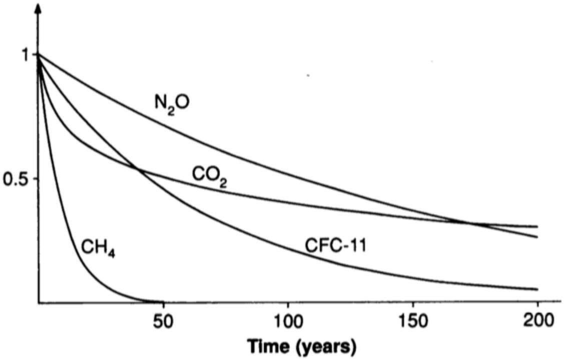
The Climate Benefit of Carbon Sequestration

Carlos A. Sierra, Susan E. Crow, Martin Heimann, Holger Metzler, Ernst-Detlef Schulze

Theoretical Ecosystem Ecology
Max Planck Institute for Biogeochemistry

May 8, 2020

Contribution of GHG emissions to atmospheric warming



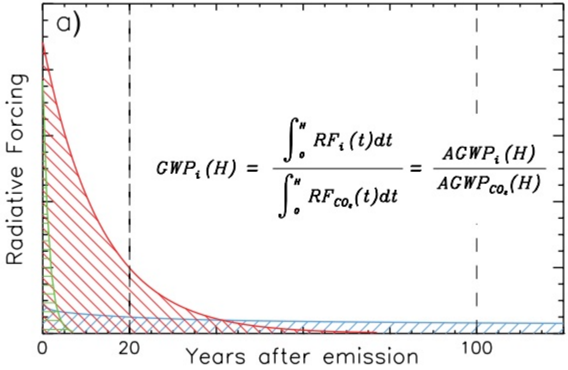
$$AG_i = \int_0^T k_i \, M_i(t) dt = k_i \int_0^T M_i(t) dt$$

Rodhe (1990, Science 248: 1217)

- The contribution of a greenhouse gas to atmospheric warming is commonly quantified as the integrated warming produced by the gas during its lifetime in the atmosphere.
- The absolute global warming potential (AG_i or AGWP_i) of a gas i quantifies this effect by integrating the fate of the gas in the atmosphere M_i multiplied by the radiative efficiency of the gas, over a time horizon T.

Max Planck Institute
for Biogeochemistry

Absolute global warming potential & global warming potential



Lashof & Ahuja (1990, Nature 344: 529)

The global warming potential of a gas i compares the AGWP of this gas with respect to the AGWP of CO_2.

Max Planck Institute for Biogeochemistry

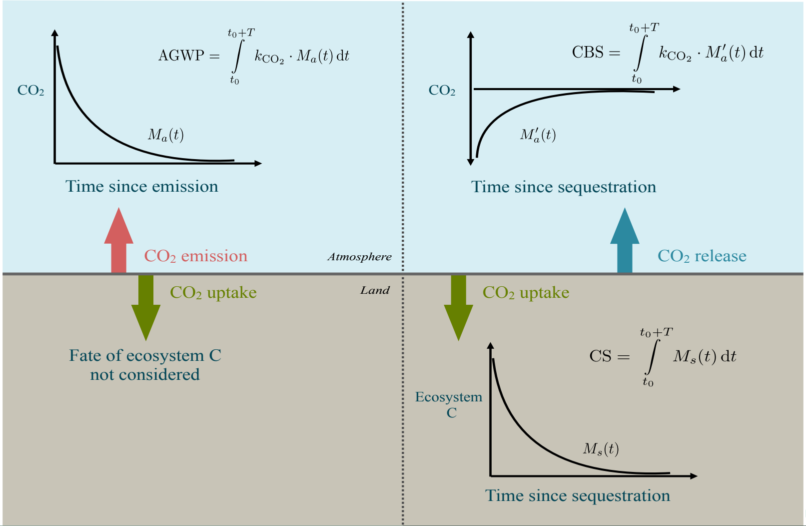
Problem and motivating question

Absolute global warming potentials take into account the fate of an emission of carbon in the atmosphere. However, there is not a related metric that takes into account the fate of an amount of carbon once it is sequestered by a sink.

How do we quantify avoided warming in ecosystems accounting for the fate of carbon once it is sequestered?

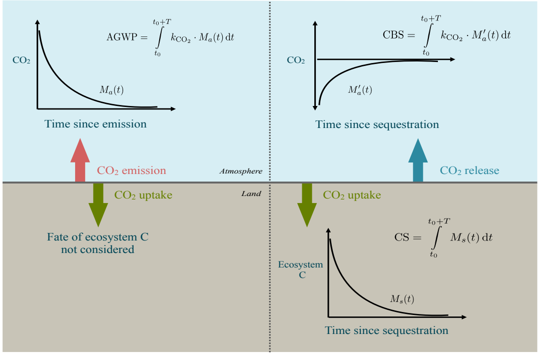
Max Planck Institute
for Biogeochemistry

Carbon Sequestration (CS) and the Climate Benefit of Sequestration (CBS)



Max Planck Institute for Biogeochemistry

Carbon Sequestration (CS) and the Climate Benefit of Sequestration (CBS)



The climate effect of a carbon emission is captured by AGWP, however there is currently not an appropriate metric to quantify the climate effect of C uptake in a land sink (left part of diagram).
We propose to quantify carbon sequestration (CS) as the integral of the fate of carbon once it is sequestered in a sink over a time horizon T, similarly as emissions in AGWP.
The climate benefit of sequestration (CBS) takes into account the uptake by the sink and the gradual return of carbon back to the atmosphere from respiratory processes or leaks from the sink.
Thus, CBS integrates the fate of the sequestered carbon multiplied by the avoided radiative effect in the atmosphere.

Max Planck Institute for Biogeochemistry

Definition of carbon sequestration

Carbon sequestration can be defined as the process of capture and long-term storage of an initial amount of carbon S_0 at time t_0 integrated over a time horizon T.

$$\mathrm{CS}(T, S_0, t_0) := S_0 \int_{t_0}^{t_0+T} M_s(t - t_0)\,\mathrm{d}t,$$

where $M_s(t - t_0)$ is the amount of carbon stored in the ecosystem, since the time it entered at t_0 until some time t.

Max Planck Institute
for Biogeochemistry

The climate benefit of sequestration (CBS)

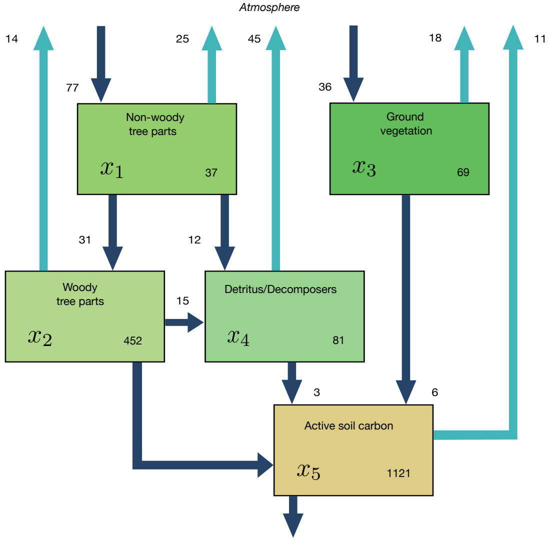
The CBS quantifies avoided warming (in W m^{-2}) of an amount of carbon sequestered at time t_0 over a time horizon T.

$$
\begin{aligned}
\mathrm{CBS}(T, S_0, t_0) &:= \int_{t_0}^{t_0+T} k_{\mathrm{CO}_2} M_a'(t) \, \mathrm{d}t, \\
&= -k_{\mathrm{CO}_2} \int_{t_0}^{t_0+T} \left(h_a(t - t_0) S_0 - (h_a \star r)(t) \right) \mathrm{d}t.
\end{aligned}
\tag{1}
$$

This is how the atmosphere 'sees' sequestration of S_0 with return of respired carbon according to $r(t)$.

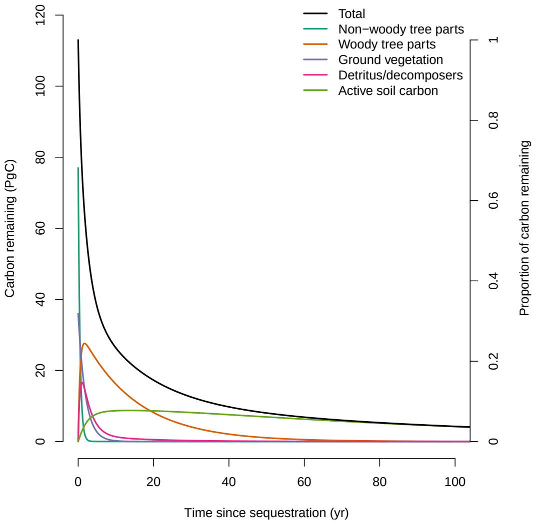
Max Planck Institute
for Biogeochemistry

A simple model of the preindustrial carbon cycle (Emanuel et al. 1981)



Max Planck Institute for Biogeochemistry

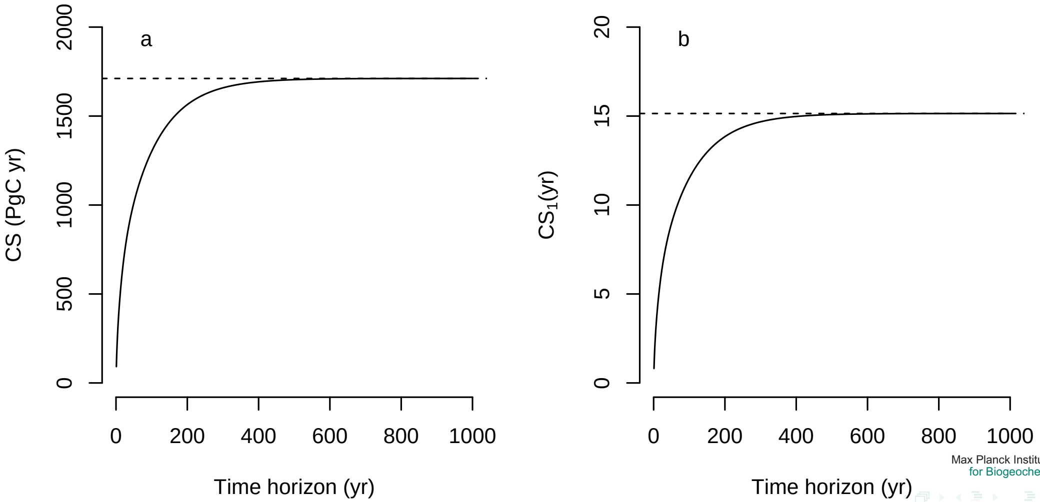
Fate of carbon uptake $M_s(t)$ in the pre-industrial biosphere



From 113 PgC sequestered in one year, a large proportion is lost back to the atmosphere by respiration. A proportion of the sequestered C by the non-woody vegetation and ground vegetation is transferred to woody parts and detritus, and a much smaller proportion ends up in soils. Most of the sequestered carbon is lost in a few decades.

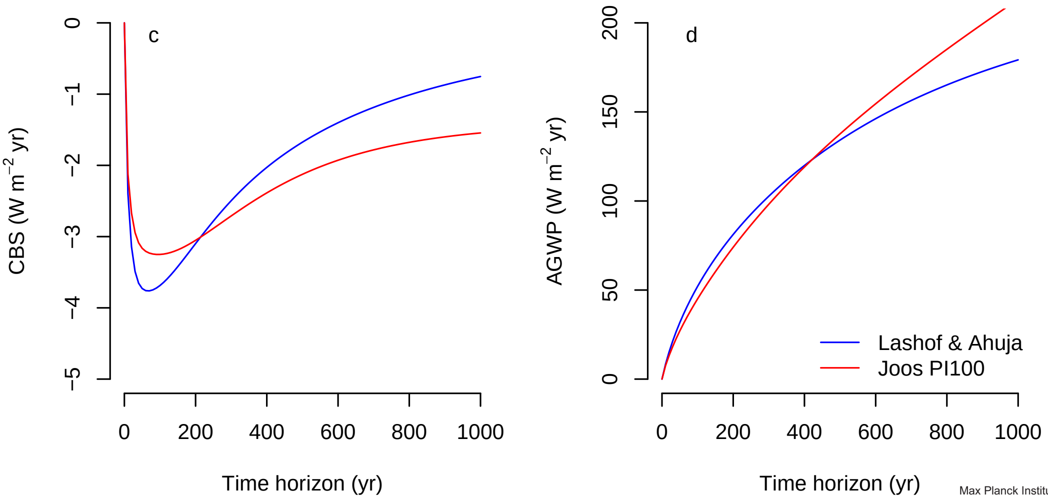
Max Planck Institute for Biogeochemistry

CS for $S_0 = 113$ PgC sequestered in one year (a) and $S_0 = 1$ (b). CS converges to steady-state stock in a, and to mean transit time in b.



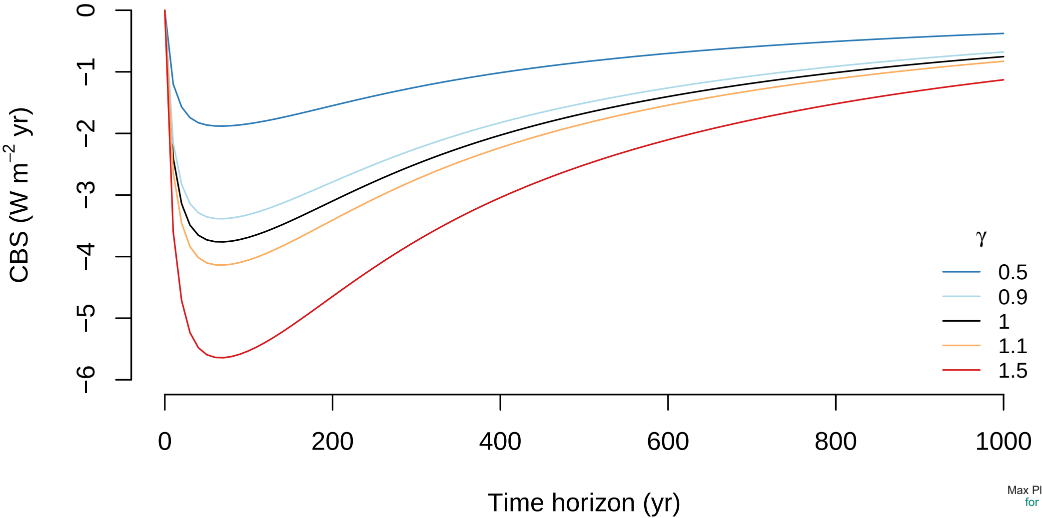
Max Planck Institute for Biogeochemistry

CBS and AGWP for two different impulse response functions



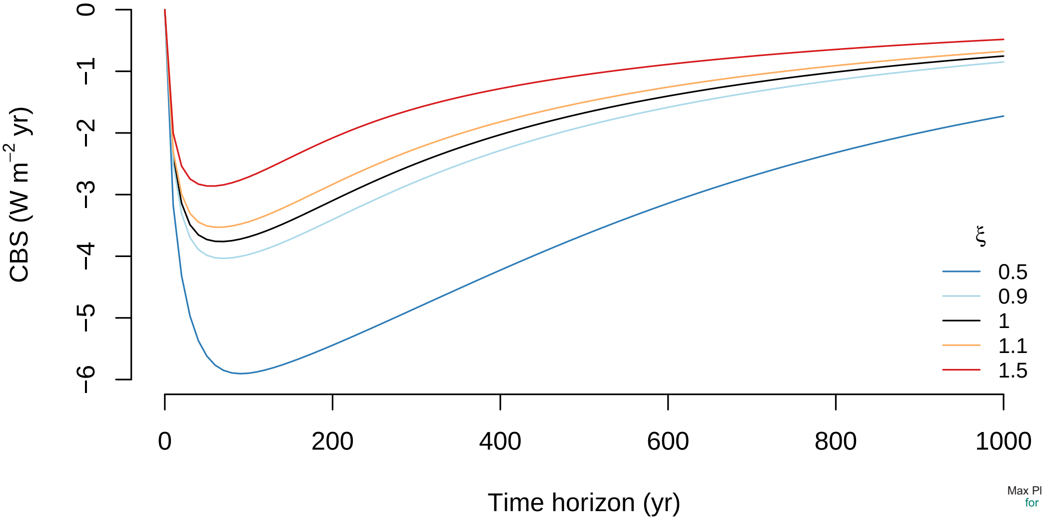
Max Planck Institute for Biogeochemistry

Managing CBS by managing inputs (γ: prop. change in inputs)



Max Planck Institute
for Biogeochemistry

Managing CBS by managing process rates (ξ: prop. change in rates)



Summary and conclusions

- We propose a metric to quantify the climate impact of sequestering carbon in sinks. It integrates the amount of carbon over the time horizon it is retained.
- The climate benefit of sequestering carbon should consider the fate of carbon in ecosystems and not the fate of carbon in the atmosphere.
- GWPs are useful to assess climate impacts of emissions, but not useful to assess benefits of sequestration.
- This framework is useful to disentangle the climate benefits of increasing carbon inputs in sinks versus the effect of extending the transit time of carbon.