Near-real-time estimates of greenhouse gas budgets

Philippe Ciais, A.Bastos, S.J. Davis, Z. Deng, S. Saatchi, B. Poulter, F. Chevallier, G. Grassi, Z. Liu, R. L. Thompson, G.A. McKinley, N. Gruber, J.P. Wigneron, S. Sitch, M. Saunois, A. d'Aspremont, T. Lauvaux, G. Broquet, J.T. Randerson, C. Albergel, L. Ott, and D. Crisp

Need for comprehensive, accurate, and low-latency information on GHG emissions and sinks

GHG emissions and removals by sinks are expected to change substantially and rapidly in the coming years with contrasting trends between countries and regions. To effectively monitor progress toward emission reduction pledges in each country, more frequent observation-based assessments of national greenhouse gas budgets are needed to support national inventories. Complementary knowledge of natural fluxes over unmanaged lands and the oceans is also required to unambiguously reconcile the foreseen reductions of anthropogenic emissions with the observed growth rates of greenhouse gases in the atmosphere, and assess the risk of missing climate targets, e.g., if natural sinks were to weaken in the future.

National Greenhouse Gases Inventories NGHGI

Currently updated each year with a latency of 2 years by Annex 1 countries / several years by non-Annex 1 countries. NGHGI cover only anthropogenic GHG emissions and removals, based on the proxy of 'managed land' for LULUCF sector.

NGHGIs often provide less complete and accurate results for non-fossil GHG fluxes, such as from AFOLU, which are also more variable from year to year. They are therefore not ideal for tracking the effectiveness of specific and targeted GHG reduction strategies.

Current Scientific Assessments, e.g., Global Carbon Project

Each year, the CO_2 budget for the previous year is published (Friedlingstein *et al.*, 2021). It provides national details only for fossil emissions. The global CH_4 budget has been analysed at a four-year interval and extends up to 2017 (Saunois *et al.*, 2020). The N_2O budget was first produced in 2020 and extends up to 2018 (Tian *et al.*, 2020).

Example of Global Carbon Budget 2021 results

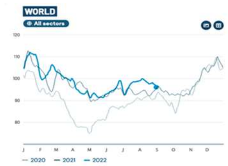
These scientific assessments use both bottom-up and top-down methods. Top-down methods, known as atmospheric inversions, use atmospheric concentration measurements from satellites and surface stations and transport models to constrain GHG surface emissions and absorptions over large regions.

Improving both approaches with Near real Time information

Both NGHGI and current scientific assessments are most useful for tracking long-term emissions in sectors, such as fossil fuel emissions. But they are not well suited for monitoring rapid changes in emissions, because they are reported at national scales, annually, with a latency of at least 2 years.

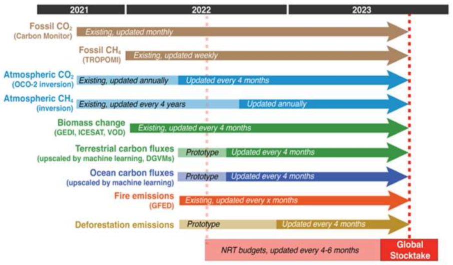
Available components of a near real time greenhouse gas analysis system

Fossil CO2 emissions Near-real-time fossil emissions estimates did not exist before the COVID-19 pandemic. Now, datasets like Carbon Monitor are updated regularly with a latency of 2 months (Liu *et al.*, 2020)



Example from Carbon Monitor at https://carbonmonitor.org

Fugitive CH_4 emissions from the fossil fuel sector Near real time estimates of a large fraction of fugitive CH_4 emissions in the fossil fuel sector from large leaks, major extraction basins and distribution pipelines have very recently been established based on atmospheric column CH_4 images taken each day e.g., by the spaceborne TROPOMI instrument (Lauvaux *et al.*, 2022). Updated each week



Components of a 'near- real-time' analysis system that could deliver observation-based estimates of global and national GHG budgets for the Global Stocktake in 2023. The timeline separates existing components, and prototypes being tested by research groups involved in this paper to deliver regular updates of key fluxes with a latency of four months.

Biomass carbon stocks changes Integrating available forest inventory data, observations of forest structure from spaceborne lidar (ICESAT-1,2, GEDI) and microwave and optical imagery in a machine learning platform (Xu et al., 2021) in near real time (3-6 months latency). Vegetation optical depth data especially L-band from SMOS and SMAP satellites are also used to track biomass C changes. There is a global dataset updated every 4 months based on the SMOS data already available.

Deforestation emissions The need for near-real-time monitoring of deforestation emissions has become even more urgent after the COP-26 pledge by more than 100 countries to stop and reverse forest area loss trends by 2030. It is possible to map land cover and land use changes with high-resolution satellite observations and attribute them to deforestation events worldwide (Harris et al., 2021; Hansen et al., 2013).

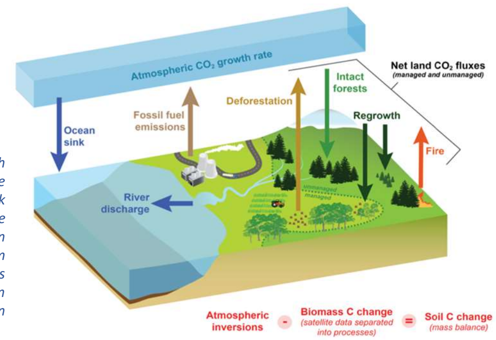
Fire emissions Burned area and fire intensity are mapped from space on an operational basis, and new datasets on fuel load (Leite *et al.*, 2022) make it possible to estimate fire emissions with latency of a few days (GFED product, van der Werf *et al.*, 2017)

A pragmatic approach to integrate available components of a near real time global GHG budget

Closure and attribution of national CO2 budgets

Achieved by combining top-down inversion estimates of net land CO2 fluxes, biomass carbon stock changes from satellites, lateral fluxes from rivers, crop and wood trade, fires and deforestation emissions

The proposed approach infers non-measurable soil carbon stock changes based on the mass balance between total CO_2 fluxes from top-down inversions and measurable carbon stock changes in biomass.



Integration strategy

While a first order attribution of AFOLU CO_2 budgets can be produced quickly with existing datasets and the proposed integration framework, new tools and approaches will be needed to further separate the carbon balance of intact forests, the recovery of carbon in secondary forests, and the carbon losses from disturbances beyond fire, such as windthrown, pests and insect's outbreaks.

Such approaches have already been applied over the US (Gu *et al.*, 2019; Williams, Gu and Jiao, 2021) and in Brazil where secondary forests return after deforestation (Heinrich *et al.*, 2021). It may be possible to generalise this approach to other regions of the globe, and eventually move from regionally-aggregated sets of forest statistics to spatially explicit estimates at a moderate resolution.

In addition to satellite data alone estimating biomass changes and disturbances, new approaches to analyse terrestrial carbon fluxes in near real time include periodical updates of process-based models such as those used in the global carbon budget, but forced by regularly updated climate fields, and data-driven land carbon models assimilating directly satellite and climate data.