Global Carbon Budget
Governance and practicalities 2 December 2018

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1 Introduction

The annual update of the Global Carbon Budget was first proposed at the 4th Scientific Steering Committee Meeting of the Global Carbon Project (GCP; *Goa*, India, July 12 – 15 2004), following a discussion on how to increase the support of the carbon research community for the climate policy process, and more generally how to improve international coordination in carbon cycle research. The updates started with a minimal effort using existing methods, but led to two seminal papers on recent trends in emissions (Raupach *et al.*, 2007) and in the carbon budget (Canadell *et al.*, 2007). A bigger effort was subsequently introduced to incorporate far more analysis and data streams (Le Quéré *et al.*, 2009), and from 2011 this has been documented using a new journal paper format of living data to increase transparency and traceability of updates and changes in methodology and data. This new journal paper format was developed by the journal *Earth Science System Data (ESSD)* to meet our needs for annual updates (Le Quéré *et al.*, 2013, Le Quéré *et al.*, 2016, Le Quéré *et al.*, 2018a, Le Quéré *et al.*, 2018b, Le Quéré *et al.*, 2015a, Le Quéré *et al.*, 2015b, Le Quéré *et al.*, 2014).

The annual updates have grown organically, striving to maintain high quality and transparency, while being manageable by a small team of scientists without dedicated core funding. Here we detail *how* the GCP team delivers these annual updates. We document the delivery process to provide transparency for collaborators and users, and to assist in other emerging efforts of similar nature. We explain the criteria and strategy used for making decisions on what is included or not in the updates, the sources of data, the timeline constraints, and the strategy for publications and authorship.

This document is written retrospectively based on what has worked and what has been achieved. The document also discusses ongoing issues and reflects on future ambitions.

2 Current arrangements for delivery of the annual update

2.1 Objectives

The objectives of the Global Carbon Budget annual release are to:

a. provide reliable carbon cycle information to assist the international policy processes on climate change and related actions
b. advance our understanding of the carbon balance in the environment, and keep track of the current consensus and remaining discrepancies in understanding
c. foster collaboration among the carbon cycle research community and a more integrated approach to using observations and models to develop a common understanding of how the carbon cycle operates

2.2 Approach

Rationale for annual frequency. The annual timing of the Global Carbon Budget updates is phased with the annual Conference of the Parties (COP) meeting of the United Nations Framework Convention on Climate Change (UNFCCC). This timing has proven useful to diffuse results widely because the UNFCCC meeting receives much media attention. Although a complete annual update may not be needed for purely scientific purposes, the regular releases have raised the general profile of carbon research in the public and has generated an expectation for the information.

Choice of incremental approach. In spite of the annual updates, we have resisted the temptation to make substantial changes in methodology every year. This incremental and low risk approach is preferred to help ensure we do not revert back on methodological changes, but rather move towards improving the budget reporting. Hence changes in data and methodology or for the reporting of new variables are considered carefully, and only integrated when we have acquired reasonable confidence that we will want and have the capacity to keep those changes in the long term.

Quality control. We implement several steps to help support a high quality release. The annual update is published as a peer-reviewed publication. The individual contributions are based on methodology published in peer-reviewed journals (i.e. we only use published data-products and models) and we document changes since publications. Individual contributors commit to updating their contributions in the long-term. We apply a number of quality-control criteria to individual data received. Budget components for the latest years are reported as 'preliminary'. All budget years are updated each release. We update a summary figure of how the existing budget differs from all previous budgets and a summary table of the changes. We keep all budget releases easily accessible for external scrutiny.

Maintaining momentum. The annual timeline requires substantial work from the carbon research community. The publication of associated papers, many published in high-impact journals, has helped keep the momentum and interest. Many of the science papers have been published along with the updates, but a growing number are offsprings that use the carbon budget archive to make additional analysis. These offsprings have been particularly valuable and are encouraged.

Maintaining capacity. The process has been possible because we have developed a practical approach with distributed responsibilities and some redundancy in expertise, and because of synergies between the day jobs of the core team and the carbon budget release (e.g. publications, impact, and to a lesser extent new funding opportunities). It is also an activity that brings an interesting diversion from our day-to-day work and opportunities to grow (e.g. in communications and policy understanding), is personally challenging but satisfying, giving the sense of providing a tangible service to society.

2.3 Roles and responsibilities

The carbon budget is delivered by a team of people with distributed responsibilities (Table 1) as follows:

- Executive team: A small team (currently 4 people) who coordinates the activity and is responsible for the overall delivery and for the quality of the product. It reports to and is overseen by the scientific committee of GCP. The Executive team and GCP take decisions by consensus about the evolution of the activity, in consultation with relevant members of the Core team.
- Core team: A larger group (currently 7 people + 4 members of the executive team) who oversee the coordination and delivery of individual components of the budget and decides on methodological and related updates. The core team writes protocols, ensures availability of the input data, determines timelines, does the quality control of individual contributions, and writes the corresponding sections in the methods paper. The core team also reviews the full paper and assists in the response to reviewers' comments.
- Contributors of key data: Individuals who provide essential data (current or past data), without which the carbon budget update could not be published or would be substantially reduced. Contributors of key data are responsible for the accurate representation of their data but are not expected to review or comment on the contribution of others or on the full paper.
- Other contributors: Individuals who make contributions that together greatly enhance the value of the effort. Contributors are responsible for the accurate representation of their own data but are not expected to review or comment on the contribution of others or on the full paper.

The GCP Scientific Committee provides critical feedback and guidance to the activity (Fig. 1). The Science and Engagement committees of Future Earth (the parent program of the GCP) also advise and support the budget, particularly on the outreach component. Other people associated with contributors of the budget also assist in the delivery of the global carbon budget update, including experts in communication and technical and clerical staff. Finally the reviewers of the *ESSD* paper provide critical comments and suggestions.

Table 1. Executive and Core team members in the Global Carbon Budget and their specific responsibilities. Core team members sometimes change depending on availabilities (e.g. SOCAT alternates between A. Olsen and D. Bakker).

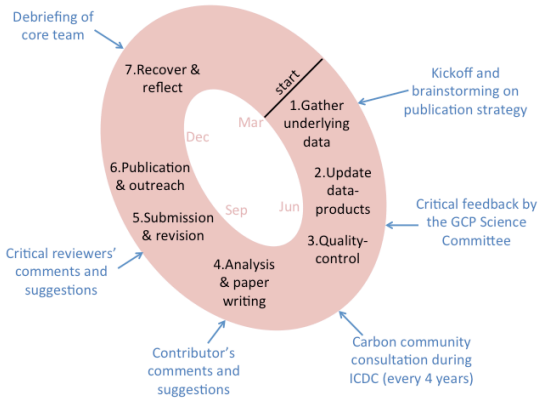
Executive team	Main specific responsibilities
Corinne Le Quéré	Oversees the process, quality, transparency and timely delivery; delivers main budget file; determines authorship
Pep Canadell	Liaises with GCP; maintains links with the broad community and with other activities
Glen Peters	Oversees all emissions data and methodology
Pierre Friedlingstein	Oversees the assessment of the land and ocean fluxes
Core team	
Robbie Andrew	Oversees all emissions data and associated files; estimates current year projection; produces figures; champions the update in several respects
Stephen Sitch	Oversees TRENDY (the land model ensemble) results
Julia Pongratz	Oversees land-use change emissions
Are Olsen / Dorothee Bakker	Quality-control of SOCAT data
Judith Hauck	Oversees oceanic models and data-products including quality-control
Philippe Ciais	Oversees the use of inversions and the Global Carbon Atlas

2.4 Timeline and publication process

The annual timing is the most critical element of our update, but is also the most challenging. The practical challenges, and how they are overcome, are discussed below. The cultural challenges are more difficult to address, and include resistance and/or difficulty to work on short timescales while maintaining high quality, and fear of possible public misunderstanding of results and uncertainty when results appear in the media.

Data submissions. The annual cycle starts around March with the gathering, preparation, and quality-control of the underlying data, such as the oceanic CO_2 data by SOCAT, the climate forcing by CRU and NCEP, and the land-cover change data. Updates of individual data products are requested as soon as the underlying data are available. The deadlines for submitting data products is set each year depending on when the underlying data becomes available, and considering other budget components. In practice, deadlines are stacked in time so all components are not delivered at the same time and it is possible to conduct quality-control and analysis sequentially. Generally the deadlines for the ocean models comes first (end of June), then the ocean-data products and land models (end of July), and the emissions (mid-August).

Figure 1. Overview of an annual cycle of the Global Carbon Budget and the consultation process. The timeline is approximate and depends on the exact publication date, which is linked to the UN COP meeting in the Autumn.



Publication strategy. The strategy for publication is discussed as part of kickoff brainstorming at the start of a budget, during the scientific steering committee of the GCP, and at the early phases of the budget cycle itself (Fig. 1). We usually plan the *ESSD* update accompanied by an analysis paper submitted in a high-impact journal. This has worked on multiple occasions, but the peer-review process of journal has meant that several papers have been delayed or rejected. The leadership of the analysis has rotated among the involved scientists (mostly the core group), depending on the angle, interest and availability.

Living data process. We have adopted the 'living data' approach developed by *ESSD*, which supports the update of existing publications and provides a peer-review for each individual update. The *ESSD* paper is largely the same as in previous years, with an update of data and methods, and some evolution of the content (usually around 10% of the paper). We work with *ESSD* to agree on a timeline for submission and review. We provide details of what has change since the last review so the reviewers can focus on the changes. *ESSD* can then secure reviewers ahead of time. We have requested a closed review, which is not aligned with the normal *ESSD* practice. However this is necessary and appropriate here because the carbon update database is downloaded most at the time of publication and because the methodology and data sources have already largely been peer-reviewed and thus the open discussion stage that is normally set in *ESSD* has essentially already been done over previous

years. When multiple publications have appeared the same year, we have worked with the Editors to exchange DOIs in final paper proofs and agree on the timing of the first release.

2.5 Authorship and reference of budget updates

Authorship. The approach to authorship has been developed in the spirit of fairness and practicality, recognising that decisions are complex and implications are broad. Issues about authorships of the carbon budget papers have been the most delicate and difficult to resolve, causing a lot of stress and in some cases also resentment. The approach to authorship has been based on the following guidelines:

- the authorship reflects the specific contributions to that paper, rather than the broader contribution to aspects of data products used in the budget
- the authorship tries to be balanced among the five components of the carbon budget
- the number of authors is manageable by the team on an annual basis, so that the tasks of coordination, the management of input, comments, affiliations and acknowledgements can be dealt with effectively and in a timely manner with available (and limited) time and resources.

The current practice is to include one author per contribution. When more than one person supports a single contribution, we ask that people rotate between years. In exceptional cases regarding the volume or difficulty of the contribution additional authors have been included. Requests for additional authors are discussed with the relevant members of the core team and with the executive team.

The order of authors in the *ESSD* paper reflects the specific contribution to a given update. The first few authors have done the lions share of the work, and are ordered following the importance of their contributions. This is generally followed by the Core team, Contributors of key data, and Other contributors, in alphabetic order within categories.

A justification of authorship is made and circulated to all authors for transparency, so that all authors are informed of the rationale for the inclusion of everyone else.

Citing the living data updates. The papers published as living data in *ESSD* are updates of previous publications, they are not independent papers. Although they have different authors and slightly different content, they would fail digital tests for plagiarism. This is clearly stated in the *ESSD* paper, but to further recognise their differences from more conventional papers, we recommend that a good practice would be:

- when citing the *ESSD* living review in publications, only cite the paper corresponding to the data used. Do not cite all previous versions unless a comparison is made between releases
- when listing the *ESSD* living review in your own publication lists, that a mention of the links between updates is made (e.g. by adding the mention 'this is an update of xxx')

ESSD has modified its web platform to easily link to all previous versions of the paper.

There are still issues regarding this format. The main issue is that to ensure the timeliness of the update, contributing authors are not expected to comment on the full paper because the volume of comment would be too large to handle. However, the current convention is that all authors are responsible for the full paper. It is not possible at this stage to both recognise contributors as authors while limiting their responsibility for the overall results. We chose the recognition above the individual responsibility and put in place measures to ensure the full paper is sound. Contributing authors can send comments throughout the year on the full paper.

2.6 Data access and use

The Global Carbon Budget data are made available in two Excel spreadsheets, one including the Global Carbon Budget data and one including the national emissions. These data are available via the ESSD publication webpage and are also centralized on the GCP web site http://www.globalcarbonproject.org/carbonbudget

Data permissions. Most of the data presented in the Global Carbon Budget are not original but are provided by research institutes and individual scientists, and are synthesized and/or combined in the annual update. The data are made available in the belief that their wide dissemination will lead to greater understanding and new scientific insights. The free availability of these data does not constitute permission for publication of the data. For research projects, if the data are essential to the work, or if an important result or conclusion depends on the data, co-authorship may need to be considered. Full contact details and information on how to cite the data are given at the top of each page in the accompanying database and are summarised in Table 2 of the *ESSD* paper.

Protocols for the use of model data. New model simulations are performed specifically for each update. Whereas the global fluxes for individual models are made available at the time of the carbon budget release, the gridded (regional) fluxes are not and need to be requested. See Appendix A for details.

Global Carbon Atlas and accessibility. The Global Carbon Atlas (http://www.globalcarbonatlas.org) was developed with funding from the Foundation BNP Paribas. It provides a platform to access the emissions by country in a friendly way, to compare two countries/regions, and to access model data. The Atlas is updated annually along with the carbon budget publication.

2.7 Outreach

Timing. The UNFCCC process is one of the key audiences of the Global Carbon Budget, and for this reason we have aimed to publish the budget during the annual Conference of the Party (COP). In particularly, we have found that high media interest occurs during the second week of the COP, and when we have a publication in a high-impact journal. The one year the carbon budget was not published in a peer review journal (2008), there was limited media interest. Coverage also varies greatly depending on national news and major international affairs on the day of publication (i.e., what else is in the news).

Key messages. Ahead of the release (about 10 days), the core group develops a 'Key messages' document, which summarises the statements and interpretation that the group would like to make, and suggests ways to minimize the risk of data misinterpretation and misuse. This document is the agreed press messages, though individuals are encouraged to add their own nuances linking to ongoing narratives in their regions or research.

Press releases, blogs, news stories. We encourage authors to prepare press releases focusing on their own contributions and/or on the current interest in their country/region (generally one per country). Even if press releases duplicate messages, a national/regional approached is very powerful as it enables journalists to contact scientists in the nation/region. Press releases are checked by the core group for their accuracy and to ensure consistency with the agreed key messages. All authors are encouraged to take part in the release by writing blogs and news stories, and on social media (Twitter, Facebook). This further strengthens the collaborative nature of the Global Carbon Budget effort and commitment to continue to contribute and to improve it.

Powerpoint presentation. The GCP produces one PowerPoint presentation with the highlights of the annul carbon budget along with an extended set of figures covering all components of the budget (http://www.globalcarbonproject.org/carbonbudget). This budget presentation is downloaded thousands of times every year and used extensively by a

broad set of actors including policy makers, academic and government scientists, tertiary education, NGOs, and businesses. We have automated many steps, in particular the figures are coded with Matlab and can be quickly updated. Nevertheless, there is substantial time invested producing the presentation and the associated messages.

Disclaimer. We have included the following disclaimer in our PowerPoint presentation (adapted from NOAA/ESRL): The Global Carbon Budget and the associated information are intended for those interested in learning about the carbon cycle, and how human activities are changing it. The information is provided as a public service, with the understanding that the Global Carbon Project team make no warranties, either expressed or implied, concerning the accuracy, completeness, reliability, or suitability of the information.

Copyright. We use the Creative Commons license CCBY, which means that material (e.g. figures) may be freely copied and modified, and used in commercial works, as long as credit is provided as indicated for each figure. We tag each figure with the source of the data.

Other material. Other associated material is produced (e.g. Infographics) with the aim to support the diffusion of key results.

COP side events. These have constituted an opportunity to explain the results directly to policymakers and a wide set of other climate change actors with more depth. These have been popular and appreciated, with 100-150 attendees in each event. We have introduced video presentations in order to limit the need for presenters to travel to the COP venues, and thus saving time and reducing the carbon footprint of the event itself. Press conferences held at the COP have also been very good vehicle for the diffusion of news.

Relationships with Stakeholders. Sustained relationships have been maintained with key Stakeholders. The UNFCCC has provided opportunities to share results with policymakers, including the annual SBSTA meetings in Bonn; other interactions with UN bodies have included UNESCO and some of its assessments. Interactions with international NGOS to provide science advice and carbon datasets have proven valuable. BNP Paribas have provided new and valuable opportunities to exchange with the private sector. Multiple interactions with national agencies, policy makers and science advisors have further provided opportunities over the years for a rich policy-science interaction.

2.8 Funding

The Global Carbon Budget is not funded centrally. Rather the individual contributors receive funding to support their own contributions. Groups of contributors have been successful to secure funding for elements of the project for limited years. The GCP has been generous in providing letters of support acknowledging contributions that have been used to help secure funding. Institutions have been very generous in supporting this activity.

3 Ambition

In 2016 we informally reviewed the interest of the community in continuing the annual updates, and their usefulness for users. We concluded that there was an appetite and interest to continue with annual updates. Some communities felt the annual frequency was not necessary (e.g. for the land and ocean sinks), but did not find appropriate to provide updates eg, in alternate years, if the emissions alone were published. Also publishing emissions alone would miss opportunities to interpret natural signals, for example during El Niño events or if there was a volcanic eruption.

The Global Carbon Budget activity continues to evolve with some key directions including:

Reduce or even eliminate the unaccounted carbon (Fig. 11 in *ESSD introduced in 2017*). This is the carbon that cannot be accounted through our current knowledge of the emissions and their partitioning among the atmosphere, land and ocean. In 2018, we introduced metrics

for the evaluation of ocean models, land models and atmospheric inversions, to document, encourage and support improvement in the models used in our analysis, and to integrate a broader range of observations in the global carbon budget.

Move to full radiative budget. GCP has started similar updates for the global methane and global N_2O budgets. Over a number of years it may be possible to report global radiative budget, including multiple greenhouse gases.

Breakdown regionally. Regional carbon budgets could be developed for some regions (e.g. USA, Europe, China, Southern Ocean). This was done as a one-off during the project RECCAP (REgional Carbon Cycle Assessment Project). A second phase of RECCAP is under development. Ideally, groups would take ownership of regional budgets and build on the data/model archive being updated for the global effort.

Monitor progress. The Global Carbon Budget already includes an annual update of the cumulative carbon budget so far. Most useful would be to include indicators to track progress in decarbonisation, as proposed by Peters et al (2017).

The GCP will continue to seek feedback from the broader community to steer the carbon budget activity towards resolving major uncertainties and producing the most valuable datasets and data products for a range of audiences.

4 Appendix A Fair use policy for model data

The data and model output provided on this site are freely available and were furnished by individual scientists who encourage their use.

Ocean models: The global annual average of the ocean sink data are available with the Global Carbon Budget publication. For the current year global carbon budget, the ocean model gridded data are available on request (judith.hauck@awi.de). If you would like to use this model output, please inform by email with a list of the scientists who will use the data, the data you intend to use, and the purpose for using the data. Your request will be copied to the scientists who produced the model archive. Please reference the source of the data or model output as a citation and in the acknowledgments. If the data or model output is central to your analysis, co-authorship should be considered. The scientists will inform you if they feel they should be offered participation as authors. If your work directly competes with an ongoing investigation, the scientists who provided the data or model output may ask that they have the opportunity to submit a manuscript before you submit one that uses their data or model output. An agreement on such matters should be reached quickly and before publishing and/or using the data for publication. All studies should be circulated to the modelling groups prior to submission.

For gridded model output from previous global carbon budgets please contact the modelling groups directly.

Dynamic global vegetation models: The global annual average of the land sink and the LUC emission data are available with the Global Carbon Budget publication.

For the current and last year global carbon budget, the full TRENDY land model gridded data are available on request (s.a.sitch@exeter.ac.uk). The TRENDY modelling groups have identified studies they will conduct with these data over the coming year. If an external study does not conflict with these studies, the data will be made available. Co-authorship of TRENDY modellers depends on the importance of the TRENDY data in the study and should be discussed with the TRENDY coordinators (S. Sitch and P. Friedlingstein) early on in the process. All studies should be circulated to the modelling groups prior to submission.

TRENDY data from previous global carbon budget are freely available, with no request for

TRENDY modellers co-authorship.

Bookkeeping models: The global annual average of the LUC emission data are available with the Global Carbon Budget publication.

The full bookkeeping output (spatially explicit/country-level) is available on request (julia.pongratz@lmu.de for BLUE, rhoughton@whrc.org for Houghton&Nassikas). If an external study does not conflict with current studies of the bookkeeping groups the data will be made available. Co-authorship of the bookkeeping modellers depends on the importance of the bookkeeping data in the study and should be discussed with the modellers early on in the process. All studies should be circulated to the modelling groups prior to submission.

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