Assessing the Durability of Ocean Iron Fertilization CO_2 Reduction

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Revised OIF Durability Estimates

- Durability quantifies the time course of the atmospheric CO_2 reduction given a mCDR action
- Previous estimates of OIF durability considered return times of remineralized C to sea surface
- Important details of CO_2 gas exchange were not included (time to equilibrium for carbonate system as well as its interactions with global atmospheric CO_2)
- Initially durability must be zero as there needs to be an ingassing of CO_2 into the ocean
- OIF CDR redistributes the DIC profile vertically & mixing during the ingassing phase wash out the CDR perturbation, reducing OIF mCDR efficiency

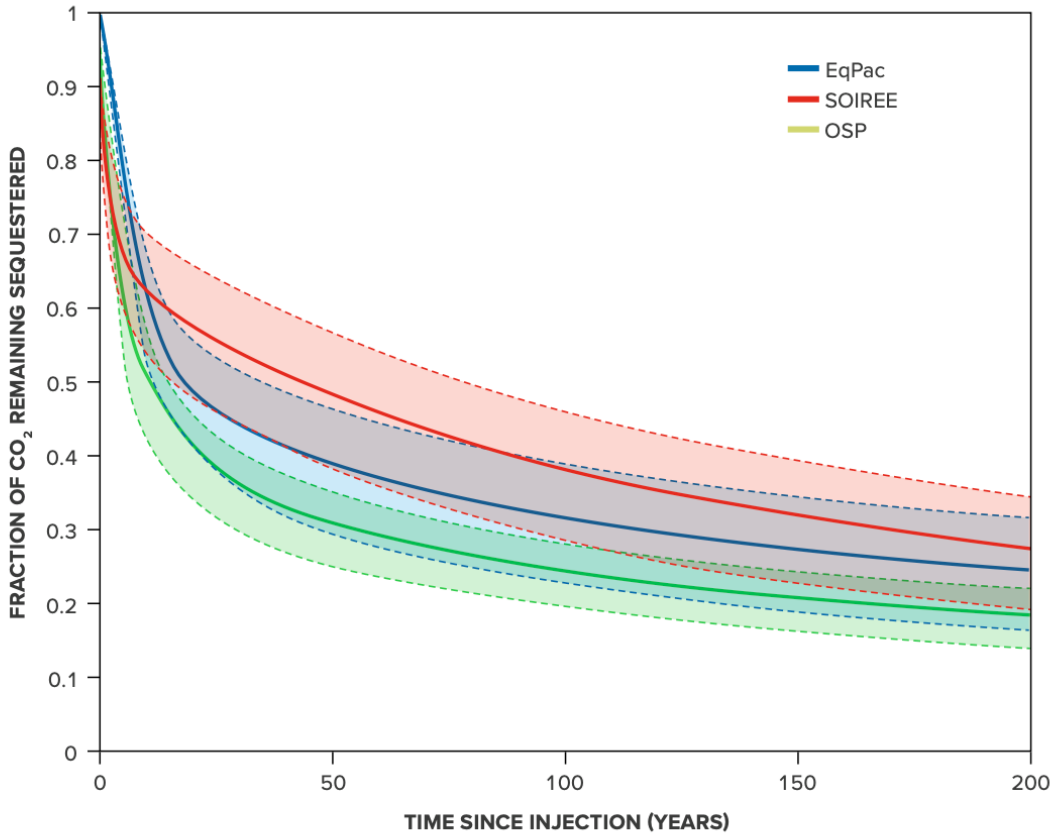


Figure 4.7. Fractions of carbon that remain sequestered (y-axis) vs time (x-axis) projected via models for the Equatorial Pacific (blue); Southern Ocean SOIREE site (red); and Ocean station P (OSP- green). The data fall within the envelope of shading (dashed lines) derived using variable remineralization rates, with a lower bound for lower carbon flux attenuation (b=0.3; characteristic of some diatom blooms) and upper bound for higher/faster remineralization vs depth (b=0.8; more typical of global ocean with average remineralization).

From ExOIS' *Pathways Forward*

Revised OIF Durability Estimates

- Model the time course of OIF mCDR CO_2 sequestration using a steady-state, global circulation inverse model (OCIM2-48L; 2° spatial & 48 vertical layers)
- Model includes an interacting atmosphere pool & finite time gas exchange enabling $\Delta CO_{2\ atm}$ to be calculated given a mCDR action (Yamamoto et al. in review – preprint available)
- To model OIF, a small amount ΔDIC_{CDR} is removed from the euphotic zone & distributed beneath it following a Martin curve ($F(z) = F_{eu}\ (z/z_{eu})^{-b}$; where b varies from 0.3 to 0.8)
- Direct Air Capture (DAC) is also modeled to assess response of the global CO_2 system
- Many assumptions: steady-state, contemporary ocean, linearized CO_2 system, scale of mCDR DIC perturbation is small, no terrestrial biosphere, no burial, etc.
- Define two metrics for mCDR durability (see Yamamoto et al., in review)

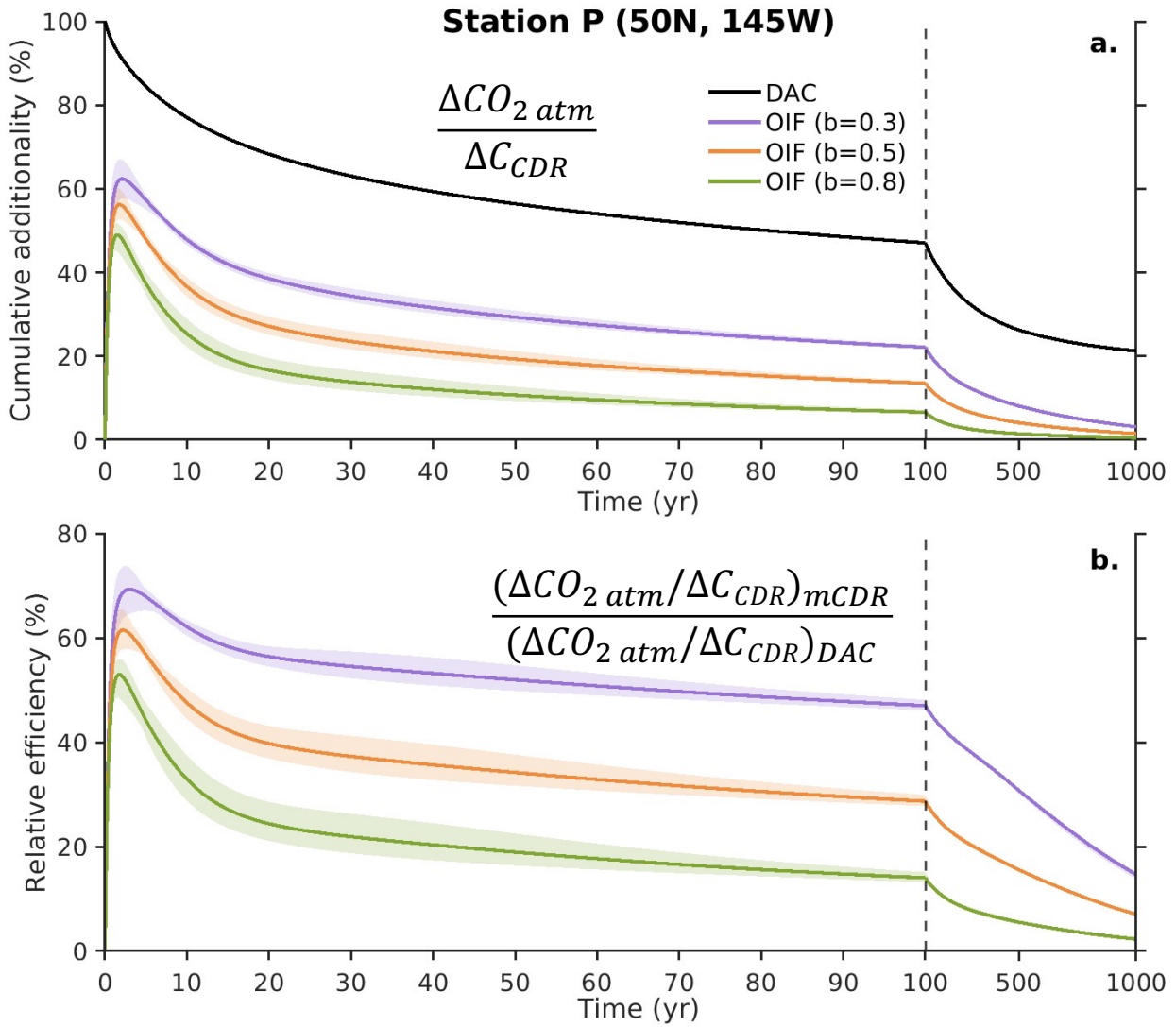
  Cumulative additionality = $\Delta CO_{2\ atm} / \Delta DIC_{CDR}$ => Focus on the air-sea system

  Relative efficiency = Cum_Add_mCDR / Cum_add_DAC => Focus on ocean storage

Revised OIF Durability Estimates

Preliminary Results (Station P):

- Cumulative additionality time course occurs in 3 stages: 1) local ingassing, 2) global outgassing, & 3) outgassing of ΔDIC_{CDR}
- The ingassing phase is ≤ 5 years at Sta P
- The "b" value is very important for setting the relative efficiency level
- Initially, ingassing interacts with vertical mixing of the ΔDIC_{CDR} perturbation, lowering relative efficiencies
- Once set (10 y), relative efficiencies decrease 33% to 130% @ 100 y (again f(b))
- Outgassing of ΔDIC_{CDR} is very slow (>100 y)



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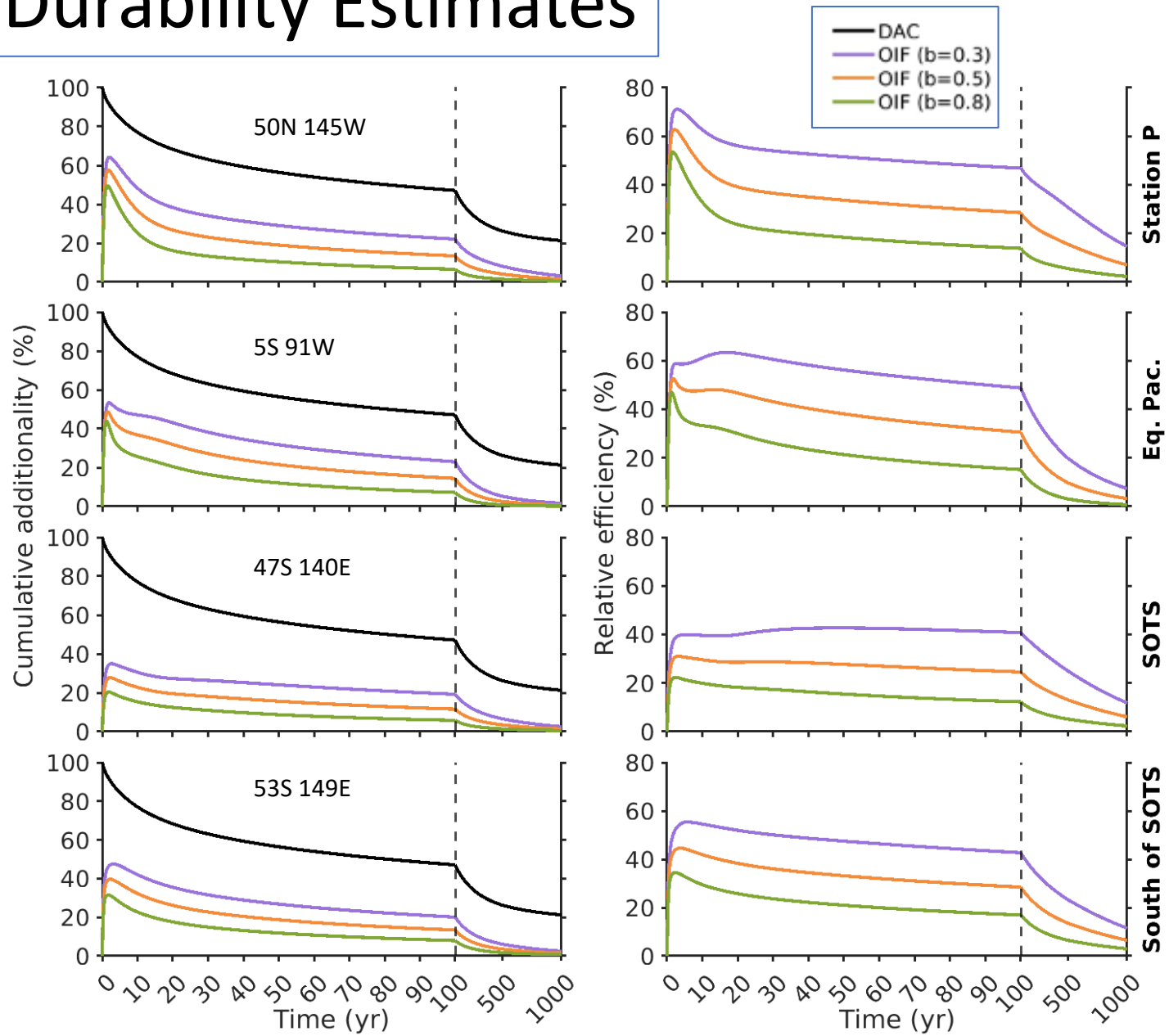
Revised OIF Durability Estimates

Preliminary Results (global):

- Durability metrics are strong functions of the assumed “b” value
- Circulation & mixing can have important roles as well
- Initial differences in relative efficiencies due to local mixing (e.g., SOTS vs. StaP)
- Late period differences due to water ventilation (EqPac vs. Sta P & SOTS)
- Between 10 & 100 y, efficiencies change little for b=0.3 (0-30%), but more for b=0.8 (60-130%)

Bottom line: OIF is inefficient, but can be durable



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Revised OIF Durability Estimates

Preliminary results:

- OIF is inefficient, yet highly durable
- Efficiency differences are driven largely by the scale of sinking flux penetration (the assumed b value) due to vertical mixing of the initial ΔDIC_{CDR} perturbation
  - Early on, OIF can be as much as ~60% of DAC, but can be much less (15% of DAC)
- Once relative efficiencies are set (2-10 y), they decrease slowly (again f(b))
  - Between 10 & 100 y, relative efficiencies change little for b=0.3 (0-30%), but these changes are much larger for b=0.8 (60-130%)
- Model is highly idealized & can be improved (spatial particle remineralization, seasonality, etc.)

Obvious Lessons:

- There are no free lunches – even DAC CDR will influence the global CO_2 balance resulting in a global outgassing reducing $\Delta CO_{2\ atm}$
- OIF efficiency can be gained by engineering deeper sinking flux penetration
- OIF pilot studies & MRV activities will need to constrain both initial ΔDIC_{CDR} perturbation and its vertical mixing (the latter is likely a task for regional ocean models)