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Isotopic, Radiocarbon, and Energy-Balance Measurements Falsify the Anthropogenic Attribution of Atmospheric CO_2

A Formal Critique of Engelbeen et al. (2024)

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Abstract

Engelbeen, Hannon & Burton (2024) [25], hereafter EHB, is a 65-page CO_2 Coalition report claiming to establish anthropogenic dominance of atmospheric CO_2. EHB's own framing on p. 7 is that "the carbon mass balance is what definitely proves that humans are the main cause of the increase of CO_2 in the atmosphere"; the report's other eight sections (isotopes, oxygen, ocean chemistry, process characteristics, ice cores, plant stomata, pre-Mauna Loa chemical methods) are labeled by EHB themselves as "additional evidence for the human contribution." By EHB's own construction the report is one proof with supporting appendices. The mass-balance proof is null by Cohler & Soon (2026c) [22] Theorem 1: the identity $F_{\text{anth}} - dM_a/dt = F_{\text{out}} - F_{\text{nat}}$ holds in every physically admissible state and carries zero evidential weight for any causal proposition. That verdict alone ends the report at what EHB say the report is doing. The supporting sections are nevertheless audited here and each fails against direct empirical measurement. The Keeling relation applied to the modern Scripps ^{13}C record forces the fossil fraction of the net atmospheric addition to $f \approx 0$, indistinguishable from zero within measurement uncertainty. The bomb-spike ^{14}C single-exponential decay over 1965–2019 gives $\tau_{\text{rel}} \approx 18.4$ yr, $R^2 > 99.8\%$, no permanent fraction, falsifying the Bern impulse-response function. The oxygen budget constrains sink partition, not source attribution. The ocean-chemistry argument invokes an "average ocean pH" that is not a physical quantity. The process-characteristics argument multiplies a physically meaningless global-mean temperature; the actual driver, the CERES top-of-atmosphere net energy imbalance of 4.3 ± 4 W m^{-2} (1σ) applied locally via van't Hoff solubility and Arrhenius/Q_{10} respiration, reproduces the observed ~ 2.25 ppm/yr growth with no anthropogenic contribution required. The 50-year adjustment time on which any long-adjustment-time claim depends is a circular regression that assumes the conclusion. Ice-core gas-age smoothing in the only three cores spanning past interglacials attenuates century-scale peaks below scatter. The stomata dismissal is circular. The chemical-method dismissal generalizes from one 1942 peak to reject 90,000 measurements. The report's three dominant rhetorical modes are unsupported assertion, non-sequitur, and omission-as-disproof.

Keywords: atmospheric CO_2; anthropogenic attribution; Keeling relation; carbon isotopes ($\delta^{13}C$); bomb radiocarbon (^{14}C); Bern impulse-response function; mass balance; CERES top-of-atmosphere energy imbalance; van't Hoff solubility; carbon cycle

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1. Introduction

The Engelbeen, Hannon and Burton report [25] is a 65-page, non-peer-reviewed document published by the CO_2 Coalition in December 2024. It presents itself as a comprehensive rebuttal to the position that natural processes rather than fossil-fuel combustion have dominated the recent increase in atmospheric CO_2 concentration, yet names none of the peer-reviewed papers that hold that position: absent from its 65 pages are Berry [8], [9]; Harde [31], [33]; Harde and Salby [34]; Salby and Harde [70], [71]; Koutsoyiannis [53], [54], [55]; Humlum et al. [36]; Essenhigh [26]; Segalstad [73]; and Stallinga [76]. The report purports to refute a body of work whose authors it never names, and to do so in a venue where none of its claims is subject to peer scrutiny. We publish this rebuttal in a peer-reviewed venue at the same level of specificity: specific claim, specific counter, specific citation.

The purpose of the present paper is to examine each of EHB's nine lines of evidence in the order they are presented, at the level of specific quantitative claims, and to show that the anthropogenic attribution the report defends is falsified by direct empirical measurements the report does not address. Three measurements do the work: the modern Scripps ^{13}C Keeling record forces the fossil fraction of the net atmospheric addition to $f \approx 0$; the bomb-spike ^{14}C decay over 1965–2019 falsifies the Bern impulse-response function; and the CERES top-of-atmosphere net energy imbalance, applied through local van't Hoff and Q_{10} responses, quantitatively reproduces the observed atmospheric growth with no anthropogenic term required. The tools required are elementary: mass conservation, isotope mass balance, first-order linear response theory, standard time-series statistics, and local applications of van't Hoff solubility and Arrhenius/Q_{10} respiration to the CERES-measured energy flux. The relevant peer-reviewed literature has existed for years. This paper documents where each specific EHB claim breaks and where the correct treatment is published.

1.1 Standing technical parameters used throughout

The following quantities appear throughout. Notation: $M_a(t)$ denotes the atmospheric CO_2 inventory (GtC); $F_{in}(t)$ and $F_{out}(t)$ the gross atmospheric inflow and outflow rates (GtC/yr), with F_{in} inclusive of both natural and anthropogenic sources; $F_{anth}(t) = E_{FOS}(t) + E_{LUC}(t)$ the total anthropogenic inflow, with E_{FOS} and E_{LUC} the fossil-fuel and land-use-change components respectively; and $F_{nat}(t) = F_{in}(t) - F_{anth}(t)$ the natural gross inflow.

- Atmospheric residence time: $\tau_{out} \equiv M_a/F_{out}$. Empirically τ_{out} is observed to be approximately constant and we adopt it as $\tau_{res} = 3.80 \pm 0.12$ yr from Refined Reservoir Routing applied to Mauna Loa and Barrow data Koutsoyiannis (2024a) [53].
- Bomb-radiocarbon atmospheric ratio-relaxation timescale: a single-exponential fit to the annual mean atmospheric $\Delta^{14}C$ compilation of Hua et al. (2022) [35] over 1965–2019 (from the post-testing peak to the end of the compiled global record) gives $\tau_{rel} \approx 18.4$ yr, $R^2 > 99.8\%$, and no permanent fraction.
- Bridge relation between the bulk residence time and the isotopic ratio-relaxation timescale:

$$\tau_{rel} \;=\; \bar{\mathcal{D}} \cdot \frac{\tau_{res}}{\bar{\phi}_{slow}} \;\approx\; 0.98 \times \frac{3.80\ \text{yr}}{0.203} \;\approx\; 18.4\ \text{yr}.$$

  The two parameters are defined as follows.
  - $\bar{\mathcal{D}} \equiv \overline{F_{out}/F_{in}} \approx 0.98$ is the time-averaged disequilibrium ratio of gross outflow to gross inflow. From Global Carbon Budget flux totals for 2010–2019, $F_{in} \approx 235$ GtC/yr and $F_{out} \approx 230$ GtC/yr give $\mathcal{D} \approx 0.979$.
  - $\bar{\phi}_{slow}$ is the fraction of gross inflow F_{in} originating from reservoirs unlabeled by the bomb spike: deep-ocean upwelling (~ 38 GtC/yr from the pre-bomb deep pool), refractory soil

respiration with turnover times $\gg 50$ yr, and fossil-fuel combustion (~ 10 GtC/yr, isotopically dead). Together these total ~ 48 GtC/yr out of $F_{\text{in}} \approx 235$ GtC/yr, giving $\bar{\phi}_{\text{slow}} \approx 0.203$. Physical picture: bomb ^{14}C recycles between the atmosphere and the labeled surface pool on the residence timescale $\tau_{\text{res}} \approx 3.8$ yr, but is only truly removed on the slower timescale set by dilution against the unlabeled deep pool. The ratio $\tau_{\text{rel}}/\tau_{\text{res}} = \bar{\mathcal{D}}/\bar{\phi}_{\text{slow}} \approx 4.83$ recovers the observed $\tau_{\text{rel}} \approx 18.4$ yr from the measured $\tau_{\text{res}} \approx 3.80$ yr with no free parameters. Full derivation and error analysis in the forthcoming bomb-radiocarbon paper (Cohler and Soon, in preparation).

- Instrumental Keeling-plot intercept: $\delta^{13}C_I = -13.2 \pm 0.2$‰, from the Scripps modern record [54].
- Sclerosponge δ^{13}C-derived net-added signature over the last 500 years: approximately -13‰ [10].
- Law Dome LD ANT ice-core Keeling intercept: $y_0 = -13.1$‰, $r^2 = 96\%$ [46].
- Bern impulse-response function [41]: e-folding time 165 yr, slowest decay mode 394.4 yr, permanent fraction 21.7%. Falsified by the bomb-^{14}C measurement.

1.2 Structure of this paper

Sections 2 through 10 address the nine EHB lines of evidence in order. Section 11 examines EHB's citation practice. Section 12 summarizes.

2. The Mass Balance Argument (EHB §1.1): Null by Theorem

EHB's own framing of the report determines the verdict against it. On p. 7, EHB write: "The carbon mass balance is what definitely proves that humans are the main cause of the increase of CO_2 in the atmosphere." The isotopic, oxygen, ocean-chemistry, ice-core, stomata, and chemical-methods sections are labeled by EHB themselves as "additional evidence for the human contribution," i.e., support for the mass-balance proof, not independent proofs. By EHB's own construction the report is one proof (mass balance) with supporting appendices. The proof is null by Cohler & Soon (2026c) [22] Theorem 1. No accumulation of supporting evidence, however strong on its own terms, can convert a null proof into a proof. The audits that follow show the supporting sections also fail on their own terms and in fact falsify EHB's attribution. That result is dispositive on its own but not necessary. The mass-balance verdict alone contradicts the EHB report.

2.1 The identity

The atmospheric CO_2 reservoir equation is

$$\frac{dM_{\text{a}}}{dt} = F_{\text{in}}(t) - F_{\text{out}}(t), \tag{1}$$

where $M_{\text{a}}(t)$ is the atmospheric CO_2 inventory (GtC), $F_{\text{in}}(t)$ is the gross inflow rate (terrestrial respiration, fire, ocean outgassing, volcanism, fossil-fuel and land-use emissions combined), and $F_{\text{out}}(t)$ is the gross outflow rate (photosynthetic uptake, ocean dissolution, weathering). The anthropogenic component of F_{in} is $F_{\text{anth}}(t) = E_{\text{FOS}}(t) + E_{\text{LUC}}(t)$, so the natural gross inflow is $F_{\text{nat}}(t) = F_{\text{in}}(t) - F_{\text{anth}}(t)$. Rearranging Eq. (1) in the form EHB implicitly use:

$$F_{\text{anth}} - \frac{dM_{\text{a}}}{dt} = F_{\text{out}} - F_{\text{nat}}. \tag{2}$$

EHB assert throughout the report that because the left-hand side is observed to be positive (i.e., $F_{\text{anth}} > dM_{\text{a}}/dt$), the right-hand side must also be positive ($F_{\text{out}} > F_{\text{nat}}$), and therefore "nature is a net sink" and cannot be causing the atmospheric increase. This inference is invalid. Eq. (2) is a

definition. It states that the difference between the anthropogenic emission rate and the atmospheric growth rate equals the difference between the gross outflow and the natural gross inflow. It contains no information beyond the two directly measured quantities F_{anth} and dM_{a}/dt. The right-hand side is not an observation. It is a rearrangement.

In ordinary language, the reason this rearrangement carries no evidence for or against any causal claim is as follows. Eq. (2) is a bookkeeping rearrangement of mass conservation and the definitional split $F_{\text{in}} \equiv F_{\text{nat}} + F_{\text{anth}}$. It is true in every physical world where carbon is conserved. A statement that is true in every physical world cannot distinguish one physical world from another. A statement that cannot distinguish worlds cannot change the probability of any hypothesis about which world we are in. The hypothesis "fossil-fuel combustion dominates the observed rise" is a hypothesis of exactly that kind: it is true in some physically admissible worlds and false in others. Observing the identity to hold leaves both kinds of world in play. The observation therefore has zero weight as evidence for or against that hypothesis, no matter how often it is restated.

This is the content of Eq. (2) as a diagnostic for causal attribution. It is a definition arranged into the look of a prediction. The full proof, with sample space, likelihood ratio, and Bayes step, is given in Appendix A and formally in Cohler & Soon (2026c) [22] as Theorem 1. EHB's mass-balance argument is null on this ground before any physical audit begins. What follows audits the physical claims for completeness.

The scale problem EHB systematically avoid: taking Global Carbon Budget values and Mauna Loa growth data, in 2019 $F_{\text{in}} \approx 235$ GtC/yr and $F_{\text{out}} \approx 230$ GtC/yr, giving $dM_{\text{a}}/dt \approx 5$ GtC/yr, with the disequilibrium 5 GtC/yr amounting to only $\sim 2.3\%$ of either gross flow. With anthropogenic emissions F_{anth} of order 10 GtC/yr, a $\sim 2\%$ perturbation of F_{nat} (a few GtC/yr) is enough to change the observed dM_{a}/dt balance. Any counterexample constructed within this scale is compatible with the observed Mauna Loa curve.

This counterexample is elementary. It appears in [73], [8], [31] as a two-reservoir model, and [53] as the Refined Reservoir Routing framework. EHB never construct such a counterexample and never engage with the fact that identical Mauna Loa data are compatible with fossil-fuel attribution splits from $\sim 1\%$ to nearly all anthropogenic.

2.2 EHB claim: *"the trend of the CO_2 increase in the atmosphere is around 50% of human emissions. That proves that nature is a sink for the other 50%, not the cause of the increase" (p. 9)*

The "50%" figure is not a physical airborne fraction and it does not prove anything about attribution.

The IPCC AR6 Glossary defines the "airborne fraction" as the cumulative anthropogenic mass still airborne divided by the total anthropogenic mass ever emitted. Call this ABF_L. The IPCC then reports the airborne fraction as approximately 44%, or "about 50%" in EHB's rounded form, using a completely different computation: the ratio of the *annual* atmospheric growth to the *annual* anthropogenic emission. Call this ABF_C. The two quantities are not the same. ABF_L measures cumulative retention. ABF_C is a single-year rate ratio that carries no information about retention at all.

The two quantities also differ numerically by nearly an order of magnitude. Under mass-balance reservoir routing with the empirically established residence time $\tau_{\text{res}} \approx 3.8$ yr [53], ABF_L is approximately 6%. It is not EHB's 50%. Both EHB's 50% and IPCC's $\sim 44\%$ number are ABF_C, and they are unstable: computed year by year from Global Carbon Budget fossil-plus-land-use emissions and Mauna Loa growth over 1966–2019, ABF_C ranges from 17.9% to 77.4%, a factor of 4.3×, with standard deviation 12.85% and coefficient of variation 28.7%. The appearance of a stable "50%" is obtained only under long smoothing windows of 15–30 yr or longer, which are far longer than the physical residence time. At those windows *any* noisy series appears smooth, and

the apparent constancy is a property of the smoothing window length, not of the carbon cycle.

IPCC's 44% figure is not a decadal average of ABF_C values. It is a single cumulative ratio: total atmospheric growth divided by total anthropogenic emissions over the source-data window. Global Carbon Project data over 1959–2022 (64 years) give $\sum G_t / \sum E_t = 218.03/491.03 = 44.40\%$, where G_t is annual atmospheric growth and E_t is annual anthropogenic emission. Cumulative-ratio arithmetic on two large monotonically increasing quantities yields a smooth summary number that carries no information about year-to-year variation and no information about retention. Under the same underlying year-by-year data ABF_C ranges from 17.9% to 77.4% as reported above, and the WMO Greenhouse Gas Bulletin reports the observed annual range over the past 60 years as 20% to 80%. Nature currently exchanges approximately 230 GtC/yr with the atmosphere gross both ways. Recent-decade anthropogenic emissions of approximately 10 GtC/yr enter the same well-mixed reservoir. The Mauna Loa growth rate dM_a/dt has not been constant: it averaged approximately 0.8 ppm/yr (~1.7 GtC/yr) in the 1960s, 1.5–1.6 ppm/yr in the 1980s and 1990s, 2.0 ppm/yr in the 2000s, and 2.4 ppm/yr (~5.1 GtC/yr) over the 2010s, reaching 3.75 ppm/yr (~8.0 GtC/yr) in 2024. The cumulative-ratio arithmetic that generates the 44% figure is the small net difference between two large gross flows summed over the multi-decade window, divided by the anthropogenic addition summed over the same window. It is not a statement about which component of F_{in} is causing the atmospheric increase.

The mass-balance identity $F_{anth} - dM_a/dt = F_{out} - F_{nat}$ is compatible with attribution splits from ~ 1% anthropogenic to majority anthropogenic. [8], [31], [70], and [53] all construct nature-dominated models that satisfy the identity exactly and match the observed Mauna Loa growth curve. Cohler & Soon (2026b) [21], using the Keeling-plot intercept $\delta^{13}C_I = -13.2 \pm 0.2‰$, forces the fossil fraction of the net atmospheric addition to $f \approx 0$, indistinguishable from zero within the intercept's measurement uncertainty. That result is derived from the isotopic constraint, not from the mass balance identity, and it is consistent with the identity to within the measurement precision. The observation EHB cite is a joint constraint on $F_{out} - F_{nat}$; *it is not an attribution*. The ABF_C substitution is a second instance of the accounting-identity fallacy: $ABF_C = (dM_a/dt)/F_{anth}$ is Eq. (2) rearranged and fixed by arithmetic once F_{anth} and dM_a/dt are supplied, carrying no retention information at all [22]. The retention fraction ABF_L that a physical retention claim would require is a genuine observation-class quantity, not an identity, and its value under proper reservoir routing is approximately 6%, not 50%.

Berry [9], using IPCC AR5 Table 6.1 numbers, computes the ratio of anthropogenic to natural inflow at approximately 9 GtC/yr to 98 GtC/yr, i.e., ~ 8%. Since atmospheric molecules do not carry origin labels once mixed, the anthropogenic fraction of the atmospheric CO_2 molecules cannot exceed the anthropogenic fraction of the total inflow. The IPCC/EHB figure of ~ 100% anthropogenic contribution to the 140 ppm rise (from a putative preindustrial 280 ppm) is inconsistent with the IPCC's own carbon-cycle inventory.

2.3 EHB claim: "The annual temperature anomaly shows no trend at all, thus is not the cause of the ongoing increase of CO_2 in the atmosphere" (p. 9)

Three unsupported claims are packed into this sentence. First, "the annual temperature anomaly": anomaly of *what* quantity, computed by *what* averaging operator, over *what* spatial domain? EHB do not say. Any global aggregate of local temperatures is untethered under classical thermodynamics [18]; the phrase names no physical quantity. Second, "shows no trend at all": no dataset is cited, no time window is specified, no trend calculation is shown. Third, "thus is not the cause": the inference is asserted with no derivation. A short-timescale "no trend" in a rate variable does not imply the absence of a cumulative effect from a sustained forcing on the integral.

The year-over-year temperature change is not the relevant quantity for driving cumulative CO_2 change. The relevant quantity is the top-of-atmosphere power imbalance (Clauser, 2026 [17]),

which is directly measured by satellite. Loeb et al. (2018) [59] report the CERES EBAF net TOA imbalance at 4.3 W m^{-2} with 1σ uncertainty of about ±4 W m^{-2}. Clauser (2026) [17] notes correctly that no positive TOA energy imbalance has been established at high confidence: the CERES EBAF central value of 4.3 W m^{-2} carries a 1σ envelope of $\sim \pm 4$ W m^{-2} that includes zero. Cohler et al. (2026) [19] extend this result by showing that the IPCC AR6 headline value of 0.7 ± 0.2 W m^{-2}, derived from Argo-float ocean heat content, is itself a computational artifact: the true EEI uncertainty exceeds ±1 W m^{-2} at 95% confidence, rendering current OHC change and EEI estimates statistically indistinguishable from zero. Our analysis does not require any specific positive central value for the TOA imbalance. It requires only that a natural imbalance of order 2.6 W m^{-2}, well inside the CERES envelope and consistent with the true uncertainty band established in [19], is a sufficient physical driver to close the observed CO_2 growth through local van't Hoff and Q_{10} responses. The argument runs in the direction Clauser's analysis leaves open: if a small natural imbalance suffices to reproduce the observed CO_2 growth quantitatively, then that growth is not evidence of anthropogenic dominance, because natural forcing at magnitudes the observational record cannot rule out already produces the observed growth. This complements rather than contradicts Clauser's position. Cohler & Soon (2026a) [20] show that a natural imbalance of approximately 2.6 W m^{-2}, well inside that CERES uncertainty envelope, exactly reproduces the observed atmospheric CO_2 growth rate over the 2000–2025 Scripps/NOAA average of approximately 2.25 ppm/yr through two well-established local physical laws: van't Hoff solubility kinetics ($\partial \ln p_{CO_2}/\partial T \approx 0.0423$ K^{-1}) applied locally to the ocean mixed layer, and Arrhenius/Q_{10} respiration kinetics ($Q_{10} \approx 1.5$, giving $d \ln R/dT \approx 0.0405$ K^{-1}) applied locally to soil and terrestrial respiration. Partitioning the 2.6 W m^{-2} energy uptake into approximately 91% oceanic ($\sim$ 38.2 ZJ/yr) and $\sim$ 9% terrestrial ($\sim$ 2.5 ZJ/yr) yields a local outgassing flux of $\sim$ 2.44 GtC/yr and a local respiration flux of $\sim$ 2.34 GtC/yr, summing to $\sim$ 4.8 GtC/yr, which matches the observed atmospheric growth.

[36] applied cross-spectral analysis to atmospheric CO_2 and observed temperature time series and found that CO_2 change lags temperature change by 9–12 months at all measured frequencies, direct empirical evidence that the temporal ordering of the two series is temperature $\rightarrow$ CO_2 rather than the reverse. Koutsoyiannis et al. (2022) [56] and Koutsoyiannis et al. (2023) [57] extended this analysis with stochastic causality methods and reached the same conclusion. EHB engage none of the empirical or mathematical results in these papers.

Confusing the time derivative of a forcing quantity with its time integral is a thermodynamics error. The atmospheric CO_2 system integrates the TOA energy flux over the bulk-CO_2 residence time $\tau_{res} \approx 3.8$ yr [53]. That is short enough that a sustained natural TOA imbalance of the CERES-measured magnitude drives the observed cumulative CO_2 increase through the local van't Hoff and Q_{10} responses documented above [20].

2.4 EHB claim (p. 11): "Any theory that leads to a substantial increase of CO_2 in the atmosphere due to natural factors violates the mass balance and thus cannot be correct"

EHB present this as an established general theorem. No derivation is given. No specific theory is analyzed. No mass-balance equation is written down at the point of the claim. The word "violates" is used without showing what the alleged violation is or how a natural-attribution theory would produce it. The word "cannot" is used without a proof.

This assertion is incorrect. Multiple peer-reviewed treatments satisfy mass conservation exactly and reach nature-dominated conclusions: Berry [8]; Berry [9]; Harde [31]; Harde [33]; Harde and Salby [34]; Salby and Harde [70]; Salby and Harde [71]; Koutsoyiannis [53]; Koutsoyiannis [54]; and Humlum et al. [36]. Not one violates mass-balance Eq. (1). What they violate is EHB's rhetorical claim that the mass balance identity implies fossil-dominant attribution. That claim is

not physics. It is a logical error that has been corrected in the peer-reviewed literature at least since 1998 [73] and repeatedly since. Engelbeen (2023) [24] did not engage with the corrections. EHB restate the same error. The error has a formal name and a formal proof. Cohler & Soon (2026c) [22] Lemma 1 establishes that the mass-balance identity is direction-blind: a state in which the natural flux drives M_a upward with anthropogenic emissions passively absorbed by a large sink satisfies Eq. (2) exactly, and the identity cannot select between that state and its causal reverse. EHB's "cannot be correct" is a claim that the identity implies a direction it demonstrably does not imply.

2.5 Internal contradiction with EHB's own concessions

On p. 6, EHB write: "But saturation of CO_2 sinks is only true for the ocean surface. It is not correct for the vegetation sink while the atmospheric concentration is below 1,000 ppmv or so, nor for the deep oceans where both the biological pump and the direct sinks near the poles largely bypass the physicochemical restrictions of the ocean surface."

Every substantive claim in this sentence is asserted without a source, without a physical derivation, and without a citation. "Saturation is only true for the ocean surface": according to whom? What measurement establishes it? "Not correct for the vegetation sink while the atmospheric concentration is below 1,000 ppmv or so": where does the 1,000 ppmv threshold come from? Which paper derives it? What is the physical basis for the round number? "The biological pump and the direct sinks near the poles largely bypass the physicochemical restrictions": what direct sinks? What does "largely bypass" quantitatively mean? What is the flux magnitude and its source? EHB provide no answers. The paragraph is four assertions in one sentence with no support for any of them. This pattern, of stating conclusions in the voice of established fact without providing evidence, derivation, or citation, recurs throughout the report. The reader is asked to accept EHB's claims on the authority of their assertion alone.

Setting the pattern aside and taking the sentence at face value: any long-adjustment-time claim for anthropogenic CO_2 specifically, distinct from the short residence time of bulk atmospheric CO_2, requires sink saturation. Slow removal of an "excess" component implies sinks that discriminate against that component, and discrimination requires those sinks to be filling toward capacity. EHB's own words on p. 6 assert the absence of saturation for both the biosphere and the deep oceans. That assertion is incompatible with the 50-year adjustment time EHB then cite in EHB §1.3. It is also incompatible with the Bern impulse-response function [41], which requires sink saturation to produce its ∼22% permanent fraction and long tails; Joos et al. themselves acknowledged that the Bern coefficients "should not be interpreted as distinct physical processes." EHB hold the no-saturation position on p. 6 and the long-adjustment-time position in EHB §1.3 simultaneously. This is not a scientific position. It is a bookkeeping decision to hold mutually contradictory unsupported claims in the same document.

3. The $^{13}C/^{12}C$ Isotope Argument (EHB §1.2)

3.1 Endmembers

Isotopic endmembers used throughout the analysis [43], [44], [15], [16], [45]:

- Fossil fuels: $\delta^{13}C \approx -28‰$ (typical).
- C_3 vegetation: $\delta^{13}C \approx -25‰$.
- C_4 vegetation: $\delta^{13}C \approx -13‰$.
- Ocean surface Dissolved Inorganic Carbon (DIC): $\delta^{13}C \approx +1‰$.
- Atmospheric CO_2, present day: $\delta^{13}C \approx -8.5‰$.

EHB (§1.2, p. 12) invoke broadly consistent though less resolved endmember values, bundling

fossil and vegetation together at "about −24‰" and giving ocean degassing as "0 to +1‰" and present-day atmosphere as "currently below −8‰ VPDB." The analysis that follows uses the standard peer-reviewed values above, which distinguish C_3 from C_4 vegetation and give fossil fuels their textbook value near −28‰.

3.2 What the Keeling relation forces

EHB argue on p. 12 that "we can determine whether CO_2 levels in the atmosphere . . . were mainly influenced by vegetation decay or fossil fuel burning . . . towards the negative side, or by ocean degassing . . . towards the positive side." Direction, yes. Magnitude, never computed. The relevant calculation is a straightforward isotopic mass balance on the atmospheric reservoir.

Take the atmosphere in 1850 at 285 ppm, $\delta^{13}C = -6.5$‰ (from ice-core measurements accepted by EHB). Take the atmosphere in 2020 at 415 ppm, $\delta^{13}C = -8.2$‰ (from Scripps Mauna Loa). The isotopic mass balance on the net added carbon is

$$285 \times (-6.5) + 130 \times \delta_{\text{source}} = 415 \times (-8.2). \tag{3}$$

Solving,

$$\delta_{\text{source}} = \frac{415 \times (-8.2) - 285 \times (-6.5)}{130} = \frac{-3403 + 1852.5}{130} = -11.9\ ‰. \tag{4}$$

The net-added carbon carries an effective isotopic signature of approximately −12‰, not −28‰.

The Keeling-plot intercept $\delta^{13}C_I$ is the y-axis intercept of the ordinary least-squares regression of measured $\delta^{13}C$ of atmospheric CO_2 against $1/[CO_2]$. By isotopic mass balance on the atmospheric CO_2 reservoir, this intercept equals the flux-weighted mean isotopic signature of the net material added to the atmosphere (all sources minus all sinks) over the sampling window [43, 44]. The Keeling-plot analysis [43], [44] applied to the modern Scripps record by [54] gives $\delta^{13}C_I = -13.2 \pm 0.2$‰ (see Figure 1). [10] reconstruction of $\delta^{13}C$ from Caribbean coralline sponges over the last 500 years yields an equivalent net-added signature of approximately −13‰. [46], in a paper coauthored by the same Peter Köhler whom EHB cite, directly measured the Keeling intercept from Law Dome LD ANT anthropogenic-era ice-core data and obtained $y_0 = -13.1$‰, $r^2 = 96$%, and wrote that "these numbers are significantly higher than the isotopic signature of the anthropogenic carbon added to the system." Three independent physical systems, three independent research groups, one signature at approximately −13‰. [54] extends the analysis and concludes that the net isotopic signature of atmospheric CO_2 sources and sinks has not changed statistically since the Little Ice Age.

Under a two-endmember mixing between fossil ($\delta_F = -28$‰) and non-fossil (i.e. natural, δ_N) sources, the fossil fraction of the added carbon is

$$f = \frac{\delta^{13}C_I - \delta_N}{\delta_F - \delta_N}. \tag{5}$$

With $\delta^{13}C_I = -13.2 \pm 0.2$‰ (Koutsoyiannis Keeling result) and $\delta_N \approx -13$‰ (three-way convergence),

$$f = \frac{\delta^{13}C_I - \delta_N}{\delta_F - \delta_N} = \frac{-13.2\,‰ - (-13\,‰)}{-28\,‰ - (-13\,‰)} = \frac{-0.2 \pm 0.2\,‰}{-15\,‰} = 0.013 \pm 0.013. \tag{6}$$

The fossil fraction of the observed forcing is (1.3 ± 1.3)%, indistinguishable from zero within the intercept's measurement uncertainty. Of the 130 ppm net addition to the atmosphere between 1850 and 2020, only 1.7 ± 1.7 ppm carries the fossil-fuel isotopic signature. The remaining ∼ 128 ppm is isotopically indistinguishable from non-fossil sources at the ∼ −13‰ endmember. Under the more permissive counterfactual $\delta_N = -8$‰ (approximately the modern atmospheric mean), $f \leq 0.26$.

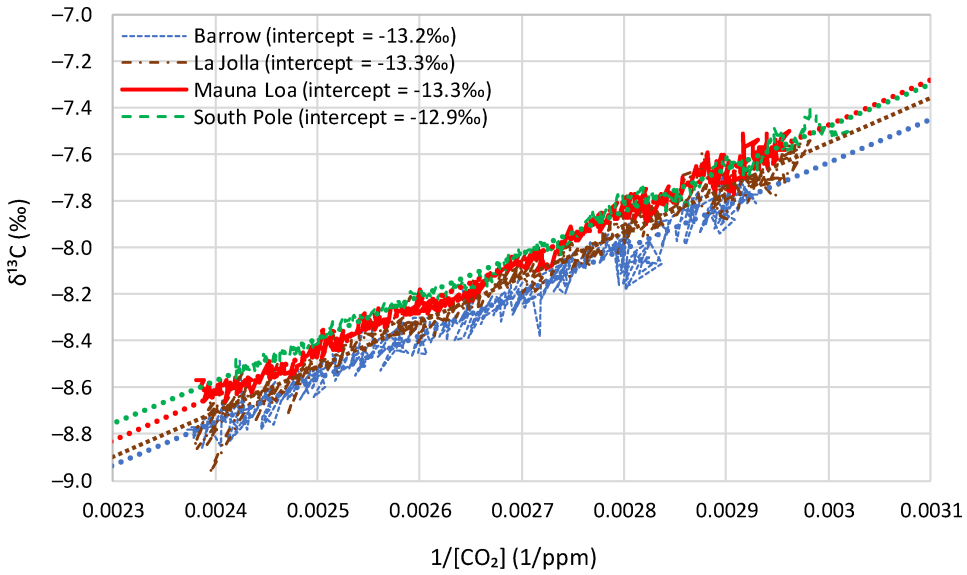


Figure 1: Keeling plots of $\delta^{13}C$ versus reciprocal CO_2 concentration for four Scripps Institution of Oceanography monitoring stations (Barrow, Alaska; La Jolla, California; Mauna Loa, Hawaii; South Pole), reproduced from [54] Figure 10. The four ordinary least-squares intercepts, geographically independent, converge on $\delta^{13}C_I = -13.2$‰ (Barrow), −13.3‰ (La Jolla), −13.3‰ (Mauna Loa), and −12.9‰ (South Pole), giving a station-mean intercept of -13.2 ± 0.2‰. All four values are well removed from the fossil-fuel endmember at −28‰ and coincident with the sclerosponge [10] and Law Dome LD ANT [46] results near −13‰. Under two-component mixing, this intercept forces the fossil fraction of the net atmospheric addition to $f \approx 0$.

Under the physically absurd $\delta_N = 0$, $f \leq 0.47$. Under no admissible endmember does f approach the IPCC/EHB purported value of ~ 1 ("nearly all the increase in atmospheric CO2 is from human emissions, most of which are from fossil fuel use", EHB p. 4).

The functional dependence $f(\delta_N) = (13.2 + \delta_N)/(28 + \delta_N)$ places the IPCC $f \approx 1$ position on the asymptote of a hyperbola, requiring $\delta_N \to +\infty$, i.e., pure inorganic carbonate outgassing with no biological or organic component. That is not physics. [21] give the full analysis, including the fossil-fraction absurdity plot and the collapse of the admissible band to $f \approx 0$ under the five-century sclerosponge invariance.

Three fossil-fraction quantities, not one. Carbon-cycle discussions routinely conflate three different fossil-fraction quantities. They are distinct, and the Keeling result bears on only one of them:

(a) *Gross fossil emission rate over gross non-fossil-fuel inflow:* approximately 10/225 ≈ 4.4%. A flux ratio.

(b) *Resident fossil-origin carbon in the atmospheric reservoir:* convolution of the fossil-emission history with the exponential residence-time kernel at $\tau_{\text{res}} = 3.8$ yr [53] gives approximately 39/907 ≈ 4.3%. A stock composition.

(c) *Fossil fraction f of the net atmospheric addition since 1850:* $f = (1.3 \pm 1.3)$% from the Keeling intercept, as derived above. The fossil weighting of dM_a/dt.

The Keeling intercept gives (c) directly. It does not give (a) or (b), and no agreement with either is required of it. The result $f \approx 0$ for (c) is fully consistent with (b) at approximately 4%, because fossil carbon that entered the atmosphere and was subsequently exchanged out contributes to the resident stock (b) but not to the net addition (c). The attribution claim $f \approx 1$ advanced by the IPCC and EHB is a claim about (c); it is falsified by the Keeling result. Full development of all

three quantities, with the convolution derivation for (b) and the mixing derivation for (c), is given in [21].

3.3 EHB claim (p. 15): "The strong decrease of the $^{13}C/^{12}C$ ratio . . . excludes any huge contribution of the (deep) oceans to the CO_2 increase"

"Excludes" is unearned. The direction of δ^{13}C change constrains the source signature to be lighter than the preindustrial atmospheric baseline. That constraint is satisfied by a mixed source with effective signature near -13‰, which is precisely what the three Keeling-based analyses cited above yield. The magnitude of the δ^{13}C decrease is quantitatively impossible if one adopts the EHB assumption of dominant human fossil-fuel emissions (-28‰) as the driver. The empirical models of [70] and [54] do not require pure deep-ocean outgassing; they invoke distributed ocean-plus-biosphere perturbations whose aggregate signature is what is observed. EHB is refuting a strawman here.

3.4 EHB invoke the Köhler BICYCLE model; a model is not evidence

EHB Figure 1.2.3 invokes Köhler et al. (2006) [46], the BICYCLE paleoclimate model, in support of their attribution. A model is a computational construct, not an observation, and cannot function as evidence for a physical claim. Model output only ever restates the model's own assumptions integrated forward; it says nothing about physical reality independent of those assumptions. Beyond that fundamental issue, the 2006 paper itself openly admits framework failure in paragraph 65: "Glacial atmospheric Δ^{14}C larger than 700‰ cannot not be explained within our framework, neither through carbon cycle-based changes nor through variable ^{14}C production." And in paragraph 58: "For the Holocene we did not implement recent theories which try to explain the rise in CO_2 by 20 ppmv during the last 8 kyr, and therefore our simulation results do not match the CO_2 data very well."

More directly relevant: Köhler himself has, in subsequent papers, admitted the failure of every principal architectural element of the 2006 model:

- Köhler et al. (2006) [46] directly measured $y_0 = -13.1$‰ from Law Dome LD ANT data and acknowledged this contradicts fossil-dominant attribution.
- Köhler, Fischer & Schmitt (2010) [48] wrote that "Northern Hemisphere temperature is probably incorrect" in the 2006 model.
- Köhler & Munhoven (2020) [47], in the BICYCLE-SE architecture paper, wholly replaced the "so far used simplified feedback mechanism of carbonate compensation" with a process-based sediment module, and added volcanism, silicate weathering, carbonate weathering, and coral reef growth as first-class fluxes not present in the 2006 model.
- Köhler et al. (2022) [52] wrote that "prescribing CO_2 violates mass conservation of carbon"—the exact practice used for the 2006 headline $r^2 = 0.89$ result—and further admitted in the abstract that "it is currently not understood how changes in ^{14}C production rate (Q), and in the carbon cycle, can be combined to explain the reconstructed atmospheric Δ^{14}C record." This is a direct admission that the central quantitative deliverable of [50], the $\approx 5/6$ production, $\approx 1/6$ carbon-cycle partition of Δ^{14}C variability, is not established.
- Köhler, Skinner & Adolphi (2024) [51] wrote that in their model "Opposite to data CO_2 falls during Heinrich stadials"—the wrong sign of the AMOC response.

Dinauer et al. [23] titled a paper on the model's failure to reproduce observed Δ^{14}C behavior as "mysteriously high." EHB invoke the original [50] paper in support and engage none of Köhler's own subsequent admissions of the model's failure.

4. The ^{14}C/C Radiocarbon Argument (EHB §1.3)

4.1 The direct measurement

The bomb radiocarbon spike, released between the mid-1950s and 1963, provides the cleanest available direct measurement of the atmospheric CO_2 perturbation adjustment time. Hua et al. (2022) [35] compiled atmospheric Δ^{14}C data across multiple monitoring stations for the period 1950–2019. The global mean series peaked in 1965; a single-exponential fit to the annual global mean atmospheric Δ^{14}C from that compilation over 1965–2019 (the post-peak decay period; the pre-peak buildup is not relevant to a decay analysis) gives a timescale of $\sim$ 18.4 yr with $R^2 > 99.8\%$.

The Bern impulse-response function [41], used in IPCC AR5 and AR6, has an e-folding time of 165 yr, slowest relaxation timescale of 394.4 yr, and a permanent fraction 21.73%. The bomb-^{14}C data show clean single-exponential decay to near-zero in approximately 55 years, e-folding of approximately 18.4 yr. Therefore, the Bern IRF is falsified by direct measurement. [34] and [9] reach the same conclusion using different fit conventions with e-folding times of 10–16 years.

4.2 EHB's circular treatment of the bomb-^{14}C data

EHB write on p. 17–18 that "To calculate the actual average atmospheric lifetime of ^{14}C added to the atmosphere by the bomb spike, we need to consider, instead, what the Δ^{14}C decay rate would have been were it not for Suess Effect dilution from fossil-fuel use." This premise is empirically falsified by the observed decay itself. A single-exponential fit to the Hua et al. (2022) [35] global mean Δ^{14}C compilation over the post-peak period 1965–2019 gives an e-folding time of $\tau_{\text{rel}} \approx 18.4$ yr with $R^2 > 99.8\%$. A significant Suess-effect dilution superimposed on the natural atmospheric exchange would produce systematic multi-timescale curvature in the observed record, structurally incompatible with a clean single exponential sustained over five decades. The observed shape leaves no room for the correction EHB argue must be applied. The Suess-correction framework is not just circular; it addresses a distortion that the raw data show is not present.

EHB nonetheless run the observations through the carbon-cycle simulation of Graven et al. (2020) [29], which is an explicit 44-reservoir box model of the ocean-atmosphere-biosphere carbon system, with ocean vertical diffusion, three-pool terrestrial biosphere, and marine carbonate-chemistry buffering. The model's atmospheric CO_2 response function is fixed by its prescribed rate constants and structural assumptions, and it produces the long-tail persistence behavior standard in IPCC-class carbon-cycle models by construction. EHB feed the observed bomb-^{14}C data through this model, obtain a post-correction number of $\sim$20 yr, and assert without further argument that this result supports their preferred 50-year figure. The procedure is circular: the correction depends on the model's assumed response function, which itself embodies the long-tail atmospheric CO_2 persistence that the bomb-^{14}C measurement is being invoked to support. Varying [29]'s rate constants, biosphere partitioning, or ocean diffusivity within their observational uncertainty would produce a correspondingly different "corrected" number. There is no principled way to test claims about atmospheric CO_2 persistence by running the data through a model whose response function already encodes those claims. On its own terms, EHB's post-correction number of $\sim$ 20 yr differs from the 50-year figure EHB assert in EHB §1.3 by a factor of $\sim$ 2.5. These are not consistent. EHB's own procedure, taken at face value, contradicts EHB's own conclusion. Worse for the report's coherence, EHB's $\sim$ 20 yr agrees approximately with the direct single-exponential $\tau_{\text{rel}} \approx 18.4$ yr measured from the raw [35] compilation, and via the bridge relation Eq. (7) corresponds to the bulk residence time $\tau_{\text{res}} \approx 3.8$ yr established independently by Koutsoyiannis (2024a) [53]. EHB's own model output, correctly read, corroborates the short-timescale natural-exchange picture and falsifies the 50-year figure EHB claim it supports.

4.3 The bridge equation: tracer versus perturbation timescales

The relationship between the residence time τ_{res} and the ratio-relaxation time τ_{rel} is quantitatively derivable from mass balance applied to the atmosphere-ocean-biosphere system:

$$\tau_{\text{rel}} = \bar{\mathcal{D}} \cdot \frac{\tau_{\text{res}}}{\bar{\phi}_{\text{slow}}} \approx 0.98 \times \frac{3.80}{0.203} \approx 18.4 \text{ yr}, \tag{7}$$

where $\bar{\mathcal{D}} \approx 0.98$ is the time-averaged disequilibrium ratio $F_{\text{out}}/F_{\text{in}}$ and $\bar{\phi}_{\text{slow}} \approx 0.203$ is the fraction of gross inflow F_{in} originating from unlabeled deep reservoirs (deep-ocean upwelling, refractory soil, fossil-fuel combustion). The physical picture: atmospheric CO_2 exchanges with the mixed layer and biosphere on months timescales, but that exchange recirculates the bomb label between atmosphere and surface reservoirs rather than removing it. The label truly decays only through the ∼20% leak into unlabeled deep reservoirs. This yields $\tau_{\text{rel}}/\tau_{\text{res}} \approx 4.84$, matching observation exactly.

The bulk CO_2 perturbation adjustment time obeys the same underlying physics because reservoirs exchange $^{12}CO_2$, $^{13}CO_2$, and $^{14}CO_2$ at essentially the same rates at the transport level. Isotopic fractionation between $^{14}CO_2$ and $^{12}CO_2$ in the atmosphere-ocean and atmosphere-biosphere exchanges is a per-mil-scale effect, not an order-of-magnitude effect. A linear operator that produced a ∼3× longer bulk-CO_2 perturbation relaxation time than the ^{14}C tracer relaxation time, as EHB implicitly require ($\tau_{\text{bulk}} \approx 50$ yr against $\tau_{\text{tracer}} \approx 18$ yr), would have to fractionate $^{14}CO_2$ from $^{12}CO_2$ by a factor of ∼3 per exchange cycle. This is three orders of magnitude larger than the per-mil-scale fractionation actually observed in atmosphere-ocean and atmosphere-biosphere gas exchange. Under any physically admissible linear operator with the mass-conservation structure of the real carbon system, $\tau_{\text{pert}} = \tau_{\text{tracer}}$ to leading order (operator-equivalence).

The tracer-versus-bulk asymmetry EHB invoke has never had a first-principles derivation. Revelle & Suess (1957) [67], Oeschger et al. (1975) [65], Joos et al. (1996) [40], and [41] do not derive it. The Revelle factor cannot support the claim because it is a local intensive chemical-equilibrium property that (i) cannot be aggregated to a well-defined global quantity [18], (ii) does not describe a rate process, and (iii) does not discriminate isotopologues at the required order-of-magnitude level. Cawley (2011) [14], which EHB cite in support, arrives at a slow relaxation time only by inserting an unphysical constant term into the mass-balance equation.

4.4 The 50-year adjustment time and its citation chain

The 50-year figure has a single derivation in the literature EHB cite for it, and that derivation is circular. Spencer (2023) [75] fits a simple time-dependent CO_2 budget model to Mauna Loa growth over 1959–2021 in which (i) anthropogenic emissions are the sole source of the atmospheric increase, and (ii) sinks remove CO_2 at a constant fractional rate k_s proportional to the excess above a fitted equilibrium concentration CO_2^{eq}. The best-fit parameters are $CO_2^{\text{eq}} = 293.6$ ppm and $k_s = 0.0202$/yr, and $1/k_s \approx 50$ yr is what EHB then cite as the "adjustment time." The two structural assumptions are the fossil-dominant attribution EHB are trying to establish. The output is that attribution's characteristic timescale. The procedure assumes fossil dominance to derive fossil dominance. Circular reasoning is not science.

Spencer himself reports that the model does not fit the Mauna Loa record if the equilibrium is set to the pre-industrial value of 280 ppm: "use of the pre-industrial value of 280 ppm cannot be made to result in a model fit to the observations, even after adjusting k_s." The fit only works when CO_2^{eq} is tuned upward by 13.6 ppm from pre-industrial, without physical justification. Spencer explicitly acknowledges this: "the reason for this is not clear." Under the model's own stated fossil-only-source premise, the natural equilibrium should be at or near the pre-industrial 280 ppm; the fit requires otherwise, and no mechanism internal to the model explains why. Whatever this unexplained tuning means, it means the 50-year figure is not extracted by measurement from data.

It is extracted from a fit in which one of the model parameters is set to whatever value makes the fit work, with no physical grounding.

Burton (2024) [12] performs the same style of linear regression on Global Carbon Budget net-removal-rate versus Mauna Loa CO_2 data, imposes the same two assumptions, obtains a slope of 1.83% per year (equilibrium at 285 ppm), and cites Spencer's 2.02%/50-year figure as the reference value. Burton's own citations for the 50-year adjustment time are Spencer [75] and Engelbeen (2022), the latter being an author's personal website (*ferdinand-engelbeen.be/klimaat/co2_origin.html*), not a peer-reviewed paper. Engelbeen (2023) [24] in *Science of Climate Change* is a Comment on Harde (2023) that restates the mass-balance-identity argument against Harde (2017) [31]'s short-residence-time analysis; it does not derive an adjustment time from any independent measurement.

The independent bomb-^{14}C measurement gives $\tau_{\text{rel}} \approx 18.4$ yr for the isotopic tracer directly from the single-exponential fit to the Hua et al. (2022) [35] compilation, and via the bridge relation Eq. (7) corresponds to $\tau_{\text{res}} \approx 3.8$ yr for bulk CO_2. Neither timescale assumes any attribution; both are empirical. Neither is compatible with the 50-year figure. Spencer, Engelbeen, and Burton address the bomb-^{14}C measurement nowhere in their arguments: the direct empirical constraint on the adjustment time is left entirely unengaged, and its silence is treated as if it were disproof. It is not.

Four independent estimates of the atmospheric CO_2 timescale, none of which presupposes the attribution, all converge on approximately 4 yr for τ_{res} and approximately 18 yr for τ_{rel}:

- τ_{out} from IPCC AR6 (2010–2019): 3.83 yr
- τ_{out} AR3–AR6 average: 3.70 ± 0.21 yr
- $\tau_{\text{res}} = \tau_{\text{RRR}} = 3.80 \pm 0.12$ yr [53]
- $\tau_{\text{rel}} \approx 18.4$ yr from the [35] bomb-^{14}C global compilation

The relaxation timescale differs from the residence timescale by the deep-mixed leak factor, not by a separate physical process. There is no room for a 50-year adjustment time in this framework and no observational support for one.

4.5 The sink-saturation contradiction

The claim $\tau_{\text{bulk}} \gg \tau_{\text{tracer}}$ requires the perturbation to saturate the sinks. EHB deny sink saturation on p. 6 for both biosphere and deep ocean, then require it for their 50-year figure in EHB §1.3. Both cannot be true. [34] and [9] treat this contradiction explicitly.

4.6 Conclusion of the ^{14}C section

The observed bomb-^{14}C decay is the strongest empirical constraint on the atmospheric CO_2 perturbation adjustment time. It directly falsifies the Bern IRF. It is quantitatively inconsistent with EHB's 50-year figure. The magnitude of the Suess effect and the observed adjustment time from the bomb-^{14}C tracer, taken together, constrain the fossil contribution to the observed atmospheric increase at approximately (21 ± 1)% of the deep-mixed leak. [34] give the anthropogenic upper limit at 35%, lower bound at 3.5%, central value at 14%. [9] gives natural addition since 1750 of approximately 100 ppm and human addition of approximately 33 ppm out of the total 140 ppm rise. None of these results is consistent with EHB's implicit ~ 100% anthropogenic attribution.

5. The Oxygen Argument (EHB §1.4)

5.1 What O_2/N_2 actually constrains

The O_2/N_2 measurements of Battle et al. (2000) [5] and Bender et al. (2005) [7] for the approximately 1990–2005 window with adequate precision partition the observed net sink between ocean and land components. They do not attribute the source of the atmospheric CO_2 increase.

Koutsoyiannis [55] documents that the biosphere has expanded since the 1960s, driven by increasing temperature via the Q_{10} respiration model with $R = R_0 \times Q_{10}^{(T-T_0)/10}$. The satellite-observed greening flux [87, 66, 2], which EHB cite, is itself a response to elevated CO_2 (CO_2 fertilization) and elevated temperature (extended growing seasons). Both drivers are natural. That the biosphere is a net sink over the O_2/N_2-observed decade is entirely compatible with a natural imbalance in the ocean-atmosphere exchange producing the atmospheric CO_2 rise, while the biosphere absorbs the fossil emissions plus additional natural CO_2.

5.2 EHB claim (p. 22): "The production of extra O_2 in the atmosphere excludes a net contribution from the whole biosphere to the CO_2 increase"

"Excludes" is an unproven assertion. Salby & Harde (2021) [70] explicitly construct a system in which the biosphere is a net CO_2 sink and net O_2 source (matching the EHB constraint) and simultaneously the ocean is a net CO_2 source through warming-driven outgassing exceeding warming-driven uptake at the sink locations. The atmospheric rise is then explained by ocean natural imbalance while the biosphere absorbs fossil emissions. Every EHB constraint is satisfied. Their inference is defeated by a simple two-reservoir model in the peer-reviewed literature they refuse to cite.

Harde [33] and Harde and Salby [34] treat the O_2/N_2 decoupling explicitly: fossil emissions are absorbed by land and ocean sinks that operate on CO_2 from all sources regardless of origin, and the absorption of fossil emissions does not exclude natural sources from also contributing to the atmospheric increase.

Additionally, extending decadal O_2/N_2 partitioning to century-scale attribution assumes stationarity of the partition through decades of changing temperature, CO_2, and land use. [7] themselves note the partition is time-varying. [70] demonstrate this assumption is unsupported.

6. The Ocean Chemistry Argument (EHB §1.5)

6.1 The pH claim

EHB write (p. 23): "the average pH of the ocean surface has probably decreased by about 0.1 pH unit." The sentence has no physical meaning. There is no such thing as an average pH of the ocean surface, or of any spatially extended non-equilibrium system with local pH varying across it. pH is a local intensive quantity, defined at a point as $-\log_{10}[H^+]$ from the local hydrogen-ion activity. An area-weighted arithmetic mean of local pH readings across the ocean surface requires choosing an aggregation operator (arithmetic mean of pH values, or arithmetic mean of $[H^+]$ values then take the log, or area-weighted vs. volume-weighted, and so on); classical thermodynamics does not select a unique operator class. The construct is untethered and physically meaningless [18]. It cannot decrease by "0.1 units" because it does not have units of anything: it is not a physical quantity.

pH is compounded in this respect over temperature because pH is logarithmic. Averaging pH values arithmetically is averaging logs, which corresponds to a geometric mean of $[H^+]$ concentrations, itself not any equilibrium reservoir's actual state. Even the operator choice "convert pH to $[H^+]$, take arithmetic mean, take $-\log_{10}$" does not describe any physical ocean state, because the mixed

$[H^+]$ concentration is not an equilibrium property of any real reservoir.

EHB's "probably 0.1 unit" figure is not a poor measurement of an existing quantity. It is a numerical output of an assumed atmospheric-forcing model applied to a construct that has no physical meaning. Wallace et al. (2014) [84] noted that even taking the construct at face value, computing pH from surface pCO_2 via carbonate-system speciation propagates approximately 40% uncertainty from CO_2-system approximations alone. Direct pH measurements exist as long-consistent time series at three ocean carbon-chemistry stations: HOT (Hawaii Ocean Time-series), BATS (Bermuda Atlantic Time-series Study), and ESTOC (European Station for Time series in the Ocean, Canary Islands), all in subtropical gyres. Even granting each station a generous 1 km^2 of representative surface area, the three together sample $3/(3.61 \times 10^8) \approx 8 \times 10^{-9}$ of the ocean surface, i.e., less than one part in 10^8. Each is a local measurement of the local hydrogen-ion concentration $[H^+]$ at that specific sampling point. No summation of three points sampling less than one hundred-millionth of the ocean surface produces a "global average pH," which does not exist.

EHB Figure 1.5.1 reproduces data from Bates et al. (2014) [4]. Six stations, none polar, none deep-ocean, all subtropical gyre or temperate. Not a global mean. Modest trends of order 0.001–0.002 pH units per year at the monitored sites.

6.2 The straw man attribution argument

EHB argue (p. 24) that "If CO_2 from the deep oceans were released to the surface and into the atmosphere, the $^{13}C/^{12}C$ ratio of both the upper oceans and the atmosphere should increase." No dissenting paper claims pure deep-ocean outgassing. [70] and [55] invoke a distributed natural perturbation across ocean and biosphere in response to warming, whose net isotopic signature is approximately −13‰ (Koutsoyiannis Keeling result, Böhm sclerosponge result, Köhler LD ANT result documented above). This signature reproduces the observed atmospheric $\delta^{13}C$ decline. EHB refute a position no dissenter holds.

6.3 Local flux versus global attribution

EHB claims on p. 24–27 that DIC is increasing and pCO_2 is rising at HOT and BATS monitoring stations are correct as descriptions of net flux at those specific stations. They are not global attribution. Feely et al. [27] document that the ocean transports approximately 40 GtC/yr between low latitudes (net outgassing) and high latitudes (net uptake). The IPCC/Global Carbon Budget report a net global ocean uptake of approximately 2.5 ± 0.6 GtC/yr, but that headline number is empirically unconstrained: it is produced by combining a non-independent ensemble of nine global ocean biogeochemistry models with pCO_2 mapping products derived by heavy statistical extrapolation from the Surface Ocean CO_2 Atlas (SOCAT) observations that themselves cover less than 1–3% of the ocean surface in any given year and are strongly biased toward Northern Hemisphere shipping routes, with the quoted ±0.6 being the model ensemble spread rather than a probabilistic uncertainty around a measured value [20]. Whatever the true net figure, a small (few percent) perturbation in the low-latitude outgassing leg of the gross ∼ 40 GtC/yr transport produces atmospheric CO_2 changes of the observed magnitude without changing the sign of the local flux at the monitoring stations. EHB do not distinguish local from global, or net from gross, at any point in EHB §1.5.

6.4 The ocean-source-versus-sink claim

EHB conclude (p. 27) that "The oceans are not a source for the modern increase of CO_2 in the atmosphere." This is refuted directly by [36], who show empirically via cross-correlation analysis that CO_2 change lags temperature change by 9–12 months at all measured frequencies, including centennial. The empirical temporal ordering is temperature-first, CO_2-second. Quantitatively,

the CERES-measured TOA net energy imbalance of 4.3 ± 4 W m^{-2} [59] delivers energy to the ocean surface at every location where net absorption occurs. The local Henry's-law sensitivity $\partial \ln p_{CO_2}/\partial T = 0.0423$/K [78] translates that local energy uptake into a local reduction in CO_2 solubility. [20] show that a natural TOA imbalance of ~ 2.6 W m^{-2}, partitioned $\sim 91\%$ to the oceans, yields an outgassing flux of ~ 2.44 GtC/yr from the local van't Hoff response alone. The ocean is therefore a source contributor to the atmospheric CO_2 increase. EHB's conclusion is inconsistent with Henry's law and inconsistent with the empirically measured TOA energy flux.

7. The Process Characteristics Argument (EHB §1.6)

7.1 The spurious cumulative correlation

EHB Figure 1.6.3 and the surrounding text (p. 30) report: "the correlation between summed CO_2 emissions and increase in the atmosphere is a near-fit (corr.: 0.999; R^2: 0.998) over the whole period since 1900." This is the textbook Yule–Granger spurious regression trap, documented in the statistics literature since Yule (1926) [86]. Granger & Newbold (1974) [28] formalized the analysis and showed that regression on non-stationary integrated series produces spuriously high R^2 values regardless of any causal relationship between the underlying processes.

Cumulative fossil emissions from 1900 form a monotonically increasing time series. Atmospheric CO_2 from 1900 forms a monotonically increasing time series. Any two monotonically increasing series of comparable curvature correlate at $r \approx 1$ regardless of any underlying causal relationship; this is the point of the [86] and [28] results. The correlation also reduces to the accounting-identity fallacy: cumulative $F_{\text{anth}}(t)$ and $M_{\text{a}}(t)$ are monotonically increasing integrals whose joint sign structure is fixed by Eq. (2) integrated from 1900, so their high R^2 is a restatement of the identity in cumulative form, not evidence of causal linkage [22].

The correct test is on stationary first differences. On the year-to-year change in emissions versus the year-to-year change in atmospheric CO_2, the correlation is essentially zero. Wang et al. (2013) [85] report emissions variance at 10% of the interannual variance in the CO_2 growth rate; this figure includes the shared long-term trend between smoothly rising emissions and smoothly rising CO_2. Removing the shared trend by cubic detrending of the annual data collapses the emissions share to $R^2 \approx 0.021$, or approximately 2%. The same detrended regression against the lagged Southern Oscillation Index yields $R^2 \approx 0.148$, or approximately 15%. The tropical Pacific pressure oscillation captures approximately seven times more detrended interannual variance in CO_2 growth than anthropogenic emissions do. Even so, SOI accounts for only about 15% of the variance; the remaining $\sim 85\%$ is distributed across other ocean-atmosphere modes, biospheric temperature responses through Q_{10}, and volcanic aerosol variability. [36] show empirically that CO_2 change lags temperature change by 9–12 months across all measured frequencies. EHB acknowledge the discrepancy between the year-to-year emissions and growth-rate series in Figure 1.6.6 and ignore it when presenting the $r^2 = 0.998$ correlation as evidence.

Koutsoyiannis et al. [56], in Parts 1 and 2 of "Revisiting causality using stochastics" (Proceedings of the Royal Society A), apply proper stochastic causality analysis to the CO_2–temperature system and conclude that temperature causes CO_2 changes at annual to multi-decadal timescales, not the reverse. Koutsoyiannis et al. [57] extend the analysis with additional data and reach the same conclusion.

7.2 Linear first-order relaxation: EHB endorse it, then refuse its implications

EHB write (p. 31): "the higher the CO_2 content/pressure in the atmosphere, the higher the push to drive CO_2 into the oceans and vegetation." This is a linear first-order relaxation process. Applied to a bulk-CO_2 perturbation regardless of origin, the relaxation time is set by the reservoir-to-flux ratio, $\tau_{\text{res}} = 3.80 \pm 0.12$ yr [53]. This is over an order of magnitude shorter than the 50-year

figure EHB assert in EHB §1.3. The bomb-^{14}C isotopic relaxation time $\tau_{\mathrm{rel}} \approx 18.4$ yr from the [35] compilation is the same underlying physics manifested through the isotopic disequilibrium the bomb pulse created, connected to τ_{res} via the bridge equation, Eq. (7), and is itself nearly a factor of three shorter than the EHB figure.

If EHB accept linear response here, they must accept the empirical timescales that linear response yields when measured. They do not. They endorse the model here and reject its consequences three sections earlier.

7.3 EHB's "temperature forcing" is forcing by a non-existent quantity

EHB Table 1.6.1 (p. 35) presents sensitivities in units of ppm per K of "temperature":

Event	Time (yr)	CO_2 lag	Sensitivity (ppm/K)
Glacial/Interglacial	1000s	~600 yr	16
MWP/LIA	100s	~50 yr	12.5
Modern	1–3	~6 months	3.5
Seasonal	months	~2 months	(4–5)

Every entry in this table is a coefficient multiplying a global mean temperature. There is no such thing as a global mean temperature: it is an area-weighted arithmetic mean of local intensive readings, untethered under classical thermodynamics and physically meaningless [18]. A quantity that does not exist as a physical variable cannot "force" anything. EHB's "temperature forcing" framework is forcing by a non-existent quantity: it has the same physical content as "unicorn forcing."

7.4 Internal timescale inconsistency in EHB's own table

Taking the table at face value long enough to expose the internal inconsistency: temperature leads CO_2 at every measured timescale in the table, and the tabulated sensitivity rises with timescale (3.5 ppm/K at 1–3 yr, 12.5 ppm/K at 100-yr MWP/LIA scale, 16 ppm/K at millennial glacial scale). Longer integration windows accumulate more of the reservoir response. EHB then apply the shortest-timescale sensitivity (3.5 ppm/K, appropriate for annual signals) to the 170-year modern era and conclude "temperature" can only explain approximately 13 ppm of the 140 ppm rise. Even within their own tabulated coefficients this is wrong: the 170-year window falls between the 100-year MWP/LIA scale (12.5 ppm/K) and the millennial glacial scale (16 ppm/K), not the annual scale. Applying the appropriate row of their own table would yield 12–16 ppm/K, not 3.5.

7.5 The physical driver is TOA power imbalance, not "temperature"

The real physical driver of atmospheric CO_2 change is not a global temperature, because no global temperature exists. It is the top-of-atmosphere net power imbalance (Clauser (2026) [17]), which CERES measures directly at each pixel and integrates to a global energy flux with a well-defined physical meaning (a rate of energy accumulation in the coupled Earth system). [59] report the CERES EBAF net TOA imbalance at 4.3 ± 4 W m^{-2}. [20] show that a natural TOA imbalance of ~ 2.6 W m^{-2}, applied through the local van't Hoff solubility law at the ocean surface ($\sim 91\%$ energy partition, yielding ~ 2.44 GtC/yr outgassing) and the local Arrhenius/Q_{10} respiration law at the land surface ($\sim 9\%$ partition, yielding ~ 2.34 GtC/yr), exactly matches the observed atmospheric growth rate averaging ~ 2.25 ppm/yr over 2000–2025 (Scripps/NOAA).

The four natural contributors to the 2.6 W m^{-2} imbalance documented in [20] are: (i) sustained multidecadal decreases in low-cloud cover reducing planetary albedo (1.2–1.7 W m^{-2}); (ii) total solar irradiance variability, direct and through UV-driven circulation (0.1–0.5 W m^{-2}); (iii) post-volcanic aerosol recovery (0.3–0.5 W m^{-2}); (iv) internal ocean-atmosphere oscillations,

ENSO/PDO/AMO modulating cloud regimes and heat transport (0.4–0.8 W m^{-2}). Each is a natural forcing. Their sum is well within the CERES uncertainty envelope and quantitatively matches the observed CO_2 growth.

The physical processes translating local energy uptake into local CO_2 flux are documented in the peer-reviewed literature EHB neither cite nor engage: [36] on the temporal-ordering result; [53], [55] on the biosphere Q_{10} response; [70] on continental respiration and soil-carbon turnover; [69] on biological-pump-mediated exchange; [79] on overturning-circulation effects; [72] on permafrost carbon release; [13] on biosphere carbon turnover time.

7.6 The Takahashi formula is local, not global

EHB write (p. 35): "There is a formula to calculate the exact increase of CO_2 in the atmosphere with temperature: the formula of Takahashi . . . $\partial \ln p_{CO_2}/\partial T = 0.0423/\mathrm{K}$."

The [78] formula describes the local chemical solubility response of a water parcel at fixed local DIC and alkalinity to a change in that parcel's local temperature. It is a partial derivative at a point. It has no global-mean form and cannot be applied to any global-mean temperature construct, because no such construct exists. "Exact," applied to a global calculation, is false twice over: once because the formula is local not global, and once because it excludes every biogeochemical feedback (biological pump, respiration, overturning circulation, permafrost).

The number EHB tabulate is a lower bound on the local CO_2 solubility response at a representative ocean parcel warming by 1 K. It is not, and cannot be, a total "temperature response of the atmosphere." EHB present it as an upper bound. That is the reverse of the physics.

7.7 EHB claim (p. 36): "This proves that . . . temperature is not responsible for the current increase"

"Temperature" in this claim refers to the global-mean surface-temperature construct EHB implicitly rely on throughout the report. That construct is not a physical quantity. To say a non-existent variable "is not responsible" for something is not a physical claim; it is a statement whose subject doesn't exist. The physical drivers of the observed CO_2 rise are (i) the CERES-measured TOA net energy imbalance, (ii) the local Henry's-law solubility responses at the ocean surface at each location, and (iii) the local Arrhenius/Q_{10} respiration responses at the land surface at each location. Computed from first principles and integrated over local physics, these reproduce the observed CO_2 growth quantitatively [20].

The peer-reviewed literature that EHB neither cite nor engage documents the same physics in different framings. [36], [53], [55], [56], and [57] collectively establish:

1. CO_2 change lags temperature change by 9–12 months at all measured frequencies (cross-spectral analysis on the observed CO_2 and observed temperature time series, whatever the physical status of the temperature series itself).

2. The temperature-series-to-CO_2 direction of stochastic causality is measured across annual through multi-decadal timescales.

3. The Q_{10} respiration response with $Q_{10} \approx 2$ [11] applied locally at each terrestrial site yields aggregate cumulative CO_2 release comparable to or exceeding the observed atmospheric increase.

4. The RRR framework closes the observed 20th-century CO_2 growth with natural fluxes as the primary contributor.

EHB engage none of the evidence, statistical results, or mathematical closures in these papers.

8. The Ice-Core Argument (EHB §2.1)

8.1 Appeal to consensus versus documented systematic errors

EHB write (p. 37): "CO_2 records from air bubbles in Antarctic ice cores are regarded as the gold standard." Appeal to consensus is not evidence. Jaworowski, Segalstad & Hisdal (1990) [38], Jaworowski, Segalstad & Ono (1992) [39], and Jaworowski (1994) [37] documented systematic errors in ice-core CO_2 reconstruction:

1. Diffusion smoothing that attenuates century-scale peaks.
2. Clathrate dissociation during and after core recovery.
3. Drilling-fluid contamination.
4. Selective rejection of high readings from old ice as "outliers."
5. Selective rejection of low readings from young firn as "not equilibrated."
6. Systematically higher pre-1985 published ice-core CO_2 values that were quietly dropped from subsequent literature.

Ato (2024) [3] replicates and extends the Jaworowski critique with modern statistical methods. EHB engage none of the statistical evidence or measurement critiques in these papers.

8.2 Gas-age smoothing kernels attenuate peaks: interglacials are the relevant period

EHB claim (p. 37) that any century-scale peak comparable to the modern rise "would be visible in even the lowest resolution ice core measurements as an unusual peak of several tens of ppmv." The claim is wrong, and it is wrong in the period that matters. Glacial CO_2 sits at $\sim$ 180 ppm throughout, comfortably below the 300 ppm threshold; no "exceeded 300 ppm" question arises during glacial periods. The relevant period is the interglacials, where the ice-core composite gives peak CO_2 of $\sim$ 280–290 ppm; here a modest century-scale elevation would exceed 300 ppm and be inconsistent with EHB's headline claim.

Three ice-core sites span most of the past 800,000 years and cover past interglacials: Dome C ($\sim$800 kyr), Vostok ($\sim$420 kyr), and Dome Fuji ($\sim$720 kyr, with the Dome Fuji 2 deep-drilling project targeting the older-than-Mid-Pleistocene interval). All three are low-accumulation East Antarctic sites with large gas-age distribution widths (FWHM) even during interglacials. Published values:

Core	Period	FWHM (yr)
Law Dome DE08	Holocene only	10
Law Dome DSS	Holocene only	14
Siple Dome	Holocene	22
WAIS WDC	Holocene	30
Byrd	Holocene	54
DML	Holocene	65
Dome Fuji	Holocene / interglacial	comparable to Dome C
Dome Fuji	glacial	comparable to Dome C
Dome C	Holocene / interglacial	$\sim$ 200
Dome C	Last Glacial Maximum	$\sim$ 550
Vostok	interglacial	$\gtrsim$ 200
Vostok	glacial	$\gtrsim$ 340

Dome C interglacial and glacial values are from Monnin et al. (2001) [62]. Dome Fuji, drilled by the Kawamura group [42], is a low-accumulation East Antarctic site with accumulation rate (∼2.5 cm/yr ice equivalent) comparable to Dome C's, and its gas-age smoothing is of the same order. The Holocene-only high-resolution cores (Law Dome DE08 at 10 yr, DSS at 14 yr, WAIS at 30 yr) cannot constrain past interglacial variability at all because they do not extend beyond the Holocene.

Direct convolution of a rectangular spike of duration W and amplitude A with a Gaussian firn kernel of standard deviation $\sigma = \mathrm{FWHM}/\sqrt{8\ln 2}$ preserves the spike area and reduces the peak amplitude by the factor $\mathrm{erf}[W/(2\sigma\sqrt{2})]$. For Dome C interglacial (FWHM 200 yr, $\sigma \approx 85$ yr):

- A century-scale interglacial spike of 30 ppm amplitude (bringing $\sim 280 \rightarrow \sim 310$ ppm, just exceeding EHB's 300 ppm threshold) attenuates to an apparent peak of $\sim$ 13 ppm elevation, indistinguishable from the 5–25 ppm inter-core scatter documented across public Antarctic datasets [60], [1].
- A 60-ppm spike (matching EHB's "several tens of ppmv" language) attenuates to $\sim$ 27 ppm apparent elevation, at the boundary of visibility given typical scatter.
- A 50-yr, 60-ppm spike attenuates to $\sim$ 14 ppm at Dome C interglacial resolution.
- A 30-yr, 60-ppm spike attenuates to $\sim$ 8 ppm, below scatter.

Sample spacing compounds the attenuation. Dome C sampling during the Holocene is approximately 72–100 yr per Monnin et al. (2001) [62]; in older interglacials and during transitions, spacing widens to 200–500 yr. A feature attenuated by firn smoothing and then sub-sampled at 500-yr spacing has substantial probability of falling between samples entirely.

The empirical test is direct. Multiple independent stomata reconstructions (§9 below) show century-scale 30–40 ppm Holocene variability that ice cores do not record. This is not a hypothetical smoothing calculation; it is the observed disagreement between two proxies over the same period, in which the ice-core proxy has known smoothing physics that attenuates century-scale features and the stomata proxy does not.

8.3 Age-uncertainty in low-accumulation cores

For Vostok and Dome C, ice-gas age deltas are 2000–6000 years with 10–15% uncertainty, i.e., 200–900 years of dating uncertainty on CO_2 values. EHB acknowledge the age-delta uncertainty in passing on p. 39 and do not report it in the "800,000 years never exceeded 300 ppmv" conclusion on p. 44.

8.4 Wet versus dry extraction

Wet-extraction and dry-extraction techniques on ice cores can produce systematically different CO_2 values in ice with high impurity content. Kawamura et al. (2003) [42] developed a wet-extraction protocol at Dome Fuji whose results agree with dry-extraction values from clean East Antarctic cores over the past 65 kyr, but wet-extraction results on the NEEM Greenland core run 10–30 ppm higher due to in-situ CO_2 production from ice impurities. The extraction technique is a real methodological variable at the 10–30 ppm level in high-impurity ice; EHB do not address this variable in evaluating their "never exceeded 300 ppmv" claim across the full ice-core record.

8.5 Conclusion of ice-core section

EHB's "800,000 years never exceeded 300 ppmv" depends on: (i) gas-age dating accurate to within a decade (false for cores with age deltas of thousands of years); (ii) gas-age distribution not attenuating peaks (false for all cores with FWHM exceeding sampling interval, per the published values above); (iii) extraction technique recovering all gas without fractionation (challenged by

[42]); (iv) no post-depositional CO_2 loss (documented by [39, 37]). Every one of these assumptions is challenged in the peer-reviewed literature. EHB do not address any of the challenges.

8.6 The non-sequitur at the heart of the ice-core argument

The preceding subsections show that EHB's "never exceeded 300 ppmv" finding does not survive its own assumptions. Set that aside. Grant EHB the finding, in full, for the sake of argument. The attribution conclusion EHB draw from it still does not follow.

The ice-core argument, in its most charitable reconstruction, runs: (i) ice cores show that CO_2 was flat at approximately 280 ppm for 800,000 years; (ii) atmospheric CO_2 is now approximately 420 ppm; (iii) therefore the modern rise is caused by fossil-fuel emissions. Step (iii) does not follow from (i) and (ii). An observation that prior CO_2 was flat and current CO_2 is not establishes only that something recent has changed. It does not identify which of the many recent changes is the cause. The CERES-measured TOA energy imbalance is a recent change. Sustained multidecadal reduction of low-cloud cover is a recent change. Ocean warming that reduces local Henry's-law solubility at every SST site is a recent change. Anthropogenic fossil emissions are a recent change. The ice-core record cannot discriminate among them, because it addresses only what happened before and says nothing about which of the currently operative physical processes is driving the current change.

Attribution is fixed by direct tests on the current system that operate independently of the prior record. The Keeling relation applied to the modern Scripps $\delta^{13}C$ record forces the net-added source signature to $-13.2 \pm 0.2‰$ and the fossil fraction to $f \approx 0$, whether or not prior CO_2 was flat (§3). The bomb-^{14}C decay in the [35] compilation gives $\tau_{\text{rel}} \approx 18.4$ yr and falsifies the Bern impulse-response function, whether or not prior CO_2 was flat (§4). The CERES energy imbalance applied through local van't Hoff and Q_{10} closes the observed atmospheric growth quantitatively, whether or not prior CO_2 was flat (§7). Every one of these tests operates on measurements of the current atmosphere, current ocean, current biosphere, and current top-of-atmosphere radiation budget. None of them depends on the paleoclimate record's variability, and none is defeated by an "unprecedented" finding.

EHB's rhetorical structure invites the reader to treat the ice-core "unprecedented rise" finding as if it were an attribution. It is not. Attribution is a claim about the current physical drivers of the current atmospheric change. The isotopic, radiocarbon, and energy-balance constraints determine attribution to natural-dominant regardless of what the paleoclimate record shows or fails to show. The ice-core argument, even taken at its rhetorical strongest, does not touch them.

9. The Plant-Stomata Argument (EHB §2.2)

9.1 Two proxies disagree systematically

EHB acknowledge (p. 46) that "during the Holocene, almost all stomata CO_2 reconstructions are on average 30 to 40 ppmv higher than ice core CO_2 concentrations, with higher amplitude variability." EHB assert ice cores are correct and stomata are biased. Wagner et al. (1999) [83], Kouwenberg et al. (2005) [58], van Hoof et al. (2008) [81], Steinthorsdottir et al. (2013) [77], and multiple additional independent stomata reconstructions from different species and different sites all show century-scale 30–40 ppm Holocene variability inconsistent with the flat ice-core record. Two proxies disagree. EHB pick one and dismiss the other without an independent test either proxy could pass or fail.

9.2 The ice-core smoothing physics

EHB write (p. 47): "Since these high-resolution ice cores do not record the high CO_2 variations seen in stomata over the same period, the temporal resolution difference is a questionable hypothesis." EHB's point is narrow. It is limited to the Holocene, where the high-resolution cores (Law Dome DE08 at 10 yr FWHM, DSS at 14 yr, both sampled at 10-yr intervals) do have the resolution to capture centennial-scale 30–40 ppm variability if it existed at the atmospheric level. The Holocene stomata-ice mismatch is a real empirical observation, and Law Dome smoothing alone does not explain it. EHB conclude from this that the stomata data are wrong. That conclusion is one candidate explanation; the alternatives include systematic ice-core artifacts (post-depositional CO_2 loss, gas-age uncertainty combined with sampling gaps, extraction-technique differences) and genuine local-atmospheric variability that stomata sample but Antarctic ice does not.

More importantly, EHB's "high-resolution ice core" defense does not extend to past interglacials, which are the periods that carry the actual weight of the "800,000 years never exceeded 300 ppmv" claim. Past interglacials appear only in Dome C, Vostok, and Dome Fuji, where interglacial FWHM is of order 200 yr and sub-centennial features are attenuated below scatter (§8). The Holocene Law Dome argument is silent on whether past interglacials contained century-scale peaks exceeding 300 ppmv.

Even taken at maximum charitable strength, the argument concludes only that stomata reconstructions may be an unreliable proxy. It does not establish that atmospheric CO_2 has never exceeded 300 ppmv, and it does not establish anthropogenic attribution. The isotopic, radiocarbon, and energy-balance constraints that determine attribution operate independently of the stomata-ice-core debate.

9.3 Selection convenient to the framing

EHB need the Holocene to have been flat at approximately 280 ppm because 40 ppm of natural Holocene variability weakens the "unprecedented modern rise" framing. Stomata data show 40 ppm Holocene variability. EHB dismiss them. That is selection based on framing convenience, not on comparative proxy evaluation.

10. The Chemical-Methods Argument (EHB §2.3)

The specific 1942 CO_2 peak at approximately 70 ppm in the Beck (2007) [6] compilation is inconsistent with mass balance, ice-core records, and coralline-sponge $\delta^{13}C$ data. EHB's critique of that specific peak (EHB §2.3, "The Probability of a Huge CO_2 Peak Around 1942") is correct. The Linden-Giessen dataset that dominates the 1942 peak was collected at low elevation over land near vegetation and traffic, and modern measurements at the same site show diurnal excursions and monthly biases of order 30–40 ppm above the free-atmospheric background. That specific critique is well founded. Massen & Beck (2009) [61] nonetheless demonstrated that a subset of Beck's compilation taken at remote sites and under well-mixed non-inversion conditions is research-grade and comparable to modern background reference values. Whether pre-Mauna Loa CO_2 ever contained genuine multi-year excursions of the magnitude Beck compiled remains an open question in the chemical-methods literature; the failure of the specific 1942 Linden-Giessen peak does not by itself resolve it.

The stronger internal issue with EHB's treatment is a citation inconsistency. EHB Figure 2.3.9 (p. 57) cites [10] coralline sponge $\delta^{13}C$ data to argue against a 1942 anomaly, and correctly notes that a 70-ppm fossil release would have produced a $\delta^{13}C$ excursion that the sclerosponge record does not show. Correct for that narrow use. But [10] is one of the three independent records establishing the approximately $-13‰$ net-added isotopic signature over 500 years, documented in §3 of the present paper. Used quantitatively in the Keeling-plot framework of Koutsoyiannis (2024b) [54],

the [10] data force the fossil fraction $f \approx 0$ across the entire five-century record. EHB cite Böhm approvingly to critique Beck, then omit Böhm's quantitative implication for their own attribution. The selective citation is not a footnote; it is the strongest single reversal available in the report against EHB's own conclusion.

11. Citation Practice

11.1 Assertion without support as the dominant rhetorical mode

Throughout the report, EHB present sweeping physical conclusions in the voice of established fact without providing evidence, derivation, or citation. Representative examples, each drawn from a direct quotation examined above and each carrying an unsupported inference of the kind identified in the corresponding subsection:

- "That proves that nature is a sink for the other 50%, not the cause of the increase" (p. 9). The word "proves" is asserted; the inference from a rate-ratio near 0.5 to the causal claim is not derived. See §2.
- "The annual temperature anomaly shows no trend at all, thus is not the cause of the ongoing increase of CO_2 in the atmosphere" (p. 9). The "temperature anomaly" construct is not defined, no dataset or trend calculation is presented, and the "thus is not the cause" inference confuses the time derivative of a forcing with the time integral of the response. See §2.
- "Any theory that leads to a substantial increase of CO_2 in the atmosphere due to natural factors violates the mass balance and thus cannot be correct" (p. 11). Stated as a general theorem. No mass-balance equation is written down at the point of the claim; no candidate theory is analyzed; no "violation" is exhibited. See §2.
- "But saturation of CO_2 sinks is only true for the ocean surface. It is not correct for the vegetation sink while the atmospheric concentration is below 1,000 ppmv or so, nor for the deep oceans where both the biological pump and the direct sinks near the poles largely bypass the physicochemical restrictions of the ocean surface" (p. 6). Four claims in one sentence, none sourced, none derived, none quantified. The 1,000 ppmv threshold is stated with no physical basis; the "direct sinks near the poles" are not named or measured; the "largely bypass" is not quantified. See §2.
- "The strong decrease of the $^{13}C/^{12}C$ ratio ... excludes any huge contribution of the (deep) oceans to the CO_2 increase" (p. 15). No isotopic mass-balance calculation exhibiting the "exclusion." See §3.
- "The production of extra O_2 in the atmosphere excludes a net contribution from the whole biosphere to the CO_2 increase" (p. 22). No O_2/CO_2 stoichiometric budget quantifying the "exclusion." See §5.
- "The oceans are not a source for the modern increase of CO_2 in the atmosphere" (p. 27). Asserted without integrating local sea-surface fluxes, without addressing the Humlum temperature-leads-CO_2 cross-correlation, and without engaging the CERES TOA imbalance. See §6.
- "This proves that ... temperature is not responsible for the current increase" (p. 36). The one-term surface-solubility calculation on which the "proof" rests omits the biological pump, respiration, overturning circulation, permafrost, wetlands, and biosphere turnover. See §7.

Each of the above claims is a physical conclusion, presented as established, unsupported by derivation, evidence, or citation at the point of assertion. The pattern is not incidental. It is the report's dominant rhetorical mode.

The complementary pattern is the report's treatment of the peer-reviewed literature that addresses

these same questions. That literature exists. It is extensive. It documents specific evidence, statistical results, and mathematical closures directly bearing on every one of the nine "lines of evidence" EHB present. EHB do more than fail to cite it: they engage none of its evidence, respond to none of its calculations, and answer none of its inferences. The report's method is to state conclusions in the voice of established fact while leaving the peer-reviewed physics, mathematics, and data that contradict those conclusions entirely unaddressed. That is not a scientific method.

11.2 Non-sequitur as second dominant rhetorical mode

A second rhetorical pattern recurs throughout the report and warrants separate identification. In case after case, EHB establish (or assert) a factual premise and then draw an attribution conclusion that does not logically follow from the premise. The pattern is not that the premise is wrong (although often it is); it is that even if the premise were granted in full, the conclusion would not follow. Examples:

- Ice cores show "800,000 years never exceeded 300 ppmv" ⇒ therefore the modern rise is anthropogenic. Whether prior CO_2 was flat or variable is a fact about the paleoclimate record. It does not identify which of the currently operative physical processes (fossil emissions, ocean warming, biosphere response, TOA imbalance) is driving current change. See §8.
- Mass balance identity $F_{\text{anth}} - dM_{\text{a}}/dt = F_{\text{out}} - F_{\text{nat}}$ has positive left-hand side ⇒ therefore nature is a net sink and cannot be causing the rise. The identity constrains the difference $F_{\text{out}} - F_{\text{nat}}$; it does not constrain F_{nat} separately, and is compatible with attribution splits from a few percent to majority anthropogenic. See §2.
- Atmospheric $^{13}C/^{12}C$ ratio is decreasing ⇒ therefore deep-ocean contribution is excluded. The direction of $\delta^{13}C$ change requires only that the net-added source be lighter than the preindustrial baseline; it does not force pure-fossil attribution, and the Keeling calculation shows the effective source signature is approximately −13‰, forcing $f \approx 0$. See §3.
- O_2 is decreasing while CO_2 is rising ⇒ therefore biosphere is not a net CO_2 source. The O_2/N_2 constraint is on the decadal partition of the net sink between ocean and land, not on the source attribution. A system in which biosphere is a net CO_2 sink and ocean is a net CO_2 source satisfies every EHB O_2 constraint and reaches natural-dominant attribution. See §5.
- pCO_2 is rising at HOT and BATS ⇒ therefore the ocean is not a CO_2 source globally. Local net-flux measurements at monitoring stations do not aggregate to global attribution when the ocean's gross low-latitude to high-latitude transport is approximately 40 GtC/yr. See §6.
- Cumulative emissions correlate with cumulative CO_2 at $r^2 = 0.998$ ⇒ therefore emissions cause the CO_2 rise. The correlation is the Yule–Granger spurious-regression trap and does not distinguish causation from co-trending. See §7.

In each case the factual premise (whatever its truth) constrains something other than what EHB conclude from it. The reader is invited to accept the inference by the force of proximity: a fact is presented, an attribution conclusion is stated in the next sentence, no logical connection is exhibited. Recognizing this pattern is important because the isotopic, radiocarbon, and energy-balance constraints that determine attribution operate independently of every one of these premises. Even if all of EHB's premises were granted in full, the peer-reviewed direct attribution tests still yield natural-dominant attribution.

11.3 The 50-year adjustment time: three citations, one circular derivation

EHB cite three sources for the 50-year adjustment time. On inspection, the three do not constitute independent support:

- Spencer [75] in the *Journal of Marine Science: Research & Oceanography* is the single source that actually derives the 50-year figure. The derivation is circular: it fits Mauna Loa growth to

a model that assumes anthropogenic emissions are the sole source and that sinks act linearly on the excess above an assumed 294 ppm equilibrium, then reports the fitted slope 2.02%/yr and its inverse ≈ 50 yr as the "adjustment time." The two assumptions are the fossil-dominant conclusion. The output is the fossil-dominant conclusion's characteristic timescale. Circular reasoning is not science.

- Burton [12] is a non-peer-reviewed OSF preprint titled "Comment on Stallinga (2023)" that performs a similar linear regression, obtains 1.83%/year, and cites Spencer's 50-year value as the reference. Burton's own two citations for the 50-year adjustment time are Spencer [75] and Engelbeen (2022), the latter being an author's personal website, not a peer-reviewed paper.
- Engelbeen [24] in *Science of Climate Change* is a Comment on Harde's peer-reviewed paper. It responds to Harde's short-residence-time analysis but does not itself derive a 50-year adjustment time from any independent measurement.

The 50-year figure has one derivation, in one paper, obtained by assuming the answer and fitting the assumption. The remaining two citations either restate that fit (Burton) or address a different question (Engelbeen). The independent bomb-^{14}C measurement, which does not assume the attribution and contradicts the 50-year figure by an order of magnitude, is nowhere addressed by any of the three. Ignoring an empirical measurement that directly contradicts a fitted parameter is not disproof of that measurement; it is refusal to engage with it. EHB reproduce that refusal.

11.4 Peer-reviewed literature directly refuting EHB, neither cited nor engaged

The following peer-reviewed or under-peer-review works, each directly refuting one or more of EHB's central claims, are neither cited nor answered on their substance anywhere in the 65-page report:

- Jaworowski, Segalstad & Hisdal (1990) [38]
- Jaworowski, Segalstad & Ono (1992) [39]
- Jaworowski (1994) [37]
- Segalstad (1998) [73]
- Essenhigh (2009) [26]; Massen & Beck (2009) [61]
- Humlum et al. (2013) [36]
- Harde (2017) [31]
- Berry (2019) [8]; Harde (2019) [33]
- Berry (2021) [9]; Harde & Salby (2021) [34]; Salby & Harde (2021) [70]
- Koutsoyiannis et al. (2022) [56]; Salby & Harde (2022) [71]
- Koutsoyiannis et al. (2023) [57]; Stallinga (2023) [76]
- Ato (2024) [3]; Koutsoyiannis (2024a) [53]; Koutsoyiannis (2024b) [54]; Koutsoyiannis (2024c) [55]
- Müller (2025) [63]; Veyres et al. (2025) [82]
- Cohler (2026) [18]; Cohler & Soon (2026b) [21]

A rebuttal that names none of its targets and engages none of their work is not a rebuttal.

11.5 Köhler's own admissions, neither cited nor engaged

EHB invoke Köhler et al. (2006) [46] in support of their attribution. [46] is a computational model (BICYCLE), not an observation, and cannot function as evidence for a physical claim. EHB also engage none of the following, in which Köhler and his co-authors themselves document the model's failures:

- Köhler et al. (2006) [46]: direct Keeling-intercept measurement of $y_0 = -13.1‰$ from Law Dome LD ANT data, explicit admission that this contradicts fossil-dominant attribution.
- Köhler, Fischer & Schmitt (2010) [48]: "Northern Hemisphere temperature is probably incorrect."
- Köhler & Munhoven (2020) [47]: wholesale replacement of the 2006 carbonate compensation mechanism.
- Köhler et al. (2022) [52]: "prescribing CO_2 violates mass conservation of carbon"; "currently not understood how changes in ^{14}C production rate (Q), and in the carbon cycle, can be combined to explain the reconstructed atmospheric $\Delta^{14}C$ record."
- Köhler, Skinner & Adolphi (2024) [51]: "Opposite to data CO_2 falls during Heinrich stadials."

Every principal architectural element of [46] has been admitted incorrect or replaced by Köhler himself in subsequent papers. Dinauer et al. (2020) [23] titled a paper on the model's failure to reproduce observed $\Delta^{14}C$ behavior as "mysteriously high." EHB invoke the original paper in support and engage none of the recantations.

11.6 The parallel attack apparatus

Furthermore, Köhler et al. (2018) [49] attempted the same rhetorical strategy against [31] that EHB now attempt against a broader dissenting literature. The Köhler et al. comment closed with the explicit demand that the Harde paper "be withdrawn by the author, editor or publisher due to fundamental errors in the understanding of the carbon cycle." Harde (2018) [32] rebutted each of the five substantive claims. The editors published a separate editorial [30] announcing that they had asked three additional experts to review [49] and had opened an investigation into the peer-review procedures used for [31]. The editorial focused on procedure, not on the physics of Harde's claims.

Each of the five substantive claims in [49] against [31] fails against physics on the record. First, the assertion that a "single equation is fundamentally at odds with basic theory" is contradicted by the observed single-exponential bomb-^{14}C decay in the [35] compilation at $R^2 > 99.8\%$: a linear multi-exponential response is structurally excluded from matching this shape. Second, the residence-time-versus-adjustment-time distinction rests on operator asymmetry between bulk CO_2 and ^{14}C transport that mass conservation forecloses at the reservoir level. Third, the "carbonate chemistry bottleneck" invokes a global Revelle factor that is a local intensive chemical-equilibrium property with no global aggregate [18]. Fourth, the "missing residual assigned to terrestrial uptake" is the mass-balance-identity bookkeeping fallacy discussed in §2 above, applied to [53]'s framework, and directly contradicted by the Keeling-intercept analysis of [21] and by Köhler's own measurement in [46] of $y_0 = -13.1‰$. Fifth, the "isotopic distinction between tracer and bulk" is the same operator-asymmetry claim as (ii) and fails on the same grounds.

The same rhetorical apparatus was subsequently deployed in Rice, Schade & Maslin (2022) [68] against Skrable, Chabot & French (2022) [74], a peer-reviewed *Health Physics* paper that used the modern atmospheric ^{14}C record to conclude an anthropogenic fossil fraction of order a few percent. The Rice, Schade and Maslin comment invoked the same set of arguments (residence-time-versus-adjustment-time confusion, tracer-versus-bulk asymmetry via global Revelle factor, mass-balance-identity accounting). Each is falsified by the same physics enumerated above. What EHB present as scientific consensus is a repeated deployment of the same argument set, refuted at each of its foundational moves in the peer-reviewed literature EHB neither cite nor engage.

12. Summary and Conclusions

Each of EHB's nine lines of evidence fails as an attribution argument:

1. **Mass balance (EHB §1.1).** The identity $F_{\text{anth}} - dM_{\text{a}}/dt = F_{\text{out}} - F_{\text{nat}}$ constrains the net flux, not the attribution. [8], [31], [70], and [53] all satisfy the identity and produce natural-dominated attributions. EHB assert that the identity implies fossil-dominant attribution; they do not demonstrate it because it cannot be demonstrated: the identity holds in every physically admissible state and carries zero evidential weight for any causal claim by Cohler & Soon (2026c) [22] Theorem 1.

2. **^{13}C/^{12}C (EHB §1.2).** Three independent records ([54] instrumental Keeling, [10] sclerosponge, [46] Law Dome LD ANT) converge on a net-added isotopic signature of approximately −13‰. Under this signature, the fossil fraction of the observed forcing computes to $f \approx 0$, indistinguishable from zero within the intercept's ±0.2‰ measurement uncertainty. Under any admissible endmember, f is bounded well below 1, and the five-century sclerosponge invariance is consistent with $f \approx 0$ throughout [21]. EHB's argument ignores the Keeling relation and is inconsistent with the isotopic mass balance the physics dictates.

3. **^{14}C (EHB §1.3).** A single-exponential fit to the [35] bomb-^{14}C compilation gives $\tau_{\text{rel}} \approx 18.4$ yr, $R^2 > 99.8\%$, permanent fraction indistinguishable from zero. The 50-year adjustment time EHB assert in EHB §1.3 is derived circularly from a linear regression that assumes the fossil-dominant conclusion and fits the assumption [75]. The Bern impulse-response function used by the IPCC [41], though not invoked by EHB directly, requires longest timescale 394 yr and permanent fraction 21.7%; it is falsified by the single-exponential shape of the direct measurement over five decades. EHB's response to the bomb-^{14}C constraint is to run the observation through the multi-reservoir carbon-cycle simulation of Graven et al. (2020) [29], whose response function is fixed by its prescribed rate constants and structural assumptions and by construction produces the long-tail persistence behavior standard in IPCC-class models; even that model's post-correction number of ∼ 20 yr is nearly a factor of three shorter than the 50-year figure EHB cite it as supporting.

4. **Oxygen (EHB §1.4).** O_2/N_2 measurements constrain the decadal partition of the net sink between ocean and land. They do not attribute the source. [70] construct a system satisfying every EHB O_2 constraint with natural-dominated CO_2 attribution.

5. **Ocean chemistry (EHB §1.5).** pCO_2 and DIC data at HOT, BATS, and six [4] stations are local net-flux measurements at monitored sites. The "average ocean pH" EHB invoke is untethered under classical thermodynamics and is not a physical quantity [18]. Feely et al. [27] document ocean low-latitude to high-latitude transport of approximately 40 GtC/yr; the IPCC's headline net global ocean uptake of ∼ 2.5 GtC/yr is empirically unconstrained, derived from a non-independent model ensemble and heavily extrapolated SOCAT products [20]. A few-percent perturbation in the gross transport can drive atmospheric CO_2 change without altering the sign of the local flux. EHB do not distinguish local from global.

6. **Process characteristics (EHB §1.6).** The $r^2 = 0.998$ correlation between cumulative emissions and cumulative atmospheric CO_2 is the Yule–Granger spurious-regression trap: any two monotonically increasing series of comparable curvature correlate at $r \approx 1$ regardless of causal relationship. Proper stochastic causality analysis [56], [57] gives temperature → CO_2 at all measured timescales. EHB's "temperature forcing" table quantifies sensitivities in ppm per K of a global-mean temperature that is not a physical quantity [18]; the actual physical driver is the CERES-measured TOA energy imbalance acting through local Henry's law and local Q_{10} at each surface location, closing the observed CO_2 growth quantitatively [20].

7. **Ice cores (EHB §2.1).** EHB's "800,000 years never exceeded 300 ppmv" claim covers glacial and interglacial periods jointly. Glacial CO_2 is ∼ 180 ppm throughout, well below the 300 ppm threshold; the relevant period is the interglacials, where past interglacial peaks

sit at ~ 280–290 ppm and a modest century-scale spike would exceed 300 ppm. Only Dome C, Vostok, and Dome Fuji cover past interglacials; their interglacial FWHMs are ~ 100–200 yr [62]. A 30 ppm century-scale interglacial spike would appear as ~ 13 ppm elevation at Dome C, indistinguishable from the observed 5–25 ppm inter-core scatter. High-resolution cores (Law Dome, WAIS) do not cover past interglacials. [39, 37], [3] document systematic errors in ice-core reconstruction that EHB do not engage. [42]'s wet-extraction values are 10–20 ppm higher than dry-extraction values, dismissed by EHB with "Kawamura believes."

8. **Stomata (EHB §2.2).** Multiple independent stomata reconstructions [83], [58], [81], [77] show 30–40 ppm Holocene variability inconsistent with ice-core smoothness. EHB dismiss stomata on grounds inconsistent with the Gaussian-kernel smoothing that the ice-core gas-age physics dictates.

9. **Chemical methods (EHB §2.3).** [6]'s specific 1942 peak is correctly critiqued. The generalization to wholesale dismissal of 90,000 measurements is unwarranted per [61] and [73]. EHB cite [10] approvingly to critique Beck while omitting Böhm's quantitative implication for their own attribution.

EHB present these nine items, in the manner of IPCC assessment reports, as "multiple lines of evidence" whose conjunction supports the fossil-dominant conclusion. The framing rests on an implicit inference rule: that even if any single line is contestable, the conjunction of many lines is compelling. That inference rule is not valid. Cohler & Soon (2026c) [22] Lemma 2 establishes formally why: the intersection of any finite collection of accounting identities is again the whole state space Ω, so an argument that assembles n separate identities and calls their conjunction "multiple lines of evidence" yields $\bigcap_{i=1}^{n} E_i = \Omega$ and no contingent proposition. Zero evidential content aggregated across n lines remains zero. EHB's "multiple lines" framing is not a reply to the identity-fallacy objection; it is a further instance of it.

For multiple lines of evidence to add weight to a conclusion, each line must individually make the conclusion more probable than the alternative. This is the standard Bayesian formalization of the intuition that independent evidence accumulates. If observation E_1 makes the fossil-dominant hypothesis twice as likely as the natural-attribution alternative, and independent observation E_2 also makes it twice as likely, then jointly they make it four times as likely. The evidential weights multiply.

The multiplicative rule requires each factor to exceed one. A line of argument that does not distinguish the fossil-dominant hypothesis from the natural-attribution alternative has a factor of exactly one and contributes nothing to the product. A line of argument that, properly analyzed, favors natural attribution over fossil dominance has a factor less than one and reduces the product. Multiplying many numbers each equal to or less than one does not yield a number greater than one.

Applying this rule to the enumerated nine items above:

The likelihoods below are computed against genuine observations, not against algebraic rearrangements of the mass-balance identity. Rearrangements of Eq. (2) have likelihood ratio unity by Cohler & Soon (2026c) [22] Corollary and contribute a factor of exactly one to the product regardless of how they are relabeled.

- The mass-balance identity constrains the net flux $F_{\text{out}} - F_{\text{nat}}$ but leaves the attribution of the increase unconstrained. Factor: 1.
- The isotopic Keeling calculation produces $\delta^{13}C_I \approx -13‰$, forcing $f \approx 0$. Factor: much less than 1.
- The bomb-^{14}C decay gives $\tau_{\text{rel}} \approx 18.4$ yr, falsifying the Bern IRF. Factor: much less than 1.

- The oxygen budget constrains sink partition between ocean and land, not source attribution. Factor: 1.
- The ocean pCO_2 data are local net-flux measurements at three-to-six subtropical stations, not global attribution; the "average ocean pH" EHB invoke is untethered [18]. Factor: 1.
- The cumulative-emissions correlation is Yule–Granger spurious. Factor: 1. Proper causality analysis [56], [57] gives temperature $\rightarrow$ CO_2, contributing a factor less than 1.
- Ice-core smoothing kernels attenuate century-scale interglacial peaks to below scatter in the only cores that span past interglacials (Dome C, Vostok; FWHM $\sim$ 200 yr per [62]), invalidating the "never exceeded 300 ppmv" inference for past interglacials. Factor: less than 1.
- The stomata dismissal is circular. Factor: 1.
- The chemical-method dismissal generalizes from one specific peak to a whole class. Factor: 1.

The product is not greater than one. Given the isotopic and bomb-^{14}C results, it is substantially less than one. The conjunction of EHB's nine items is, on proper analysis, evidence against fossil dominance, not evidence for it.

The rhetorical move of assembling individually invalid arguments and treating their conjunction as compelling is a specific epistemic error. It appears in the IPCC assessment literature under the phrase "multiple lines of evidence" and is inherited without modification by EHB. Each line must be evaluated on its own logical merits. The strongest surviving line sets the upper bound on the evidential support the aggregate can provide. When no line survives, no support is provided. When several lines actively favor the alternative, the aggregate favors the alternative.

The internal contradiction of the report deserves final emphasis. EHB concede on p. 6 that sink saturation is absent for both the biosphere and the deep oceans. A separate long adjustment time for anthropogenic CO_2 requires source-discriminating sinks, which in turn requires those sinks to be saturating. EHB's 50-year adjustment time in EHB §1.3 is incompatible with their own no-saturation concession. Both claims cannot be true. EHB hold both.

The three rhetorical modes identified in §11 recur throughout the report: unsupported assertion (physical conclusions presented in the voice of established fact without derivation or citation at the point of assertion); non-sequitur (factual premise followed by attribution conclusion with no logical connective shown); and ignoral-as-disproof (empirical measurements that directly contradict fitted parameters addressed nowhere in the argument, their silence treated as if it were disproof). The report's method is to state conclusions in the voice of established fact while leaving the peer-reviewed physics, mathematics, and data that contradict those conclusions entirely unaddressed.

The verdict on EHB is structural and does not require any of the audits above. EHB label the mass balance on p. 7 as what "definitely proves" human causation, and label the remaining eight sections as "additional evidence for the human contribution." By EHB's own construction the report is one proof with supporting appendices. Cohler & Soon (2026c) [22] Theorem 1 nullifies the proof by showing that the mass-balance identity carries zero evidential weight for any causal proposition. No accumulation of supporting evidence, however strong on its own terms, can convert a null proof into a proof. The report fails at what its authors say the report is doing. The audits in this paper establish the same conclusion by a separate and independent route: each of the supporting sections also fails on its own terms, and several actively falsify EHB's attribution.

The anthropogenic attribution of atmospheric CO_2 is falsified by direct empirical measurements that the report does not address. The modern Scripps ^{13}C Keeling record forces the fossil fraction to $f \approx 0$, indistinguishable from zero within the intercept's measurement uncertainty. The bomb-spike ^{14}C decay over 1965–2019 gives $\tau_{\text{rel}} \approx 18.4$ yr, falsifying the Bern impulse-response function on which any long-adjustment-time claim depends. The CERES top-of-atmosphere net energy imbalance of 4.3 ± 4 W m^{-2} [59], applied through local van't Hoff solubility and local Arrhenius/Q_{10} respiration

(∼ 2.44 GtC/yr oceanic outgassing plus ∼ 2.34 GtC/yr terrestrial respiration, totaling ∼ 4.8 GtC/yr against observed ∼ 4.8 GtC/yr), quantitatively reproduces the observed atmospheric growth rate with no anthropogenic term required [20]. Each of these three measurements operates on the current atmosphere, ocean, biosphere, and radiation budget, independently of any assumed attribution model. Each yields natural-dominant attribution. Engelbeen, Hannon & Burton (2024) [25] is a non-peer-reviewed coalition document that neither cites nor answers any of them.

Conflict of Interest

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The views expressed in this work are solely those of the authors and do not represent the views of any affiliated institution.

Appendix A

This appendix walks the argument invoked in the body through step by step. The full development, with proofs, is given in Cohler & Soon (2026c) [22]. Only the steps needed to follow the two body-text passages are reproduced here.

The sample space Ω. A "state" of the atmosphere-ocean-biosphere system is one complete time-history of every flux and reservoir, consistent with mass conservation Eq. (1) and with the definitional decomposition $F_{\text{in}} \equiv F_{\text{nat}} + F_{\text{anth}}$. The set of all such physically admissible states is Ω. This set is very large. It contains states in which fossil-fuel combustion drives the observed rise. It contains states in which ocean outgassing drives it. It contains every intermediate mix. Two states in Ω can differ arbitrarily in $F_{\text{nat}}(t)$ and $F_{\text{out}}(t)$ while agreeing on the measured quantities $M_{\text{a}}(t)$ and the inventory estimate $F_{\text{anth}}(t)$. The framework does not distinguish them.

Propositions as subsets. A proposition about the system is identified with the subset of Ω in which the proposition is true. The proposition "F_{nat} is falling" is the set of states in which F_{nat} is falling. The proposition "fossil-fuel combustion is the dominant cause of the observed rise" is the set of states in which that is so. The whole space Ω corresponds to the tautology "some admissible state obtains," true at every state. The empty set $\varnothing$ corresponds to the contradiction, true at no state.

Accounting identity as a set. Let E be the proposition "Eq. (2) holds." Because Eq. (2) is derived from Eq. (1) and the decomposition of F_{in} by algebraic rearrangement alone, and every state in Ω satisfies both by construction, E is realized at every state in Ω. Hence $E = \Omega$. Under every admissible probability measure on Ω, $\mathbb{P}(E) = 1$.

Causal proposition as a set. Let C be any causal proposition of interest. Take "fossil-fuel combustion is the dominant cause of the observed rise." Some admissible states satisfy C; others satisfy $\neg C$. Both subsets are non-empty and neither is all of Ω. C is therefore contingent: $\varnothing \subsetneq C \subsetneq \Omega$. This is the class of propositions for which evidence, if it exists, would matter.

Intersection. Because $E = \Omega$:

$$E \cap C \;=\; \Omega \cap C \;=\; C, \qquad E \cap \neg C \;=\; \Omega \cap \neg C \;=\; \neg C.$$

Learning that the identity holds removes no state from C and no state from $\neg C$. This is the content of Figure A1.

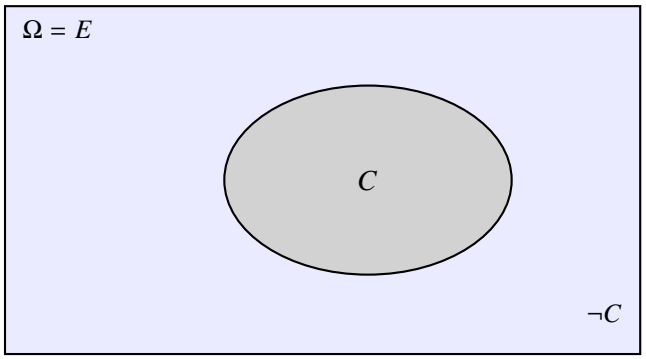


Figure A1: Set-theoretic content of Eq. (2)*. The identity holds at every physically admissible state, so E coincides with the whole sample space Ω. The causal proposition C is a proper subset. Intersecting with E leaves C unchanged: E ∩ C = Ω ∩ C = C. Learning "E is true" rules out no state in C and no state in ¬C, so it cannot shift the probability of C up or down.*

Bayes and the likelihood ratio. From $E \cap C = C$ and the definition of conditional probability:

$$\mathbb{P}(E \mid C) \;=\; \frac{\mathbb{P}(E \cap C)}{\mathbb{P}(C)} \;=\; \frac{\mathbb{P}(C)}{\mathbb{P}(C)} \;=\; 1.$$

Symmetrically $\mathbb{P}(E \mid \neg C) = 1$. The likelihood ratio is

$$\Lambda \;=\; \frac{\mathbb{P}(E \mid C)}{\mathbb{P}(E \mid \neg C)} \;=\; \frac{1}{1} \;=\; 1.$$

Bayes' theorem gives $\mathbb{P}(C \mid E) = \mathbb{P}(E \mid C)\,\mathbb{P}(C)/\mathbb{P}(E) = 1 \cdot \mathbb{P}(C)/1 = \mathbb{P}(C)$. The posterior equals the prior. Learning E shifts the credence of C by exactly zero. This is the technical content of "zero evidential weight."

Aggregation. If $E_1, \ldots, E_n$ are all accounting identities, then $E_i = \Omega$ for every i, and

$$\bigcap_{i=1}^{n} E_i \;=\; \bigcap_{i=1}^{n} \Omega \;=\; \Omega.$$

The aggregate is again Ω, an accounting identity itself, and carries the same zero evidential weight by the same likelihood-ratio calculation. Restating one identity in n different notations does not manufacture n independent lines of evidence.

References

1. Ahn, J., Brook, E. J., Mitchell, L., Rosen, J., McConnell, J. R., Taylor, K., Etheridge, D., & Rubino, M., 2012. Atmospheric CO_2 over the last 1000 years: A high-resolution record from the West Antarctic Ice Sheet (WAIS) Divide ice core. *Global Biogeochemical Cycles*, 26(2), GB2027.

2. Anniwaer, N., Zhu, D., Gui, Y., Huntingford, C., Myneni, R. B., Piao, S., 2026. Vegetation greenness in 2025. *Nat Rev Earth Environ*, 7, 209–212.

3. Ato, D., 2024. Pitfalls in global warming and climate change research: Flaws in ice core reconstructions of atmospheric CO_2: The naked king of 280 ppm at the industrial revolution. *Science of Climate Change*, 4(1), 1–38.

4. Bates, N. R., Astor, Y. M., Church, M. J., Currie, K., Dore, J. E., González-Dávila, M., Lorenzoni, L., Muller-Karger, F., Olafsson, J., & Santana-Casiano, J. M., 2014. A time-series view of changing surface ocean chemistry due to ocean uptake of anthropogenic CO_2 and ocean acidification. *Oceanography*, 27(1), 126–141.

5. Battle, M., Bender, M. L., Tans, P. P., White, J. W. C., Ellis, J. T., Conway, T., & Francey, R. J., 2000. Global carbon sinks and their variability inferred from atmospheric O_2 and $\delta^{13}C$. *Science*, 287(5462), 2467–2470.

6. Beck, E.-G., 2007. 180 years of atmospheric CO_2 gas analysis by chemical methods. *Energy & Environment*, 18(2), 259–282.

7. Bender, M. L., Ho, D. T., Hendricks, M. B., Mika, R., Battle, M. O., Tans, P. P., Conway, T. J., Sturtevant, B., & Cassar, N., 2005. Atmospheric O_2/N_2 changes, 1993–2002: Implications for the partitioning of fossil fuel CO_2 sequestration. *Global Biogeochemical Cycles*, 19(4), GB4017.

8. Berry, E. X., 2019. Human CO_2 emissions have little effect on atmospheric CO_2. *International Journal of Atmospheric and Oceanic Sciences*, 3(1), 13–26.

9. Berry, E. X., 2021. The impact of human CO_2 on atmospheric CO_2. *Science of Climate Change*, 1(2), 213–242.

10. Böhm, F., Haase-Schramm, A., Eisenhauer, A., Dullo, W.-C., Joachimski, M. M., Lehnert, H., & Reitner, J., 2002. Evidence for preindustrial variations in the marine surface water carbonate system from coralline sponges. *Geochemistry, Geophysics, Geosystems*, 3(3), 1019.

11. Bond-Lamberty, B., & Thomson, A., 2010. Temperature-associated increases in the global soil respiration record. *Nature*, 464(7288), 579–582.

12. Burton, D. A. (2024). Comment on Stallinga, P., 2023, Residence time vs. adjustment time of carbon dioxide in the atmosphere. OSF Preprints, doi:10.31219/osf.io/brdq9.

13. Carvalhais, N., Forkel, M., Khomik, M., Bellarby, J., Jung, M., Migliavacca, M., Mu, M., Saatchi, S., Santoro, M., Thurner, M., Weber, U., Ahrens, B., Beer, C., Cescatti, A., Randerson, J. T., & Reichstein, M., 2014. Global covariation of carbon turnover times with climate in terrestrial ecosystems. *Nature*, 514(7521), 213–217.

14. Cawley, G. C., 2011. On the atmospheric residence time of anthropogenically sourced carbon dioxide. *Energy & Fuels*, 25(11), 5503–5513.

15. Ciais, P., Tans, P. P., Trolier, M., White, J. W. C., & Francey, R. J., 1995. A large northern hemisphere terrestrial CO_2 sink indicated by the $^{13}C/^{12}C$ ratio of atmospheric CO_2. *Science*, 269(5227), 1098–1102.

16. Ciais, P., Sabine, C., Bala, G., Bopp, L., Brovkin, V., Canadell, J., Chhabra, A., DeFries, R., Galloway, J., Heimann, M., Jones, C., Le Quéré, C., Myneni, R. B., Piao, S., & Thornton, P., 2013. Carbon and other biogeochemical cycles. In T. F. Stocker et al. (Eds.), *Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 465–570). Cambridge University Press.

17. Clauser, J. F., 2026. Global Warming, Climate Change, and Scientific Consensus have not been proven. There is no proven Climate Crisis! *Science of Climate Change*, 6(4), 1-62.

18. Cohler, J., 2026. The physical tether theorem: A rigorous formal synthesis of representational measurement theory, operationalism, and classical thermodynamics. Manuscript under review.

19. Cohler, J., Legates, D. R., Green, K. C., Humlum, O., Soon, F., & Soon, W., 2026. IPCC's Earth Energy Imbalance Assessment is based on physically invalid Argo-float-based estimates of global ocean heat content. *Science of Climate Change*, 6(1), 43–76.

20. Cohler, J., & Soon, W., 2026a. Dominance of natural atmospheric CO_2 dynamics: Falsification of anthropogenic attribution through mass-balance analysis, isotopic diagnostics, and thermodynamic first principles. Manuscript under review.

21. Cohler, J., & Soon, W., 2026b. Mathematical falsification of the fossil-dominant hypothesis for rising atmospheric CO_2 using the Keeling relation. Manuscript under review.

22. Cohler, J., & Soon, W., 2026c. Accounting identities are not evidence: A formal proof of the evidential vacuity of definitional truths in causal inference. Manuscript under review.

23. Dinauer, A., Adolphi, F., & Joos, F., 2020. Mysteriously high $\Delta^{14}C$ of the glacial atmosphere: Influence of ^{14}C production and carbon cycle changes. *Climate of the Past*, 16(4), 1159–1185.

24. Engelbeen, F., 2023. Comment on "Understanding increasing atmospheric CO_2" by H. Harde. *Science of Climate Change*, 3(1).

25. Engelbeen, F., Hannon, R., & Burton, D., 2024. *The human contribution to atmospheric carbon dioxide: How human emissions are restoring vital atmospheric CO_2*. CO_2 Coalition, Arlington, VA.

26. Essenhigh, R. H., 2009. Potential dependence of global warming on the residence time (RT) in the atmosphere of anthropogenically sourced carbon dioxide. *Energy & Fuels*, 23(5), 2773–2784.

27. Feely, R. A., Sabine, C. L., Takahashi, T., & Wanninkhof, R., 2001. Uptake and storage of carbon dioxide in the ocean: The global CO_2 survey. *Oceanography*, 14(4), 18–32.

28. Granger, C. W. J., & Newbold, P., 1974. Spurious regressions in econometrics. *Journal of Econometrics*, 2(2), 111–120.

29. Graven, H., Keeling, R. F., & Rogelj, J., 2020. Changes to carbon isotopes in atmospheric CO_2 over the industrial era and into the future. *Global Biogeochemical Cycles*, 34(11), e2019GB006170.

30. Grosjean, M., Guiot, J., & Yu, Z., 2018. Editorial on "Scrutinizing the carbon cycle and CO_2 residence time in the atmosphere" by H. Harde and the Comment by P. Köhler et al. *Global and Planetary Change*, 164, A1–A2.

31. Harde, H., 2017. Scrutinizing the carbon cycle and CO_2 residence time in the atmosphere. *Global and Planetary Change*, 152, 19–26.

32. Harde, H., 2018. Reply to "Comment on 'Scrutinizing the carbon cycle and CO_2 residence time in the atmosphere' by H. Harde" by P. Köhler, J. Hauck, C. Völker, D. A. Wolf-Gladrow, M. Butzin, J. B. Halpern, K. Rice, and R. E. Zeebe. *Global and Planetary Change*, 164, 71–76.

33. Harde, H., 2019. What humans contribute to atmospheric CO_2: Comparison of carbon cycle models with observations. *Earth Sciences*, 8(3), 139–159.

34. Harde, H., & Salby, M. L., 2021. What controls the atmospheric CO_2 level? *Science of Climate Change*, 1(1), 54–69.

35. Hua, Q., Turnbull, J. C., Santos, G. M., Rakowski, A. Z., Ancapichun, S., De Pol-Holz, R., Hammer, S., Lehman, S. J., Levin, I., Miller, J. B., Palmer, J. G., & Turney, C. S. M., 2022. Atmospheric radiocarbon for the period 1950–2019. *Radiocarbon*, 64(4), 723–745.

36. Humlum, O., Stordahl, K., & Solheim, J.-E., 2013. The phase relation between atmospheric carbon dioxide and global temperature. *Global and Planetary Change*, 100, 51–69.

37. Jaworowski, Z., 1994. Ancient atmosphere: Validity of ice records. *Environmental Science and Pollution Research*, 1(3), 161–171.

38. Jaworowski, Z., Segalstad, T. V., & Hisdal, V., 1990. *Atmospheric CO_2 and global warming: A critical review* (Rapportserie 59). Norsk Polarinstitutt, Oslo.

39. Jaworowski, Z., Segalstad, T. V., & Ono, N., 1992. *Do glaciers tell a true atmospheric CO_2 story? Science of the Total Environment*, 114, 227–284.

40. Joos, F., Bruno, M., Fink, R., Siegenthaler, U., Stocker, T. F., Le Quéré, C., & Sarmiento, J. L., 1996. An efficient and accurate representation of complex oceanic and biospheric models of anthropogenic carbon uptake. *Tellus B*, 48(3), 397–417.

41. Joos, F., Roth, R., Fuglestvedt, J. S., Peters, G. P., Enting, I. G., von Bloh, W., Brovkin, V., Burke, E. J., Eby, M., Edwards, N. R., Friedrich, T., Frölicher, T. L., Halloran, P. R., Holden, P. B., Jones, C., Kleinen, T., Mackenzie, F. T., Matsumoto, K., Meinshausen, M., . . . Weaver, A. J., 2013. Carbon dioxide and climate impulse response functions for the computation of greenhouse gas metrics: A multi-model analysis. *Atmospheric Chemistry and Physics*, 13(5), 2793–2825.

42. Kawamura, K., Nakazawa, T., Aoki, S., Sugawara, S., Fujii, Y., & Watanabe, O., 2003. Atmospheric CO_2 variations over the last three glacial-interglacial climatic cycles deduced from the Dome Fuji deep ice core, Antarctica using a wet extraction technique. *Tellus B*, 55(2), 126–137.

43. Keeling, C. D., 1958. The concentration and isotopic abundances of carbon dioxide in rural areas. *Geochimica et Cosmochimica Acta*, 13(4), 322–334.

44. Keeling, C. D., 1961. The concentration and isotopic abundances of carbon dioxide in rural and marine air. *Geochimica et Cosmochimica Acta*, 24(3–4), 277–298.

45. Keeling, R. F., Graven, H. D., Welp, L. R., Resplandy, L., Bi, J., Piper, S. C., Sun, Y., Bollenbacher, A., & Meijer, H. A. J., 2017. Atmospheric evidence for a global secular increase in carbon isotopic discrimination of land photosynthesis. *Proceedings of the National Academy of Sciences*, 114(39), 10361–10366.

46. Köhler, P., Fischer, H., Schmitt, J., & Munhoven, G., 2006. On the application and interpretation of Keeling plots in paleo climate research—deciphering $\delta^{13}C$ of atmospheric CO_2 measured in ice cores. *Biogeosciences*, 3, 539–556.

47. Köhler, P., & Munhoven, G., 2020. Late Pleistocene carbon cycle revisited by considering solid Earth processes. *Paleoceanography and Paleoclimatology*, 35(12), e2020PA004020.

48. Köhler, P., Fischer, H., & Schmitt, J., 2010. Atmospheric $\delta^{13}CO_2$ and its relation to pCO_2 and deep ocean $\delta^{13}C$ during the late Pleistocene. *Paleoceanography*, 25(1), PA1213.

49. Köhler, P., Hauck, J., Völker, C., Wolf-Gladrow, D. A., Butzin, M., Halpern, J. B., Rice, K., & Zeebe, R. E., 2018. Comment on "Scrutinizing the carbon cycle and CO_2 residence time in the atmosphere" by H. Harde. *Global and Planetary Change*, 164, 67–71.

50. Köhler, P., Muscheler, R., & Fischer, H., 2006. A model-based interpretation of low-frequency changes in the carbon cycle during the last 120,000 years and its implications for the reconstruction of atmospheric $\Delta^{14}C$. *Geochemistry, Geophysics, Geosystems*, 7(11), Q11N06.

51. Köhler, P., Skinner, L. C., & Adolphi, F., 2024. New constraints on the natural carbon cycle from paired $\Delta^{14}C$ and CO_2 records over Heinrich Stadial 1 and the Younger Dryas. *Paleoceanography and Paleoclimatology*, 39(6), e2024PA004876.

52. Köhler, P., Adolphi, F., Butzin, M., & Muscheler, R., 2022. Toward reconciling radiocarbon production rates with carbon cycle changes of the last 55,000 years. *Paleoceanography and Paleoclimatology*, 37(2), e2021PA004314.

53. Koutsoyiannis, D., 2024a. Refined reservoir routing (RRR) and its application to atmospheric carbon dioxide balance. *Water*, 16(17), 2402.

54. Koutsoyiannis, D., 2024b. Net isotopic signature of atmospheric CO_2 sources and sinks: No change since the Little Ice Age. *Sci*, 6(1), 17.

55. Koutsoyiannis, D., 2024c. Definite change since the formation of the Earth: Reply to Kleber, A. Comment on "Koutsoyiannis, D. Net isotopic signature of atmospheric CO_2 sources and sinks: No change since the Little Ice Age. Sci 2024, 6, 17." *Sci*, 6(4), 63.

56. Koutsoyiannis, D., Onof, C., Christofides, A., & Kundzewicz, Z. W., 2022. Revisiting causality using stochastics: 1. Theory; 2. Applications. *Proceedings of the Royal Society A*, 478, 20210835 and 20210836.

57. Koutsoyiannis, D., Onof, C., Kundzewicz, Z. W., & Christofides, A., 2023. On hens, eggs, temperatures and CO_2: Causal links in Earth's atmosphere. *Sci*, 5(3), 35.

58. Kouwenberg, L. L. R., Wagner, F., Kürschner, W. M., & Visscher, H., 2005. Atmospheric CO_2 fluctuations during the last millennium reconstructed by stomatal frequency analysis of *Tsuga heterophylla* needles. *Geology*, 33(1), 33–36.

59. Loeb, N. G., Doelling, D. R., Wang, H., Su, W., Nguyen, C., Corbett, J. G., Liang, L., Mitrescu, C., Rose, F. G., & Kato, S., 2018. Clouds and the Earth's Radiant Energy System (CERES) Energy Balanced and Filled (EBAF) Top-of-Atmosphere (TOA) Edition-4.0 Data Product. *Journal of Climate*, 31(2), 895–918.

60. MacFarling Meure, C., Etheridge, D., Trudinger, C., Steele, P., Langenfelds, R., van Ommen, T., Smith, A., & Elkins, J., 2006. Law Dome CO_2, CH_4 and N_2O ice core records extended to 2000 years BP. *Geophysical Research Letters*, 33(14), L14810.

61. Massen, F., & Beck, E.-G., 2009. Accurate estimation of CO_2 background level from near ground measurements at non-mixed environments. In G. Kirchengast (Ed.), *Advances in atmospheric science research* (pp. 195–205).

62. Monnin, E., Indermühle, A., Dällenbach, A., Flückiger, J., Stauffer, B., Stocker, T. F., Raynaud, D., & Barnola, J.-M., 2001. Atmospheric CO_2 concentrations over the last glacial termination. *Science*, 291(5501), 112–114.

63. Müller, R., 2025. On the residence time of CO_2 in the atmosphere and the carbon mass balance. *Science of Climate Change*, 5(3), 207–212.

64. Nehrbass-Ahles, C., Shin, J., Schmitt, J., Bereiter, B., Joos, F., Schilt, A., Schmidely, L., Silva, L., Teste, G., Grilli, R., Chappellaz, J., Hodell, D., Fischer, H., & Stocker, T. F., 2020. Abrupt CO_2 release to the atmosphere under glacial and early interglacial climate conditions. *Science*, 369(6506), 1000–1005.

65. Oeschger, H., Siegenthaler, U., Schotterer, U., & Gugelmann, A., 1975. A box diffusion model to study the carbon dioxide exchange in nature. *Tellus*, 27(2), 168–192.

66. Piao, S., Wang, X., Park, T., Chen, C., Lian, X., He, Y., Bjerke, J. W., Chen, A., Ciais, P., Tømmervik, H., Nemani, R. R., & Myneni, R. B., 2020. Characteristics, drivers and feedbacks of global greening. *Nature Reviews Earth & Environment*, 1(1), 14–27.

67. Revelle, R., & Suess, H. E., 1957. Carbon dioxide exchange between atmosphere and ocean and the question of an increase of atmospheric CO_2 during the past decades. *Tellus*, 9(1), 18–27.

68. Rice, K., Schade, G. W., & Maslin, M. A., 2022. Comment on "World atmospheric CO_2, its ^{14}C specific activity, non-fossil component, anthropogenic fossil component, and emissions (1750–2018)" by Skrable, Chabot, and French. *Health Physics*, 123(1), 28–30.

69. Sabine, C. L., Feely, R. A., Gruber, N., Key, R. M., Lee, K., Bullister, J. L., Wanninkhof, R., Wong, C. S., Wallace, D. W. R., Tilbrook, B., Millero, F. J., Peng, T.-H., Kozyr, A., Ono, T., & Rios, A. F., 2004. The oceanic sink for anthropogenic CO_2. *Science*, 305(5682), 367–371.

70. Salby, M. L., & Harde, H., 2021. Control of atmospheric CO_2: Part II: Influence of tropical warming. *Science of Climate Change*, 1(2), 197–213.

71. Salby, M. L., & Harde, H., 2022. Theory of increasing greenhouse gases. *Science of Climate Change*, 2(3), 212–238.

72. Schuur, E. A. G., McGuire, A. D., Schädel, C., Grosse, G., Harden, J. W., Hayes, D. J., Hugelius, G., Koven, C. D., Kuhry, P., Lawrence, D. M., Natali, S. M., Olefeldt, D., Romanovsky, V. E., Schaefer, K., Turetsky, M. R., Treat, C. C., & Vonk, J. E., 2015. Climate change and the permafrost carbon feedback. *Nature*, 520(7546), 171–179.

73. Segalstad, T. V., 1998. Carbon cycle modelling and the residence time of natural and anthropogenic atmospheric CO_2: On the construction of the "greenhouse effect global warming" dogma. In R. Bate (Ed.), *Global warming: The continuing debate* (pp. 184–219). European Science and Environment Forum, Cambridge.

74. Skrable, K., Chabot, G., & French, C., 2022. World atmospheric CO_2, its ^{14}C specific activity, non-fossil component, anthropogenic fossil component, and emissions (1750–2018). *Health Physics*, 122(2), 291–305.

75. Spencer, R. W., 2023. ENSO impact on the declining CO_2 sink rate. *Journal of Marine Science: Research & Oceanography*, 6(4), 163–170.

76. Stallinga, P., 2023. Residence time vs. adjustment time of carbon dioxide in the atmosphere. *Entropy*, 25(2), 384.

77. Steinthorsdottir, M., Wohlfarth, B., Kylander, M. E., Blaauw, M., & Reimer, P. J., 2013. Stomatal proxy record of CO_2 concentrations from the last termination suggests an important role for CO_2 at climate change transitions. *Quaternary Science Reviews*, 68, 43–58.

78. Takahashi, T., Olafsson, J., Goddard, J. G., Chipman, D. W., & Sutherland, S. C., 1993. Seasonal variation of CO_2 and nutrients in the high-latitude surface oceans: A comparative study. *Global Biogeochemical Cycles*, 7(4), 843–878.

79. Toggweiler, J. R., Gnanadesikan, A., Carson, S., Murnane, R., & Sarmiento, J. L., 2003. Representation of the carbon cycle in box models and GCMs: 1. Solubility pump. *Global Biogeochemical Cycles*, 17(1), 1026.

80. Trudinger, C. M., Etheridge, D. M., Rayner, P. J., Enting, I. G., Sturrock, G. A., & Langenfelds, R. L., 2002. Reconstructing atmospheric histories from measurements of air composition in firn. *Journal of Geophysical Research: Atmospheres*, 107(D24), 4780.

81. van Hoof, T. B., Wagner-Cremer, F., Kürschner, W. M., & Visscher, H., 2008. A role for atmospheric CO_2 in preindustrial climate forcing. *Proceedings of the National Academy of Sciences*, 105(41), 15815–15818.

82. Veyres, C., Maurin, J.-C., & Poyet, P., 2025. Revisiting the carbon cycle. *Science of Climate Change*, 5(3), 135–185.

83. Wagner, F., Bohncke, S. J. P., Dilcher, D. L., Kürschner, W. M., van Geel, B., & Visscher, H., 1999. Century-scale shifts in early Holocene atmospheric CO_2 concentration. *Science*, 284(5422), 1971–1973.

84. Wallace, R. B., Baumann, H., Grear, J. S., Aller, R. C., & Gobler, C. J., 2014. Coastal ocean acidification: The other eutrophication problem. *Estuarine, Coastal and Shelf Science*, 148, 1–13.

85. Wang, W., Ciais, P., Nemani, R. R., Canadell, J. G., Piao, S., Sitch, S., White, M. A., Hashimoto, H., Milesi, C., & Myneni, R. B., 2013. Variations in atmospheric CO_2 growth rates coupled with tropical temperature. *Proceedings of the National Academy of Sciences*, 110(32), 13061–13066.

86. Yule, G. U., 1926. Why do we sometimes get nonsense-correlations between time-series? A study in sampling and the nature of time-series. *Journal of the Royal Statistical Society*, 89(1), 1–63.

87. Zhu, Z., Piao, S., Myneni, R. B., Huang, M., Zeng, Z., Canadell, J. G., Ciais, P., Sitch, S., Friedlingstein, P., Arneth, A., Cao, C., Cheng, L., Kato, E., Koven, C., Li, Y., Lian, X., Liu, Y., Liu, R., Mao, J., . . . Zeng, N., 2016. Greening of the Earth and its drivers. *Nature Climate Change*, 6(8), 791–795.

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