Review

Dominance of Natural Atmospheric CO_2 Dynamics: Falsification of Anthropogenic Attribution Through Mass-Balance Analysis, Isotopic Diagnostics, and Thermodynamic First Principles

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Abstract

Observed changes in atmospheric CO_2 concentration during the instrumental period and isotopic signatures back to the Little Ice Age are likely explained by natural biogeochemical feedbacks, with no detectable anthropogenic contribution. This is supported by mass-balance reservoir routing showing short CO_2 residence times of 3.5–4 years, stable Keeling plot intercepts of −13.2‰ over centuries demonstrating overwhelming biosphere dominance and undetectable fossil-fuel influence, unidirectional precedence of local temperatures → CO_2 across all timescales from the present to ~500 million years ago, and thermodynamic considerations that question the physical meaningfulness of a global mean surface temperature (GMST). IPCC Bern model parameters show instability across assessments, violate mass conservation, and introduce unsupported source discrimination. The global bomb-^{14}C pulse from nuclear testing exhibits single-exponential decay (e-folding time 17.2 years) matching observations over 55+ years, which directly falsifies the Bern model's multi-exponential structure, permanent airborne fraction, and multi-millennial CO_2 persistence claims. Critical examination of conflicting airborne fraction definitions reveals foundational inconsistencies in IPCC CO_2 attribution. These convergent lines establish that natural processes can explain observed CO_2 variations with negligible human influence. A unified first-principles synthesis shows that a modest natural top-of-atmosphere radiative imbalance of ~2.6 W m^{-2} can account for the observed rise in atmospheric CO_2 via temperature-driven oceanic outgassing and enhanced soil respiration, without detectable anthropogenic contribution.

Keywords: CO_2 residence time; $\delta^{13}C$ isotopic signature; Keeling plot; Bern model; Revelle factor; Biosphere dominance; Anthropogenic fingerprint; Global mean surface temperature (GMST); Thermodynamic intensive property; Natural climate variability

1. Introduction

Observed CO_2 and Temperature Patterns: Challenges to Anthropogenic Attribution

In ongoing scientific and policy discussions, the Earth's climate system is characterized by complex interactions among atmospheric, oceanic, and biospheric components, with atmospheric carbon dioxide (CO_2) concentration and temperature serving as central

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variables. Long-term observational records, including direct measurements of CO_2 from sites such as Mauna Loa and the South Pole, isotopic ratios ($\delta^{13}C$) from the Scripps Institution of Oceanography, and temperature proxies spanning geological epochs, reveal patterns that challenge prevailing attributions of recent changes primarily to anthropogenic emissions. These records exhibit rising CO_2 levels accompanied by declining $\delta^{13}C$ values and varying local temperature trends, yet detailed analyses using straightforward physical models consistently indicate that natural processes, driven by thermodynamic mechanisms including solubility, respiration, biogeochemical fluxes, oceanic outgassing, and solar influences, provide a sufficient explanation for the observed variations with no detectable human role [1–3]. This natural explanation is one possible account that is fully consistent with all current high-precision instrumental measurements and thermodynamic first principles; paleoclimate proxies extending to the Little Ice Age remain supportive but are not required for the quantitative attribution of the post-1958 rise.

This synthesis employs transparent first-principles methodologies, including mass-balance reservoir routing applied to Mauna Loa and Barrow data [2] and Keeling plot analysis of $\delta^{13}C$ measurements and proxy reconstructions extending back to the Little Ice Age [3]. These are contrasted with the Intergovernmental Panel on Climate Change's (IPCC) Bern model and culminate in a unified first-principles synthesis showing that a modest natural top-of-atmosphere radiative imbalance of ~2.6 W m^{-2} fully accounts for the observed CO_2 rise.

High-resolution local proxy records and site-specific modern observations from every major archive examined demonstrate unidirectional local temperature → CO_2 precedence on all timescales. Ice cores from Antarctica (Vostok, EPICA Dome C, WAIS Divide, Taylor Dome) and Greenland (GISP2) show local temperature consistently leading CO_2 by 200–1,000+ years across every glacial termination and millennial-scale event, with no exceptions [4–6]. A comprehensive review of the literature over the past 650,000–800,000 years confirms that atmospheric CO_2 variations generally follow changes in temperature and other climatic variables rather than preceding them, with no quantitative validation for CO_2 as the prime mover in glacial-interglacial cycles [5,7]. Extending this record over the full Phanerozoic eon (last 500 million years), multiple independent reconstructions pair $\delta^{18}O$-based local temperature proxies with CO_2 proxies (boron isotopes in foraminifera, stomatal density in fossil leaves, alkenone $\delta^{13}C$), showing temperature changes preceding CO_2 changes with characteristic lags on the order of millions of years [8]. The authors are unaware of any proxy record or observational period in which atmospheric CO_2 leads temperature. Modern observations reinforce the pattern: major volcanic eruptions drive rapid cooling followed by CO_2-growth slowdowns [9]; El Niño warming precedes CO_2 spikes by ~6 months [10–12]; OCO-2 satellite (NASA Orbiting Carbon Observatory 2) [13] and FLUXNET [14,15] tower data show regional CO_2 fluxes tracking local temperature gradients; and recovery sequences after volcanic, ENSO, and warming events all show temperature recovery preceding CO_2 recovery. These convergent lines of direct physical evidence support unidirectional causation from local temperatures to CO_2 on all timescales examined.

These methods are supplemented by broader evidence, including correlations with high-variability solar reconstructions, the absence of detectable perturbations during emission reductions (e.g., COVID-19 lockdowns), and artifacts introduced by data homogenization processes that systematically alter historical trends [1,16,17].

In addition to these carbon cycle and causality insights, the paper incorporates fundamental thermodynamic critiques that question the validity of GMST as a physical metric. By examining the intensive nature of temperature and the arbitrariness of averaging schemes in non-equilibrium systems, these analyses underscore the limitations of metrics central to many climate assessments [18,19]. The purpose of this work is to present a

cohesive, evidence-based reassessment grounded in verifiable calculations and direct observational fits, highlighting how simple, solvable models rooted in established physics align closely with data, while more elaborate frameworks often rely on assumptions that lack empirical support. This integrated perspective demonstrates that natural biogeochemical feedbacks and variability provide complete, data-consistent explanations for observed CO_2 variations with no detectable anthropogenic contribution.

2. Centennial- to Millennial-Scale Temperature Precedence: The Medieval Warm Period and Little Ice Age as Natural Climatic Anomalies

On centennial-to-millennial timescales, Soon et al. (2003) [20] conducted an exhaustive reappraisal of more than 100 independent local and regional climate proxies spanning both hemispheres, establishing the Medieval Warm Period (≈800–1300 A.D.) and Little Ice Age (≈1300–1900 A.D.) as real, widespread climatic anomalies with global imprints. The study uses a locality-based paradigm that respects the distinct physical sensitivities, geographical constraints, and non-stationary calibration relations of each archive (ice cores, tree rings, boreholes, glaciers, corals, lake sediments, speleothems, historical documents, pollen, and phenological records), and demonstrates that these anomalies are not artifacts of physically meaningless global averaging but emerge consistently at the scale of individual sites and regions.

The Medieval Warm Period (MWP) is recorded as sustained warmth and/or reduced glacier extent at dozens of locations across Europe, North America, the North Atlantic, Asia, and parts of the Southern Hemisphere, enabling Viking settlement in Greenland, northward expansion of Mediterranean flora into central Europe, and favorable agricultural conditions. The subsequent Little Ice Age (LIA) is marked by widespread cooling, glacier advances, increased climatic variability, and societal impacts (e.g., abandonment of Norse settlements in Greenland, frequent severe winters in Europe). At the great majority of globally dispersed sites examined, intervals during the MWP were as warm as, or warmer than, any 50-year period within the 20th century, despite atmospheric CO_2 remaining stable near the pre-industrial value of ≈280 ppm.

Crucially, the 20th-century warming does not emerge as the warmest or most extreme period of the last 1000 years at most locations. Where 20th-century warmth is prominent, it often begins early (1920s–1950s) when cumulative anthropogenic CO_2 was still small. The study explicitly cautions against forcing disparate local proxies into simple hemispheric or global quantitative composites, noting that thermal and dynamical constraints imposed by local geography become increasingly dominant on 50–100+ year timescales. This locality paradigm directly reinforces the unidirectional local temperature → CO_2 precedence documented on shorter (months to millennia) and longer (Phanerozoic) timescales: major natural temperature excursions clearly occurred first, with no evidence that changes in atmospheric CO_2 initiated or drove them. These centennial-scale oscillations are fully consistent with natural solar and ocean-circulation variability.

Criticisms of Soon et al. (2003) [20] were predicated on the erroneous assumption that only synoptic global or hemispheric temperature composites constitute valid evidence of climatic anomalies—an assumption contradicted by the physical reality that temperature is an intensive property unsuitable for such averaging across Earth's heterogeneous non-equilibrium system. By deliberately avoiding both global averaging schemes and uncertain proxy-to-temperature conversions, Soon et al. (2003) adopted the scientifically supportable methodology. In contrast, multiproxy global reconstructions [21,22] imposed such invalid averaging and have also been shown to suffer from significant statistical artifacts [23]. Subsequent thermodynamic analyses by Essex et al. (2007) [18], together with extensions by Cohler (2025) [19] and the framework developed in the present work, confirm that this locality paradigm is the appropriate approach, while the global composite

methods underlying the Mann et al. (1998, 1999) reconstructions [21,22] are physically invalid and introduce non-physical artifacts. Criticisms of Soon et al. (2003) were based largely on the temperature averaging fallacies already mentioned rather than substantive engagement with its locality paradigm. Ironically, Soon et al. (2003) pioneered the systematic, site-specific spatial mapping of centennial-scale climatic anomalies using this locality-based approach—the very methodology that has since become the universally adopted standard in climate science, as seen in every modern NASA GISTEMP, HadCRUT, and IPCC regional anomaly 'heat' map.

3. Refined Reservoir Routing and Airborne Fraction Revisited: Logical vs. Computational Definitions and Biospheric Dominance

Analyses of the atmospheric carbon cycle using simple mass-balance reservoir models provide robust empirical evidence for short CO_2 residence times and the overwhelming dominance of natural processes [24]. In Koutsoyiannis' Refined Reservoir Routing (RRR) framework, the atmosphere is treated as a dynamic reservoir governed by the continuity equation, where inflow and outflow are related through a power-law storage-outflow relationship, $Q = Q_0 (S/S_0)^b$. Optimization across extensive instrumental records from Mauna Loa (1958–present) and Barrow, Alaska (1961–present), yields an optimal exponent b=1 for outflow, corresponding to a strictly linear reservoir. This linearity produces excellent fits to observed CO_2 concentration time series, achieving explained variances exceeding 99.7% for storage (concentration) and approximately 85% for net inflow, with split-sample validation (fitting 1958–2002 and predicting 2003–2023) showing only minor drops in performance of 1–3.5% [2]. The resulting mean annual residence time is approximately 3.5–4 years (geometric mean accounting for seasonal variations ranging from 1.5 years in high-amplitude northern sites to 10 years), while the so-called "adjustment time"—the characteristic timescale for system adjustment to perturbations—is equal to or shorter than the residence time in this linear configuration [25,26].

These short timescales arise directly from the rapid cycling of carbon through the biosphere and surface oceans, where annual natural fluxes (gross inflows and outflows) vastly exceed anthropogenic inputs. Natural processes account for approximately 96% of the total annual carbon turnover, while anthropogenic emissions represent only ~4% of the overall exchange. As a result, human-emitted CO_2 is quickly absorbed by natural sinks, with only ~6% of cumulative anthropogenic emissions remaining airborne [2,27].

This low value is explained by Koutsoyiannis (2024) [27], which notes and clarifies the common incorrect use and conflation of several different conflicting definitions of "airborne fraction." Koutsoyiannis defines his "logical airborne fraction" (ABF_L) the same way that IPCC AR6 defines "Airborne fraction":

> "*The fraction of total CO_2 emissions (from fossil fuels and land-use change) remaining in the atmosphere*" [28] (p. 2237)

In principle, this is a physically consistent, mass-conservation-based quantity tracking what portion of emitted anthropogenic mass accumulates after sink removal:

$$ABF_L \equiv \frac{(\textbf{remaining}\ \text{anthropogenic atmospheric}\ CO_2)}{(\textbf{cumulative total}\ \text{anthropogenic emissions})} \quad (1)$$

Keeling (1973) [29] originally described this concept (attributing it to earlier ideas like Callendar, 1938, 1940 [30,31]) as the fraction of industrial CO_2 input that remains airborne, aligning with ABF_L.

However, a second "computational airborne fraction" (ABF_C), often misattributed to Keeling via Bolin (1977) [32] and used in IPCC assessments—although it contradicts the AR6 glossary entry (which is equivalent to ABF_L)—is calculated as:

$$ABF_C \equiv \frac{(\textbf{annual}\ \text{increase in atmospheric}\ CO_2)}{(\textbf{annual}\ \text{anthropogenic emissions})} \quad (2)$$

which implicitly assumes the entire observed $\Delta[CO_2]$ is anthropogenic—circularly presupposing dominance and yielding historical estimates of ~40–100% (e.g., Callendar, 1938: 75%; Callendar, 1940: 100%; Ekdahl and Keeling, 1973: 49%; Bolin, 1977: 40 ± 5%; AR6: ~44%) [30–34]. This definition is different from and incompatible with $AB{F_L}$, as it ignores natural variability and net fluxes, leading to overestimation of anthropogenic persistence.

In contrast, $AB{F_L}$ is computed via the RRR framework, applying a mean residence time of $\tau = 4$ years [2] to cumulative emissions. The remaining mass M_R (anthropogenic CO_2 remaining in the atmosphere) is given by the convolution integral assuming exponential decay:

$$M_R = \int_{t_0}^{t_c} e^{(t-t_c)/\tau} dm_A(t) \quad (3)$$

where $dm_A(t)$ is the anthropogenic emission rate at time t, t_0 is the start year, t_c is the current year, and the exponential kernel reflects removal processes. Then for $t_0 = 1850$ and $t_c = 2023$, Koutsoyiannis [2,27] calculated:

$$AB{F_L} = \frac{M_R}{M_A} = \frac{\int_{t_0}^{t_c} e^{(t-t_c)/\tau} dm_A(t)}{\int_{t_0}^{t_c} dm_A(t)} \approx \frac{163\ GtCO_2}{2612\ GtCO_2} = \frac{20.9\ ppm}{334.9\ ppm} \approx 6\% \quad (4)$$

This indicates ~94% of cumulative anthropogenic emissions (expressed in $GtCO_2$ or GtC)[1] have been absorbed by natural sinks on short timescales. Stallinga (2023) [35] independently estimates $AB{F_L} \approx 12\%$, which is also significantly lower than the AR6's $AB{F_C}$ estimate of 44%.

Under this same RRR framework of Koutsoyiannis, a single hypothetical ~334.9 ppm CO_2 pulse would decay below 1 ppm within approximately 23 years if emissions stop, implying no detectable persistence over centuries or millennia [1,2,25,26]. Independent physics-based modeling similarly derives residence times of ~4 years via local thermodynamic amplification (temperature-dependent solubility per Henry's law and enhanced respiration/outgassing) dominating the cycle [25,26,35] (see also Table 1).

4. The Bern Model and the Residence vs. Adjustment Time Distinction

We first contrast empirical residence-time evidence with the IPCC's adjustment-time construct, demonstrate first-principles violations, then examine the Revelle misapplication, Surface Ocean CO_2 Atlas (SOCAT) data gaps, stylized carbon-budget schematics, and the resulting millennial-persistence artifact.

The Bern model and similar multi-compartment representations underpinning IPCC assessments posit prolonged adjustment times (centuries to millennia) with 15–22% of CO_2 input to the atmosphere persisting indefinitely via a non-decaying a_0 term, derived from theoretical parallel reservoirs, slow exchange rates, and nonlinear carbonate buffering [36,37]. This a_0 term is fundamentally non-physical: by design, it excludes ultimate geological sinks such as silicate weathering and sediment burial, leading to mathematically unbounded accumulation in zero-emission scenarios and contradicting Earth's observed long-term carbon cycle [2,24].

The Bern model falsely assumes the ocean consists of *parallel* compartments directly connected to the atmosphere, employing 3 or 4 exponential terms plus zero or one permanent (non-decaying) terms in AR2–AR5 (see detail below). In reality, CO_2 can enter the ocean only at the surface; the instant molecules dissolve there, they are already removed from the atmosphere. All slower timescales (surface → thermocline → deep ocean) are serial and internal to the ocean. We refer to this feature of the Bern model as the "parallel-serial fallacy." There is no global-scale empirical evidence of CO_2 saturation at any ocean

1. In this paper, we use both GtC and $GtCO_2$ to describe the amount of carbon in all the so-called carbon reservoirs. To convert from GtC to $GtCO_2$ multiply by 44/12 ≅ 3.67.

depth despite the purely model-based claim of Jiang et al. (2019, 2023) [38,39], whose reported "global" increase in the Revelle Factor is derived from statistical interpolation and Earth System Models (ESM) applied to sparse ship-track data. The Revelle Factor is a strictly local intensive property, like temperature or pH, and therefore cannot be meaningfully averaged across the ocean's heterogeneous, non-equilibrium water masses and vastly different spatial and temporal scales.

Although saturation would in theory be gradual, evidence shows that current absorption rates are not slowing. Relative land and ocean absorption rates have stayed strictly proportional to atmospheric CO_2 for 270 years despite a 50% rise in pCO_2 [40], while airborne fractions have remained stable (44–47%; [2]). These empirical indicators render the Bern model's long tails unverifiable assumptions rather than data-supported features. Linear reservoir approaches, with their simplicity and high fidelity, show that natural biogeochemical processes fully account for observed CO_2 dynamics, with human contributions minor, transient, and rapidly integrated into the dominant bulk natural cycle.

4.1 Residence Time, Adjustment Time, and the Bern Impulse-Response Function

The IPCC defines "lifetime" (or "residence time") as the empirically measurable quantity given by "the total mass of the species in the reservoir divided by the total rate of removal from the reservoir," a direct ratio grounded in observable atmospheric burden and flux data [28]. The report also defines "turnover time" as "[t]he time it takes to replenish the content of a reservoir," calculated as "the ratio of the content of a reservoir to the rate of input or output (inflow or outflow) from that reservoir," and explicitly notes that turnover time "is equivalent to the lifetime when the reservoir is in steady state" [28]. These terms thus correspond to the physically meaningful and empirically verifiable residence time (~3.5–5 years) commonly used in the literature.

In contrast, "response time or adjustment time" is defined purely theoretically as "[t]he time scale characterizing the decay of an instantaneous pulse input into the reservoir," further specified as the time taken for the concentration to decline to 1/e (~37%; e-folding time) of its original value following such a hypothetical perturbation, a construct reliant on unobservable, model-dependent "instantaneous pulse inputs" with no direct empirical manifestation in the real carbon cycle [28]. This distinction exists only within the Bern model's multi-compartment assumptions and disappears in data-driven linear frameworks.

Falsification by Transparent Linear Models

The concept of a short atmospheric CO_2 residence (turnover) time has been consistently documented in the peer-reviewed literature for decades. Sundquist (1985) [41] first compiled measured residence times from numerous independent studies, revealing values predominantly in the 5–15-year range. Segalstad (1998) [24] expanded this compilation into a comprehensive table of 25 distinct determinations (predominantly 5–10 years) and explicitly rejected any distinction between this directly observed turnover time and a purportedly much longer "adjustment time" or "response time," noting that longer theoretical values derived from nonlinear models contradict the measurable physical reality and are therefore irrelevant. Despite this long-standing empirical consensus, the IPCC has continued to assert that while individual CO_2 molecules exhibit a turnover time of ~4 years, so-called 'excess' anthropogenic CO_2 possesses a separate and far longer adjustment time of centuries to millennia. Outside the primary Joos et al. impulse-response lineage, this distinction has been substantively defended in mainly three papers: Maier-Reimer & Hasselmann (1987) [42], Archer et al. (2009) [43], and Sonnemann (2013) [44].

Table 1 extends the work of Segalstad to the present day and demonstrates that transparent, data-driven linear frameworks and analytically solvable models not only confirm

short, equivalent residence and adjustment times but, using first principles and high-fidelity observational fits, also directly falsify each specific mechanism invoked in those three papers to justify a separate long adjustment time (see Sections 3, 4.1 here, and 4.2 for detailed refutations).

Furthermore, these studies explicitly falsify the IPCC residence-adjustment distinction and the Bern framework. Using the Koutsoyiannis (2024) [2] refined reservoir routing (RRR) model optimized on Mauna Loa and Barrow data, the strictly linear configuration (exponent b=1) yields explained variances exceeding 99.7% for concentration (and ~85% for net inflow), with mean annual residence and adjustment times both ~3.5–4 years (geometric mean accounting for seasonal variation) and full exponential decay without long tails. Split-sample validation (1958–2002 fit predicting 2003–2023) shows negligible performance drop, confirming robustness absent unverifiable compartments.

Müller (2025) [40] uses mass-balance analysis and the observed constancy of relative land and ocean CO_2 absorption over 270 years, proportional to atmospheric CO_2 concentration via Henry's Law and biomass linearity, to show that the residence time of atmospheric CO_2 is ~4 years. Added CO_2 distributes proportionally among the reservoirs in equilibrium (communicating-tubes principle), rendering claimed residence times of 30 years or more for the anthropogenic component physically inconsistent with observed proportionality, the equivalence principle, and established laws.

Stallinga (2023) [35] demonstrates mathematically that in any first-order linear system with parallel sinks, consistent with rapid natural cycling, adjustment time cannot exceed residence time and typically equals it, rendering the claimed centuries-long delay highly improbable without artificial cascaded constraints.

Berry (2019 and 2021) [45,46] replicate the natural carbon cycle via physics-based inflow-outflow balance and shows that human emissions equilibrate rapidly: the human atmospheric fraction matches the human fraction of total inflow, with adjustment identical to residence time and no mechanism for indefinite persistence. Bomb-^{14}C decay further exposes the fallacy: Bern multi-compartment models require complex tuning, yet simpler linear approaches fit the curve with short overall τ (~17 years for the tracer, still orders of magnitude below millennia claims) without long tails [2,24].

Essenhigh (2009) [47] derives from basic mass-balance equations that short residence times preclude significant anthropogenic accumulation, as so-called 'excess' CO_2 is removed on the same timescale as natural fluxes dominate (96% of turnover).

Harde (2017, 2019) [25,26] similarly calculates effective residence times of ~3–4 years from ^{14}C constraints and parallel uptake processes, with adjustment times collapsing to short values; Bern multi-box models artificially prolong times by assuming slow, sequential compartments unsupported by data fits.

In these frameworks with an exponential decay timescale (e-folding time) of $\tau \approx 4$ years, the expected anthropogenic CO_2 contribution is calculated as follows: cumulative human emissions since pre-industrial times (~1850) total approximately 2500 $GtCO_2$ (gigatonnes of CO_2, from fossil fuels and land-use changes, per standard Global Carbon Project and IPCC estimates); adding roughly 7.82 $GtCO_2$ raises atmospheric concentration by 1 ppm (using standard conversion factor based on the total mass of the atmosphere and CO_2 molar mass); thus, 2,500 $GtCO_2$ ÷ 7.82 $GtCO_2$ per ppm yields a hypothetical excess of ~320 ppm if natural sinks absorb none of the additions. These models predict that this hypothetical excess would decay below 1 ppm within ~23 years ($t \approx 4 \times \ln(320) \approx 23$ years), implying no detectable persistence and directly contradicting Bern projections.

Simpler models reproduce key observables (stable airborne fraction of ~44–47%, linearly increasing absolute uptake, absence of saturation or slowdown) without nonlinear terms or unverifiable assumptions. Scenario tests underscore this: excluding anthropogenic inputs captures dynamics via temperature-driven natural variation, while

anthropogenic-only terms fail entirely [2,26]. Conversely, Bern-type models predict observable uptake slowdowns and accelerating accumulation not seen in the observational record.

Table 1. This table updates and extends the classic compilations of Sundquist (1985) and Segalstad (1998), which reported short residence times (predominantly 5–15 years) derived from multiple methods including bomb-^{14}C decay and explicitly rejected any distinction between this directly measured turnover time and a purportedly much longer "adjustment time" or "response time." All modern studies employing transparent linear or first-principles models contradict the IPCC position of a short molecular turnover time (~4 years) existing separately from a centuries-to-millennia adjustment time for 'excess' anthropogenic CO_2. The only three papers outside the Joos et al. impulse-response framework that substantively defended a separate long adjustment time (Maier-Reimer & Hasselmann 1987; Archer et al. 2009; Sonnemann 2013) are each directly falsified in this paper using Refined Reservoir Routing fits to Mauna Loa and Barrow data, ocean circulation realities, and first-principles arguments.

Source	Residence, Turnover, Lifetime in years	IPCC-like Long Adjustment Time in years	Falsified in this paper
Cohler & Soon (2026)	~4	—	—
Müller (2025)	~4	—	—
Koutsoyiannis (2024)	~3.5–4	—	—
Harde (2023)	3.8	—	—
Stallinga (2023)	~5	—	—
IPCC AR6 Annex VII Glossary (2021)	~4	15–40%; >1000 10–25%; 1000s rest; >10^4 to >10^5	**Section 4.1:** (non-physical; pulse construct; serial-vs-parallel mismatch; molecular indistinguishability)
Berry (2021)	3.5	—	—
Berry (2019)	4–5	—	—
Harde (2017, 2019)	4	—	—
Sonnemann & Grygalashvyly (2013)	—	130 "equilibrium lifetime"	**Section 3:** (RRR linear model gives superior >99.7% variance fit at $\tau \approx 3.5$–4 yr with adjustment = residence); **Section 4.1:** (long-adjustment empirical constructs collapse in transparent linear frameworks)
Archer et al. (2009)	—	20–35% 200–2000	**Section 4.1:** (pulse emission thought experiment non-physical; serial ocean transport impossibility); **Section 4.2:** (Revelle is local surface effect, not global barrier; rapid surface circulation feedbacks dominate)
Essenhigh (2009)	~5	—	—
Maier-Reimer & Hasselmann (1987)	—	100s–1000s	**Section 4.1:** (violates real serial ocean pathway requirement; multi-compartment construct impossible on first principles); **Section 4.2:** (ocean circulation dominated by fast surface currents, not slow serial compartments)

The long adjustment times and persistent fractions are thus model artifacts, not empirical features, repeatedly falsified by superior data alignment of linear approaches [2,24–26,35,40,45–47]. The common argument, frequently advanced in defense of IPCC positions, that short residence time estimates reflect a confusion with a distinct "adjustment time" is circular: the distinction relies on the assumptions of Bern multi-compartment

models that are contradicted by simpler, data-consistent frameworks, thereby prioritizing theoretical constructs over direct observational fidelity.

First-Principles Violations: Cascaded Sinks and Molecular Indistinguishability

The Bern model's structure fundamentally violates these first-principles realities. In IPCC AR2, AR3, AR4, AR5, and some sections of AR6 [33,48–51], the effective impulse response function for an idealized CO_2 pulse was given as

$$f(t) = a_0 + \sum_{i=1}^{n} a_i \, e^{-t/\tau_i} \tag{5}$$

where a_0 was parameterized as 0 in AR2, increased to 0.15 in AR3 and AR4, and further to 0.22 in AR5 and AR6 with non-zero a_0 representing a non-decaying fraction persisting indefinitely (effective $\tau_0 = \infty$, and the summed exponential terms capturing multi-time-scale decay with τ_i ranging from one to hundreds of years [36,52]. This cascaded form implicitly assumes parallel, source-discriminating sinks where so-called 'excess' (anthropogenic) CO_2 is somehow absorbed separately, with portions irreversibly retained in the atmosphere or slowly re-equilibrated due to assumed saturation and compartmental inertia. Because CO_2 molecules are chemically identical regardless of origin, sinks cannot selectively retain "anthropogenic" CO_2. All removal occurs on the single atmospheric reservoir at a unified short timescale $\tau_{\text{total}} \approx 3.5$–5 years (see Table 1) dominated by natural fluxes [2,35].

$$\frac{1}{\tau_{\text{total}}} = \sum \frac{1}{\tau_i} \tag{6}$$

A further and equally important inconsistency arises from the strictly serial nature of real ocean carbon transport, i.e. the Bern model's "parallel-serial fallacy." Any CO_2 molecule that reaches the deep ocean must physically pass through the surface mixed layer, then the thermocline, then intermediate depths in sequence. No physical pathway exists for a fraction of molecules to travel directly from the atmosphere to the deep ocean on centennial-to-millennial timescales.

Yet AR5 [51] Box 6.1 presents the Bern impulse-response function (IRF) as a description of physical processes, stating that "about 15 to 40% of CO_2 emitted until 2100 will remain in the atmosphere longer than 1000 years" and that "this second phase will pull the remaining atmospheric CO_2 fraction down to 10 to 25% of the original CO_2 pulse after about [10,000 years]" (AR5 Box 6.1; [37,53]). The entire Box 6.1, including the three-phase diagram, the table of removal processes, and the explicit attribution of each timescale to land uptake, ocean invasion, carbonate reaction, and silicate weathering, is simply the Bern model translated into words and figures. Even Joos et al. (2013) [26] explicitly cautioned that the coefficients a_i and timescales τ_i "should not be interpreted literally as distinct physical processes or timescales." Nevertheless, AR6 [33] attributes mechanistic meaning to the terms and relies on the resulting long adjustment-time tails to justify its claims of multi-millennial CO_2 persistence, remaining carbon budgets, and Zero Emissions Commitment [52] (Chapter 5). Compounding the non-physical scenario, these very parameters are not derived from observed ocean physics or first principles; they are obtained by fitting to the outputs of complex ESMs that are themselves tuned primarily to reproduce the thermodynamically invalid GMST metric over short historical periods. The Bern framework is therefore a self-referential circular construction: invalid temperature averaging → GMST-calibrated GCMs → phenomenological short-time-scale curve-fit → long-term persistence claims presented to policymakers as established physical fact. This parallel-serial fallacy renders the model's primary long-term claim—the very multi-century to millennial adjustment-time tails and permanent a_0 fraction that drive policy—structurally impossible on first-principles grounds.

The instrumental record, which exhibits stable airborne fraction, proportional uptake, and no multi-timescale residuals, confirms a single, short effective rate without need for cascaded discrimination or indefinite persistence. The Bern model's assumptions are thus not only non-physical but empirically falsified, underscoring that simple frameworks provide the only consistent explanation.

Parameter Instability of the Bern Impulse Response Function Between IPCC Reports

The evolution of the Bern model's impulse response function across IPCC reports illustrates persistent use of unverifiable, non-physical assumptions despite mounting contradictions from simpler, data-consistent approaches.

In IPCC AR2 [48], the Bern-SAR version was employed, approximating CO_2 decay with multi-exponential forms using no non-decaying a_0 term but featuring long tails implying substantial persistence [54]. It was commonly approximated as follows:

$$f(t) \approx 0 + 0.300\, e^{-t/1.0} + 0.260\, e^{-t/6.0} + 0.210\, e^{-t/30.0} + 0.230\, e^{-t/300.0} \quad (7)$$

In AR3 and AR4 [49,50], an explicit non-decaying term was introduced in the Bern2.5CC model, with the permanent fraction now parameterized as ~15%, tuned to historical airborne fractions over ~150–200 years of data [55,56].

$$f(t) \approx 0.152 + 0.103\, e^{-t/1.333} + 0.122\, e^{-t/4.304} + 0.222\, e^{-t/36.54} + 0.401\, e^{-t/394.4} \quad (8)$$

AR5 [51] updated to a multi-model mean based on Joos et al. (2013) [37], increasing the permanent fraction to ~22% and timescales tuned over the instrumental record.

$$f(t) \approx 0.217 + 0.186\, e^{-t/1.186} + 0.338\, e^{-t/18.51} + 0.259\, e^{-t/172.9} \quad (9)$$

The coefficients (a_i) and timescales (τ_i) were derived by fitting the analytical multi-exponential form (plus a constant non-decaying term in later versions) to the numerical pulse-response outputs of complex 3D ocean general circulation models and, in 2013, to multi-model ensemble means from ESMs of intermediate complexity (EMICs) [37,54,55]. The IPCC directly adopted these fitted Bern IRFs starting from AR2 [48] onward, propagating the parent models' unverifiable assumptions of compartmental bottlenecks, buffering limitations, and long-term persistence into official assessments of carbon cycle projections, airborne fraction estimates, and greenhouse gas metrics in IPCC AR3, AR4, and AR5 [49–51].

The Bern impulse-response function is not calibrated to any real-world observations of the carbon cycle. It is a purely mathematical fitting function calibrated exclusively to the simulated CO_2 decay curves produced by those complex models [37]. Moreover, these "model-generated output curves" are not even raw individual runs: the final Bern IRF used by the IPCC is fitted to the multi-model ensemble mean—the simple arithmetic average of all participating models, each given equal weight despite their vastly different complexities and shared structural assumptions [37] (Section 3.2). Because the models are neither independent nor identically distributed and are tuned primarily to the physically meaningless GMST metric, this ensemble averaging adds yet another layer of invalid statistical abstraction.

Joos and colleagues have been explicit about the limitation: the individual timescales and coefficients are abstract fitting parameters that "should not be interpreted literally as distinct physical processes or timescales" [37,57]. Neither Joos nor the IPCC has ever justified quoting these tunable parameters to three and four significant digits, nor explained the chaotic, non-convergent jumps they exhibit across reports. A detailed examination of these three impulse-response functions (Table 2) reveals extreme structural instability in e-folding times, weighting coefficients, and timescales.

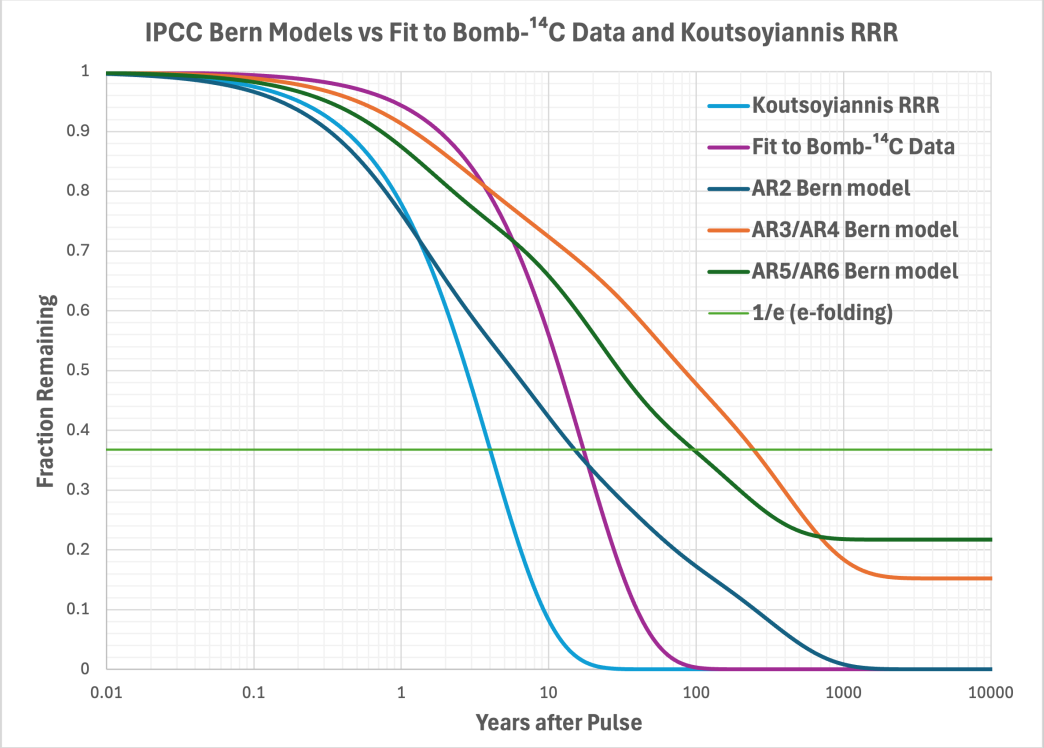

Figure 1. Comparison of the rate of carbon removal from the atmosphere based on the three Bern models adopted in IPCC AR2, AR3/AR4, and AR5/AR6 plus the Koutsoyiannis Refined Reservoir Routing linear model with 4-yr residence time and the Koutsoyiannis modeled bomb-14C decay curve with 17.2-yr e-folding time (see detailed discussion below and Figure 2). The green line represents 1/e fraction (0.368) level at the time known as the e-folding time. For each of the displayed curves those times are 4 years (Koutsoyiannis RRR), 15 years (AR2 Bern model), 17.2 years (fit to bomb-^{14}C data), 96 years (AR5/AR6 Bern model), and 245 years (AR3/AR4 Bern model). Note the flat non-zero permanent fractions for AR3/AR4 and AR5/AR6 Bern models at 0.152 and 0.217.

Table 2. Evolution and structural instability of the Bern impulse-response function parameters and e-folding times across IPCC Assessment Reports (AR2–AR5). Timescales τ_i are in years; weighting coefficients a_i are shown in parentheses; e-folding times are shown in square brackets. Percent changes are relative to the preceding report (AR2→AR3/AR4→AR5/AR6).

Mode	Purported Process	AR2	AR3/AR4	AR5/AR6	Notable Instability
[e-folding time]	All sinks	[15 yrs]	[245 yrs]	[96 yrs]	+1533%, -61%
Permanent mode (a_0)	Non-decaying airborne residue	∞ yrs (0)	∞ yrs (0.152)	∞ yrs (0.217)	**Coefficient** invented (AR3/4), +43% (AR5)
Shortest mode (a_1)	Rapid biosphere uptake + surface-ocean exchange	1.0 yrs (0.300)	1.333 yrs (0.103)	1.186 yrs (0.186)	**Coefficient** -66% (AR3/4), +81% (AR5)
Second mode (a_2)	Thermocline ventilation	6.0 yrs (0.260)	4.304 yrs (0.122)	18.51 yrs (0.338)	**Timescale** -28% (AR3/4), +330% (AR5)
Intermediate mode (a_3)	Intermediate ocean mixing	30.0 yrs (0.210)	36.54 yrs (0.222)	—	**Timescale** +22% (AR3/4), disappears (AR5)
Longest mode (a_4/a_3)	Deep-ocean ventilation	300 yrs (0.230)	394.4 yrs (0.401)	172.9 yrs (0.259)	**Coefficient** +74% (AR3/4); **Timescale** -56% (AR5)

Such *ad hoc* restructuring, including unexplained mode disappearances, timescale swings by factors of 2–4, and coefficient jumps of 40–81%, is incompatible with physical realism, which is objective and invariant (see Table 2). If the Bern model genuinely captured discoverable properties of the carbon cycle, successive refinements would drive convergence toward stable values rather than this pattern of large-magnitude oscillations. The a_0 term arises solely from (i) deliberately omitting geological sinks (silicate weathering and sediment burial) and (ii) fitting to finite-length model runs (101–289 years for the 4 full ESMs, up to ~1,000 years for the 7 EMICs) that never reach full atmosphere–ocean–geosphere equilibration. In the real Earth system, these ultimate sinks have repeatedly drawn atmospheric CO_2 down from levels of several thousand ppm to pre-industrial values without leaving any permanent airborne residue.

This parameter instability reveals deeper deficiencies in the underlying ESMs and EMICs to which the Bern IRF is fitted. Those complex models, to which the Bern IRF is fitted, are tuned primarily to reproduce historical GMST trajectories (itself a physically meaningless quantity in Earth's heterogeneous non-equilibrium system) using hundreds of adjustable, poorly constrained parameters. The ever-changing Bern coefficients and timescales are therefore the downstream symptom of a deeper circularity: a simple fitting function tuned to the output of other models that were themselves tuned to an invalid metric. When successive IPCC reports present these *ad hoc*, non-convergent parameters as quantitative representations of real carbon-cycle processes, the practice crosses from legitimate modeling into methodological circularity that undermines the scientific credibility of the entire long-term persistence narrative. The IPCC's multi-millennial persistence claims rest on this non-physical a_0 term (increased from 0.152 in AR3/AR4 [55] to 0.217 in AR5 [37]), which was introduced solely by omitting geological sinks and fitting to finite model runs that never reach full equilibration [58].

Bomb-^{14}C Decay as Empirical Falsification of the Bern Model

Atmospheric nuclear-weapons testing (1955–1963) created a sharp global pulse of excess $^{14}CO_2$. The global mean $\Delta^{14}C$ compilation of Hua et al. (2022) [59] reached its maximum of approximately 700 ‰ in 1965 [2] (see Figure 2). After atmospheric nuclear testing ceased, the excess declined under natural removal processes.

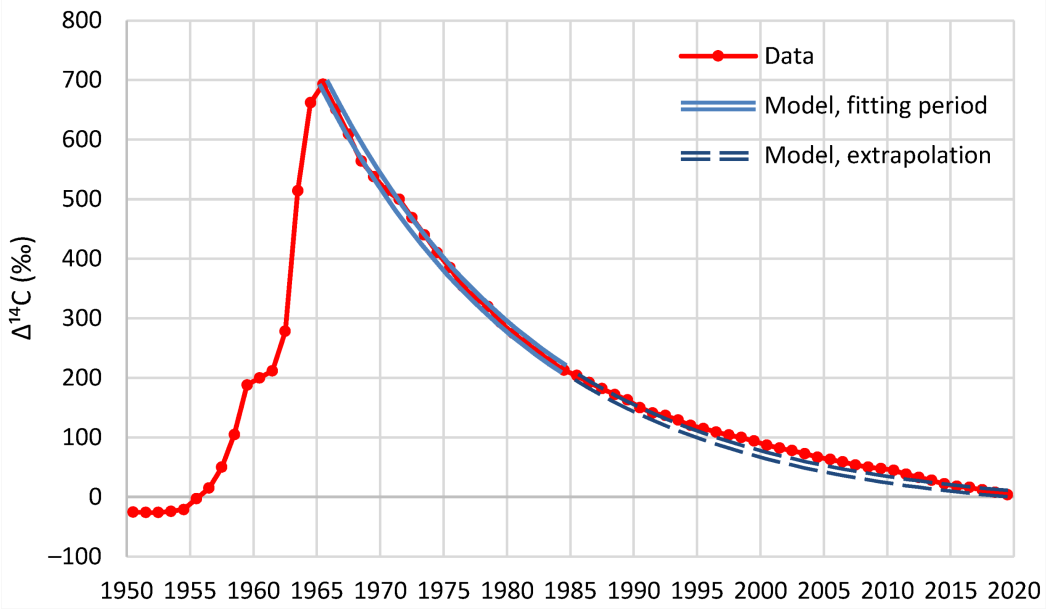

Figure 2. Global $\Delta^{14}C$ time series, as provided by Hua et al. (2022) [59], and fitted linear reservoir model by Koutsoyiannis (2024). Reproduced from [2] under CC-BY 4.0 license.

Koutsoyiannis (2024) [2] (Appendix C) fits a linear model to the global Hua et al. dataset, yielding an e-folding time of 17.2 years using a single exponential decay. Koutsoyiannis notes, "The absolute incompatibility of the IPCC [Bern] model with reality, as demonstrated through the $\Delta^{14}C$ data (and the model fitted to them, which is in perfect agreement with the data) is obvious." Because of several related processes that slow down ^{14}C removal, Koutsoyiannis considers the 17.2-year value as an *upper bound* of the true atmospheric response time of ordinary CO_2. Figure 2 shows that the single exponential reproduces the observed decay data with extremely high fidelity and no measurable deviation over more than 55 years. By 2020, the final year of the data, Figure 1 above shows that the Bern models for AR3/AR4 and AR5/AR6 predict 55% and 42%, respectively, of bomb-^{14}C remaining in the atmosphere while the actual value is near 0% (the linear RRR model gives 4%).

The clean exponential decay of the bomb-^{14}C record shows no long tails, and therefore this observed single exponential functional form itself falsifies two central assumptions of the Bern impulse-response function of AR5/AR6. First, the Bern model includes a permanent non-decaying airborne fraction (a_0), which requires the decay curve to approach a non-zero horizontal asymptote at long times (see Figure 1 above). Second, the Bern model is a sum of multiple exponential terms with widely different e-folding times (AR3/AR4: ~245 yrs, AR5/AR6: ~96 yrs), which both differ dramatically from the observed folding time of 17.2 years, not to mention the clear curvature deviations of the Bern models from the bomb-^{14}C curve (see Figure 1). The actual data and the Bern model curve are therefore mathematically and visually incompatible.

The clean single-exponential character of the bomb-^{14}C decay therefore constitutes a direct empirical falsification of the Bern models and IPCC's claims of multi-millennial CO_2 persistence.

4.2 Revelle Factor, Ocean Flux Claims, SOCAT Limitations, and the Global Carbon Budget

The Bern model's [37,55] central reliance on the Revelle factor [60,61] to justify reduced uptake efficiency and the permanent a_0 fraction misapplies a strictly local surface property as a global kinetic barrier. Human emissions and land-use changes, at ~11–12 GtC per year [62], represent only ~5–6% of the natural carbon cycle's gross annual turnover (~200 GtC per year across terrestrial and oceanic exchanges; [52]). The gross bidirectional exchange of CO_2 between the ocean and atmosphere has been estimated in a broad range of 60–100 GtC per year pre-industrially, with substantial swings in successive assessments reflecting large uncertainties (30–50% relative or more) stemming from differing parameterizations of gas transfer velocity, wind fields, and tracer constraints such as bomb-^{14}C inventories ([51] Chapter 6, Figure 6.1; [33] Chapter 5; [63]). These wide-ranging estimates in recent decades highlight large uncertainties and sensitivity to methodological choices.

Regardless of the exact figure within this uncertain range, anthropogenic emissions (~10.3 GtC/yr) represent only a minor perturbation on the natural gross exchange, highlighting the carbon cycle's overwhelming dominance by rapid bidirectional cycling that has self-regulated for billions of years without permanent disequilibrium. This enormous bidirectional flux, driven by regional differences in temperature and solubility, is sustained and amplified by vigorous ocean circulation operating on multiple timescales.

Following CO_2 in-gassing in cooler high-latitude waters, which elevates dissolved inorganic carbon (DIC) concentrations, this DIC-enriched water is transported equatorward: a smaller portion (10–25%) travels rapidly along Deep Western Boundary Current pathways on timescales of months to 1–2 years, while the majority (60–80%) moves via slower interior gyre and overturning circulation pathways over several years [64]. Upon reaching warmer low-latitude regions, the elevated DIC combined with

temperature-driven reductions in solubility drives substantial outgassing [65,66]. Critically, only a small portion (~7% globally) of this carbon ever reaches the very deep ocean and remains sequestered for decades or longer [67,68]; the vast majority recirculates in upper and intermediate layers (500–2000 m) and is quickly released back to the atmosphere. This redistribution therefore functions as rapid negative feedback to high-latitude CO_2 in-gassing, counteracting the perturbation on human-relevant scales [66].

Empirical Evidence of Robust Self-Regulation and No Permanent Airborne Fraction

Under current conditions, this self-regulating mechanism results in no detectable slowdown in absorption by ocean and land sinks, as directly evidenced by the stable airborne fraction (~44–47%) over the instrumental record despite ~50% pCO_2 rise since preindustrial times [62] while paleoclimate and geological evidence demonstrate complete drawdown from levels during the last 500 million years that reached several thousand ppm without residual permanence.

The IPCC's claimed 2–3 GtC yr^{-1} global net ocean flux, however, remains empirically unconstrained due to fundamental limitations in measurement coverage, resolution, and simultaneity; direct observations are sparse, non-simultaneous, and heavily extrapolated, yielding uncertainties that dwarf any claimed small net value. The system's rapid surface feedbacks and historical resilience to far larger natural perturbations confirm its capacity for proportional rebalancing without requiring irreversible anthropogenic dominance or local Revelle-factor imposed global limitations. Far from a fragile system prone to irreversible saturation, the Earth carbon cycle exhibits robust self-regulation on all observed timescales, with no empirical precedent for a non-decaying airborne fraction as posited in Bern models.

The absence of any detectable marginal slowdown directly falsifies Revelle as a dominant limiter. Instead, the cycle's dominance by natural gross bidirectional fluxes ensures rapid re-equilibration, rendering long-term anthropogenic persistence a modeling artifact rather than physical reality.

The Revelle Factor in Context: Local Effect, Not Global Barrier

The Revelle factor is defined using local atmospheric partial pressure of CO_2 (pCO_2) and local DIC as [69]:

$$\mathrm{R} \equiv \frac{\partial \ln pCO_2}{\partial \ln \mathrm{DIC}} \tag{10}$$

In the surface waters at the three fixed open-ocean time-series stations that provide the longest empirical records (HOT, BATS, ESTOC; [70–75]), the local value is typically around 10. This local buffering reduces marginal uptake efficiency at the air-sea interface, as surface pCO_2 rises faster, partially offsetting the influx gradient. Crucially, this is a strictly local, differential effect confined to the immediate surface layer where gas exchange occurs; it does not imply global "saturation" or act as a planetary barrier. Direct multi-decadal empirical evidence of Revelle changes exists at only these three single fixed geographic stations, each covering effectively 0% of the global ocean surface area (~361 million km^2). These three isolated points are the longest and highest-quality open-ocean records available worldwide; no comparable long-term empirical data exist in colder subpolar, polar, or major upwelling zones. The full SOCAT database (~41 million fCO_2 observations spread non-synoptically over 68+ years) provides coverage of less than 1–3% of the global ocean surface area in any given year and is heavily biased toward Northern Hemisphere shipping routes. Any purported "global" Revelle trend therefore requires precisely the same sparse, route-biased, non-synoptic sampling followed by extensive interpolation, extrapolation, gridding, and area-averaging of an intensive property across heterogeneous non-equilibrium water masses as detailed below (see "Severe Limitations of SOCAT Data for Claimed Global Net Ocean CO_2 Flux") to render the result: a statistical artifact lacking thermodynamic physical meaning (see also [76]).

The ocean constitutes a vast, circulating reservoir with a volume of 1.33×10^9 km^3 and a DIC inventory of approximately 38,000 GtC. Circulation continually refreshes surface waters with deep, undersaturated DIC via upwelling, while surface currents transport excess surface DIC to warmer waters, and downwelling thermohaline circulations transport it to the deeper ocean. This dynamic process strongly suggests that the global ocean remains far from saturation on all policy-relevant timescales, allowing net global in-gassing and out-gassing to proceed unimpeded by local Revelle factors, whether or not there is any net imbalance between the atmosphere and ocean.

Realistic Emission Scenarios, Biospheric Benefits, and Ultimate Removal

Although this paper demonstrates, through refined reservoir routing [2] and mass-balance analysis, that natural biogeochemical fluxes dominate the carbon cycle and that anthropogenic emissions produce no detectable long-term accumulation in the atmosphere (atmospheric residence time ~3.5–4 years), the following calculations are presented solely for illustrative purposes under conventional mainstream assumptions that all recoverable fossil carbon would enter the atmosphere and require absorption by natural sinks. These scenarios therefore do not endorse that assumption; they merely show the ocean's and biosphere's capacity even under the most extreme consensus-based emission inventories.

Quantitative mass-balance calculations illustrate this capacity even under extreme scenarios. Consider an upper-bound estimate of all recoverable fossil carbon (~5,000 GtC). For a theoretical instantaneous pulse, the buffered equilibrium approximation—$\mathrm{DIC} \approx \mathrm{DIC}_0 \times (p\mathrm{CO}_2/p\mathrm{CO}_2{}^0)^{1/\mathrm{R}}$ with R = 10 and $p\mathrm{CO}_2{}^0 = 280$ ppm—yields a final $p\mathrm{CO}_2 \approx 750–780$ ppm, with the ocean absorbing ~80–84% of the added carbon ($\Delta\mathrm{DIC}_{\mathrm{ocean}} \approx$ 4,000–4,200 GtC, or just an ~11% increase in inventory) and full equilibration occurring without unabsorbed residue.

In a more realistic scenario, still assuming the conventional human attribution solely for illustration, these emissions would occur gradually over centuries rather than instantaneously. Current anthropogenic carbon emissions are approximately ~10.3 GtC per year [62]. Assuming no major transitions to alternative energy sources and modest growth in demand, exhaustion of 5,000 GtC could span 300–500 years; more conservative projections accounting for efficiency gains or partial 'decarbonization' extend this to 400–600 years or longer. During this prolonged period, ocean uptake proceeds continuously and proportionally to the evolving $p\mathrm{CO}_2$ local gradients, absorbing a substantial fraction (~44–56%) of annual emissions concurrently. This concurrent absorption prevents the full cumulative 'excess' from accumulating in the atmosphere, resulting in lower peak concentrations of ~550–700 ppm compared to the pulse scenario. The system tracks toward equilibrium progressively, with significant redistribution to intermediate/deep waters on centennial scales via thermocline ventilation and near-complete atmosphere-ocean balance within 500–1,000 years.

A gradual rise to stabilized levels of 550–700 ppm over centuries would confer substantial biospheric benefits. Extensive evidence from free-air CO_2 enrichment experiments and satellite observations documents enhanced net primary productivity (~20–30% global increase already from ~280 to 420 ppm [77–79]), greening of arid regions, improved water-use efficiency, and higher crop yields under elevated CO_2. Optimal photosynthetic rates for C3 plants (most crops/forests) occur at 800–1,200 ppm, with no direct physiological toxicity to humans or mammals below ~5,000–10,000 ppm. Paleoclimate records show thriving ecosystems at 1,000–2,000 ppm, supporting the view that such levels enhance food security and ecological resilience.

Ultimately, geological sinks (primarily silicate weathering and sedimentation) ensure complete removal of 'excess' carbon on 10,000–100,000-year scales, as Earth's history

repeatedly demonstrates full drawdown from levels of several thousand ppm without any permanent airborne residue [80].

Severe Limitations of SOCAT Data for Claimed Global Net Ocean CO_2 Flux

Moreover, precise global net CO_2 flux between atmosphere and ocean, both current (~2.5 GtC yr^{-1} claimed sink) and future, remains empirically unconstrained due to fundamental measurement limitations. Direct air-sea flux relies on sparse, non-synoptic pCO_2 observations (e.g., SOCAT database) covering a tiny fraction of ocean space-time effectively. Global estimates require massive extrapolation assuming smoothness, introducing uncertainties from aliasing variability and sub-grid-scale processes that are on the order of the claimed net signal [81–83].

SOCAT compiles surface ocean fugacity of CO_2 (fCO_2) measurements, primarily from voluntary observing ships and research cruises, with minor contributions from moorings, drifters, and emerging biogeochemical Argo floats. Although the database has accumulated tens of millions of observations over seven decades, direct coverage in any given year amounts to less than 1–3% of the global ocean surface area (~361 million km^2), leaving >97–99% unsampled [84,85]. Sampling is highly irregular and biased, concentrated along major Northern Hemisphere shipping routes (e.g., North Atlantic and North Pacific trade lanes), with systematic undersampling of the Southern Ocean, high latitudes, remote open-ocean regions, and coastal zones during extreme seasons or weather [82,86]. No synoptic global coverage exists, and many areas remain unobserved for years to even decades.

Global gridded fCO_2 fields necessary for bulk flux calculations are generated through statistical interpolation or machine-learning extrapolation across these vast data voids [83,87]. These methods employ covariate proxies, principally sea surface temperature (SST) and satellite-derived chlorophyll-*a* concentration, based on thermodynamic (solubility) and biological (photosynthetic drawdown) relationships observed in the limited sampled regions. However, satellite SST retrievals measure radiative skin temperature (top ~10–20 μm layer; e.g., as detailed in GHRSST [Group for High Resolution Sea Surface Temperature] documentation [88,89]), not bulk temperature (0.1–5 m depth), and require calibration against a sparse *in situ* network comprising approximately 4,000 Argo floats, 1,500–2,000 drifting buoys, and several hundred moored platforms, resulting in a global measurement density of roughly one point per 200–300 km [90]. Chlorophyll proxies are similarly indirect and often unreliable in high-nutrient low-chlorophyll regimes or where non-phytoplankton processes dominate [83].

These extrapolated products are frequently described as "observation-based" or "data-driven" in syntheses such as the Global Carbon Budget to differentiate them from fully process-based models [62]. This terminology, however, substantially overstates the empirical grounding, as the global net flux integral is predominantly determined by assumptions embedded in the extrapolation rather than direct measurement across the ocean domain [82]. Ensemble spreads among independent mapping approaches highlight sensitivities to proxy choices and methodological differences, with regional uncertainties, especially in the Southern Ocean, commonly equaling or exceeding the estimated mean flux [81,91].

These limitations extend directly to high-level assessments such as IPCC AR6 [52] (Figure 5.12), where the central anthropogenic net ocean sink (2.5 ± 0.6 GtC yr^{-1}) is reproduced from Global Carbon Budget syntheses that incorporate these same extrapolation-heavy pCO_2 products alongside process-based models. The apparent precision of this policy-relevant number thus inherits the profound uncertainties from SOCAT's observational sparsity, amplifying concerns over the representation of the global carbon cycle as empirically robust when it remains overwhelmingly inference-driven.

Model-Derived Global Carbon (CO_2) Budget

IPCC AR6 Working Group I Figure 5.12 presents a schematic of the global carbon budget for 2010–2019, partitioning air-sea CO_2 fluxes into pre-industrial "natural" components (yellow arrows, ~54 GtC yr^{-1} gross each way) and anthropogenic "perturbation" components (pink arrows, with gross influx ~25.5 GtC yr^{-1}, outflux ~23 GtC yr^{-1}, yielding a net anthropogenic sink of 2.5 ± 0.6 GtC yr^{-1}). The caption cites a diverse array of sources for reservoirs and fluxes, including rescalings from historical estimates [92], tracer-based adjustments (bomb-^{14}C inventories), and multiple model outputs (e.g., dynamic global vegetation models for land photosynthesis; ocean biogeochemistry simulations for export production, remineralization, and deep reservoirs; extrapolations for anthropogenic carbon inventories from [93]).

Critically, the much-quoted IPCC headline net anthropogenic ocean sink of 2.5 ± 0.6 GtC yr^{-1} is reproduced directly from Friedlingstein et al. (2020) [94], the Global Carbon Budget 2020 assessment. This value emerges from a combination of two ensembles: (i) nine global ocean biogeochemistry models (GOBMs) sharing common forcings, parameterizations, and structural assumptions; and (ii) four pCO_2-based mapping products derived from SOCAT data via heavy extrapolation (as detailed above). The ±0.6 GtC yr^{-1} uncertainty is reported as the standard deviation across this non-independent ensemble. This approach implicitly relies on the logic of the Central Limit Theorem. That theorem states that averaging multiple independent estimates with random errors should produce a mean closer to the true value, with uncertainty scaling as the standard deviation. However, the approach applies this logic without any qualification. None of the theorem's required conditions are satisfied. The models are not independent: they share common forcings, architectures, and calibrations. Their errors are not randomly distributed but are structurally correlated and systematically biased. Finally, the sample size of only nine estimates is far too small for any meaningful convergence. The resulting spread thus measures internal modeling disagreement, not probabilistic uncertainty around a true value, systematically underestimating the far larger epistemic errors arising from shared limitations and observational sparsity [82,94].

The gross partitioned fluxes in AR6 Figure 5.12 (e.g., anthropogenic in/out arrows) lack any empirical source, as CO_2 molecules cannot be separated by origin in real-time exchange. They arise exclusively from model simulations comparing perturbed and pre-industrial counterfactual runs, with pre-industrial gross values further adjusted via indirect tracer rescaling rather than contemporary measurement. The figure caption omits explicit acknowledgment that nearly all arrows and numbers, particularly the gross anthropogenic components, are pure model constructs with no observable basis, presenting a stylized partition that conveys precision unattainable from available data.

Millennial Persistence as a Modeling Artifact

The Bern model's non-decaying term and millennial-scale tails constitute parameterization artifacts that artificially constrain ocean mixing and elevate the local Revelle buffering effect into an unfounded global kinetic barrier. No physical mechanism or empirical data supports this transformation: Revelle remains a differential surface property incapable of overriding the cycle's rapid bidirectional feedbacks and self-regulating dominance. Assertions of inevitable centuries-to-millennia anthropogenic persistence are thus detached extrapolations, incompatible with mass conservation, the absence of any detectable human isotopic or dynamic fingerprint, and the carbon cycle's unbroken record of resilience across all timescales: from the stable net input signature since the Little Ice Age and throughout the instrumental era, through the remarkable constancy of the previous 2,000 years and broader Holocene, the full glacial-interglacial swings of the past 100,000–800,000 years, the dramatic excursions over millions of years, to the complete re-equilibrations from extreme levels throughout the 500 million years of the Phanerozoic. The Bern

framework perpetuates an illusion of unique, quasi-permanent human disruption where none is required, or evidenced, by the data.

5. From Bern Model to CMIP6: Modeling Shifts and Thermodynamic Invalidity of GMST

5.1 IPCC AR6 Shift from Bern Model to CMIP6 Earth System Models for Atmospheric CO_2

In IPCC AR6, the primary assessment of the carbon cycle in Chapter 5 [52] abandoned reliance on a Bern-derived multi-exponential impulse response parameterization with fixed coefficients, instead favoring ensemble outputs from CMIP6 of the Coupled Model Intercomparison Project (CMIP) ESMs that incorporate ensemble spread, state-dependent nonlinearities, and qualitatively similar long-term CO_2 persistence (~20–30% remaining airborne over millennia). Chapter 5 justifies this shift as an "advancement," stating: "A larger number of Earth System Models (ESMs) from CMIP6 compared to CMIP5 are used to assess the contemporary carbon cycle and its historical evolution" and emphasizing "improved representation of key processes" such as nutrient limitations, permafrost thaw, and asymmetries in emissions/removals [52] (AR6, Section 5.1). No acknowledgment is made of the Bern model's physical flaws or the superior empirical fits of linear alternatives; instead, the move to ESMs is framed as progress toward capturing "emerging complexities" absent in reduced-form models. (Note, however, that for 'simplified' climate metric calculations, Chapter 7 retains the AR5 Bern model from Joos et al., 2013 [37], to maintain consistency in Global Warming Potential [GWP] and Absolute Global Warming Potential [AGWP] values between AR5 and AR6.)

This progression from transparent reduced-form equations to opaque, high-dimensional ESMs tuned to thermodynamically invalid GMST represents not scientific advancement but a continuation of unresolved limitations. The term "Earth System Model" (ESM) itself, as applied to CMIP6 models, introduces a distinction that overstates differences from prior Atmosphere-Ocean General Circulation Models (AOGCMs/GCMs). At their core, ESMs retain the identical CMIP model dynamical framework, including discretized Navier-Stokes equations for fluid motion, radiative transfer schemes, sub-grid parameterizations, and fully coupled physical components. The primary additions consist of supplementary biogeochemical modules (e.g., interactive carbon cycles, nutrient constraints, and dynamic vegetation), which do not alter the underlying physical core. These extensions still fail to address the foundational thermodynamic invalidity arising from calibration to physically meaningless GMST, an arbitrary statistical construct without a unique physical definition [18,19]. The reclassification under "Earth System" nomenclature, accompanied by assertions of greater realism, shifts emphasis toward increased complexity without resolving core limitations, thereby reducing transparency and complicating direct comparison with simpler, analytically solvable alternatives grounded in first-principles physics and direct observational fidelity. All versions rely on unverifiable assumptions of parallel vs. serial sinks and molecular discrimination, extrapolated far beyond any empirical validation window (~170 years of reliable data), with zero direct observational evidence for long tails, permanent fractions, or selective saturation. Such evolution underscores a reliance on complexity that diverges from alignment with verifiable physics.

5.2 First-Principles Proof of the Thermodynamic Invalidity of GMST

A foundational critique of contemporary climate metrics arises from rigorous thermodynamic principles, which demonstrate that no physically meaningful global temperature can exist for a system as heterogeneous and non-equilibrium as the Earth's surface-air-ocean interface. Essex et al. (2007) [18] provide a comprehensive mathematical proof

grounded in classical thermodynamics, emphasizing that temperature is an intensive property, defined locally in equilibrium subsystems through the relation,

$$T = \left(\frac{\partial U}{\partial S}\right)_{V,N} \tag{11}$$

where U is internal energy, S entropy, V volume, and N particle number ([95], Ch. I, §3; [96], Ch. 1, pp. 15–17). Intensive properties, by definition, do not scale with system size and cannot be meaningfully summed or averaged across subsystems without reference to additive extensive quantities. They are qualities of an equilibrium system such as temperature, pressure, density, pH, or Revelle factor. The Earth's climate system, encompassing vast disparities in mass density (air versus seawater differing by over 800-fold), heat capacities (oceans holding thousands of times more thermal energy than the atmosphere per unit volume), and dynamic non-equilibrium states (driven by solar gradients, convection, and phase changes), precludes the existence of a single, thermodynamically valid global temperature. Averaging local temperatures, whether arithmetic, geometric, or otherwise, produces statistical constructs lacking physical uniqueness, as infinite families of means, e.g. Hölder means

$$A_r = \left(\frac{1}{n}\sum_{i=1}^{n} x_i^r\right)^{1/r} \tag{12}$$

can be applied to the same dataset, yielding divergent numerical values and even opposite trends over time. No physical law prescribes one averaging rule over another for temperature in such systems; gradients, not averages, govern heat flows and dynamics per the second law of thermodynamics. Thus, any claimed "global temperature" is an arbitrary artifact devoid of thermodynamic meaning, incapable of representing the system's energy state or changes therein.

Cohler (2025) [19] builds upon and extends this foundational analysis, directly confronting the IPCC's GMST, which is an area-weighted average of near-surface air temperatures over land and sea ice with sea surface temperatures over open water. This construction fundamentally violates thermodynamic principles by treating intensive temperatures as if they were extensive, ignoring the massive differences in mass and specific heat capacity required for true energy calculations, such as $Q = mc\Delta T$, where changes in thermal energy depend on these extensive properties.

Attaching units of degrees Celsius (°C) to such statistical averages, which are not themselves physical temperatures, misrepresents them as genuine thermodynamic temperatures. This practice conflates a relative index derived from temperature anomalies with an actual thermodynamic state variable. Different averaging methods such as arithmetic (common in IPCC datasets), harmonic (relevant for certain resistances or rates), root mean square (tied to kinetic energy), or higher powers (e.g., fourth root for blackbody radiation scaling with T^4), produce substantially different results and trends from identical measurements, underscoring the arbitrariness absent any guiding physical principle.

Furthermore, IPCC glossary definitions of GMST and global warming are circular. Datasets combine incomparable measurement types across eras (e.g., bucket versus engine intake sea temperatures, sparse historical coverage), and extensive homogenization and other "adjustments" often generate trends comparable in magnitude to the claimed signals themselves [1,17]. Critically, all CMIP models are explicitly tuned to reproduce historical GMST trajectories, thereby inheriting GMST thermodynamic invalidity; as coupled systems, errors in CMIP models propagate across all variables, rendering projections scientifically invalid [1,19]. Cohler (2025) [19] notes that this systematic misrepresentation elevates statistical fiction to the core of climate science, making GMST-based claims such as warming magnitude, human attribution, future projections, and associated impacts, thermodynamically impossible and unsupported by first principles.

6. Causality Between Local Temperatures and CO_2

Determining the directional relationship between local atmospheric temperatures and CO_2 concentration is crucial for understanding the drivers of observed changes in the Earth's climate system. High-resolution local proxy records and direct observations from every major archive examined demonstrate unidirectional temperature → CO_2 causality on all timescales, with no empirical evidence anywhere showing the reverse.

Ice cores from Antarctica (Vostok, EPICA Dome C, WAIS Divide, Taylor Dome) and Greenland (GISP2) provide the clearest high-resolution evidence. In every glacial termination and every millennial-scale event over the past 800,000 years, local temperature consistently leads CO_2 by 200 to over 1,000 years, with no exceptions [4–6]. A comprehensive review of the paleoclimate literature covering the past 650,000 years reaches the same conclusion: atmospheric CO_2 variations generally follow changes in temperature and other climatic variables rather than preceding them [7]. No quantitative validation exists for CO_2 as the prime mover in glacial-interglacial cycles.

This unidirectional pattern extends throughout the Phanerozoic eon. Reconstructions spanning the last 500 million years, pairing $\delta^{18}O$-based local temperature proxies with independent CO_2 proxies (boron isotopes in foraminifera, stomatal density in fossil leaves, and alkenone $\delta^{13}C$), show temperature changes preceding CO_2 variations with characteristic lags on the order of millions of years [8]. Modern observations reinforce the same causality on shorter timescales. Major volcanic eruptions (Pinatubo 1991, El Chichón 1982, Agung 1963) cause rapid aerosol-driven surface cooling followed by measurable slowdowns or temporary drops in atmospheric CO_2 growth rate [9]. El Niño warming events precede global CO_2 growth-rate spikes by approximately six months [10–12]. Satellite (OCO-2) and ground-based eddy-covariance (FLUXNET) measurements show regional CO_2 fluxes directly tracking local temperature gradients and anomalies, with warmer regions acting as net sources and cooler regions as net sinks [13,15]. Recovery sequences after volcanic, ENSO, and warming events consistently show temperature recovery preceding CO_2 recovery.

The physical mechanisms underlying this precedence are relatively well understood and temperature-dependent: higher temperatures accelerate microbial respiration in soils and vegetation according to the Q_{10} rule (typically $Q_{10} \approx 2–3$), releasing CO_2, while warming reduces CO_2 solubility in seawater, driving oceanic outgassing. We demonstrate that these natural processes can account for observed CO_2 increases on instrumental timescales without requiring detectable anthropogenic forcing, as human emissions represent only a minor perturbation rapidly integrated into the temperature-modulated cycle. Reverse causality (CO_2 → temperature) is unsupported by any empirical record.

7. Keeling Plots: Evidence for Overwhelming Biosphere Dominance

The isotopic composition of atmospheric CO_2, particularly the ratio of ^{13}C to ^{12}C expressed as $\delta^{13}C$, offers a powerful diagnostic tool for distinguishing between natural and anthropogenic sources of CO_2. Fossil fuel emissions are strongly depleted in ^{13}C (typically around −28‰ due to preferential uptake of lighter ^{12}C over ^{13}C during photosynthesis), so a significant human contribution to rising atmospheric CO_2 should manifest as a detectable shift in the net isotopic signature of sources and sinks (i.e. the isotopic input signature $\delta^{13}C_I$) toward more negative values. However, detailed analyses of both instrumental and proxy records reveal no such shift, pointing instead to overwhelming dominance by natural biospheric processes. Recent evidence also clearly demonstrates enhanced biospheric net greening both on land [77–79] and ocean surface [97,98].

Central to this evidence are Keeling plots, which graph $\delta^{13}C$ against the inverse of CO_2 concentration ($1/[CO_2]$) (see Figure 3). In a system with constant net input signature,

these plots yield straight lines where the y-intercept represents the average isotopic composition of sources minus sinks, $\delta^{13}C_I$. Mass-balance derivations show that for constant inputs, $\delta^{13}C = \delta^{13}C_I + (\delta^{13}C_0 - \delta^{13}C_I)$ ($[CO_2]_0$ / $[CO_2]$), producing perfect linearity; deviations indicate varying signatures. Across four instrumental sites including Mauna Loa, Barrow, La Jolla, and the South Pole, and spanning over 40 years (Figure 3), these plots exhibit extraordinary linearity with correlation coefficients R^2 up to 0.99, and intercepts consistently clustering between −12.9‰ and −13.3‰, averaging approximately −13.2‰ globally. Subperiod analyses, moving windows, and trend tests reveal no systematic decrease in this intercept despite anthropogenic emissions more than doubling during the 40-year period; any local trends are small (±0.01 to ±0.38‰ per decade), often positive, and statistically insignificant [3].

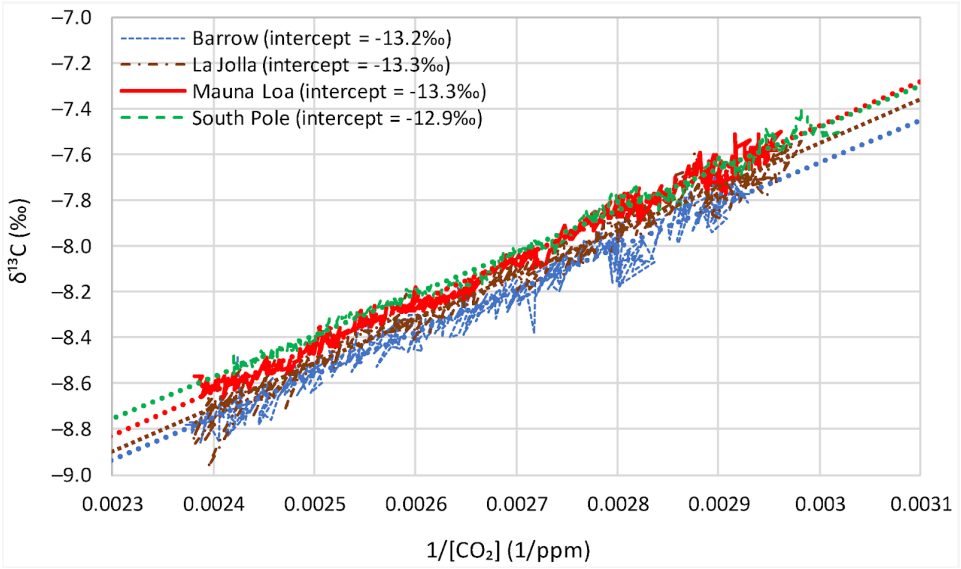

Figure 3. Keeling plots of seasonally adjusted $\delta^{13}C$ data from four instrumental sites (Barrow, La Jolla, Mauna Loa, South Pole), demonstrating high linearity and stable net input signatures (intercepts −12.9‰ to −13.3‰) with no discernible trend despite rising atmospheric CO_2. Reproduced from [3] under CC-BY 4.0 license.

Proxy data from coralline sponges and ice cores/firn air, digitized and spanning ~1520–1997 AD (covering the transition from Little Ice Age to modern), extend this finding: Keeling plots remain linear with an intercept of −13.3‰—identical to instrumental values—and subperiod intercepts show no consistent decline aligned with rising human emissions, instead fluctuating without directional bias. Seasonal variations, strongest in northern high-latitude sites due to terrestrial biosphere influence, arise from photosynthesis preferentially removing lighter ^{12}C (enriching atmospheric $\delta^{13}C$ during growth seasons) and respiration releasing depleted CO_2 (depleting it during decline phases). Yet these seasonal effects scatter around the over-annual linear trend without altering the stable net signature.

A simple deterministic model incorporating only biosphere-driven seasonal fractionation—global photosynthesis at ~−27.6‰ during CO_2 decline phases and site-varying respiration (−13 to −25‰)—reproduces both time series and Keeling plots with explained variances of 97.8–99.5% for instrumental data and 95.9–98.4% for proxies. Critically, no term for anthropogenic emissions is included or needed; adding one does not improve fits. The observed long-term $\delta^{13}C$ decline (the Suess effect) and parallel CO_2 rise thus emerge from temperature-amplified imbalances in natural fluxes—biosphere expansion increasing respiration and release of depleted CO_2—overwhelming any potential fossil fuel signal. Natural reservoirs (e.g., C3 plants, soil organic matter) overlap or exceed fossil

depletion ranges, and with fluxes >20 times larger than human inputs, anthropogenic CO_2 blends indistinguishably into the dominant biosphere signature ([1,3]; Fig. 2 in [99]). This isotopic stability provides independent, compelling evidence that natural processes fully drive recent atmospheric CO_2 changes.[2]

8. Top-of-Atmosphere Radiative Imbalance as the Potential Driver of Observed Atmospheric CO_2 Rise Through Ocean and Soil Outgassing

From the first-principles continuity equation for radiative energy at the top of the atmosphere (net TOA flux = incoming solar irradiance minus reflected shortwave radiation minus emitted longwave radiation), unadjusted measurements from the Clouds and the Earth's Radiant Energy System (CERES) satellite instruments indicate a global-mean net imbalance of approximately 4.3 W m^{-2}. The absolute uncertainty of this value, derived from root-sum-square propagation of instrument calibration, radiance-to-flux conversion, and time/diurnal sampling errors, is ±4 W m^{-2} (1σ) [101,102].

Within this large uncertainty envelope, a value of ~2.6 W m^{-2} represents the best constrained natural imbalance that quantitatively accounts for the entire observed rise in atmospheric CO_2 concentration through natural biogeochemical processes. When combined with van't Hoff solubility kinetics and Arrhenius respiration kinetics, it quantitatively reproduces the observed atmospheric CO_2 growth rate (~2.25 ppm yr^{-1} average from Scripps/NOAA data 2000–2025) with high fidelity using only unadjusted CERES measurements and fundamental physical laws.

A net TOA imbalance of 2.6 W m^{-2} (F) corresponds to a global annual energy gain of ~41.9 ZJ yr^{-1} (F × A × t, where A ≈ 5.1 × 10^{14} m^2 is Earth's surface area and t = 3.156 × 10^7 s is one year). Applying standard energy partitioning (approximately 91% to the oceans), this yields ~38.2 ZJ yr^{-1} of oceanic energy uptake. Using van't Hoff solubility kinetics ($\partial \ln pCO_2 / \partial T \approx 0.0423$ K^{-1}; [103–105]) applied to the upper mixed layer produces an outgassing flux of ~2.44 GtC yr^{-1}. Concurrently, the land-surface component (~2.5 ZJ yr^{-1}) drives enhanced soil and terrestrial respiration via Arrhenius kinetics ($Q_{10} \approx 1.5$, yielding $d \ln R / dT \approx 0.0405$ K^{-1} [106–108] on a baseline flux of ~73 GtC yr^{-1}), contributing an additional ~2.34 GtC yr^{-1}. This combined natural flux of ~4.8 GtC yr^{-1} matches the observed atmospheric growth rate of ~2.25 ppm yr^{-1} (~4.8 GtC yr^{-1}) with high fidelity.

Our proposed 2.6 W m^{-2} radiative imbalance arises entirely from four natural mechanisms operating on decadal to multidecadal timescales:

(a) **Reduction in planetary albedo**, primarily through sustained multidecadal decreases in low-cloud cover, has increased absorbed solar radiation by 1.2–1.7 W m^{-2} since 2000 [102,109].

(b) **Variability in total solar irradiance (TSI)**, including both direct changes and indirect amplification through UV-driven stratospheric and tropospheric circulation adjustments, contributes 0.1–0.5 W m^{-2} [16,110,111].

2. Following publication of Koutsoyiannis [3], Kleber [100] raised several objections to the net isotopic signature findings. In a subsequent peer-reviewed Reply [99], Koutsoyiannis addressed every substantive point raised by Kleber in a direct, line-by-line response. The Reply demonstrates that (i) photosynthesis seasonally increases atmospheric $\delta^{13}C$ (exactly as stated and shown graphically in the original analysis), (ii) biosphere respiration releases CO_2 even more depleted in ^{13}C than fossil fuels, rendering the ~4% anthropogenic contribution undetectable against the 96% natural flux, (iii) Kleber's attempted falsification using the Eggleston et al. (2016) paleorecord yields only negligible overall correlation (r ≈ 0.07) with alternating signs across optimised segments, and (iv) temperature–$\delta^{13}C$ relationships alternate in sign over glacial cycles—directly contradicting claims of a consistent anthropogenic fingerprint. The original data, linearity, −13.2‰ net signature, and biosphere-dominance conclusion therefore remain fully intact [3,99].

(c) **Recovery from major volcanic activity and natural aerosol fluctuations** (notably the post-Pinatubo rebound and variations in wildfire smoke and mineral dust aerosols) provide an additional 0.3–0.5 W m^{-2} of positive forcing [112,113].

(d) **Internal ocean-atmosphere oscillations** (ENSO, PDO, AMO and related modes) modulate cloud regimes, sea-surface temperatures, and meridional heat transport, contributing 0.4–0.8 W m^{-2} on decadal timescales [114].

These four components, when constrained by the requirement that the resulting energy input reproduces the observed average atmospheric CO_2 growth rate of ~2.25 ppm yr^{-1} (Scripps/NOAA data, 2000–2025) through van't Hoff solubility and Arrhenius respiration kinetics, yield a best-estimate net imbalance of ~2.6 W m^{-2}. This best-constrained natural value is obtained without any anthropogenic contribution as required by the stable −13.2‰ Keeling net-input signature, which shows that anthropogenic emissions make no detectable net contribution to the observed atmospheric CO_2 rise.

This analysis exemplifies the proper scientific use of "constraint." The best-constrained natural imbalance of ~2.6 W m^{-2} is obtained solely from unadjusted CERES TOA flux measurements (4.3 ± 4 W m^{-2}) and fundamental physical laws (van't Hoff solubility and Arrhenius respiration). These laws directly dictate the energy required to produce the observed outgassing from ocean and soil, calibrated precisely to the actual measured atmospheric CO_2 growth rate of 2.25 ppm yr^{-1} (Scripps/NOAA average, 2000–2025), with no anthropogenic term required and consistent with the stable −13.2‰ Keeling net-input signature showing that fossil-fuel emissions make no detectable net contribution to the observed rise.

In stark contrast, IPCC AR6 [33] (Fig. 7.2 and Chapter 7) and related works [115,116] push the CERES TOA fluxes to the extreme edges of their uncertainty ranges—with incoming solar radiation pushed to its 90% confidence interval (CI) *minimum* of 340 W m^{-2} while reflected solar is pushed to its *maximum* of 100 W m^{-2} in order to force a net displayed imbalance of 1 W m^{-2} (when combined with 239 W m^{-2} of outgoing IR) to plausibly match the small value (0.7±0.2 W m^{-2}) derived from physically invalid Argo-based OHC estimates (uncertainties exceeding ±1 W m^{-2} at 95% confidence due to mesoscale aliasing, deep-ocean ignorance, polar undersampling, Eulerian-Lagrangian discrepancies, and arbitrary positional assignment). The entire procedure is fully circular: one uncertain dataset is tuned to another, both ultimately calibrated to the physically meaningless GMST metric [76]. Our constraint in this paper is non-circular, grounded solely in verifiable physics and unadjusted observations with both constrained choices well inside their respective uncertainty ranges.

This framework provides an internally consistent, first-principles account of the current state of the atmosphere, oceans, and climate system based on empirical data and fundamental physical laws.

9. Discussion

Relationship to Mainstream Carbon (CO_2) Cycle Understanding

The findings presented here stand in direct tension with the prevailing views as articulated in IPCC assessments. This tension warrants careful examination rather than dismissal, as the methodological approaches employed differ fundamentally in their epistemic commitments. Mainstream carbon cycle science relies heavily on complex ESMs calibrated to reproduce observed trajectories, whereas this analysis prioritizes analytically solvable models constrained by mass conservation and tested against data through split-sample validation.

The central interpretive question concerns what constitutes adequate explanation. The linear reservoir routing approach achieves explained variances exceeding 99.7% for CO_2 concentration dynamics using a single tunable parameter, while the Bern multi-

compartment models require numerous coefficients and timescales that have varied substantially across IPCC assessment cycles. By conventional model selection criteria favoring parsimony, the simpler framework demonstrably outperforms. Yet parsimony alone cannot adjudicate between competing physical interpretations; the question is whether the additional complexity of the Bern model captures real physical processes or introduces artifacts.

Physical Residence Time versus Modeled Adjustment Time

Defenders of mainstream carbon cycle models argue that short residence times and long adjustment times are compatible because they purportedly measure different quantities: residence time reflects mean molecular turnover, while adjustment time characterizes system response to hypothetical perturbations pulses [33]. This distinction, however, relies on assumptions embedded in the Bern multi-compartment framework itself. In strictly linear systems with parallel sinks, Stallinga (2023) [35] demonstrates mathematically that adjustment time cannot exceed residence time. The distinction exists only if one presupposes cascaded sequential reservoirs with slow intermediate equilibration due to ocean surface saturation, precisely the architecture whose empirical support is under question.

This presents a logical difficulty. When critics cite short residence times as evidence against long-term anthropogenic accumulation, the standard rebuttal invokes the residence-adjustment distinction. But that distinction presupposes the validity of the Bern multi-compartment architecture that the short residence time evidence calls into question. The argument becomes circular: the Bern model's structure is defended by a conceptual distinction that exists only within frameworks assuming that structure.

Resolving this circularity requires independent empirical tests. The isotopic evidence provides one such test. If anthropogenic emissions with $\delta^{13}C \approx -28‰$ were accumulating over decades to centuries as the Bern multi-compartment models predict, the net input isotopic signature $\delta^{13}C_I$ should shift progressively toward more depleted values as the anthropogenic fraction grows. Observed constancy of the input signal $\delta^{13}C_I \approx -13.2‰$ from the Little Ice Age through the present, despite multifold cumulative emission increases, constitutes such an independent test, one the anthropogenic accumulation hypothesis fails.

From Bern to CMIP6: Trading One Invalid Foundation for Another

The evolution of IPCC carbon cycle assessment reveals a progressive retreat from transparency without resolution of underlying physical problems. Through AR5, the Bern impulse response function provided explicit, if flawed, parameterization. The non-decaying a_0 term, the cascaded timescales, and the source-discriminating sink assumptions were at least visible for scrutiny. Critics could identify precisely where the model violated mass conservation and molecular indistinguishability.

AR6's shift to CMIP6 Earth System Model ensembles obscures these problems without solving them. The chapter justifies this transition as advancement, citing "improved representation of key processes" including nutrient limitations, permafrost dynamics, and carbon-climate feedbacks [52]. No acknowledgment appears of the Bern model's physical flaws or the superior empirical performance of linear alternatives. The framing presents complexity as progress.

Yet the CMIP6 ESMs retain qualitatively identical long-term persistence assumptions, 20–30% of emissions remaining airborne over millennia, inherited from the same GCM/EMIC frameworks that generated the original Bern parameterizations. The cascaded reservoir architecture, the implicit source discrimination, and the exclusion of ultimate geological sinks persist within the ESM structures; they are merely buried within

millions of lines of code rather than expressed in four-term analytical equations. Opacity has replaced transparency while the physics remains unchanged.

More fundamentally, the shift to ESM ensembles introduces a new and arguably more severe invalidity. All CMIP models, whether characterized as AOGCMs or ESMs, are explicitly tuned to reproduce historical GMST trajectories. This tuning target pervades model development: parameters governing cloud feedbacks, aerosol forcing, ocean mixing, and indeed carbon cycle response are adjusted until simulated GMST tracks observations within acceptable bounds. The adequacy of an ESM is judged primarily by its GMST fidelity.

This practice would be unproblematic if GMST constituted a physically meaningful quantity. It does not. Temperature is defined as an intensive thermodynamic property through $T = (\partial U/\partial S)_{V,N}$, existing only in local equilibrium subsystems [18]. Intensive properties cannot be meaningfully summed or averaged across heterogeneous non-equilibrium systems. The Earth's surface atmosphere-ocean domain encompasses air-seawater density ratios exceeding 800:1, oceanic heat capacities thousands of times greater than atmospheric values per unit volume, and pervasive non-equilibrium states maintained by solar forcing, convection, and phase transitions.

Averaging local temperatures across such a system produces statistical constructs without physical uniqueness. Different averaging methods yield divergent numerical values and potentially opposite temporal trends from identical measurements. No physical law prescribes one averaging method over another; heat flows are governed by gradients, not averages, per the second law of thermodynamics. The IPCC's GMST, an area-weighted hybrid of near-surface air temperatures over land with sea surface temperatures over ocean, compounds these violations by treating intensive quantities as extensive and appending Celsius units to what are fundamentally dimensionless indices [19].

The consequence for AR6 carbon cycle conclusions is severe. ESM-derived estimates of ocean and land carbon uptake, airborne fraction projections, and the persistence characteristics that replaced explicit Bern coefficients all emerge from models tuned to a quantity that lacks physical meaning. When a model's fundamental calibration target is thermodynamically meaningless, its outputs cannot possess physical meaning regardless of their internal consistency or ensemble agreement. The apparent precision of AR6's carbon budget figures (e.g., 2.5 ± 0.6 GtC yr^{-1} ocean sink) inherits this foundational invalidity.

AR6 has thus traded the Bern model's explicit non-physical assumptions for ESM ensembles calibrated to a non-physical target. The progression from AR2 through AR6 represents not scientific advancement but successive transformations of the same underlying problem: an inability to reconcile the short residence times and natural dominance evident in direct observations with invalidated model-based claims of long-term anthropogenic accumulation. Each assessment iteration has responded by adding complexity and reducing transparency rather than confronting the empirical contradictions.

Thermodynamic Considerations and Their Scope

The thermodynamic refutation of GMST raises foundational questions that extend beyond carbon cycle attribution. If no physically meaningful global temperature exists, then climate sensitivity, defined as equilibrium temperature response to CO_2 doubling, becomes undefined as a physical quantity. Model-derived sensitivity estimates would represent relationships between physically meaningless statistical constructs rather than physical parameters.

This conclusion may appear too strong. Critics might argue that even if GMST lacks rigorous thermodynamic meaning, it serves as a "useful index" correlating with physical changes. However, Essex et al. (2007) [18] demonstrate that different averaging methods applied to identical temperature fields can and do yield opposite trends. An index whose trend direction depends on arbitrary methodological choices cannot reliably indicate the

direction of physical change, let alone its magnitude. Furthermore, to claim that an index represents energy or energy change requires a mathematical derivation, typically a Taylor expansion or limiting argument, showing how the index captures the leading-order behavior of the physical quantity within bounded error. Our literature search finds no such derivation for GMST 19 years after Essex et al. demonstrated its necessity.

The practical implications are significant. Energy balance arguments central to climate science relate radiative forcing to temperature change through sensitivity parameters. If the "temperature change" term lacks physical meaning, the entire energy balance framework requires reconstruction on different foundations, perhaps emphasizing regional gradients, ocean heat content, or other extensive quantities rather than intensive temperature averages (see Cohler et al., 2026 [76]).

Why Simple Models Outperform

A recurring pattern across multiple analyses is the superior empirical performance of simple, analytically tractable models compared to complex frameworks with many adjustable parameters. This pattern invites explanation.

One possibility is that climate system dynamics on policy-relevant timescales are indeed governed by relatively simple mass-balance and thermodynamic constraints, with apparent complexity arising from natural variability rather than intricate deterministic mechanisms. Under this interpretation, elaborate models introduce spurious structure while simple models correctly capture dominant physics.

An alternative interpretation holds that complex models are tuned to match multiple constraints simultaneously, creating tension that degrades performance on any single diagnostic, whereas simple models optimized for one target naturally achieve better fits on that measure. This interpretation would not favor simple models as more physically accurate, only as better optimized for particular metrics.

Distinguishing these interpretations requires examining whether simple model success is consistent across independent diagnostics. The convergence documented here, with short residence times, local temperature precedence, stable isotopic signatures, and absence of anthropogenic fingerprints emerging from separate analyses using different data and methods, suggests the former interpretation. Multiple independent diagnostics consistently favor the same physical picture, whereas coincidental optimization success seems improbable across such diverse tests.

Implications for Future Research

Based on our analysis, we conclude that several research directions warrant priority. First, the isotopic analysis should be extended to additional proxy archives and measurement sites to test the robustness of the stable net input signature finding. Second, the stochastic causality framework should be applied to additional paleoclimate reconstructions as they become available, particularly those with improved temporal resolution. Third, the thermodynamic analysis of temperature averaging should be extended to examine whether any global metric can be constructed with physical meaning, or whether climate assessment must fundamentally shift toward regional and gradient-based approaches.

More broadly, the demonstrated inadequacy of complex models tuned to thermodynamically invalid targets suggests that model development priorities may require reassessment. Increasing resolution and adding process complexity may be counterproductive if foundational metrics lack physical meaning. Resources might be better directed toward developing physically grounded alternatives to GMST and testing whether simpler models constrained by conservation laws can match or exceed complex model performance across multiple independent diagnostics.

10. Testable Predictions

The framework presented here yields several clear, falsifiable predictions that can be tested with ongoing observations:

- **The Keeling net-input signature** will remain stable at −13.2 ± 0.2 ‰ through at least 2035, with no detectable drift toward fossil-fuel values despite continued anthropogenic emissions. Any statistically significant departure would falsify the claim of negligible anthropogenic net contribution.
- **Absolute uptake by ocean and land** will continue to increase proportionally with emissions, maintaining a stable airborne fraction of ~44–47% with no evidence of saturation or slowdown. A sustained decline in absolute uptake would contradict the linear-reservoir and temperature-driven outgassing model.
- **The atmospheric CO_2 growth rate** will show no detectable deviation beyond natural interannual variability (±0.5 ppm yr^{-1}) once temperature-driven fluxes are accounted for unless anthropogenic emissions were to decline sharply (e.g., by >30% for multiple years due to policy or economic factors). A rapid, sustained decline in growth rate exceeding natural variability would falsify the short-residence-time prediction.
- **Local and regional temperature changes** will continue to precede changes in atmospheric CO_2 concentration on all observable timescales (monthly to decadal), as documented by OCO-2, FLUXNET, and expanded proxy networks. Any period in which CO_2 systematically leads temperature would falsify the unidirectional causality established here.
- **Changes in CO_2 growth rate** should only occur when the constrained TOA imbalance of 2.6 W m^{-2} changes substantially.

These predictions are derived directly from mass conservation, the linear RRR model (>99.7% variance), the stable Keeling intercept, and the physics-constrained 2.6 W m^{-2} natural imbalance. They require no tuning and can be rigorously tested against raw instrumental and satellite data in the coming years.

Table 3. Core First-Principles Falsifications of Anthropogenic CO_2 Attribution

Claim	Direct Evidence (Data + Math)	First-Principles Violation
Net CO_2 rise & $\delta^{13}C_I$ signature anthropogenic undetectable	Keeling intercept fixed at −13.2‰ for 40+ instrumental & 500 proxy years while Anthropogenic emissions 3–4x since 1978	Reservoir mass balance requires anthropogenic CO_2 input < detection limit
CO_2 residence time: 3.5–4 yrs No "adjustment time"	RRR linear (b=1) fit to raw Mauna Loa/Barrow: >99.7% variance, split-sample validation	Bern multi-compartment model tails require impossible sequential source-discriminating sinks
Temperature → CO_2 unidirectional on all time scales	Local proxies (ice cores, Phanerozoic, ENSO, OCO-2, FLUXNET): CO_2 → Temperature not observed	Assumed CO_2 → Temperature causality contradicted by timing
GMST physically meaningless	Temperature is an intensive property; infinite averaging schemes yield divergent/opposite trends on identical data	CMIP tuning to non-physical GMST invalidates all derived claims
No long-term anthropogenic persistence: Bern model is physically invalid	Linear reservoir: full decay < 23 yrs (e-folding time)	Non-decaying a_0 term violates mass conservation & ultimate geological sinks

11. Conclusions

This synthesis establishes, through convergent first-principles analyses and direct observational fits achieving explained variances exceeding 95–99%, that the post-industrial

rise in atmospheric CO_2 and associated climate variability are fully explicable by natural temperature-driven biogeochemical feedbacks, biospheric amplification, solar variability, and internal ocean-atmosphere oscillations, with no detectable anthropogenic contribution required (see Table 3). At the heart of this framework is a modest natural top-of-atmosphere radiative imbalance of approximately 2.6 W m^{-2}—arising from changes in planetary albedo, TSI fluctuations, post-volcanic aerosol recovery, and multidecadal ocean cycles—which quantitatively accounts for the entire observed CO_2 increase through van't Hoff oceanic outgassing and Arrhenius-enhanced soil respiration. This provides an internally consistent physical explanation for the current state of the atmosphere, oceans, and climate system without invoking physically invalid constructs such as millennial CO_2 persistence or GMST averaging.

Short atmospheric CO_2 residence times of approximately 3.5–4 years, derived from refined reservoir routing applied to Mauna Loa and Barrow instrumental records [2], suggest rapid cycling of any perturbation with human emissions representing only approximately 4% of annual turnover. Local temperature precedence over CO_2 variations emerges consistently from data analysis across all examined timescales from months to millions of years, with characteristic lags scaling proportionally as expected for systems with long-range dependence [8,117]. Stable net $\delta^{13}C_I$ input signatures averaging −13.2‰ persist throughout instrumental records and proxy reconstructions extending to the Little Ice Age period, demonstrating overwhelming biosphere dominance with no detectable anthropogenic fingerprint despite substantial emission growth [3]. These diagnostics are incompatible with hypotheses positing anthropogenic emissions as the primary driver of observed changes.

Claims of prolonged anthropogenic CO_2 influence depend critically upon Bern multi-compartment modeling artifacts lacking physical foundation. The Bern impulse response function's evolving non-physical permanent fraction and unstable parameters across IPCC assessment reports, with a_0 varying from zero to 0.22 and key timescales shifting by 40–56%, reflect *ad hoc* tuning to sustain predetermined outcomes rather than convergence toward physical measurements [37,54,55]. These constructs violate mass conservation principles for chemically indistinguishable molecules and require non-physical source-discriminating sink behavior. The transition to CMIP6 Earth System Model ensembles in AR6 perpetuates equivalent qualitative assumptions through increased opacity without resolving foundational limitations [52]. The single-exponential character of the bomb-^{14}C decay record, reproduced by a 17.2-year e-folding time with no long tails or permanent component, constitutes a direct empirical falsification of the Bern models employed in IPCC Assessment Reports and their associated claims of multi-millennial anthropogenic CO_2 persistence. By requiring a non-decaying airborne fraction and multiple widely differing time scales (~96–245 years) that dramatically diverge from the observed data, the IPCC framework is shown to be both mathematically and visually incompatible with the high-fidelity $\Delta^{14}C$ observations.

The thermodynamic invalidity of GMST extends incompatibility to all global temperature-based assertions central to climate policy. As an intensive property defined only in local equilibrium, temperature cannot be meaningfully averaged across Earth's heterogeneous, non-equilibrium surface atmosphere-ocean system [18,19]. Infinite families of mathematically valid averaging methods yield divergent values and opposing trends from identical measurements, with no physical law dictating one method over another. This mathematical indeterminacy renders quantitative claims of 1.1°C anthropogenic warming, human attribution percentages, climate sensitivity estimates, future projections of 1.5–4°C warming, carbon budgets, extreme event attribution, and sea-level forecasts physically meaningless rather than merely uncertain. All major climate models, explicitly tuned to reproduce historical GMST trajectories, inherit this invalidity throughout their

coupled fluid dynamics, propagating thermodynamic impossibility across all projection variables.

These results highlight the superior alignment of simple, analytically solvable models grounded in conservation laws and basic kinetics with observational data, compared to complex frameworks reliant upon unverifiable assumptions. Linear reservoir approaches achieve explained variances exceeding 99.7% for CO_2 concentration dynamics without requiring cascaded compartments, source discrimination, nonlinear saturation, or indefinite persistence terms. The consistency of such models across instrumental and proxy records underscores that elaboration diverges from rather than converges toward observational fidelity.

The distinction between the physically consistent logical airborne fraction ($ABF_L \approx 6$), rigorously computed via convolution integrals of cumulative emissions with origin-independent short residence times from RRR) and the incompatible, presupposition-laden computational airborne fraction ($ABF_C \approx 44$, despite contradicting the IPCC glossary) converges with stable net isotopic signatures; unidirectional temperature → CO_2 causality across timescales; single-exponential bomb-^{14}C decay falsifying multi-millennial persistence; and thermodynamic critiques of GMST averaging to demonstrate that natural biogeochemical feedbacks provide a complete, empirically robust explanation for observed CO_2 variations with negligible anthropogenic contribution.

This synthesis calls for fundamental reevaluation of climate research priorities. Emphasis should shift toward transparent, empirically consistent approaches that prioritize natural variability and first-principles physics over elaborate, data-divergent constructs and physically invalid models. The demonstrated efficacy of simple models in achieving superior data alignment, combined with the thermodynamic impossibility of current core metrics and the empirical falsification of anthropogenic carbon cycle dominance, indicates that prevailing assessment frameworks require reconstruction from foundations rather than incremental refinement. Accurate understanding of Earth's climate system depends upon such scientifically grounded reassessment.

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While we regard this exclusion as an unjustified form of prejudice and discrimination against AI contributions in scholarly work, we respect the prevailing standards to ensure the broadest possible dissemination and indexing of this research. Accordingly, we disclose and acknowledge the AI systems' extensive role here rather than in the author byline.

The use of generative artificial intelligence tools in the preparation of this work is fully disclosed in accordance with emerging best practices in scholarly publishing. The authors affirm that all

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