom-up scientific inventories for QA/QC of the country-scale inventories developed by the NGHGI community is differences in definitions for different types of emissions.[17]

The development and expansion of Earth Observation (EO) networks and satellite data relevant to the carbon cycle have the potential to greatly improve NGHGIs, bookkeeping and Dynamic Global Vegetation Models, but are still underused. The following sub-sections describe two promising approaches for addressing this problem.

3.3.1. Protocols for Reconciling National GHG Inventories with Scientific Bottom-up Inventories and Top-Down Budgets

Engaging in an open dialogue between the scientific community and stakeholders at the IPCC and NGHGI agencies is fundamental to define protocols for comparing and reconciling bottom-up national inventories with bottom-up scientific GHG inventories and top-down budgets. It should also reduce uncertainties in estimates of GHG budgets, improve comparability of different approaches (definitions, sectors, uncertainties of each approach) and identify mismatches that can reveal problematic sectors.

Case studies in the scientific literature demonstrate the added value of this approach and support a deeper integration of EO data in models used to quantify different terms of carbon budgets and attribute them to specific processes. Among those studies is the REgional Carbon Cycle Assessment and Processes project phase-2 (RECCAP2), part of the Global Carbon Project.[18] The objective of that study was to produce the best possible regional budgets of CO_2, CH_4 and nitrous oxide (N_2O) in a globally consistent way while accounting for both emissions covered by GHG inventories and terrestrial and oceanic fluxes not covered by those inventories. To meet this objective, the RECCAP2 group considered both top-down budgets and bottom-up inventories. They also engaged directly with NGHGI agencies to improve understanding of the methods used by each community to estimate GHG sources and sinks and to evaluate the potential of systematic Earth observations from satellites and in situ sensors to improve national inventories. In addition to these efforts, it is also necessary to work with stakeholders in

[17] Ciais et al., Definitions and methods to estimate regional land carbon fluxes for the second phase of the REgional Carbon Cycle Assessment and Processes Project (RECCAP-2), Geoscientific Model Development, 2022. https://doi.org/10.5194/gmd-15-1289-2022

[18] Bastos et al., On the use of Earth Observation to support estimates of national greenhouse gas emissions and sinks for the Global stocktake process: lessons learned from ESA-CCI RECCAP2, Carbon Balance and Management, 2022. https://doi.org/10.1186/s13021-022-00214-w

the policy community to identify or develop space-based products that quantify emissions changes associated with national-scale policy-related GHG reduction strategies (e.g., changes in energy sources, nature-based GHG-reduction strategies).

Recommendation: CEOS should work with its partners in the scientific community and with the IPCC-TFI and the NGHGI community to develop commonly accepted tools and protocols for comparing and reconciling bottom-up NGHGI inventories with top-down and bottom-up GHG products derived from space-based EO.

CEOS should reinforce these efforts by working closely with the scientific and NGHGI communities and the IPCC to develop a series of protocols for comparing and reconciling these methods for tracking GHG emissions and removals. This effort should exploit tasks being conducted in support of the GHG and AFOLU Roadmaps. CEOS should also foster more continuous interactions among the top-down (i.e., the Orbiting Carbon Observatory Multi-model Intercomparison Project, OCO-MIP) and bottom up (e.g., GCP/RECCAP) scientific communities with the objective of developing products that are fully reconciled, within their uncertainties, at national scales for all but the smallest nations.[8, 9, 19]

Recommendation: CEOS should work actively with these partners and the IPPC-TFI to identify commonly accepted protocols for comparing and reconciling NGHGI inventories with scientific inventories.

3.3.2. AFOLU Products Supporting Bottom-up National Inventory Development

Once the bottom-up inventories and top-down budgets created by CEOS and its partners in the scientific community are more completely reconciled, CEOS should work with the IPCC-TFI and the NGHGI community to co-develop and deliver harmonized, space-based products supporting bottom-up national inventory development for Biennial Transparency Reports (BTRs).

One source of error in the bottom-up national inventories for AFOLU developed by the NHGHI community is the use of obsolete, incomplete or inaccurate estimates of the aerial coverage or classification of land use change activity. Another source of error is the use of Tier 1 emission factor databases for land use change that are not representative of their local environment.

In principle, once reconciled, the bottom-up GHG inventories and top-down GHG budgets developed by the CEOS AFOLU and GHG TT can be combined to produce more complete and traceable regional-scale emission factor databases for use in the NHGHIs reported in the BTRs. For example, space-based land cover maps can be combined with maps of above ground biomass (AGB) to provide more complete, observation-based

[19] Deng et al., Global greenhouse gas reconciliation 2022. Earth System Science Data. 2025. https://doi.org/10.5194/essd-17-1121-2025

estimates of land carbon stocks over forests. Changes in these maps over time can be analysed to yield estimates of stock change activity on regional scales. These estimates of stock changes can then be combined with top-down estimates of CO_2 fluxes to yield observation estimates of CO_2 emission factors (e.g., the rate of change in atmospheric CO_2 abundance associated with the observed change in forest carbon stocks). This approach combines key land cover and AGB initiatives described in the AFOLU roadmap with the top-down fluxes described in the GHG Roadmap. In principle, these products could be validated over the Biomass Reference Measurement sites (BRM) defined in the AFOLU Roadmap and then expanded to other regions.

Recommendation: Once the regional-scale bottom-up and top-down GHG products are adequately reconciled, the CEOS AFOLU, AC-VC and GHG TT should:

- Identify and recommend global, land cover and land use change maps best suited for quantifying land use activity on national scales;
- Identify and recommend the best (harmonized) global, space-based products for quantifying changes in above-ground biomass (AGB) stocks reported in BTRs and tracked in NDCs; and
- Explore ways to combine land use change, AGB and GHG products to develop sub-national to regional-scale emission factor databases for land use and land use change emissions estimates for use in developing bottom-up inventories.

3.3.3. Key CEOS Entities and Partners

Key CEOS entities that could contribute to this effort include the GHG and AFOLU Teams, the AC-VC and WGCapD. The specific roles are similar to, but slightly broader than those defined in Section 3.2, because here, the objective is to not only produce, but to harmonize the top-down and bottom-up products, and to socialize the protocols used for reconciliation. In addition, broader participation by Land Surface Imaging Virtual Constellation (LSI-VC) may be needed to identify the best space-based products for quantifying land use and land use change. Here, SEO support may be critical for developing user-friendly, web-based tools that will facilitate access to these products by the policy and NGHGI communities. In addition,

WGCapD should work with subject matter experts in the AFOLU, AC-VC and GHG TT to develop lesson plans for building the capacity needed within these communities to use the products in a uniform, self-consistent way to build and validate GHG inventories.

Recommendation: WGCapD should work with subject matter experts on the AFOLU, GHG TT and AC-VC GHG teams and with the NGHGI community to develop capacity building materials that provide a transparent explanation of the information content and uncertainties of these products.

3.3.4. Timelines and Reporting Requirements

Reconciled, top-down and bottom-up products should be compiled and documented at biennial intervals, to support BTR and NDC development and assessment process and to facilitate efforts by Parties to track progress toward their NDCs. The AFOLU team should

work with LSI-VC to provide updated land use change maps at biennial intervals to support the BTRs. Efforts to harmonize AGB products are already under way and should also target the delivery of updated nation-scale products on biennial intervals.

The effort to produce updated emission factor databases (task 3) will have to follow the development, validation and reconciliation of the top-down GHG budgets and bottom-up GHG inventories described in the previous two sub-sections. This could take up to a decade. However, once those objectives are met, these groups should plan to produce updated products on biennial intervals.

On yearly to biennial timescales, the AFOLU team should work with its partners in the AC-VC GHG and GHG Task teams to produce at least one citable, peer-reviewed scientific publication describing the reconciled bottom-up inventories and top-down GHG budgets. Capacity building activities (webinars, workshops) describing these products should also be conducted at annual to biennial intervals to support these activities. The annual Earth Information Day and other activities throughout the COPs provide valuable opportunities to report progress across the stakeholder community. The AFOLU team and its partners in the GHG TT and AC-VC should report their progress and plans as part of their regular reports to the CEOS Strategic Implementation Team (SIT) and at the annual spring SIT meeting and fall Technical Workshop as required.

3.4. Detecting and Monitoring the Largest Emitters of CO_2 and CH_4

High-spatial-resolution, facility-scale GHG plume monitors complement the regional-scale global mappers with greater sensitivity to emissions from intense, CO_2 and CH_4 point sources, such as large fossil-fuel-fired power plants, or large CH_4 pipeline leaks. The GHG Roadmap identifies two specific areas where a more comprehensive, international effort to coordinate high-spatial resolution observations of GHGs would provide benefits to the policy and regulatory communities. The first addresses the attribution of emission sources to specific sectors and facilities. The second identifies standards and best practices that can be shared by public-sector space agencies and New Space organizations.

3.4.1. Source Attribution

While regional-scale global GHG mappers provide reliable estimates of the integrated net emissions from a region or nation, they often provide less direct insight into specific facilities or sectors responsible for those emissions. This information is critical for compiling and maintaining bottom-up GHG inventories or managing emissions. Observations by individual, high-spatial-resolution GHG plume monitors or coordinated "tip-and-cue" observations, where these systems are tasked to follow up on sites where global mappers have detected enhanced CO_2 or CH_4 concentrations, are now being used to monitor intense emission sources.[20] Improved coordination of these observations

[20] https://atmosphere.copernicus.eu/cams-methane-hotspot-explorer-app-new-interactive-emissions-detection-tool

would enable more rapid revisits to support alerts and mitigation action, where appropriate. This coordination would also facilitate the attribution of top-down CO_2 and CH_4 fluxes derived from inverse models to specific categories of specific emissions sectors to support the development and verification of bottom-up national inventories submitted to the UNFCCC.

The GHG TT has taken the lead in the effort to coordinate the observations collected by global mappers with those from plume monitors across the civil space and New Space communities. The AC-VC is helping to coordinate ongoing efforts by members of the scientific community who are developing and implementing improved methods for detecting and quantifying emissions from intense CO_2 and CH_4 plumes. Other key partners in this effort include United Nations Environmental Program (UNEP) International Methane Emissions Observatory (IMEO), which is using high-resolution CH_4 plume data as critical inputs to its Methane Alert and Response System (MARS).

Recommendation: CEOS should work with its partners in UNEP IMEO to coordinate observations from CH_4 global mappers with those collected by high-resolution plume monitors to support alerts and to monitor emissions from the largest methane point sources.

3.4.2. Standards and Best Practices

The adoption of common, internationally recognized standards for the collection, analysis, documentation and distribution of space-based GHG products could improve the interoperability and transparency of both civil space and New Space GHG products. This would enhance confidence in the trustworthiness of these products to stakeholders in the commercial, financial and policy communities.

To foster the development of standards and best practices, members of the CEOS AC-VC worked closely with standards organizations including the U.K. National Physical Laboratory (NPL) and the U.S. National Institute for Standards and Technology (NIST) and scientists at Lawrence Berkeley National Laboratory to produce the CEOS *Common Practices for Quantifying Methane Emissions from Plumes Detected by Remote Sensing.* This document promotes consistency in the generation, validation, reporting, and quality assessment of CH_4 emission estimates derived from remotely sensed radiances. It also encourages coordination of controlled release experiments for assessing the detection limits and accuracy of CH_4 fluxes derived from these observations.

While existing CEOS efforts have focused primarily on methane emissions from discrete point sources, this work provides a framework that could be expanded to compile standards and best practices for monitoring intense CO_2 plumes from large fossil-fuel-fired power plants and large industrial sources. That effort could provide policy makers and GHG inventory compilers with a transparent, independent approach for track changes in CO_2 as well as CH_4 emissions associated with GHG emission policies and regulation efforts.

Recommendation: CEOS should work with its partners (e.g., GCOS, WMO), the IPCC-TFI and members of the scientific community to define standards and best practices collecting, analysing, documenting and delivering high-spatial resolution, space-based observations of CO_2 emissions over large fossil fuel fired power plants and industrial sources to track changes in emissions associated with user demand or emissions reduction policies and regulations.

3.4.3. Key CEOS Entities and Partners

Thus far, the key CEOS entities that have focused on tracking large emission sources have been the AC-VC GHG Group and the GHG TT. The primary external partners have been the UNEP IMEO and the individual public sector and New Space agencies operating high-spatial-resolution plume mappers. CEOS should encourage this consortium to continue and reinforce its collaboration to meet these objectives. WGCapD should work with subject matter experts in the AC- VC and GHG TT to develop lesson plans needed to inform and build capacity within both the data-gathering community (public sector and New Space) and the stakeholder community (fossil fuel industry, policy and regulatory communities). These capacity building materials should describe the information content and uncertainties in these data as well as the standards and common practices for their collection, documentation and distribution.

3.4.4. Timelines and Reporting Requirements

In general, the latencies for identifying and reporting large emission anomalies is much shorter than that for other activities here. For example, the IMEO MARS program has targeted a latency of less than one day for reporting large leaks associated with the extraction, transport and storage of CH_4. This short timescale places stringent constraints on data acquisition, downlink and analysis systems. High-frequency, low-latency observations of large CO_2 emission sources, such as fossil fuel fired power plants would also facilitate efforts to assess the impacts of emissions reduction policies or to identify opportunities for additional emissions reductions.

On annual timescales, CEOS should continue to foster interactions among key partners and stakeholders by encouraging participation in its regular VC and WG meetings. In addition, at biennial intervals, the GHT-TT should work with its partners in the AC-VC and at IMEO to produce at least one citable, peer-reviewed scientific publication describing their progress in monitoring the largest CO_2 and CH_4 emission sources.

CEOS should exploit the annual Earth Information Day and other activities throughout the COP to inform stakeholders on progress and challenges in these areas. The GHG TT and AC-VC GHG team should report their progress and plans on these tasks as part of their regular reports to the CEOS Strategic Implementation Team (SIT) and at the annual spring SIT meeting and fall Technical Workshop as required.

4. CEOS Support for Adaptation

4.1. Introduction and Policy Context

Human-caused climate impacts are already being felt across every region of the world. With impacts becoming more frequent and intense as the world warms, climate adaptation has become a global necessity. Effective adaptation requires not only developing viable solutions but also the ability to monitor threats and vulnerabilities and evaluate progress across various scales and dimensions. These assessments, in turn, necessitates meaningful indicators, metrics, and corresponding datasets. Earth Observation (EO) data, particularly from space-based systems, offers significant potential to support the tracking of targets under the Global Goal on Adaptation (GGA) and the development of associated indicators.

Adaptation is defined by the IPCC as the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. This includes adjusting to increasing extreme events, sea level rise, increased climate variability, and associated impacts. Adaptation involves a wide range of reactive and proactive actions aimed at lowering climate risk by reducing exposure and vulnerability to climate hazards and increasing adaptive capacity. While traditionally viewed as a local issue, the transboundary and cascading nature of climate risks increasingly demands effective adaptation at multiple scales, including the global level.

The GGA, outlined in Article 7.1 of the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement, aims to enhance adaptive capacity, strengthen resilience, and reduce vulnerability to climate change, contributing to sustainable development and ensuring an adequate adaptation response within the context of the temperature goals stated in Article 2. Article 7 also encourages countries to plan for adaptation through National Adaptation Plans (NAPs) and to integrate adaptation into their Nationally Determined Contributions (NDCs).

Since the signing of the Paris Agreement, subsequent Conferences of the Parties have developed a framework for the Global Goal on Adaptation (GGA, Article 7.2 of the PA), comprising eleven global targets based around sectors and the adaptation policy cycle.[21] The seven theme or sectoral targets are Water (9a), Food & Agriculture (9b), Health (9c), Ecosystems and Biodiversity (9d), Infrastructure and Human Settlements (9e), Poverty eradication (9f), and Cultural heritage (9g). Four other targets (10a-10d) refer to the policy cycle: 1. Impact, Vulnerability and Risk Assessment, 2. Planning, 3. Implementation, 4. Monitoring and Evaluation. The GGA targets a 2030 timeframe and adaptation indicators are being developed to track progress towards the GGA framework. These indicators are expected to be adopted at COP 30 (November 2025).

The criteria for assessing the indicators are based loosely on the following specifications coming from UNFCCC SB60 meeting (June, 2024):

(a) adaptation-relevance;
(b) quantitative/qualitative aspects;

[21] Decision 2/CMA.5, https://unfccc.int/sites/default/files/resource/cma2023_16a01E.pdf?download

(c) data availability;
(d) capacity to reflect local/national/regional circumstances;
(e) applicability across contexts;
(f) ease of interpretation;
(g) clarity of methods;
(h) aggregability and dis-aggregability across social dimensions;

The increased global focus on adaptation, through the adoption of global targets and the subsequent development of indicators, provides a much-needed framework for informing, focusing, and guiding action. That framework has been comparatively lacking relative to mitigation efforts. Global scale methods and data are essential to track this progress, highlighting the critical role that EO can play. One such effort is the UN's Early Warning for all (EW4All), which seeks to ensure that everyone is protected from hazardous weather, water, or climate events through life-saving early warning systems.

Despite overall progress, the world is not collectively on track towards achieving climate mitigation or adaptation goals. Monthly and now annual breaches of 1.5°C global temperatures serve as a stark reminder of the urgent need to increase ambition and accelerate climate action. The IPCC 6th Assessment report[22] concludes that the effectiveness of adaptation for reducing climate risk will decrease with increasing global warming, showing that mitigation and adaptation must go together hand-in-hand rather than opting for one over the other.

If climate impacts exceed those accommodated by adaptation efforts, even when fully implemented, then losses and damages occur. The term, Loss and Damage (L&D), originates from the Warsaw Mechanism on Loss and Damage (2013). That initiative intends to 'address loss and damage associated with impacts of climate change, including extreme events and slow onset events, in developing countries that are particularly vulnerable to the adverse effects of climate change.'

A Fund for responding to Loss and Damage serving the Paris Agreement is presently being established and operationalised.[23] This Loss and Damage Fund can succeed only if many countries contribute to it, and if it relies on transparent criteria for justly distributing its means. Scientific findings that clearly link loss and damage to climate change could encourage states to contribute financially and to identify the recipients of the fund's disbursement mechanisms. If such findings can serve as unbiased criteria, they are likely to increase acceptance of the fund.

In principle, attribution science can provide a solid, unbiased basis for tracing climate trends to loss and damage. This approach assesses links between extreme weather events to anthropogenic climate change by ascertaining whether and to what extent certain events have become more frequent or more intense because of climate trends. Changes in the probability or frequency of occurrence of such events can be derived using climate models. Furthermore, trend attribution can identify and ascribe

[22] https://www.ipcc.ch/report/ar6/wg2/chapter/summary-for-policymakers/

[23] https://unfccc.int/fund-for-responding-to-loss-and-damage

slow-onset events such as, sea level rise to climate change. Attribution science might also contribute to the identification of donor states and legitimate claimants due to the ability to provide a more precise allocation of polluter states and those particularly vulnerable to the adverse effects of climate change.

A transparent, reproducible and flexible framework that formalizes how end-to-end attribution could inform litigation by assessing whose emissions are responsible and for which harms have been outlined in Calahan and Mankin (2025)[24]. A protocol for probabilistic extreme event attribution analyses has been proposed by Philip et al. (2020)[25]. The first step in this process is the analysis of observational data. For attribution studies to be robust, they must be based on high-quality long-term observational data and accurate climate models.

4.2. CEOS and Agency Contributions to Date

Space-based Earth observations gather information about the physical, chemical, and biological systems of the planet. Space-based EO is crucial to the climate adaptation process by providing independent, accessible information with consistent and broad spatial coverage, useful for identifying and quantifying climate risks and monitoring adaptation measures. EO data is objective, repeatable, and globally consistent, although challenges exist in data disaggregation, integration with socio-economic factors, and establishing long-term baselines.

CEOS coordinates civil spaceborne EO missions and promotes interoperable EO data and tools and plays a key role in supporting adaptation policy through:

- **Ensuring Continuity of Missions**: CEOS works to ensure the continued operation of critical EO sensors. These missions provide the long-term, consistent data records necessary for monitoring climate variables and changes relevant to adaptation.
- **Essential Climate Variables (ECVs)**: GCOS defines 55 ECVs, many of which (37) can be measured from space. CEOS-CGMS WGClimate supports these ECVs, which are foundational for monitoring the climate system and understanding its changes. Space agencies use ECVs as the basis for their long-term EO planning and the creation of Fundamental Climate Data Records (FCDRs). CEOS maintains an ECV inventory, serving as a gateway to this information.[26]
- **Analysis Ready Data (ARD)**: CEOS promotes the development of ARD to make EO data easier for users to process and apply. This addresses historical constraints related to technical barriers and the need for specialized expertise and develops standards for high-level datasets.[27]

[24] Callahan, C.W., Mankin, J.S. Carbon majors and the scientific case for climate liability. *Nature* 640, 893–901 (2025). https://doi.org/10.1038/s41586-025-08751-3
[25] Philip, S., Kew, S., van Oldenborgh, G. J., Otto, F., Vautard, R., van der Wiel, K., King, A., Lott, F., Arrighi, J., Singh, R., and van Aalst, M.: A protocol for probabilistic extreme event attribution analyses, Adv. Stat. Clim. Meteorol. Oceanogr., 6, 177–203, https://doi.org/10.5194/ascmo-6-177-2020, 2020.
[26] https://climatemonitoring.info/ecvinventory/
[27] https://ceos.org/ard/

- **Working Group on Disasters**: CEOS engages through Working Group on Disasters (WGDisasters) to deliver EO products for preparedness and disaster risk reduction.

While space-based EO informs numerous adaptation studies, its full potential remains under-exploited due to intrinsic limitations and an underdeveloped value chain. Currently, most applications that use space-based EO focus on the hazard component of the Risk Framework (hazard, exposure, vulnerability, and response). Here, space-based EO can provide climate hazard information, and to a lesser degree exposure to climate threats. There is less current use of EO for assessing climate vulnerability or monitoring highly synthesised compound indicators relevant to adaptation outcomes.

The use of space-based EO is often less visible in efforts attempting to attribute hazards or vulnerabilities to human-induced climate change for two reasons. First, these data must be incorporated into models to provide the traceability from cause to effect. Second, in these applications, space-based EO products are often not as useful as *in situ* EO due to their relatively short records, discontinuities, limited resolution and large biases compared to ground-based observations. Some of these limitations can be addressed through ongoing improvements in precision, accuracy, resolution and coverage provided by space-based EO. Others might be addressed through the development of new, purpose-built EO products.

4.3. Main Stakeholders and Initiatives for Engagement

Effective support for climate adaptation requires engagement with a diverse set of stakeholders and initiatives across multiple levels, both within and outside the UN system. These stakeholders and partners, and their primary roles are summarized in the following two sub-sections and in Figure 1.

4.3.1. Within the UN System

- **UNFCCC and its Bodies**: This includes the Conference of the Parties (COP), the Subsidiary Body for Scientific and Technological Advice (SBSTA), the Subsidiary Body for Implementation (SBI), the Adaptation Committee (AC), and the Least Developed Countries Expert Group (LEG). The ongoing process to define indicators for the GGA Framework presents a critical opportunity for EO integration. EO can support reporting requirements under the Enhanced Transparency Framework (ETF) and contribute to the GSTs.
- **Global Goal on Adaptation (GGA)**: Tracking progress towards the 11 global targets of the GGA is paramount. EO can support monitoring across thematic areas like agriculture, biodiversity, extremes, and health. There is a need to investigate how EO can provide systematic, sustainable intelligence for GGA indicator derivation.
- **National Adaptation Plans (NAPs)**: NAPs are the primary vehicle for countries to plan and implement adaptation actions. EO data and services can enhance the quality, accuracy, and comprehensiveness of NAPs, particularly for vulnerability and risk assessments, monitoring, and reporting. Engagement with LEG is crucial for supporting LDCs in this process.

- **Global Climate Observing System (GCOS)**: As a co-sponsored program addressing UNFCCC's systematic observation agenda, GCOS is a fundamental partner. GCOS defines Essential Climate Variables (ECVs) for monitoring climate change as well as their observational requirements. The GCOS Adaptation Task Team (GATT) focuses specifically on how global observations can support adaptation. GCOS highlights the need for improved data resolution, completeness, and integration with non-climatic data for local adaptation.
- **World Meteorological Organization (WMO)**: WMO co-sponsors GCOS and plays a critical role in the UN's Early Warning for All initiative (EW4ALL), leading its Pillar on detection, observation, monitoring, analysis, and forecasting.
- **Intergovernmental Panel on Climate Change (IPCC)**: IPCC assessments provide the scientific basis for understanding climate risks and adaptation needs. Engaging with the IPCC process and their selected experts helps identify observational needs. As an Annex to the Working Group II Report, the latest Assessment Report (AR7) will feature Technical Guidelines for Assessing Climate Change Impacts and Adaptation Including Indicators, Metrics and Methodologies.
- **Other UN Entities**: UNEP (co-sponsor of GCOS, Adaptation Gap Report), UNESCO-IOC (co-sponsor of GCOS), ISC (co-sponsor of GCOS), UNDRR (Sendai Framework, MHEWS), UN-Habitat (New Urban Agenda, sustainable urban development), FAO, WFP (food security, early warning). EW4ALL is supported by the UN Development Programme (UNDP), UN Environment Programme (UNEP), UN Office for Disaster Risk Reduction (UNDRR) and the International Telecommunication Union (ITU).

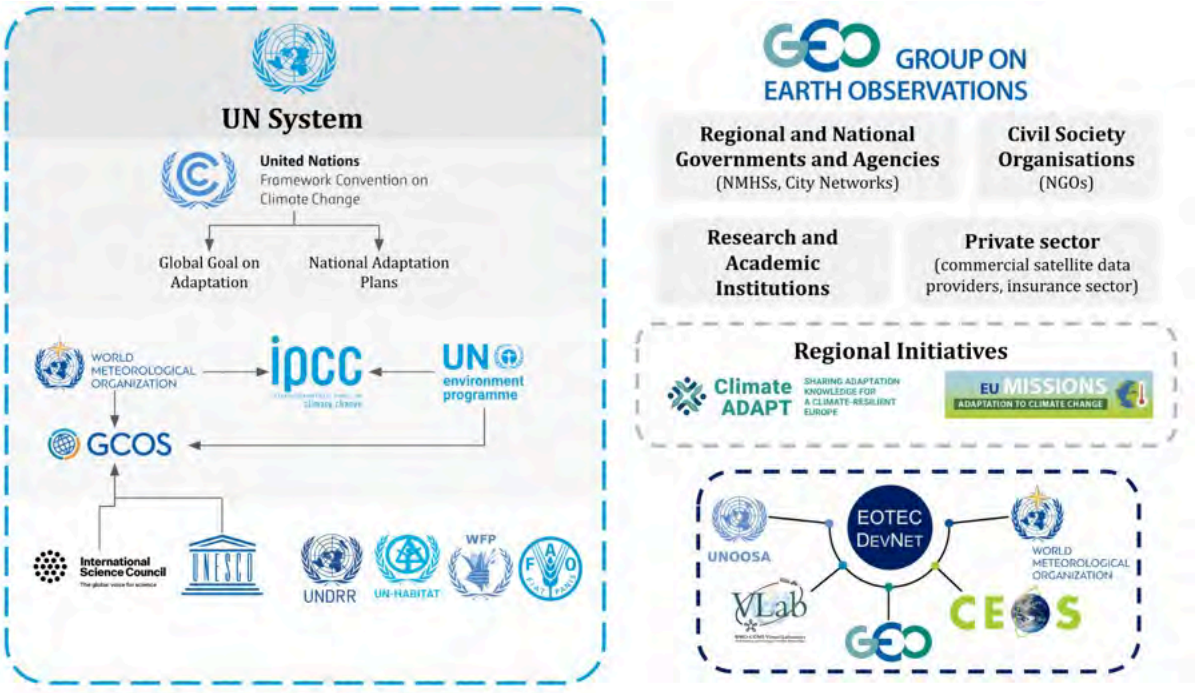


Figure 1: Key stakeholders and partners in climate adaptation.

4.3.2. Outside the UN System

- **Group on Earth Observations (GEO)**: GEO promotes the uptake and use of EO data across sectors and governance levels, complementing CEOS efforts. GEO has initiatives directly supporting NAPs (GEO-GNAP, GEO NAP Toolkit) and specific adaptation themes like agriculture (GEOGLAM) and urban areas (GEO for Cities).
- **Coordination Group on Meteorological Satellites (CGMS):** CGMS coordinates the large fleet of operational satellites used for weather fore- and nowcasting, climate and environmental monitoring. It plays an essential role supporting the EW4ALL initiative with the provision of observations in real time and climate data records. It is partnering with CEOS in the joint Working Group on Climate.
- **International Federation of Red Cross and Red Crescent Societies (IFRC)**: World's largest humanitarian network and the lead of the UN's EW4ALL Pillar on Preparedness and response capabilities.
- **Regional and National Governments and Agencies**: National Meteorological and Hydrological Services (NMHSs) are key for the provision of *in situ* data and climate services as well as the integration of satellite data into such services. Ministries responsible for agriculture, environment, health, disaster management, and planning are end-users of adaptation information. Regional entities like the European Environment Agency (EEA) play a crucial role, particularly in Europe.
    - **City Networks**: Networks like the Global/European Covenant of Mayors, C40 Cities, and Local Governments for Sustainability (ICLEI) are important users, implementing adaptation plans at the local level.
    - **Research and Academic Institutions**: These institutions are vital for developing methodologies, processing data, and providing capacity building.
    - **Private Sector**: Commercial satellite providers contribute data. The insurance/reinsurance sector is a key user of EO for risk assessment and developing financial products like parametric insurance.
    - **Civil Society Organizations**: NGOs and community groups are important for local knowledge and implementation of adaptation measures.
- **Relevant Regional Initiatives**:
    - European Commission's Mission on Adaptation[28]
    - The World Climate Research Programme (WCRP) Core Project on Regional Information for Society (RIfS)[29]
- **EOTEC DevNet:** The Earth Observation Training Education and Capacity Development Network (EOTEC DevNet) brings together over one thousand colleagues from across the CEOS, GEO, UNOOSA, WMO and CGMS network. Its aim is to extend the reach of EO capacity building and increase the use of EO in decision-making. A central effort is collaboration among EO capacity building

[28] https://climate-adapt.eea.europa.eu/en/mission
[29] https://www.wcrp-rifs.org/

providers through regional communities of practice, thematic working groups and an online member platform. EOTEC DevNet is working on formulating a concept for Climate Adaptation Working Groups (CAWG), in partnership with CMIP. CEOS should continue to partner with EOTEC DevNet and engage in the CAWG, to develop and deliver capacity building activities to support the Global Stocktake.

4.4. Added value of CEOS and GEO Partnership on Climate Adaptation

CEOS and GEO have complementary roles, with CEOS focusing on coordinating space-based observations and GEO on promoting the broad uptake and use of EO data. This provides a strong foundation for collaboration in supporting climate adaptation.

- **Mutual Support**: GEO initiatives like the GEO NAP Guidance on Agriculture and GEO for Cities support the uptake of EO for NAPs and urban adaptation, directly aligning with CEOS's goal of ensuring EO data serves policy needs. Similarly, the standardized, interoperable data and tools promoted by CEOS facilitate GEO's capacity building and data integration efforts.
- **Coordinated Support to Parties**: Collaboration between CEOS and GEO can lead to more coordinated support for countries in using EO for adaptation reporting and planning, such as developing joint guidance for NAP reporting.
- **Bridging the Gap**: GEO's focus on stakeholder engagement and capacity building, particularly in developing countries and subnational entities, is essential for translating CEOS's technical advancements into actionable information for adaptation decision-makers. This helps bridge the "last mile" challenge in the EO value chain.
- **Joint Initiatives**: Initiate joint activities like Adaptation Roundtables to facilitate co-design of EO products and services tailored to adaptation user needs.

4.5. Near-term Recommendations and Lead CEOS Entities

The following recommendations exploit existing structures, partnerships and ongoing activities within CEOS to support the adaptation goals of the PA and it GSTs:

Recommendation: CEOS should map ECVs and other amenable EO products to GGA indicators, documenting potential EO products and services and their links to the indicators being developed and adopted for tracking progress under the Global Goal on Adaptation. This should also promote the use of ARD principles to enhance usability for national reporting systems.

Lead: CEOS-CGMS WGClimate, CEOS ARD Team.
Support: WGCapD, CEOS Ad Hoc Team on Sustainable Development Goals (SDG)

Recommendation: CEOS should enhance discoverability of adaptation-relevant Climate Data Records (CDRs). This involves improving access to information about existing data records, focusing on thematic indicators relevant to climate impacts and resilience. It also includes an adaptation-focused analysis of gaps in the ECV inventory and a focus on attribution science in support of the loss & damage mechanism. These efforts should promote the use of ARD principles to enhance utility of EO products for national reporting systems.

Lead: CEOS-CGMS WGClimate.
Support: GCOS, GEO, CEOS SEO, CEOS ARD Coordination Team.

Recommendation: CEOS should explore ways to support the NAP process. For example, CEOS could collaborate with GEO to develop guidance and resources that help countries, particularly LDCs, integrate EO data and information effectively into their National Adaptation Plans, from initial risk assessment and planning to monitoring and evaluation. This ensures that EO capabilities align with UNFCCC reporting needs and national/local contexts.

Lead: CEOS & GEO
Support: CEOS Agencies with existing GEO engagement, CEOS Virtual Constellations (such as the LSI-VC and AC-VC).

Recommendation: Connect with IPCC AR7 process (e.g., contribute to the expert review, facilitate an expert meeting with WGII) to ensure the development of the IPCC Adaptation Technical Guidelines reflect EO capabilities. Once published, develop a CEOS supplementary guidance note.

Lead: CEOS & GEO
Support: CEOS Agencies with existing GEO engagement, CEOS Virtual Constellations (such as the LSI-VC and AC-VC).

Recommendation: CEOS should showcase adaptation use cases that employ EO data. Establish a repository of successful examples where EO has been applied to support adaptation actions across various sectors (e.g., agriculture, urban planning, disaster risk reduction, ecosystem management). These case studies, potentially drawn from agency-led projects, would demonstrate the value and feasibility of using EO for adaptation and encourage wider adoption.

Lead: CEOS Agencies through WGClimate, SEO & SIT Team support for website, CEOS Working Group on Disasters (WGDisasters), individual CEOS Agencies.
Support: CEOS SEO, CNES

Recommendation: CEOS should work with WMO, CGMS and other partners to refine space-based observations, derived products and delivery systems to reduce vulnerability to emerging climate threats. Increased support for UN initiatives, such as the UN's Early Warning for All (EW4All), should be explored.

Lead: CEOS-CGMS WGClimate
Support: WGDisasters, WGCapD, WMO.

Recommendation: CEOS should reinforce its partnership with EOTEC DevNet and engage in the CAWG, to develop and deliver capacity building activities to support the adaptation goals of the Global Stocktake.

Lead: WGCapD

Support: WGClimate, WGDisasters, LSI-VC

By focusing on these areas and leveraging existing structures and partnerships, CEOS can significantly enhance the role of Earth Observation in supporting global and local efforts to adapt to a changing climate, contributing substantively to the goals of the Paris Agreement and informing processes like the Global Stocktake.

4.6. Future Opportunities to Support for Adaptation (Next 10 Years)

To fully leverage the potential of Earth Observation in supporting climate adaptation under the PA, CEOS should systematically integrate adaptation priorities into its strategic planning and activities over the next decade. Based on the identified needs and gaps, key recommendations include:

1. **Prioritise Adaptation in Data Coordination**: Systematically embed adaptation needs, informed by the GGA and NAP processes, into CEOS's climate data coordination efforts. Ensure that the ECV framework evolves to better serve adaptation requirements, including higher spatial and temporal resolution data, particularly at regional and local scales.
2. **Ensure Continuity and improve the utility of EO data for Adaptation**: Advocate for and contribute to ensuring the long-term continuity of relevant EO data records needed to monitor adaptation progress over policy-relevant time horizons (e.g., decades). Improve the accessibility and usability of adaptation-relevant data and products for non-EO experts and a wide range of users (from policymakers to local administrators). This involves developing more highly synthesised, actionable products and services and user-friendly interfaces like web-based dashboards. Focus on addressing data gaps and improving data quality, completeness, and interoperability for adaptation purposes.

3. **Support standardised Adaptation Indicators**: Actively contribute to the development and uptake of standardised, quantitative EO-derived adaptation indicators that can support the planning, implementation and monitoring of adaptation actions and their outcomes, addressing the current lack of such metrics. Prioritise indicators relevant to the GGA targets and ensure that observational capabilities meet their requirements. Enhance and develop new EO-based indicators that capture aspects of exposure and vulnerability, going beyond purely a hazard approach. Where possible, these indicators should also infer information on limits to adaptation and loss and damage.
4. **Promote and connect with Climate Projection Modelling including by Leveraging Digital Twins**: Facilitate the use of EO data in adaptation scenario modelling to evaluate the potential effectiveness of adaptation measures and assess combined climate risks across different time scales. Connect with initiatives like the Baseline Variables for Earth System Modelling Project[30] supported by the Coupled Model Intercomparison Project (CMIP), in which a subset of priority variables is scoped, specifically for impact and adaptation assessments. Explore how CEOS capabilities and data can contribute to and benefit from digital twins for climate adaptation and weather-induced extremes, to develop more actionable intelligence and "last-mile" applications for policymakers.
5. **Foster Community Engagement:** Support the development of an active, coherent adaptation intelligence community involving space-based data providers, scientists, policymakers, and users, based on strong co-design principles. Invest in capacity development initiatives tailored to adaptation user communities, particularly in developing countries, to enhance their ability to access, process, interpret, and apply EO data and products for adaptation planning and implementation. This should be done in collaboration with national institutions.
6. **Expand Global Coverage**: Where feasible, expand the spatial coverage and granularity of key adaptation-related EO products and services to provide consistent information at local scales globally, particularly in data-scarce regions (e.g., very high-resolution urban-scale information). Ensure products and services contain uncertainty characterisation for traceability and rigour. Collaborate with international partners like WMO and GEO on global initiatives to achieve this.

4.7. Timelines and Reporting Requirements

The near-tear-term recommendations described in Section 4.5 should be appraised at yearly, or at most biennial intervals, to support the development and assessment of NAPs and to facilitate efforts by Parties to track progress toward the GGA. Where relevant, the lead CEOS team should work with its internal and external partners to produce at least one citable, peer-reviewed scientific publication describing the products and tools produced as well as the results of their application. Section 4.6 describes long-term objectives, citing a 10-year timeline for full implementation.

[30] https://doi.org/10.5194/gmd-18-2639-2025

Capacity building activities (webinars, workshops) should be conducted at annual to biennial intervals to support these activities. A key opportunity to communicate these scientific products to these audiences is the annual Earth Information Day and other activities throughout the COPs. CEOS and its partners should work with the UNFCCC to fully exploit these opportunities. The CEOS entities listed above should report their progress and plans as part of their regular reports to the CEOS SIT and at the annual spring SIT meeting and fall Technical Workshop as required.

5. CEOS Support for Means of Implementation

5.1. Introduction and Policy Context

Space-based Earth observations provide accurate, timely global, information about the state of the climate and its emerging trends that impact populations, their food and water supplies and their economic activity. These include GHG emissions, temperature changes, sea and land ice sheet dynamics, sea-level rise, the frequency and intensity of extreme weather, droughts, floods, wildfires and other climate-related hazards.

Space-based EO and models informed by these data can support means of implementation of low-GHG, climate-resilient development across all project phases and cycles of financial instruments (incl. design, implementation, monitoring and evaluation, impact assessment), and more specifically through:

- **Risk identification:** Identifying and/or attributing climate trends that contribute to potentially adverse conditions threatening vulnerable populations, communities, and economic sectors; and providing an evidence-based approach for assessing future climate-related risks and plans for designing effective risk reduction strategies. For example, satellite observations can reveal areas prone to flooding, wildfires, or sea-level rise, which can pose significant risks to physical assets or supply chains. Those observations and derived models can be integrated into International Financial Institutions' (IFIs) risk screening tools (such as those introduced by the International Finance Corporation (IFC) and Multilateral Investment Guarantee Agency (MIGA), or the World Bank's Climate Change Knowledge Portal) as well as different financial instruments, improving efficiency of resource targeting and optimisation of investment and implementation mechanisms;
- **Risk Management:** Space-based observations can be analysed to assess the impacts of changes in temperature or precipitation on crop yields or provide estimates of loss and damage associated with severe weather attributable to climate change, thereby enabling a more accurate assessment and quantification of the financial needs of countries affected, including the direct integration into disaster risk finance and parametric insurance mechanisms (e.g. SEADRIF); and
- **Tracking and Reporting:** Space based observations can provide a coherent and transparent mechanism for monitoring the effectiveness of national- to regional-scale GHG emissions reduction or adaptation investments such as the

World Bank's Program-for-Results (PforR) or sustainability linked bond (SLB) financial instruments that link disbursement of funds or return interest rates respectively directly to the achievement of specific programme results, aiming to improve the design and implementation of development programmes, enhance institutional capacity, and achieve sustainable impact.

To date, there has been little effort to coordinate activities to support the means of implementation and climate finance objectives of the PA across CEOS. However, individual CEOS agencies and partners have explored opportunities to support the climate finance assessment, decision making, implementation and monitoring processes. These efforts showcase an extensive series of use cases that should be explored further at scale.

The European Space Agency (ESA) has been working with International Financial Institutions (IFIs) such as Multilateral Development Banks for almost 2 decades to mainstream the application and integration of EO observations in development operations and specifically for assessing climate-related risks (such as droughts and floods) at national scales. One example is the extensive collaboration with the World Bank through ESA's Global Development Assistance (GDA) programme, which resulted in the establishment of the Bank's Digital Earth Partnership[31] programme, hosted by the Global Facility on Disaster Reduction and Recovery (GFDRR). ESA has also successfully cooperated with other IFIs such as International Fund for Agricultural Development (IFAD), Asian Development Bank (ADB) and Inter-American Development Bank (IDB) to help strengthen their climate narrative through integration of EO-based information when soliciting project co-financing from climate funds. More recently, dedicated collaboration schemes have been established by ESA with the major environment and climate funds (incl. GCF, GEF, CIF, AF; c.f. section 5.3) to further facilitate strategic considerations of the use of EO at programmatic levels. This new type of cooperation aims to make EO an integral part of how climate risks are assessed, how adaptation investments are designed, and how results are monitored and reported. By doing so, the ability of countries and development partners to access, manage, and demonstrate the impact of climate finance are strengthened via tailored EO services that are aligned with project goals, national priorities, and climate finance requirements.

The UK Space Agency, through its International Partnership Programme (IPP), funded the CommonSensing project,[32] which used space technology to assess vulnerabilities of Small Island Developing States (SIDS) to rising sea levels. This information was used by Pacific SIDS (Fiji, Solomon Islands, Vanuatu) to develop successful climate finance proposals.

These use cases show that, in general, evidence-based approaches based on space-based EO are welcomed by both public-sector and private climate finance community because they: a) provide greater certainty that an intervention will address impacts in any given

[31] https://www.gfdrr.org/en/digitalearthpartnership
[32] https://sa.catapult.org.uk/projects/commonsensing/

area of focus; b) facilitate better upfront planning and design of investments; and c) mitigate potential risks to those investments. Overall, wider adoption of EO across climate finance and adaptation portfolios is recognised to support the transparency, effectiveness, and scalability of climate finance instruments.

Recommendation: CEOS should review the lessons learned from the ongoing efforts by individual agencies to support Means of Implementation and climate finance, and identify opportunities for expanding their scope and impact by coordinating efforts across its agencies and partners. It should then work with the development finance community and national institutions to develop fit-for purpose products, tools and services to address these needs.

CEOS should also exploit the insights gained from its efforts to support the mitigation and adaptation objectives of the PA to play a larger role in the development and distribution of products and services, including capacity building, to support climate finance decisions. For example,

- Top-down GHG budgets and bottom-up GHG inventories, and their input datasets could be exploited to identify investment opportunities that would reduce GHG emissions or preserve and expand natural GHG sinks, such as forests or mangroves;
- Regional scale observations of crop and forest health, crop yields and their response to climate fluctuations (floods, drought, heat waves) and extreme weather could provide insight into opportunities and risks to food security and other economic disruptions; and
- Observations of precipitation, snow accumulation, reservoir level and soil moisture could be combined to predict and mitigate the impacts of climate change on water security. These data could also identify regions where near-real-time access to weather and climate data, combined with early warning systems could mitigate loss and damage from climate related disasters.

In general, these types of products require no fundamentally new types of space-based EO. However, new tools may be needed that can combine relevant datasets to produce custom products addressing these needs. For example, the crop yield forecasts might require the combination of space-based CO_2, solar-induced chlorophyll fluorescence (SIF), soil moisture, precipitation and temperature data. Forest health or nature-based carbon offset assessments might require combining these datasets with land cover and above-ground biomass data. Similarly, water security products might require tools to combine synthetic aperture radar or lidar data (reservoir levels, snow depth), with precipitation and microwave soil moisture data. Such tools exist across CEOS agencies and the science community, but have not been consistently developed and targeted for this UNFCCC financial mechanism application. In addition, associated capacity development will be needed to foster the use of these tools and linked information products by non-technical specialists and practitioners in the climate finance community as well as stakeholders in developing countries.

Recommendation: CEOS should explore opportunities where the products and tools developed to support the Mitigation and Adaptation goals of the PA can be adapted to support the Means of Implementation objectives as well.

5.2. Key CEOS Organizations Supporting Means of Implementation

- **WGClimate** - Subject matter experts on ECVs relevant to means of implementation and key interface between CEOS and the UNFCCC;
- **WGDisasters** - Subject matter experts on weather and climate related risks, the human and economic losses associated with climate-related disasters and the potential for EO for disaster-related risk management;
- **WGCapD** - Subject matter experts on communications and capacity development supporting CEOS agencies and partner organizations with communications and training needed to build awareness of the availability and the information content of space-based EO products relevant to means of implementation as well as appropriate methods for building and further developing the skills needed to apply products and tools developed by CEOS, its partners, as well as stakeholders in developing countries;
- **LSI-VC** - Subject matter experts for high spatial resolution land imagery for climate risk assessments, risk management and for quantifying the areal extent of loss and damage associated with climate-related disturbances;
- **AFOLU and GHG Teams** - Subject matter experts on space-based measurements of GHG emissions and removals associated with human activities and climate change and their changes over time; and
- **SDG Coordination Group** - Subject matter experts on space-based EO supporting sustainable development, providing the primary interface with the Group on Earth Observations (GEO) Earth Observations for Sustainable Development Goals (EO4SDG) initiative and the UN.

5.3. Key Stakeholders and Potential New Partners Supporting Means of Implementation

Key players in the climate finance community who have interacted with the EO community include:

- **The Global Environment Facility (GEF)**[33] - The GEF, established in 1991, is a family of funds for the environment, including the Special Climate Change Fund SCCF and the Least Developed Countries Fund (LDCF), established by UNFCCC parties in 2001 and mandated to serve the Paris Agreement. GEF has served as an operating entity of the Convention's financial mechanism since the UNFCCC's

[33] https://www.thegef.org/

entry into force in 1994. Aside from its function serving UNFCCC, the GEF is a financial mechanism addressing a total of 6 global conventions. The World Bank hosts the GEF Secretariat and acts as the fund's trustee;

- **The Green Climate Fund (GCF)**[34] – Established by the UNFCCC in 2010 at COP 16 to assist developing countries in their response to climate change by facilitating finance flows supporting mitigation and adaptation projects; designated as an operating entity of the Convention's financial mechanism since 2011. The Fund's secretariat is hosted by the Republic of Korea, while the World Bank is acting as the fund's permanent trustee administering the Green Climate Fund Trust Fund;
- **The Adaptation Fund (AF)**[35] - Established in 2010 to finance adaptation projects and programmes in developing countries that are parties to the Kyoto Protocol and are particularly vulnerable to the adverse effects of climate change.
- **The Climate Investment Funds (CIF)**[36] - Established in 2008, deploying highly concessional finance to empower transformations in clean technology, energy access, climate resilience, nature-based solutions, and other areas. The CIF adopts a flexible, country-led programmatic approach and specific partnership model working exclusively with multilateral development banks (MDB) as implementing entities, thereby strongly leveraging blended finance instruments;
- **The Fund for Responding to Loss and Damage (FRLD)**[37, 38] – Established in 2022 at COP 27 to help developing countries to respond to climate disasters that contribute to significant loss of life or property. The Fund's secretariat is hosted by the World Bank, which also acts as fund trustee;
- **The World Bank**[39] – An international financial institution (IFI) that provides financial and technical assistance to developing countries, which includes a focus on reducing GHG emissions and building resilience to impacts of climate change;
- **The International Monetary Fund (IMF)**[40] - A funding mechanism that works to achieve sustainable growth and prosperity for its 191 member countries, including an objective to help institute fiscal and macroeconomic policies addressing climate-related challenges. Climate-related risks and opportunities are mainstreamed into the IMF's macroeconomic and financial policy advice and climate considerations are embedded in the Fund's bilateral and multilateral surveillance, capacity development, and lending;

CEOS partners supporting means of implementation include:

- **Group of Earth Observation (GEO)** - Pioneered ways for using EO to support both public sector and private sector climate finance decisions;

[34] https://unfccc.int/process/bodies/funds-and-financial-entities/green-climate-fund
[35] https://www.adaptation-fund.org/about/governance/
[36] https://www.cif.org/
[37] https://unfccc.int/fund-for-responding-to-loss-and-damage;
[38] https://www.frld.org/
[39] https://www.worldbank.org/en/topic/climatechange/overview
[40] https://www.imf.org/en/Topics/climate-change#highlights

- **World Meteorological Organization (WMO)** - Partnered with the Green Climate Fund (GCF)[41] to provide global access to climate information, tools and guidance to develop the scientific basis for climate action decisions.
- **United Nations (UN) entities** - such as the **Food and Agriculture Organization (FAO)** and the **UN Environment Programme (UNEP)** - act as implementing and accredited entities for various of the above-listed financial instruments under the UNFCCC financial mechanism, including, e.g., the GEF and GCF.

5.4. Timelines and Reporting Requirements

The products and tools described in this section should be assessed and reported at yearly, or at most biennial intervals, to support efforts by the UNFCCC and Parties to track progress toward the PA. Where relevant, lead CEOS teams should work with internal and external partners to produce at least one citable, peer-reviewed scientific publication describing the products and tools produced as well as their impact on climate finance.

Capacity building activities (webinars, workshops) should be conducted at annual to biennial intervals to foster the use of space-based EO to support risk identification and management and to monitor the impacts of climate finance. CEOS and its partners should work with the UNFCCC to report progress in these efforts at the annual Earth Information Day and other venues throughout the COPs. The CEOS entities listed above should report their progress and plans as part of their regular reports to the CEOS SIT and at the annual spring SIT meeting and fall Technical Workshop as required.

6. Coordinating GST support across CEOS entities

To support the diverse range of mitigation, adaptation and means of implementation objectives of the PA within the context of a best-efforts organization, CEOS must closely coordinate its efforts, fully exploiting available synergies among the products, tools and services it might develop to address these needs. Fortunately, there are ample synergies to exploit. For example, for mitigation, the bottom-up inventories provide the priors used in the inverse models used to derive top-down fluxes from space-based GHG measurements. The tools developed to derive land sector activity data from space-based land cover products can be repurposed to identify emerging climate vulnerabilities for communities, their infrastructure and commerce, supporting adaptation. Systems designed to monitor hazards for disaster risk assessment, communication and preparedness serve both the adaptation and means of implementation goals of the PA. Similarly, the GHG monitoring products and tools developed to address PA's mitigation goals can be repurposed to monitor and report the effectiveness of greenhouse gas emissions reduction investments.

[41] GCF and WMO agree to strengthen science in climate response

In addition to identifying and exploiting synergies like those summarized above, the activities performed by CEOS entities to support the GSTs must be carefully coordinated to maximize their benefits within the time constraints imposed by the PA's annual, biennial and five-year reporting requirements. This time constraint will require closer coordination among the Working Groups, Virtual Constellations and Ad Hoc Teams producing the products, tools and services supporting the GSTs. The need to co-develop many of these items with representatives of a diverse stakeholder and user community will also require additional external interactions by the CEOS entities. Coordinating these activities may require additional oversight and management by the CEOS Strategic Implementation Team (SIT).

Finally, to gain additional recognition for its contributions to the PA and its GSTs, these CEOS entities should regularly publish citable, peer-reviewed, consensus reports documenting the space-based EO products, tools and services delivered to support the GSTs. These reports are essential to advertise the availability, information content and limitations of these products to foster their use in the science, policy, regulatory and climate action communities. In addition, only citable, peer-reviewed reports are included in climate assessments, like those conducted by the IPCC. While the IPCC Assessment Reports and most climate assessments focus primarily on future climate predictions based on model results, or observation-based reports on specific regions, these CEOS reports should stand on their own by providing the first global consensus reports based on space-based observations of the Earth.

Prior to the first GST, the CEOS SIT monitored progress supporting the mitigation goals of the PA by progressively increasing the visibility of these activities at the annual SIT meetings. Those activities included reviews of progress on the CEOS-CGMS GHG White Paper and GHG Roadmaps, the AFOLU Roadmap, and the progress toward the delivery of the top-down GHG budgets to support the first GST. If that level of oversight can be maintained, it should be possible to meet most of the goals described here, given that not all of these activities must be initiated immediately. Some activities can be prioritized while others can be introduced as resources become available.

7. Conclusion and Way Forward

Systematic, space-based observations of the Earth provide the scientific foundation for tracking climate change on regional to global scales. CEOS and its member agencies are now using these data to address the needs of a broad range of stakeholders in the science, policy, and regulatory communities. This document expands and sharpens the CEOS strategy for exploiting this information to support the implementation of the Paris Agreement and its Global Stocktakes, applying the lessons learned from participation in the first GST. More generally, the actions recommended here could improve access to space-based Earth observations and foster their use to mitigate the impacts of climate change and improve climate resilience.

To support the mitigation goals of the PA, CEOS should maintain its focus on space-based estimates of CO_2 and CH_4 emissions and removals. However, it should expand these efforts to deliver reconciled top-down budgets and bottom-up inventories at spatial and temporal scales that resolve GHG emissions and removals from small and medium-sized countries as well as large countries. Once adequately reconciled, these top-down and bottom-up products should be combined to yield improved, harmonized space-based estimates of activity and emission factors for the land biosphere that can be used by the NGHGI community to develop more complete accurate estimates of emission and removals by the AFOLU sector. In addition, CEOS should work with the IMEO and other partners to use high-spatial-resolution observations to monitor emissions from the largest CO_2 and CH_4 sources to assess the impact of climate policy on these emissions.

To foster the use of these products in the GSTs, these space-based GHG products and protocols for their use in inventory development and QA/QC should be developed in collaboration with the NGHGI community and the IPCC-TFI. CEOS should also coordinate ongoing efforts by its agencies and work more closely with its partners to provide capacity building for the policy and NGHGI user community to better explain the information content and limitations of the space-based products and their utility in managing GHG emissions and removals.

Space-based products spanning a broad range of Essential Climate Variables (ECV) are needed to support the adaptation goals of the PA and its GST because climate change will affect different regions and societies in different ways. Because of this, different types of information are needed to enhance adaptive capacity, strengthen resilience, and reduce vulnerability to climate change, while contributing to sustainable development. CEOS is already pursuing a number of activities supporting these efforts. These include ensuring the continuity of critical space-based observations, maintaining and expanding the list of ECVs being monitored, promoting the development of Analysis Ready Data products to foster their use by non-specialists in the policy, regulatory and climate action communities, engaging with Disaster Working Groups to and supporting Sustainable Development Goals.

To enhance the utility of space-based products and services supporting adaptation, CEOS should foster more interactive collaborations with both its partners and stakeholders to develop and deliver products that are both more fit for purpose and timely. For example, CEOS should work more closely with the UNFCCC and the Parties to the PA to develop ECV-based products that more directly address the development of NAPs and support the GGA. CEOS should also support two-way capacity building to foster community engagement across the globe to better assess climate threats, vulnerabilities and information needs. Initial actions include improving the discoverability of adaptation-relevant CEOS Climate Data Records including those useful for climate attribution science in support of the loss & damage mechanism, mapping of amenable EO products to GGA indicators, supporting the NAP development and assessment process, and showcasing adaptation use cases.

Global space-based Earth observations can support the means of implementation and climate finance objectives of the PA by providing the information needed to identify and manage emerging climate-related risks and vulnerabilities. They also provide a transparent way to monitor the progress of investments intended to mitigate the impacts of climate change. Historically, CEOS has not attempted to coordinate the development or delivery of space-based products or services addressing climate finance and means of implementation. However, some of its entities (e.g., WGDisasters, SDG Coordination Group) and partners (e.g., GEO, WMO) have had more interactions with this community. In addition, some CEOS agencies and partners have engaged more directly with key stakeholders serving these needs, providing insights into the types of use cases that CEOS might effectively address in the future.

Initial CEOS efforts to address the means of implementation goals of the PA might include working with partners such as those involved in EW4ALL to co-develop space-based products that could be used for assessing rapidly-evolving climate risks such as coastal flooding, wildfire, flash droughts, or other climate-related threats to food or water security. They might include co-developing space-based products for climate impact assessments, or for rapidly assessing the areal extent loss and damage associated with severe weather or other climate extremes. To make a significant contribution to these goals, it is critical that CEOS begin a more active dialog with the UNFCCC, the climate finance community and with the affected parties to ensure that the products, tools and services are fit for purpose.

To support the diverse range of mitigation, adaptation and means of implementation objectives of the PA within the context of a best-efforts organization, CEOS will have to fully exploit available synergies among the products, tools and services it might develop to meet these needs. Fortunately, there are numerous such synergies to exploit. In addition, the GST support activities performed by CEOS entities must be carefully coordinated to maximize their benefits within the time constraints imposed by the PA. Some activities may have to be prioritized while others can be introduced as resources become available. Finally, to gain additional recognition for its contributions to the PA and its GSTs and to support effective climate action by the science, policy, regulatory and commercial sectors, CEOS should regularly publish citable, peer-reviewed consensus reports documenting the use of space-based EO products for these applications. These reports could then be included in the IPCC assessment reports, which form the scientific basis for the GSTs.

ANNEX A: Contributors

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ANNEX B: Acronyms and Abbreviations

AC	Adaptation Committee (of UNFCCC)
AC-VC	Atmospheric Composition Virtual Constellation (of CEOS)
AF	The Adaptation Fund
AFOLU	Agriculture, Forestry and Other Land Use
AR7	Assessment Report 7 (of IPCC)
ARD	Analysis Ready Data (of CEOS)
BTR	Biennial Transparency Reports
°C	Degrees Celsius
CEOS	Committee on Earth Observation Satellites
CGMS	Coordination Group for Meteorological Satellites
CH_4	Chemical formula for the methane molecule
CIF	The Climate Investment Funds
COP	Conference of the Parties (of UNFCCC)
CO_2	Chemical formula for the carbon dioxide molecule
CO2M	Copernicus Carbon Dioxide Monitoring Mission
DGVM	Dynamic Global Vegetation Models
DRR	Disaster Reduction and Recovery
ECV	Essential Climate Variable
EDF	Environmental Defense Fund
EEA	European Environment Agency
EID	Earth Information Day
EO	Earth observation
EOTEC DevNet	Earth Observation Training Education and Capacity Development Network
ESA	European Space Agency
ETF	Enhanced Transparency Framework of the Paris Agreement

FAO	Food and Agriculture Organization of the United Nations
FCDR	Fundamental Climate Data Records
G3W	Global Greenhouse Gas Watch (of WMO)
GATT	GCOS Adaptation Task Team
GCF	Governor's Climate and Forest Task Force
GCOS	Global Climate Observing System
GCP	Global Carbon Project
GEF	Global Environment Facility
GEO	Group on Earth Observations
GFCS	Global Framework for Climate Services (of WMO)
GGA	Global Goal on Adaptation
GHG	Greenhouse Gas
GHG TT	Greenhouse Gas Monitoring Task Team (within the Joint CEOS-CGMS WGClimate)
GOGM	Global Ocean Biogeochemical Model
GST	Global Stocktake (under the UNFCCC 2015 Paris Agreement)
ICLEI	Local Governments for Sustainability
IDB	Inter-American Development Bank
IFAD	International Fund for Agricultural Development
IFC	International Finance Corporation
IFI	International Financial Institutions
IFRC	International Federation of Red Cross and Red Crescent Societies
IG3IS	Integrated Global Greenhouse Gas Information System (of WMO)
IMEO	International Methane Emission Observatory (of UNEP)
IOC	Intergovernmental Oceanographic Commission of (UNESCO)
IPCC	Intergovernmental Panel on Climate Change
IPP	International Partnership Programme (of UK Space Agency)

ISC	International Scientific Committee (of UNESCO)
ITU	International Telecommunication Union
L&D	Loss and Damage
LDCF	Least Developed Countries Fund
LEG	Least Developed Countries Expert Group (of UNFCCC)
LSI-VC	Land Surface Imaging Virtual Constellation (of CEOS)
MARS	Methane Alert and Response System (of UNEP IMEO)
MHEWS	Multi-Hazard Early Warning Systems (of UNDRR)
MIGA	Multilateral Investment Guarantee Agency
N_2O	Chemical formula for nitrous oxide, a greenhouse gas
NAP	National Adaptation Plan
NDC	Nationally Determined Contribution to the global response to climate change
NGHGI	National Greenhouse Gas Inventory
NGO	Non-governmental organization
NIST	U.S. National Institute for Standards and Technology
NMHS	National Meteorological and Hydrological Services
NPL	U.K. National Physical Laboratory
NRDC	Natural Resources Defence Council
OCO MIP	Orbiting Carbon Observatory Multi-model Intercomparison Project
PA	Paris Agreement
pCO_2	Partial pressure of CO_2 in seawater
PforR	World Bank's Program-for-Results (PforR)
QA/QC	Quality Assurance and Quality Control
RECCAP	REgional Carbon Cycle Assessment and Processes
SBI	Subsidiary Body for Implementation (of UNFCCC)
SBSTA	Subsidiary Body for Scientific and Technological Advice (of UNFCCC)

SBI	Subsidiary Body for Implementation (of UNFCCC)
SDG	Sustainable development goals
SEADRIF	Southeast Asia Disaster Risk Insurance Facility
SEO	System Engineering Office (of CEOS)
SIF	Solar-induced Chlorophyll Fluorescence
SIT	Strategic Implementation Team (of CEOS)
SLB	Sustainability linked bond
SIDS	Small Island Developing States
TFI	Taskforce on Inventories (of IPCC)
TT	Task Team
UNDP	UN Development Programme
UNDRR	United Nations Office for Disaster Risk Reduction
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
WFP	UN World Food Program
WGCapD	Working Group on Capacity Development and Data Democracy (of CEOS)
WGCV	Working Group on Calibration and Validation (of CEOS)
WGClimate	Working Group on Climate (of CEOS)
WGDisasters	Working Group on Disasters (of CEOS)
WGISS	Working Group on Information Systems and Services (of CEOS)
WMO	World Meteorological Organisation
XCH_4	refers to column-averaged dry air mole fractions of CH_4
XCO_2	refers to column-averaged dry air mole fractions of CO_2