Towards Near real time/operational carbon budgets:

Philippe Ciais, Zhu Liu, Zhu Deng, Brendan Byrne, Stephen Sitch, Ana Bastos, Frédéric Chevallier, Jean Pierre Wigneron, Guido van Der Werf, Niki Gruber and lot of collaborators

LSCE
University of Exeter
MPI-BGC Jena
NASA Goddard Space Flight Center
Columbia University
ETH Zürich
UCI
Atmosphere Monitoring Service atmosphere.copernicus.eu
INRAE
清華大學 Tsinghua University
KAYRROS
JPL Jet Propulsion Laboratory California Institute of Technology
Southern University of Science and Technology
esa European Space Agency

We've been steering by looking in the rearview.
Advances (spurred by COVID) offer decision makers timely feedback to support more agile and adaptive management of carbon emissions and natural sinks.

Bastos *et al.*
Carbon Balance and Management (2022) 17:15
https://doi.org/10.1186/s13021-022-00214-w

Carbon Balance and Management

COMMENT   Open Access

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

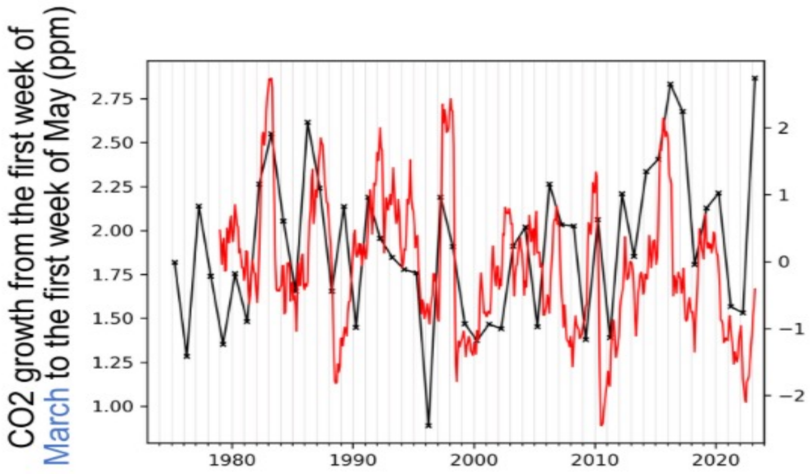
Ana Bastos[1*], Philippe Ciais[2], Stephen Sitch[3], Luiz E. O. C. Aragão[3,4,5], Frédéric Chevallier[2], Dominic Fawcett[3], Thais M. Rosan[3], Marielle Saunois[2], Dirk Günther[6], Lucia Perugini[7], Colas Robert[8], Zhu Deng[9], Julia Pongratz[10,11], Raphael Ganzenmüller[10], Richard Fuchs[12], Karina Winkler[12,13], Sönke Zaehle[1] and Clément Albergel[14]

Current status

- Annual analysis of the global CO_2 budget by the Global Carbon Project
    - Annual mean fluxes for year n-1
    - Based on ocean and land models, only annual fossil emissions are given per country
- RECCAP2 chapters
    - Last two decades with process attribution of fluxes
- Global CH_4 budget by GCP
    - Decadal estimates
    - Combination of multiple inversions and bottom-up inventories
    - Last update to 2017, current update to extend to 2020
- Global N_2O budget by GCP
    - Decadal estimates
    - First publication in 2020
    - Last update to 2018, current update to extend to 2020
- UNFCCC submissions
    - Latency of 1+ years for Annex 1 countries
    - Latency of 10+ years for non Annex 1 countries

What are the applications of NRT budgets ?

- Quantify the impact of recent climate extremes (fire, drought)
- Assess very recent changes of emissions & drivers
- Abnormal recent changes in the seasonal CO_2 and CH_4 growth rates
- Better learn about models differences through a living comparison

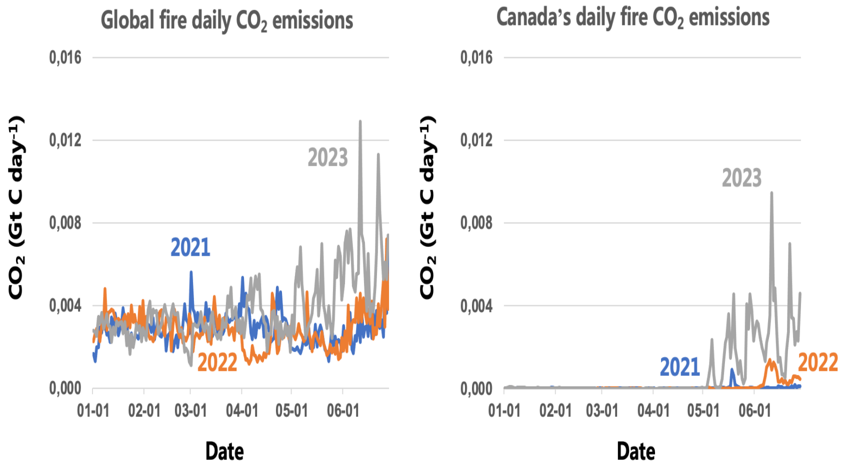


What should be the minimum latency of ‘NRT’ ?

- Media ask for numbers in a week
- Quarterly emission budgets valuable with a month lag

Could NRT budgets be of lower quality than annual budgets ?

- Would a small ensemble of ‘volunteer’ models differ from GCP?



Should we use observations or models ?

Existing capabilities for near real time GHG budgets

- NRT estimates of fossil emissions
  - CH_4 fossil emissions GMW – Kayrros ≈ 40% of fossil emissions updated each month
  - CO_2 Carbon Monitor daily national budgets & emissions maps at 10 km updated each month
- NRT global inversions of CO_2 and CH_4 fluxes
  - NRT in-situ concentration from NOAA, ICOS, RAMCES networks (subset of global data)
  - Inversions need a spindown of ≈ 4 months
  - Satellite XCO_2 and XCH4 from OCO2 and GOSAT updated each year
  - E.g. Copernicus CAMS results are already available for CO_2 updated each 4 month
- NRT land and ocean fluxes
  - Land observations and models updated each 4 month [pilot with 3 models]
  - Ocean observations and models

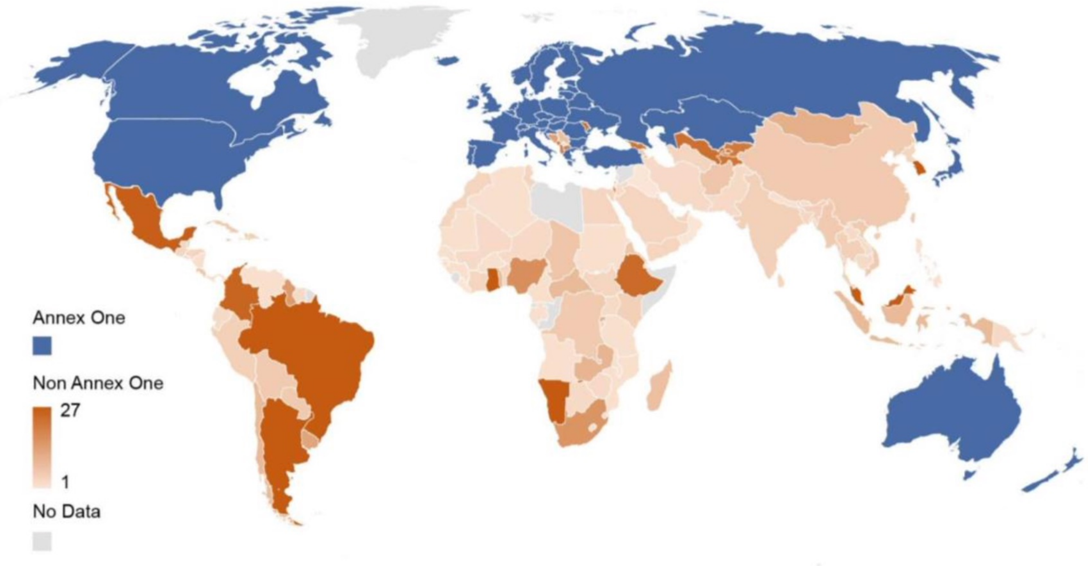
Comparing inversions with UNFCC inventories


https://doi.org/10.5194/essd-2021-235
Preprint. Discussion started: 13 August 2021

Open Access Earth System Science Data Discussions

Comparing national greenhouse gas budgets reported in UNFCCC inventories against atmospheric inversions

Zhu Deng[1,*], Philippe Ciais[2,*], Zitely A. Tzompa-Sosa[2], Marielle Saunois[2], Chunjing Qiu[2], Chang Tan[1], Taochun Sun[1], Piyu Ke[1], Yanan Cui[3], Katsumasa Tanaka[2,4], Xin Lin[2], Rona L. Thompson[5], Hanqin Tian[6], Yuanzhi Yao[6], Yuanyuan Huang[7], Ronny Lauerwald[8], Atul K. Jain[9], Xiaoming Xu[9], Ana Bastos[10], Stephen Sitch[11], Paul I. Palmer[12,13], Thomas Lauvaux[2], Alexandre d'Aspremont[14], Clément Giron[14], Antoine Benoit[14], Benjamin Poulter[15], Jinfeng Chang[16], Ana Maria Roxana Petrescu[17], Steven J. Davis[18], Zhu Liu[1], Giacomo Grassi[19], Clément Albergel[20], and Frédéric Chevallier[2]



New methodologies are developed to use atmospheric inversions results and make them comparable with UNFCCC reports and inventories

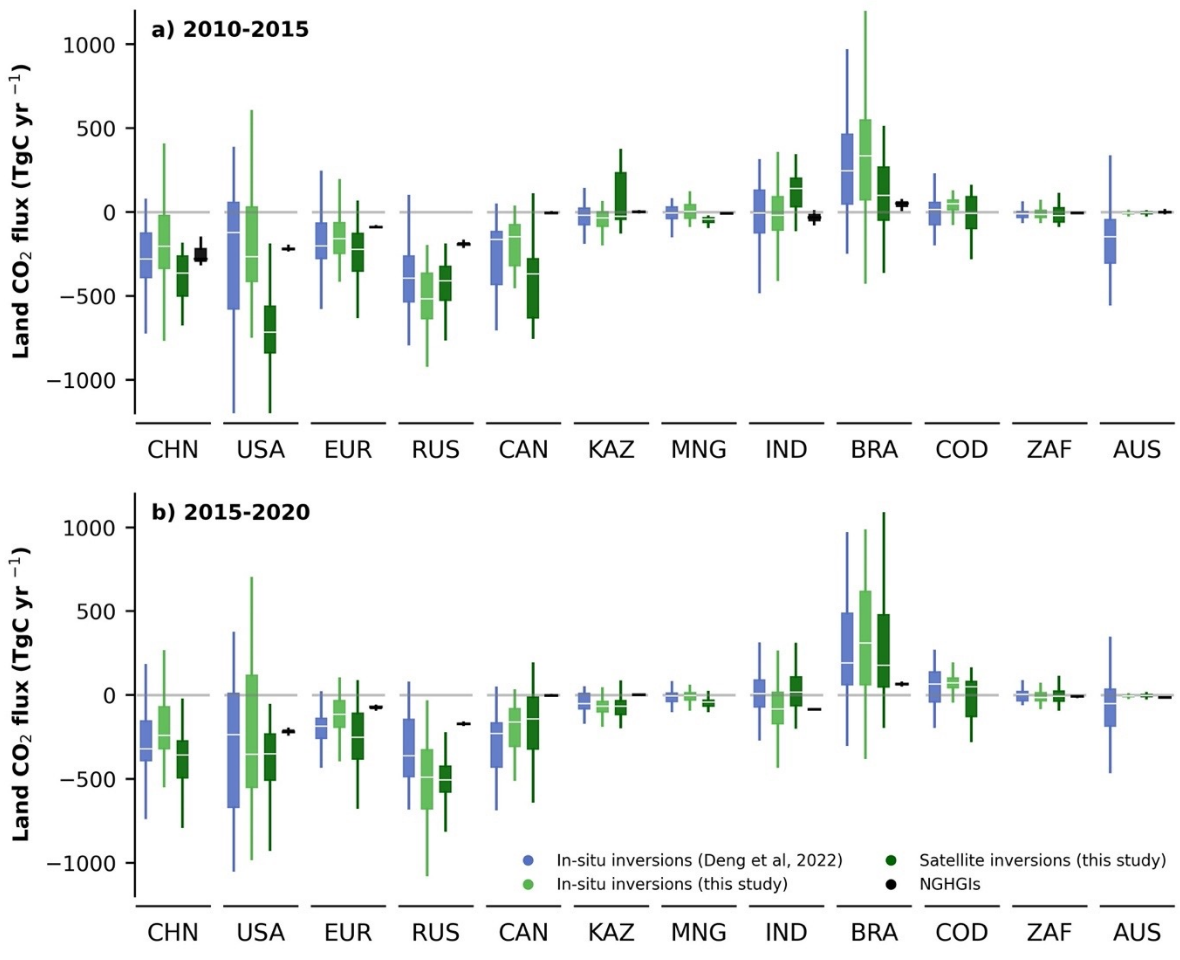
Global (managed land) sink from inventories = 0.3
Global (managed land) sink from inventories * = 1.4

Global (managed land) sink from inversions = 1.3
Global (all land) sink from inversions = 1.4

GtC y-1

** Updated and gap filled by Grassi et al. 2022*

Comparing inversions with UNFCC inventories

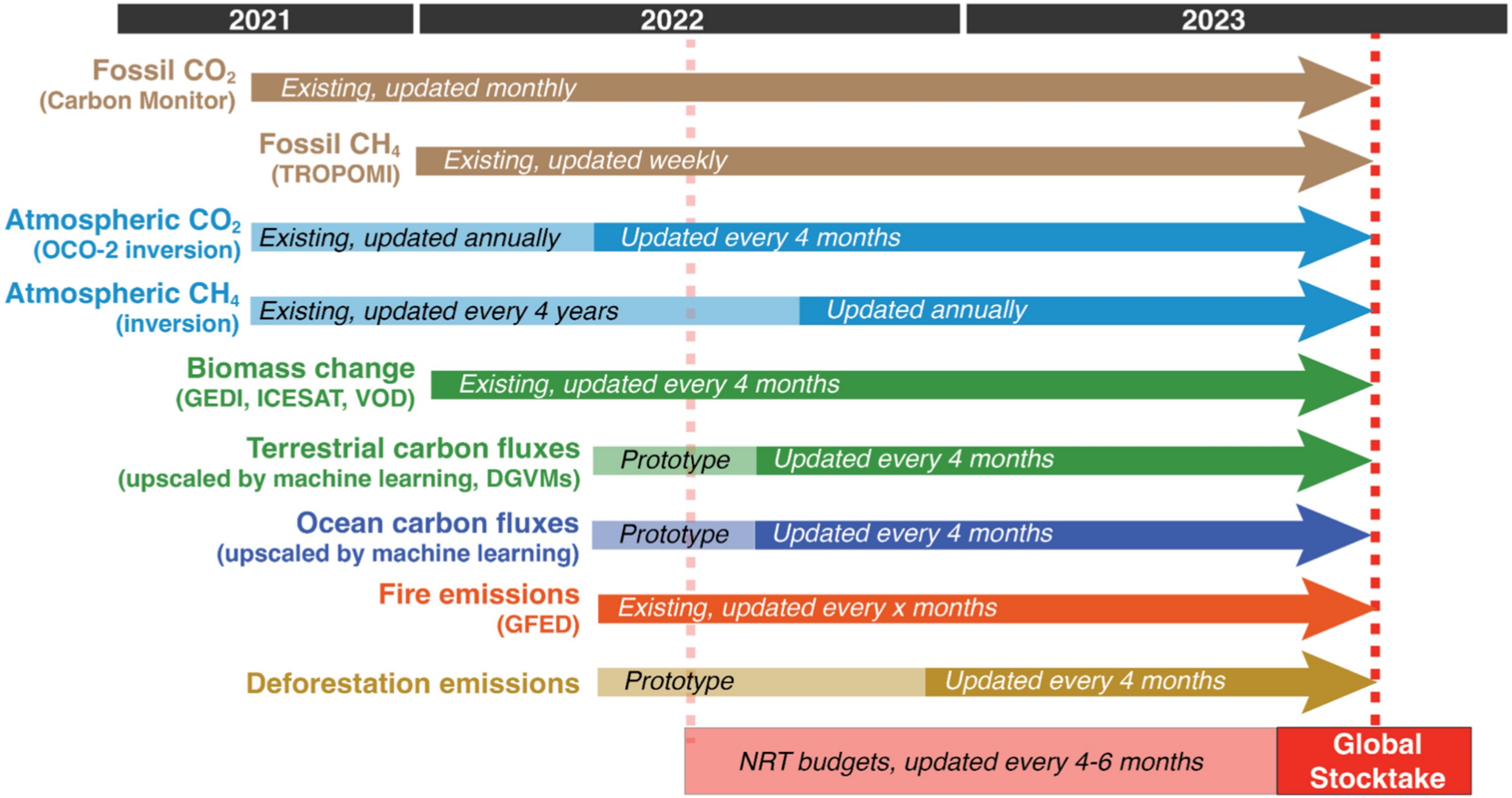


- Data processing pipeline is operational – results until 2022
- Inversion update from OCO2 products is 4 month
- From in-situ data is ≈ 1 year

Available research datastreams allow:

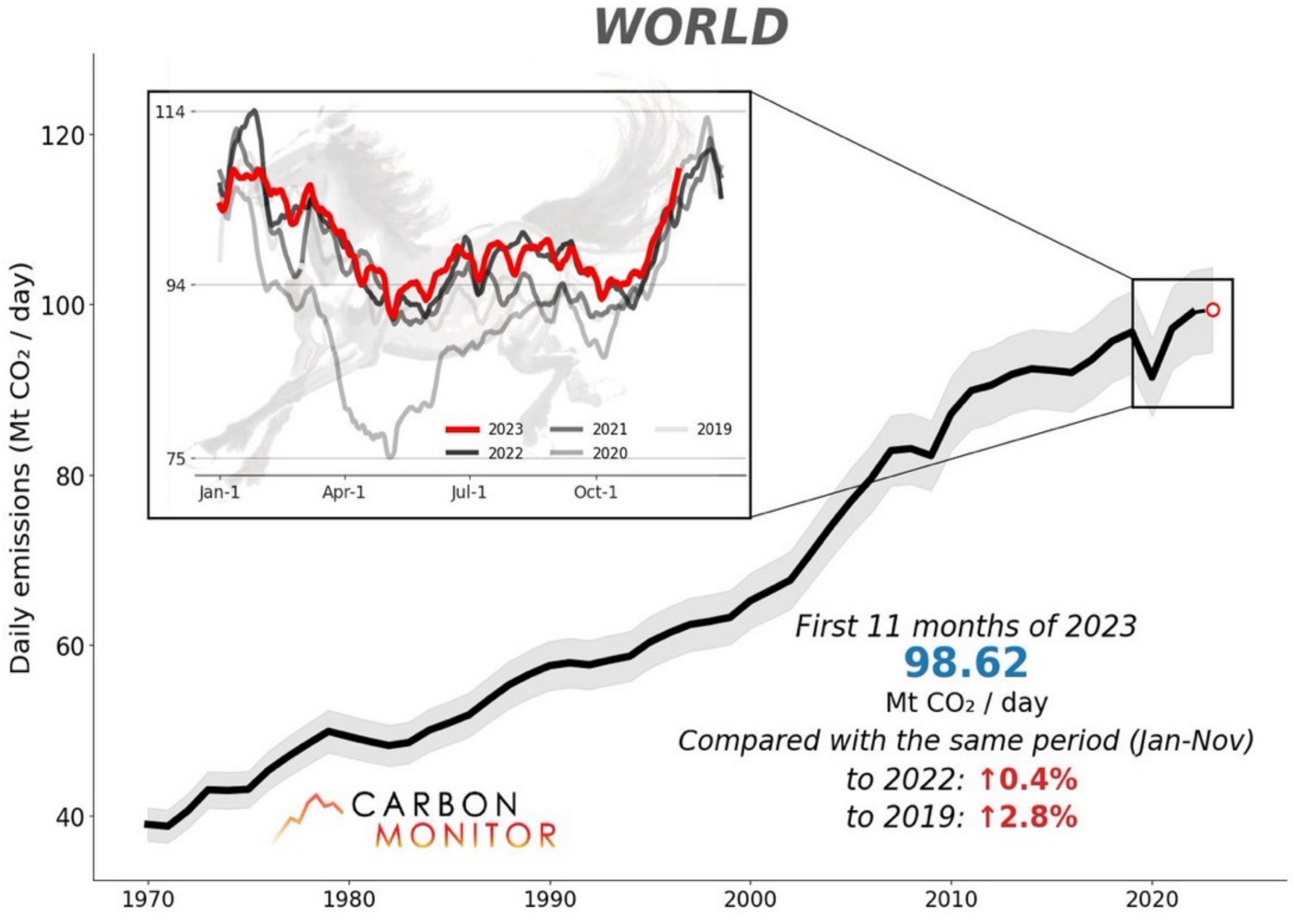
=> Global & National assessments of emissions and sinks at 4 months intervals

Ciais et al. Nature, in review



reccap-2 cci

Carbon Monitor near real time fossil CO_2 emissions until Dec 1st 2023



Monitoring global carbon emissions in 2021

Zhu Liu[1], Zhu Deng[1], Steven J. Davis[2], Clement Giron[3] and Philippe Ciais[4]

Following record-level declines in 2020, near-real-time data indicate that global CO_2 emissions rebounded by 4.8% in 2021, reaching 34.9 $GtCO_2$. These 2021 emissions consumed 8.7% of the remaining carbon budget for limiting anthropogenic warming to 1.5 °C, which if current trajectories continue, might be used up in 9.5 years at 67% likelihood.

Monitoring global carbon emissions in 2022

Zhu Liu, Zhu Deng, Steve Davis & Philippe Ciais

All data freely available
https://carbonmonitor.org

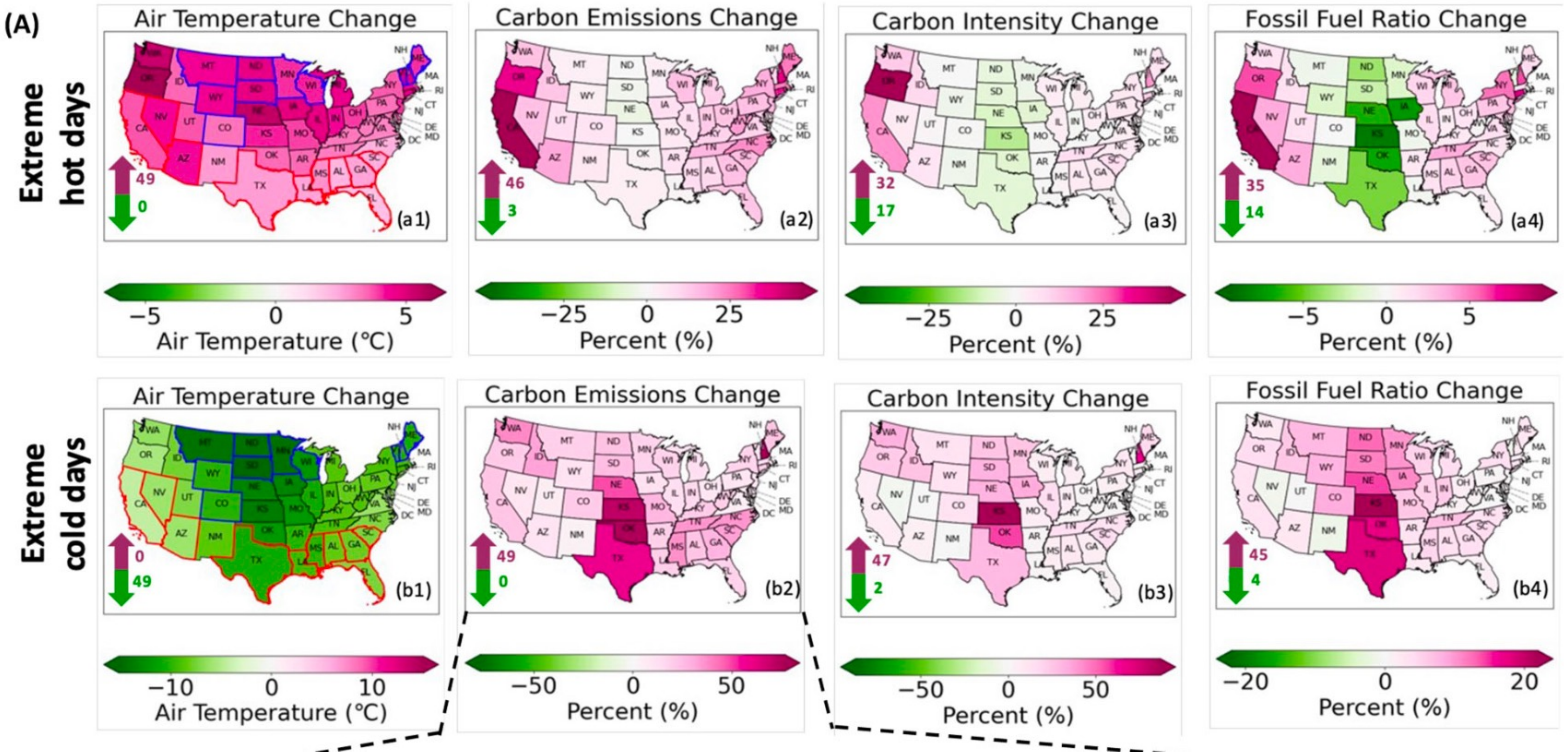
communications
earth & environment

ARTICLE

https://doi.org/10.1038/s43247-023-01147-z OPEN

Reliance on fossil fuels increases during extreme temperature events in the continental United States

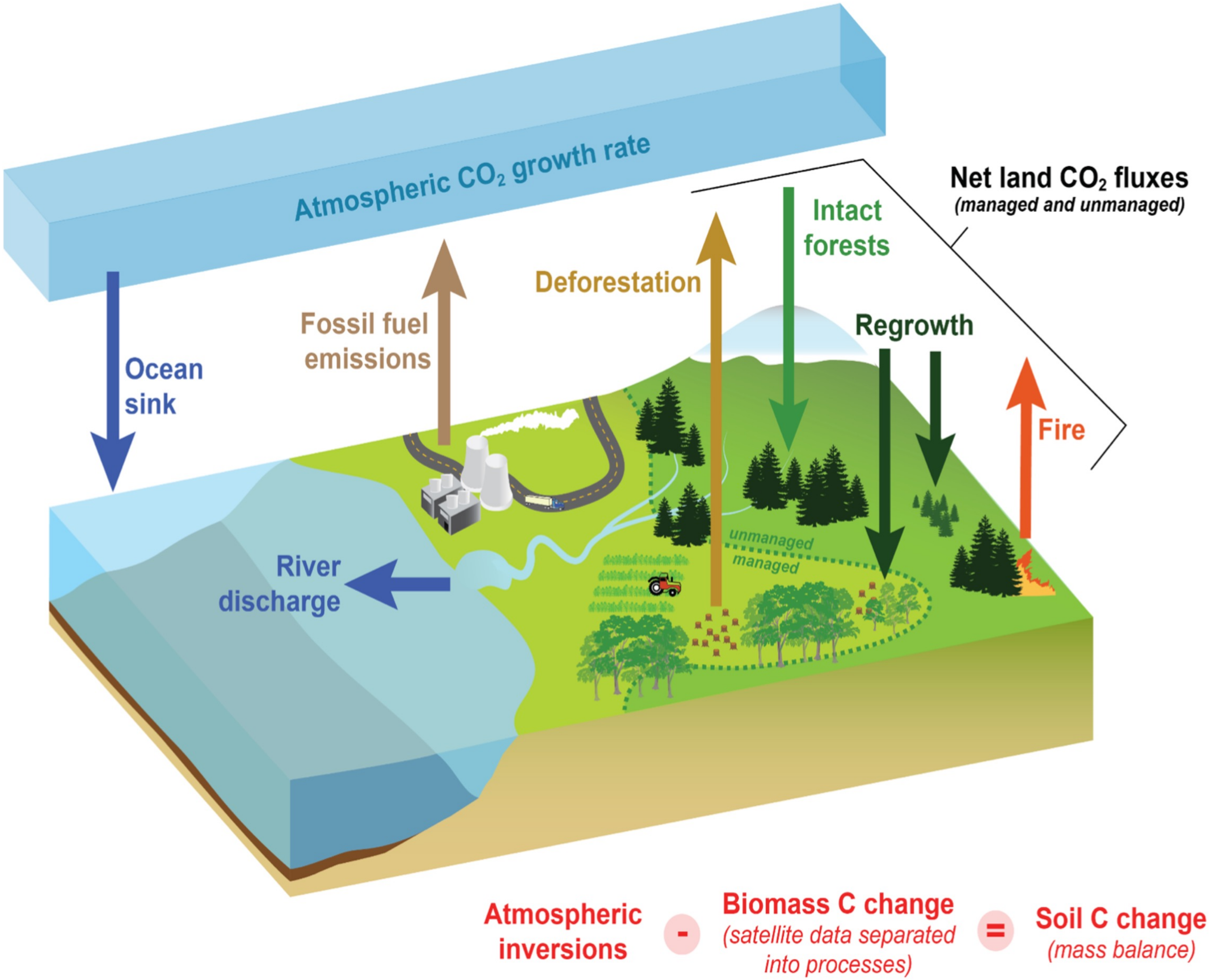
Wenli Zhao [1,2✉], Biqing Zhu [3], Steven J. Davis [4], Philippe Ciais [3], Chaopeng Hong [5], Zhu Liu [6] & Pierre Gentine [1✉]



Near-real time daily carbon emission maps (Carbon Monitor)

Zhu Liu*, et al., *Nature* 2015
Zhu Liu*, et al., *Nature Climate Change* 2016
Zhu Liu*, et al., *Nature Communications 2020*
Zhu Liu*, *et al., Scientific Data 2020*
Xinyu Dou,…Zhu Liu*, The Innovation 2021
Xinyu Dou,…Zhu Liu*, Scientific Data 2022
Biqing Zhu,…Zhu Liu*, Scientific Data 2023

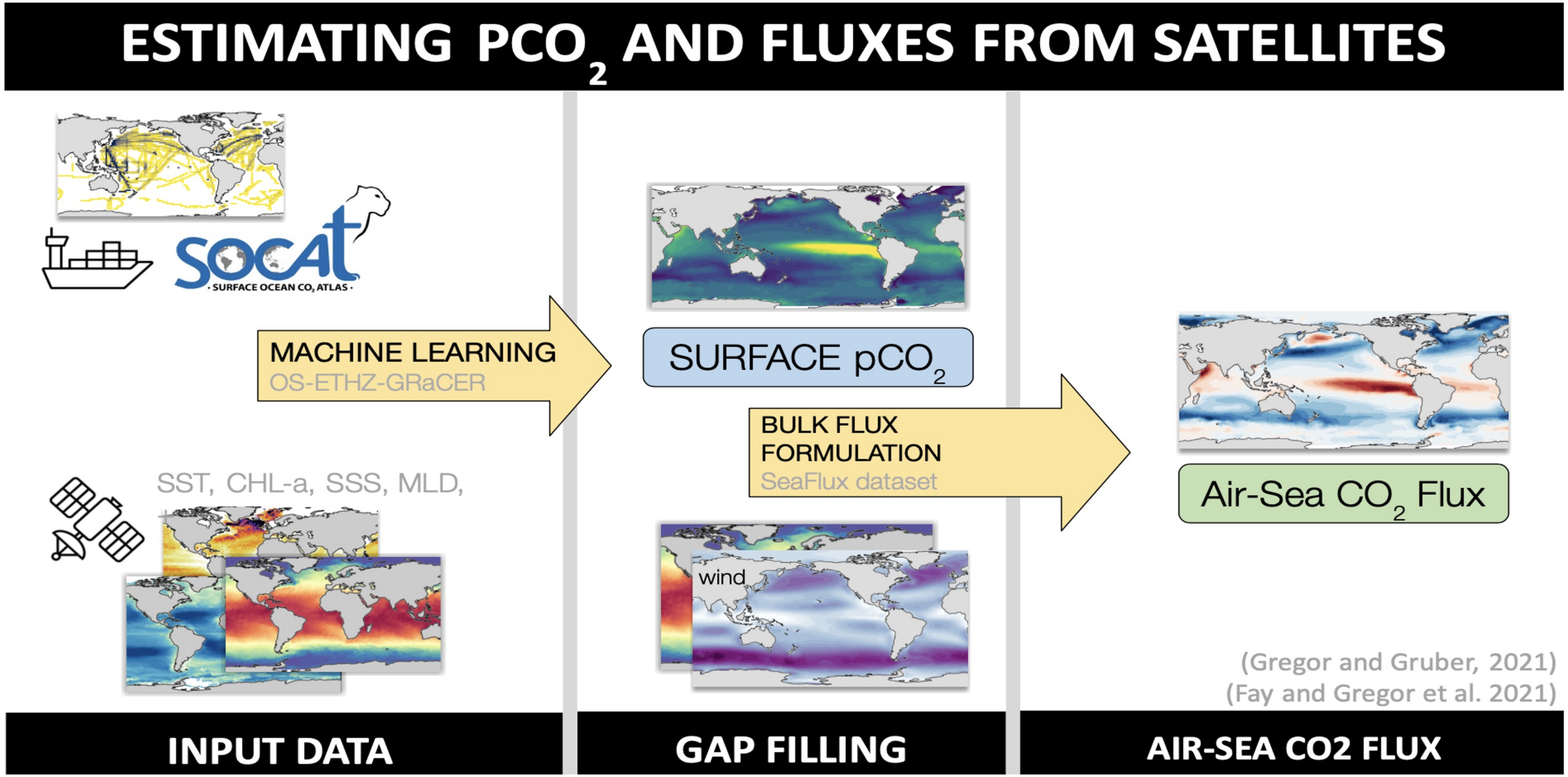
Near Real time attribution of global / national CO2 budgets



1. **Inversions**
   Land CO_2 flux
1. **Correction of lateral fluxes**
   Land carbon stock change
1. **NRT biomass C change**
1. **Observable biomass C losses in NRT**
   Fire emissions
   Deforestation CO_2 emissions
1. **Remaining CO2 flux**
   Forest growth / regrowth sink
   Soil C storage change

Better prior for inversions : NRT air-sea CO_2 fluxes

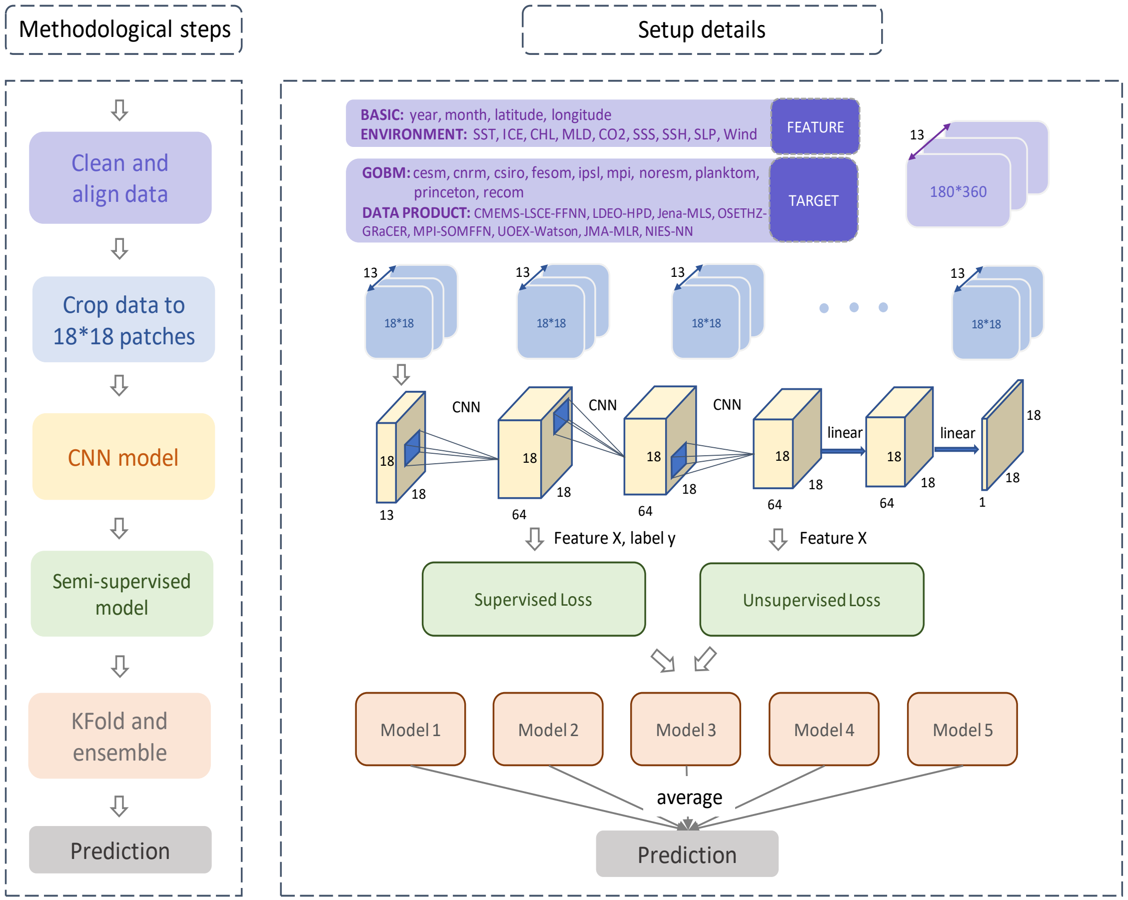
Based on Ml, surface in situ pCO2 and satellte observations of the ocean surface SST, CHl, SSS, MLD

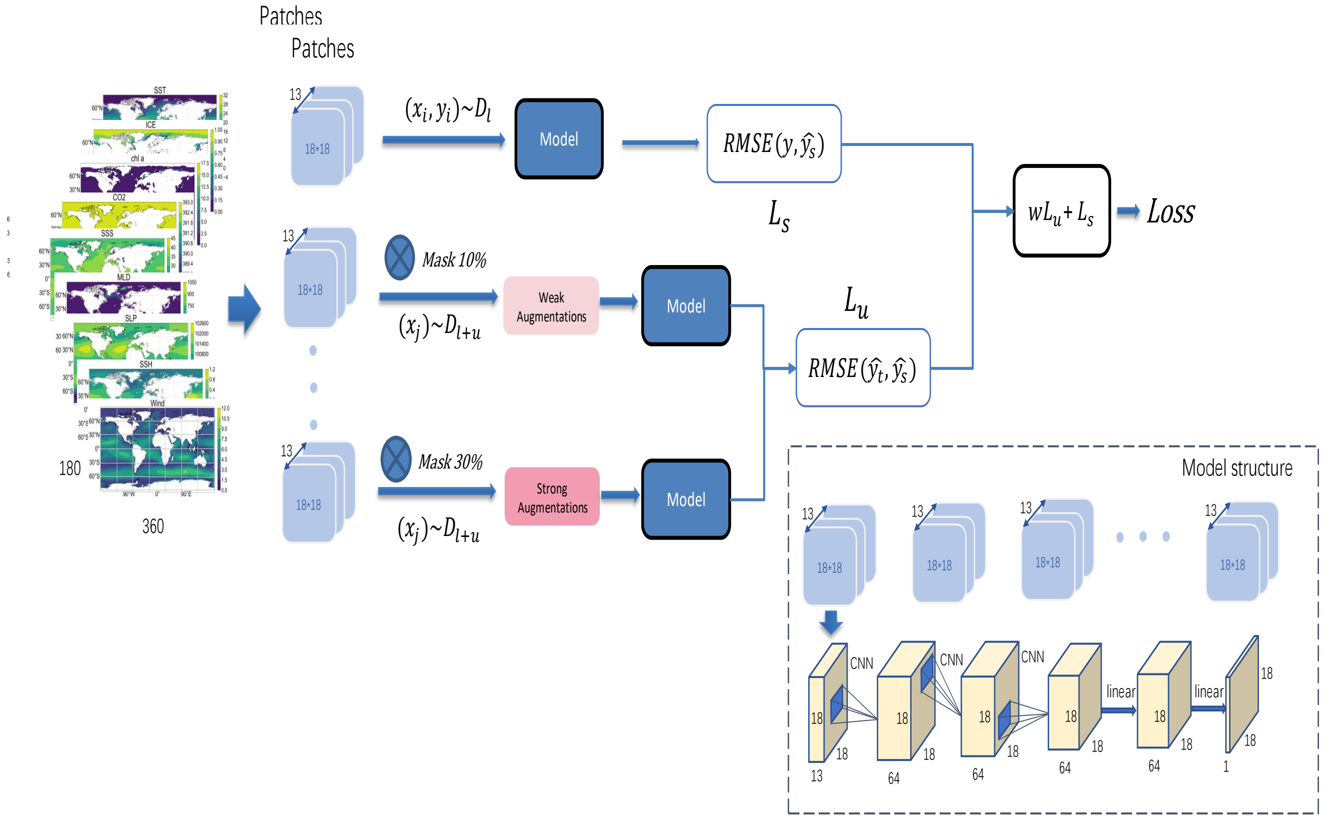


L Gregor and N Gruber, ETH ; G Mc Kinley Columbia University

Confidential – please do not cite

DL emulators of ocean models (process based and data driven)





DL emulators of ocean models (process based and data driven)

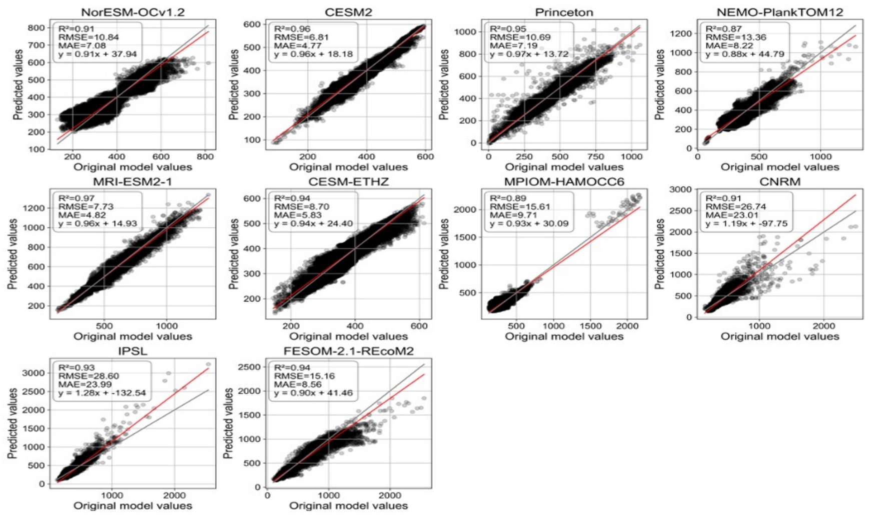


Figure 7. Correlation between CMO-NRT predictions and original outputs for each of the 10 GOBMs during 2020-2021. The red lines show the best-fit line from total least-squares regression. The grey lines represent the 1:1 regression.

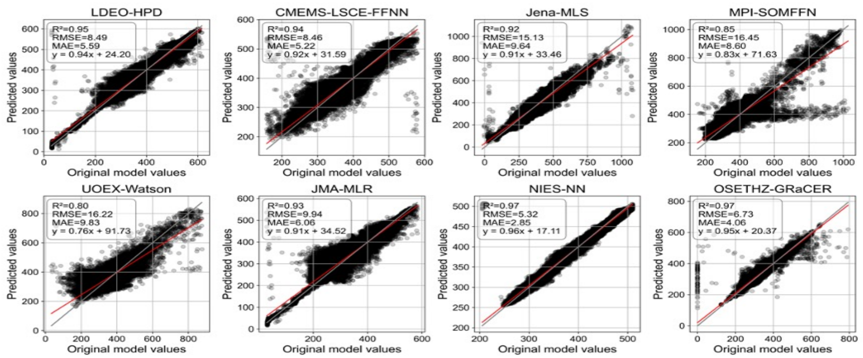


Figure 8. Correlation between CMO-NRT predictions and original outputs for each of the 8 data products during 2020-2021. The red lines show the best-fit line from total least-squares regression.

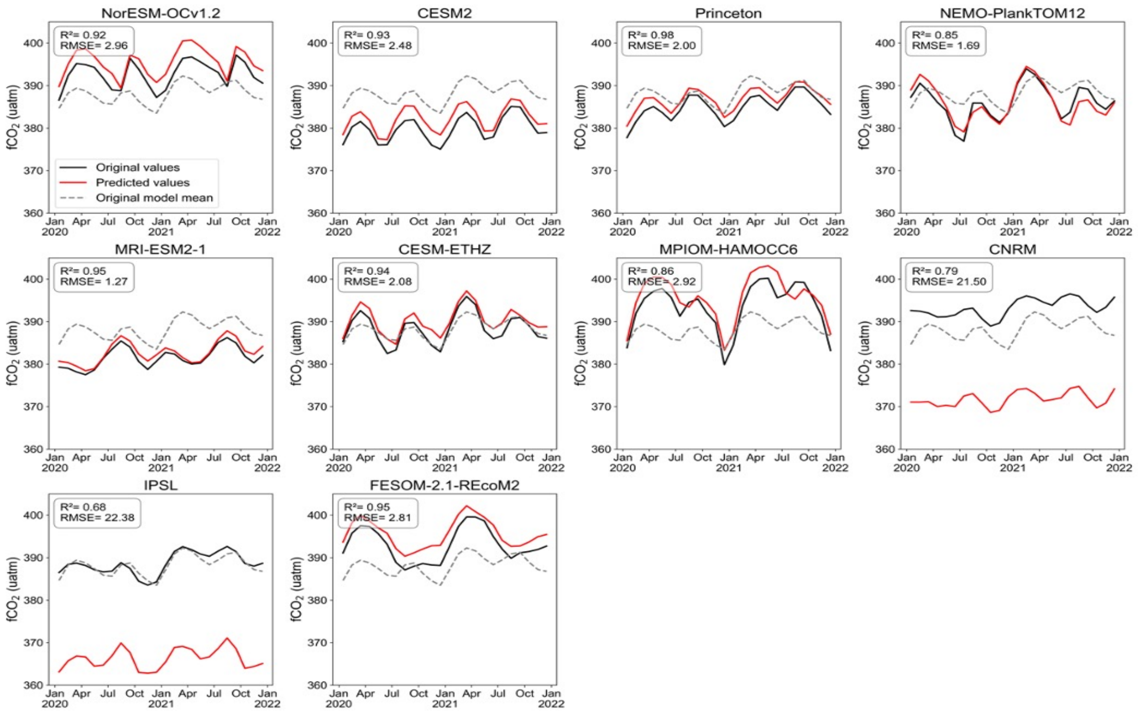


Figure 11. Comparison of global average monthly fCO2 between CMO-NRT predictions and original outputs for each of the 10 GOBMs during 2020-2021. The red lines are the predicted results from CMO-NRT. The black lines are the original results from GOBMs. The dashed grey lines are the average results of 10 GOBMs.

Can be extended to DGVMs and maybe atmospheric inversions

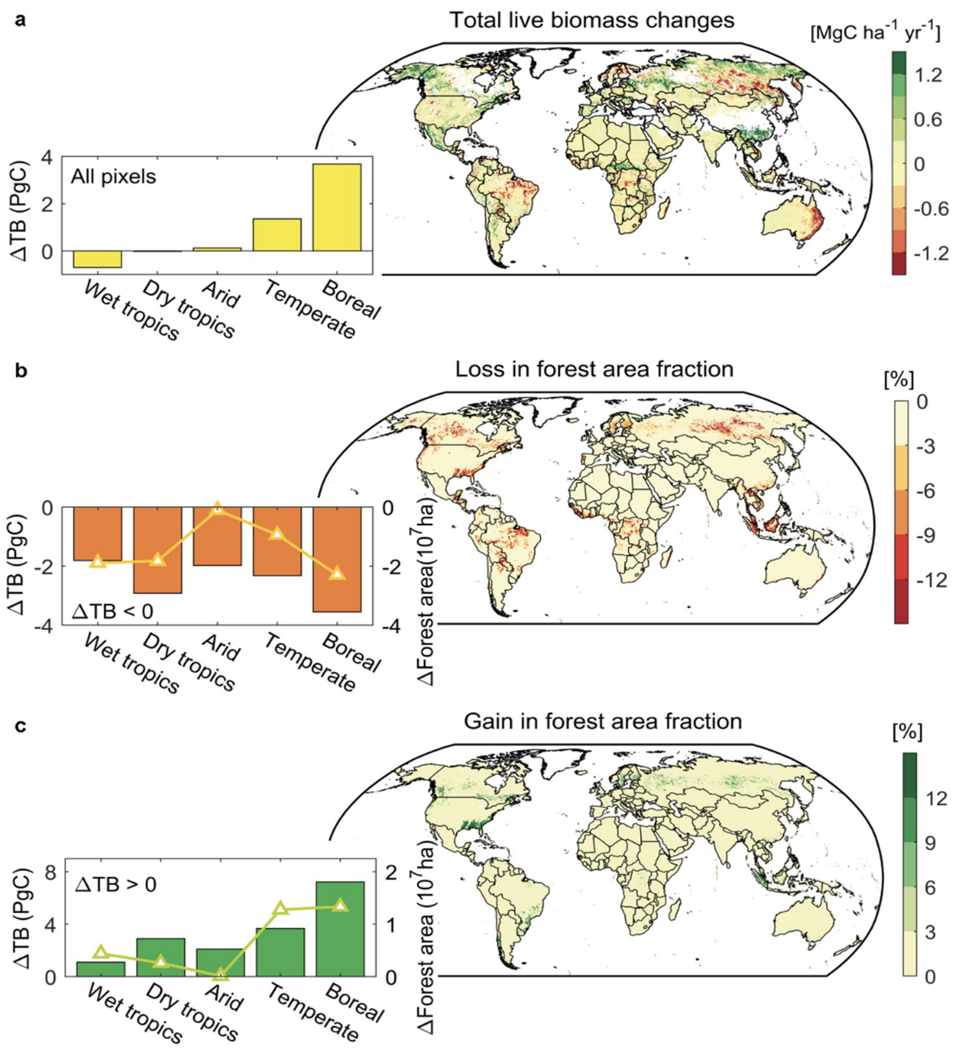
Better prior for inversions + attribution of C flux anomalies NRT fluxes from DGVM (A Bastos, S Sitch et al.)

Example : the drought of 2022 in Europe, China …
2022 in perspective: NBP (net C flux anomaly)
3 DGVM models are run with a 4-mon update

Figure 1 Timeline for fast-track simulations by DGVMs each year (Yr) and interactions with the GCB cycle.

Global NRT monitoring of biomass C changes with satellites

www.kayrros.com/biomass-watch/ SMOS and SMAP satellites



Global coverage
20 km resolution

Updated each 4 months

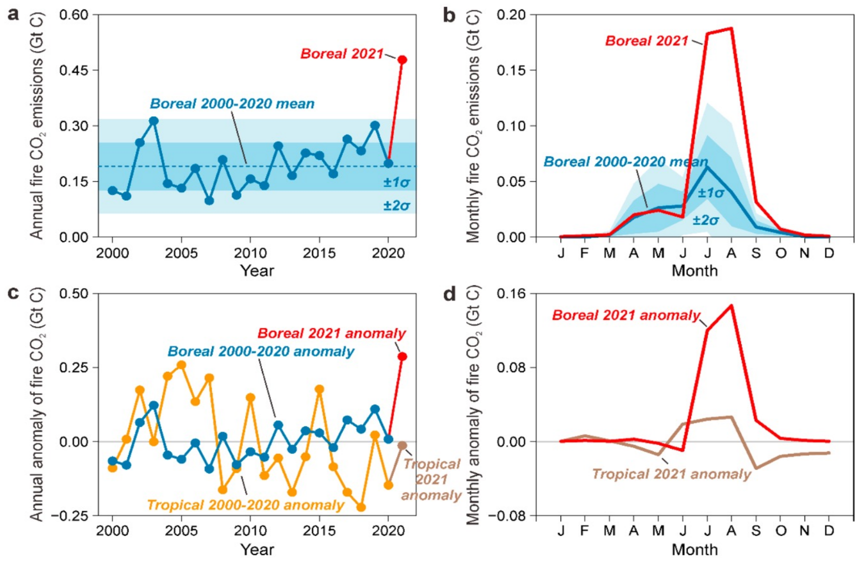
National data compared to UN inventories

Observable losses : NRT monitoring of fire C emissions

Global emission of carbon monoxide with the PYVAR SACS assimilation system

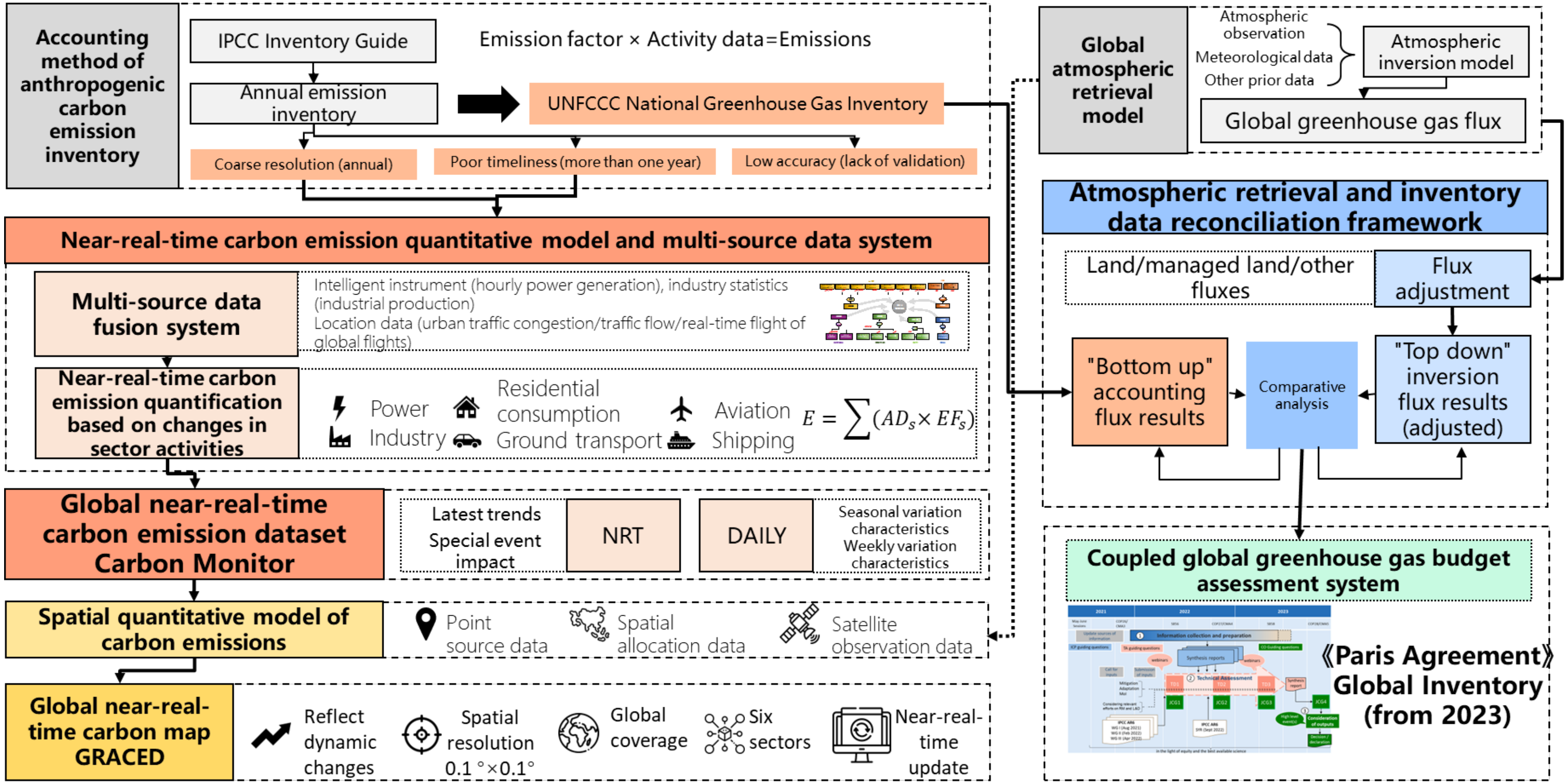
Applied to assess the emission anomaly in 2021 due to boreal and arctic fires

Publication in press in Science, 2023
Zheng et al.

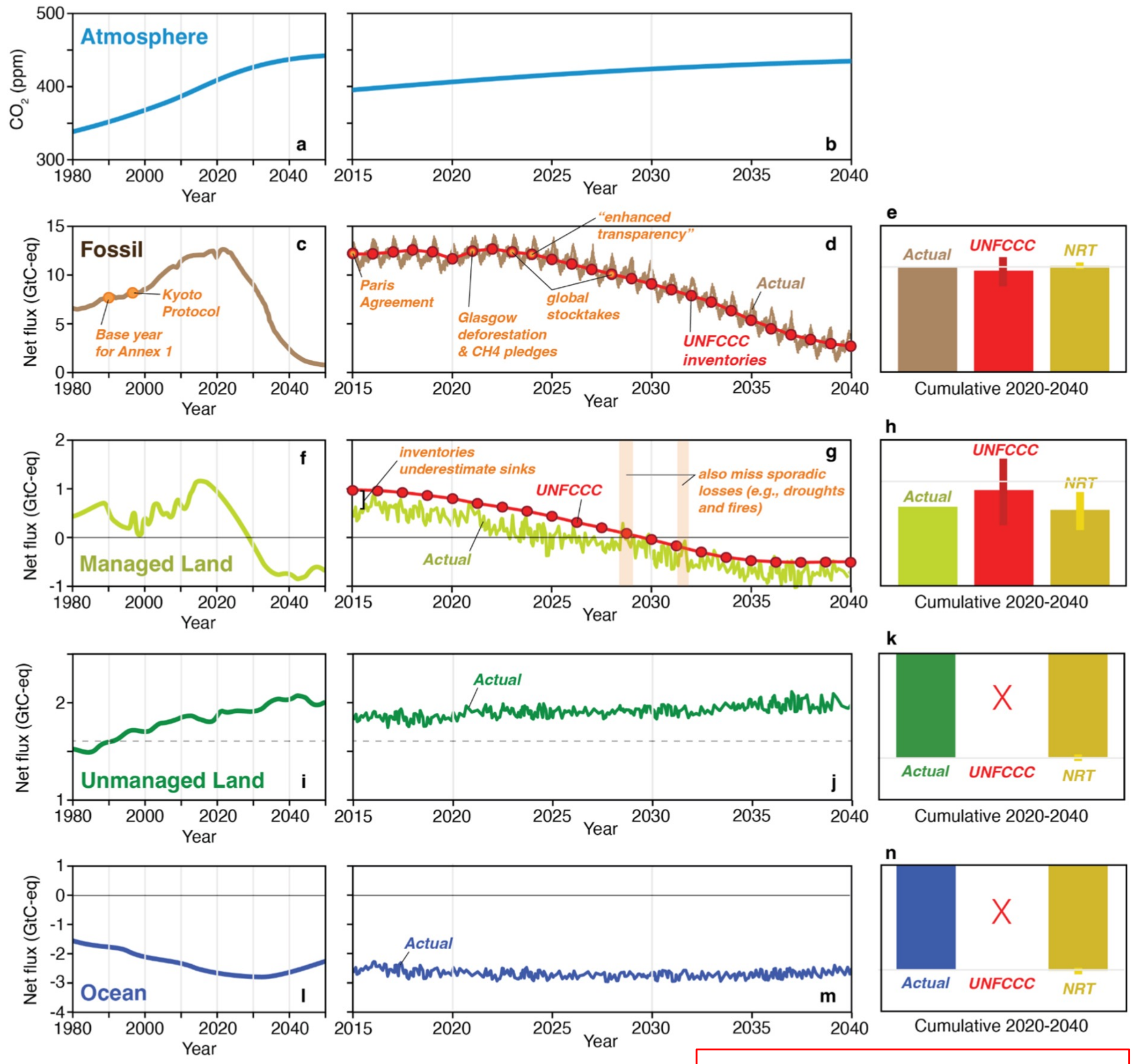


Top
down

NRT carbon accounting model



Conclusion



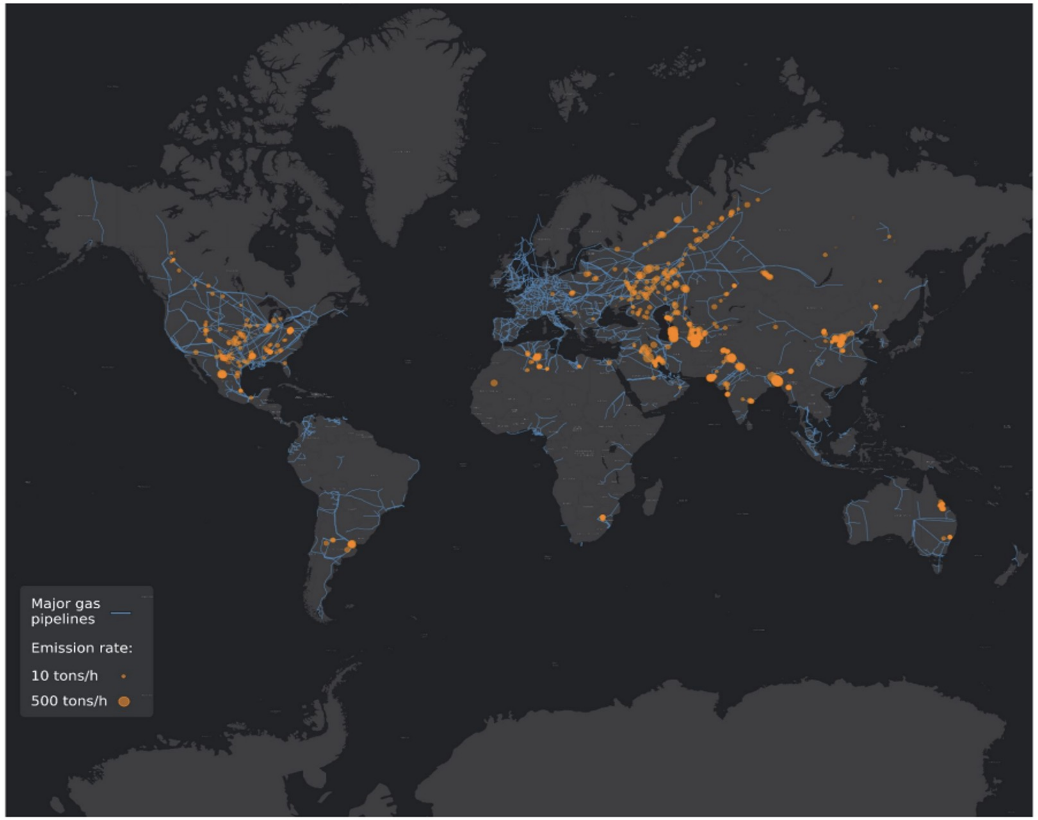
Near real time global CH4 and CO2 budgets are now possible

Coverage and separation of managed / unmanaged land

Understand extreme events and evaluate emerging carbon feedbacks

Impacts of extreme weather events and economic shocks on fossil CO2 and CH4 emissions

Sentinel-5P near-real time monitoring of CH_4 emissions for ultra-emitters



RESEARCH

GREENHOUSE GASES

Global assessment of oil and gas methane ultra-emitters

T. Lauvaux[1*], C. Giron[2], M. Mazzolini[2], A. d'Aspremont[2,3], R. Duren[4,5], D. Cusworth[6], D. Shindell[7,8,9], P. Ciais[1,10]

Methane emissions from oil and gas (O&G) production and transmission represent a considerable contribution to climate change. These emissions comprise sporadic releases of large amounts of methane during maintenance operations or equipment failures not accounted for in current inventory estimates. We collected and analyzed hundreds of very large releases from atmospheric methane images sampled by the TROPOspheric Monitoring Instrument (TROPOMI) between 2019 and 2020. Ultra-emitters are primarily detected over the largest O&G basins throughout the world. With a total contribution equivalent to 8 to 12% (~8 million metric tons of methane per year) of the global O&G production methane emissions, mitigation of ultra-emitters is largely achievable at low costs and would lead to robust net benefits in billions of US dollars for the six major O&G-producing countries when considering societal costs of methane.

<u>Global coverage</u>

Ultra emitters > 20 tCH_4 per hour with TROPOMI

Represents 5 to 80% of national emissions from inventories

Lower detection of leaks > 5 tCH_4 per hour using PRSMA, Sentinel-2, Gaofeng …

LSCE

KAYRROS

Near real time estimates of fossil CH_4 regional emissions for major extraction basins (represents ≈ 35% of fossil CH4 emissions)

Tropomi + high resolution atm inverse models

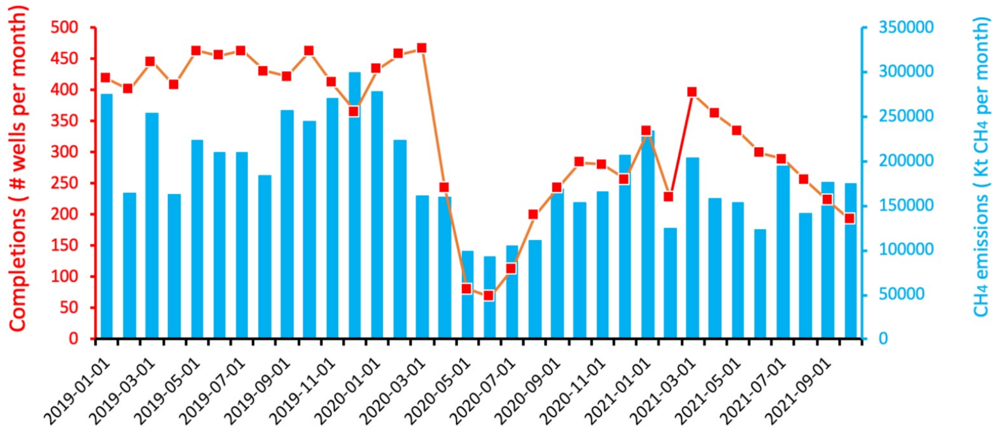
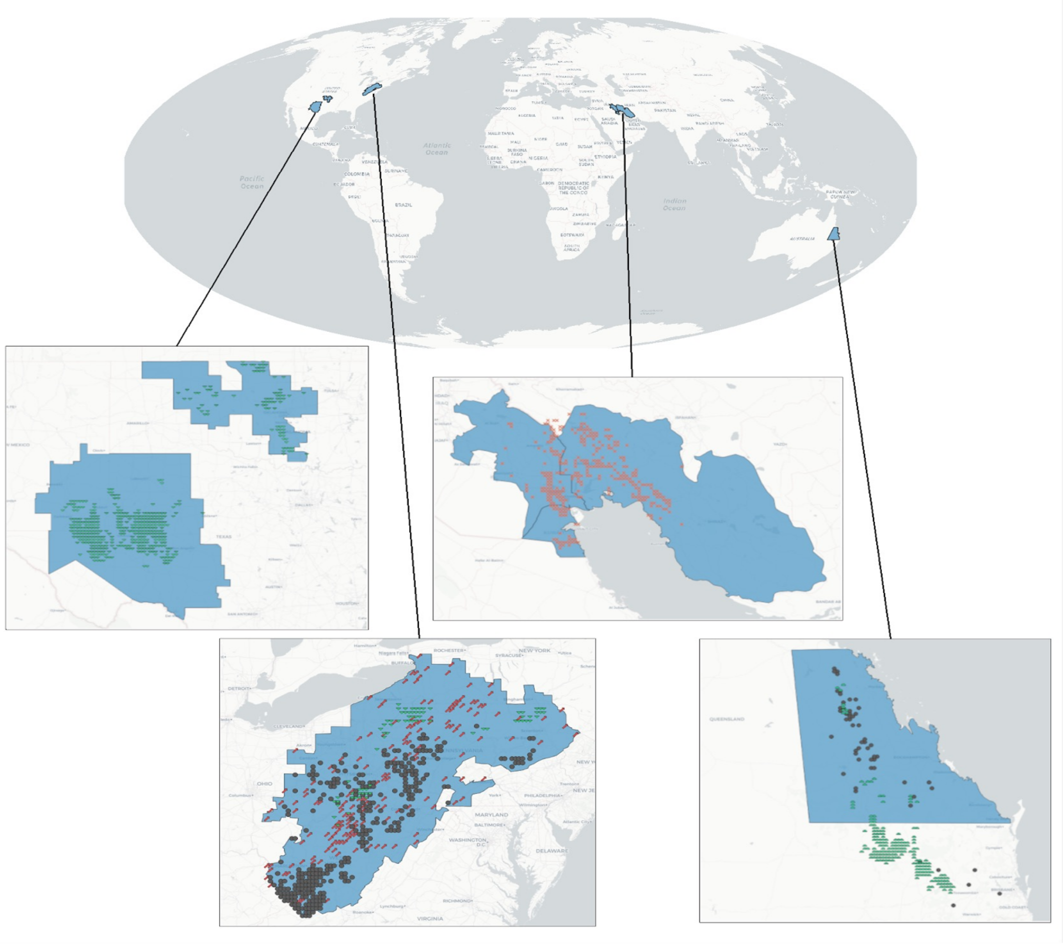


Figure 2. Emissions of CH_4 (blue) from the Permian shale oil and gas basin in the US and well completion rates (red).



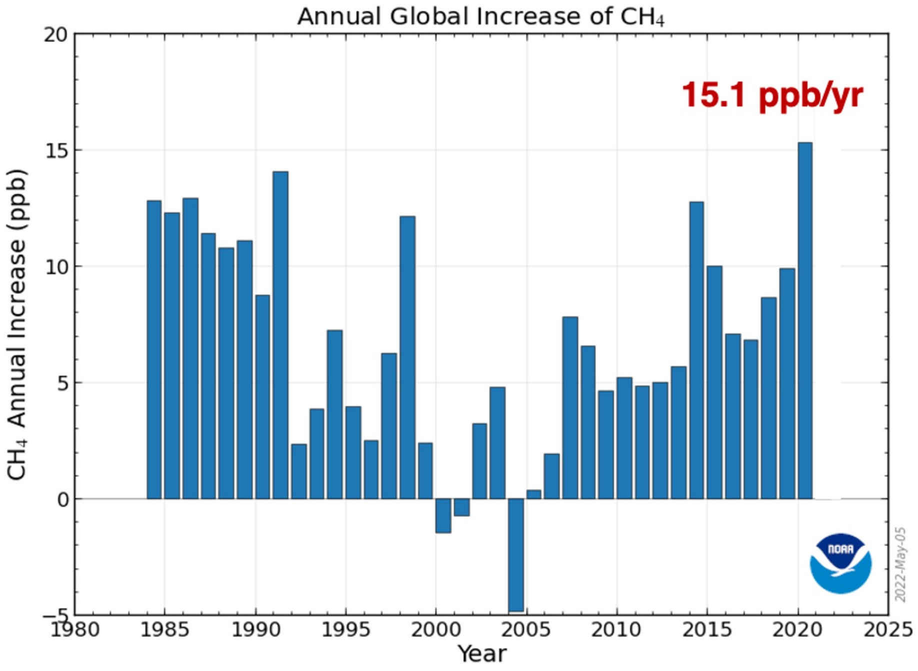
Coverage : seven major oil, gas, coal basins representing 25% of global fossil CH4 emissions

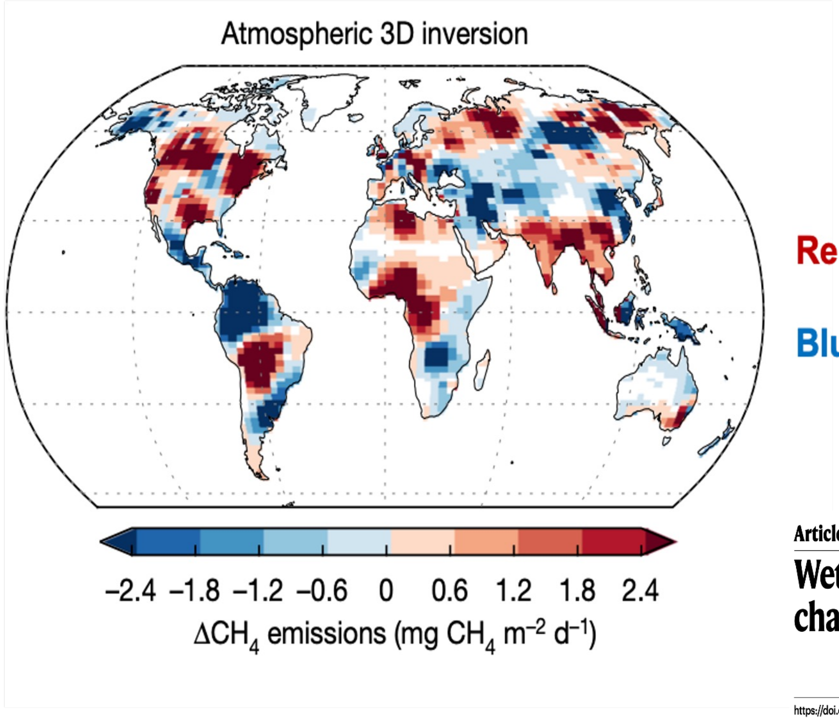
KAYRROS

Global methane emissions anomaly in 2020 and 2021

Global emissions of methane with the LMDZ INCA PYVAR data assimilation system

Applied to understand the acceleration of atmospheric methane growth in 2020 and 2021





Red : more emissions in 2020

Blue : less emissions in 2020

Article

Wetland emission and atmospheric sink changes explain methane growth in 2020

https://doi.org/10.1038/s41586-022-05447-w
Received: 25 January 2022
Accepted: 14 October 2022

Shushi Peng[1,2,3], Xin Lin[4], Rona L. Thompson[5], Yi Xi[1,2], Gang Liu[1,2], Didier Hauglustaine[4], Xin Lan[6,7], Benjamin Poulter[8], Michel Ramonet[4], Marielle Saunois[4], Yi Yin[9], Zhen Zhang[10], Bo Zheng[11,12] & Philippe Ciais[4,13]

Thank you for your attention

Transitioning from research to operational (atmospheric CO2 inversions)

- Copernicus leading the way (as demonstrated in previous slides)

- OCO-2 MIP benefits from global participation across countries adds modeling teams from seven countries: Australia, Canada, China, France, Japan, India, USA .
  a. Not operational, can we move towards annual updates

- Increasing contribution of inverse modelling groups to both OCO MIP and GCP (CAMS, CMS-Flux, CarbonTracker, etc)

From Pep:

During the discussion, I think it is important to also discuss what it all means for the current budget activities:

- What would be the distinctive niche and contributions between current global budget activities and the operational and NRT budgets.
- If distinct, how the products and work can help each other, or are we seeing more of an evolution that ultimate one should replace the other.
- How can a broad GCP support the scientific community to align better with the products that stakeholders need, both policy and science.