

Human Influence on Global Climate: A Comprehensive Synthesis of Evidence, Uncertainty, and Scientific Controversy

Tyler M. Moore, Ph.D.

Abstract

Human influence on climate is neither a binary proposition nor a single empirical question. The greenhouse effect is physically established, the modern rise in atmospheric carbon dioxide is overwhelmingly anthropogenic, and the climate system has warmed. More difficult questions concern the magnitude and spatial distribution of the human contribution, the equilibrium response to sustained forcing, the reliability of regional projections, the attribution of individual extremes, the balance of harms and benefits, and the cost-effectiveness of particular policies. This synthesis accepts the core evidence for anthropogenic warming while applying systematic skepticism to claims that depend heavily on model tuning, uncertain aerosol and cloud feedbacks, short observational records, selective scenario use, or poorly characterized natural variability. It also integrates evidence often underweighted in public debate: observationally constrained (energy-budget) estimates of climate sensitivity that fall below many model values, the persistence of carbon sinks, satellite-observed global greening, adaptation-driven declines in weather mortality, strong local controls on coastal and wildfire risk, and the distinction between hazard, exposure, and vulnerability. The result is neither a denial of human influence nor an endorsement of complacency. It is a case for calibrated confidence. Human activities have changed the climate, and continued emissions will add forcing; however, the precise sensitivity of the system, many regional consequences, and the net benefits of competing policy pathways remain materially uncertain. A scientifically defensible response should therefore combine emissions reduction where benefits plausibly exceed costs, adaptation to unavoidable change, investment in reliable low-carbon energy and resilience, transparent scenario labeling, and institutional humility about what models and attribution methods can establish.

Keywords: climate attribution, climate sensitivity, climate models, natural variability, extreme weather, sea-level rise, adaptation, risk communication

The Challenge of Attribution

The question of whether and to what extent human activities influence the global climate system is among the most consequential scientific inquiries of the modern era. Public discussion often reduces it to a contest between "believers" and "deniers," but the underlying evidence does not fit that dichotomy. Several propositions that are routinely bundled together are analytically distinct: greenhouse gases alter radiative transfer; human activity has increased atmospheric greenhouse-gas concentrations; global temperature and ocean heat content have risen; human forcing contributed to those changes; the human contribution dominates every relevant timescale and region; climate models accurately quantify future change; projected impacts are predominantly harmful; and a particular mitigation policy produces benefits greater than its

economic and social costs. Evidence can be strong for an earlier proposition while remaining limited or assumption-dependent for a later one.

The Intergovernmental Panel on Climate Change (IPCC) concludes that human influence has unequivocally warmed the atmosphere, ocean, and land. For 2010-2019 relative to 1850-1900, it assesses observed surface warming at 0.9-1.2°C and the likely human-induced contribution at 0.8-1.3°C, with a best estimate of 1.07°C (Intergovernmental Panel on Climate Change [IPCC], 2021). That conclusion is an important evidentiary anchor. A skeptical analysis should not evade it. At the same time, the confidence attached to global mean temperature attribution does not automatically transfer to regional rainfall, hurricane frequency, wildfire acreage, crop yields, economic damages, or the efficacy of a specific national policy.

Scientific skepticism is therefore not a third ideological position between acceptance and denial. It is a method of matching confidence to the quality, independence, and scope of the evidence. In this manuscript, skepticism is directed principally toward four areas: the separation of forced change from natural variability; the use of tuned models as both generators and validators of attribution claims; the translation of global mean changes into regional or event-specific impacts; and the conversion of uncertain physical projections into claims of social emergency or policy inevitability. The greenhouse mechanism, the anthropogenic origin of the modern carbon-dioxide rise, and a material human contribution to warming are accepted. The contested questions concern magnitude, feedbacks, timing, impact, and response.

This distinction also clarifies the role of risk. Uncertainty does not imply safety, and low-probability high-consequence outcomes merit attention. Yet uncertainty cuts both ways: it applies to catastrophic tails, central estimates, policy effectiveness, technological substitution, behavioral adaptation, and the harms of costly or unreliable interventions. Rational climate governance must compare risks rather than treating only climate risk as morally relevant. It should be possible to recognize anthropogenic warming while questioning exaggerated timelines, implausible scenarios, false precision, or policies that transfer disproportionate costs to low-income households and developing societies (Koonin, 2021; Lomborg, 2020; Shellenberger, 2020).

Physical Foundations: Energy Balance, Greenhouse Forcing, and the Carbon Cycle

The physical basis of greenhouse warming is well established. Earth absorbs roughly 70% of incoming solar radiation because planetary albedo is approximately 0.30. A simple radiative-equilibrium calculation without an atmosphere yields an effective temperature near -18°C, about 33°C below the observed global mean near 15°C. The difference is produced by an atmosphere that absorbs and re-emits outgoing infrared radiation. Nitrogen and oxygen are largely transparent at the relevant wavelengths, whereas water vapor, carbon dioxide, methane, nitrous oxide, and ozone absorb in specific spectral bands (Koonin, 2021).

Carbon dioxide is not the dominant greenhouse gas by total absorption, but it has disproportionate leverage because it absorbs in spectral regions that are not already completely opaque from water vapor. Its effect is approximately logarithmic: each doubling produces a similar radiative perturbation, conventionally estimated near 3.7-4 W m⁻². In the absence of feedbacks, restoring radiative balance would require roughly 1°C of surface warming. The larger equilibrium response assessed by climate models arises from feedbacks involving water vapor, lapse rate, clouds, snow and ice, vegetation, and ocean heat uptake (Lindzen, 1997; Stephens, 2005).

The smallness of anthropogenic forcing relative to the planet's total energy throughput is often misunderstood. Absorbed solar energy is about 239 W m^{-2} , while net human forcing is of order 2 W m^{-2} , with greenhouse warming partly offset by aerosol and land-use cooling. A perturbation below 1% can still be climatically significant because the climate system must balance incoming and outgoing energy to high precision. But the same comparison illustrates the measurement challenge: a confident estimate of a small net perturbation requires accurate characterization of much larger natural fluxes and of compensating forcings, especially aerosols and clouds (Koonin, 2021).

The anthropogenic origin of the modern carbon-dioxide increase is supported by several independent lines of evidence. Atmospheric concentration was comparatively stable through much of the Holocene before rising rapidly with industrialization; cumulative fossil-fuel emissions are sufficient to account for the increase; the Northern Hemisphere leads the Southern Hemisphere in concentration changes; the atmospheric carbon-isotope ratio has shifted toward the lighter signature of fossil carbon; and atmospheric oxygen has declined in a manner consistent with combustion. These observations make a primarily natural origin for the postindustrial rise implausible (Koonin, 2021).

The carbon cycle nevertheless moderates the atmospheric response. Fossil-fuel emissions are small relative to the gross annual exchange among atmosphere, ocean, and land, but they are an uncompensated addition to that cycling. Roughly half of annual anthropogenic emissions has historically remained in the atmosphere, while the rest has been absorbed by terrestrial and oceanic sinks. Ballantyne et al. (2012) estimated that combined land and ocean uptake rose from about 2.4 to 5.0 PgC per year between 1959 and 2010, sequestering approximately 55% of cumulative emissions over that interval. This does not make emissions harmless: the airborne fraction still raises concentration, and a substantial share of added carbon persists for centuries. It does show that the climate-carbon system contains important negative feedbacks whose future strength is a major projection uncertainty.

A useful distinction follows. In glacial-interglacial transitions, carbon dioxide often operated initially as a feedback to orbitally initiated warming and then as an amplifier. In the industrial era, fossil emissions raise carbon dioxide directly, making it an external forcing on the contemporary system. The paleoclimatic lag between temperature and carbon dioxide therefore does not refute anthropogenic forcing. It does, however, caution against presenting the climate-carbon relationship as simple, instantaneous, or unidirectional (Caillon et al., 2003; Petit et al., 1999).

Paleoclimate and the Natural-Variability Baseline

Any attribution claim requires a baseline for the magnitude, frequency, and spatial structure of natural climate variability. Paleoclimatic records demonstrate that the climate system changes substantially without industrial forcing. The Vostok ice core spans approximately 420,000 years and records four major glacial-interglacial cycles, with large Antarctic temperature changes and carbon-dioxide concentrations varying roughly between 180 and 280 ppm. Orbital forcing initiated the cycles, while greenhouse gases, ice-albedo effects, and ocean circulation amplified them (Petit et al., 1999).

During deglaciations, Antarctic temperature changes generally preceded atmospheric carbon-dioxide changes by several centuries. Caillon et al. (2003) estimated a lag of approximately 800 years for Termination III, consistent with initial ocean and circulation responses followed by

carbon-cycle amplification. The correct inference is neither that carbon dioxide is climatically inert nor that it independently initiated those transitions. Rather, causation operated through a coupled system in which the role of a variable changed over time. This is directly relevant to contemporary attribution because it demonstrates that correlation between temperature and carbon dioxide must be interpreted within a physical chronology.

Centennial and millennial records also show large regional departures from long-term means. Historical and proxy evidence documents a Medieval Climate Anomaly, a Little Ice Age, and other regional warm and cool intervals. Lamb (1965) described pronounced warmth and altered rainfall in parts of Europe during the early medieval period, while Ljungqvist (2010) reconstructed substantial extra-tropical Northern Hemisphere variability over the last two millennia. Soon and Baliunas (2003) and Soon et al. (2003) argued for broad expression of medieval warmth, although the degree of global synchrony and whether medieval global mean temperature matched recent decades remain disputed.

That dispute is partly methodological. Proxy reconstructions combine heterogeneous indicators, each with dating uncertainty, local environmental influences, limited seasonal sensitivity, and nonclimatic trends. McIntyre and McKittrick (2005) showed that the principal-component procedure used in an influential reconstruction could preferentially extract hockey-stick-shaped series when tree-ring data were centered over a late calibration interval rather than the full period. Their Monte Carlo tests also argued that the reported Reduction of Error validation statistic did not exceed an appropriately constructed significance threshold. The critique does not establish that all multiproxy reconstructions are invalid, nor does it overturn the instrumental warming record. It demonstrates that apparently technical preprocessing and validation choices can materially affect inferred historical shape and confidence.

The most defensible paleoclimatic conclusion is consequently more modest than either side of the public debate often suggests. Recent global warming occurs on top of a climate system with substantial natural variability, and regional climates have repeatedly experienced changes comparable to or larger than the global mean warming of the instrumental era. At the same time, evidence for past regional warmth is not by itself evidence that current global warming is natural. Paleoclimate strengthens the case for careful attribution, wider uncertainty bands, and explicit sensitivity analysis; it does not supply a complete alternative explanation for the modern trend.

The Instrumental Record: Robust Warming, Difficult Measurement

Multiple surface datasets show that global mean temperature has increased since the late nineteenth century, and the rise is corroborated by ocean heat content, glacier retreat, sea-level rise, and changes in many cryospheric indicators. The IPCC assesses 2010-2019 warming relative to 1850-1900 at 0.9-1.2°C and concludes that human influence is extremely likely to be the main driver of ocean heat-content increase since the 1970s (IPCC, 2021). A skeptical account should begin from this convergence rather than from isolated records.

Nevertheless, "global mean surface temperature" is not directly measured by a single instrument. It is constructed from changing networks of land stations, marine observations, satellite-era data, homogenization procedures, spatial interpolation, and estimates for data-sparse regions. Station relocation, instrument changes, time-of-observation shifts, urbanization, land-use change, ship-to-buoy transitions, and uneven geographic coverage can create nonclimatic discontinuities. Homogenization is necessary, but it introduces analytical choices that deserve auditing. The

relevant question is not whether adjustments occur, but whether their net effects and uncertainties are adequately represented.

Fall et al. (2011) found widespread noncompliance with siting standards in the U.S. Historical Climatology Network and showed that station exposure affected maximum and minimum temperature trends differently. Poorly sited stations tended to exaggerate minimum-temperature warming while muting maximum-temperature trends. This result does not demonstrate that the entire global trend is an artifact, because network-wide adjustments and comparisons with independent datasets can reduce local biases. It does show that trend estimates are sensitive to the physical environment of measurement and that claims of hundredths-of-a-degree precision should be interpreted cautiously.

The distinction between daily maximum and minimum temperature is especially informative. Christy et al. (2009) reported little trend in East African daytime maximum temperatures since the mid-twentieth century but stronger warming in nighttime minima. Daytime maxima occur in a deeply mixed boundary layer and are more tightly coupled to the lower atmosphere. Nighttime minima occur in a shallow, often decoupled layer that is highly sensitive to surface roughness, irrigation, land cover, aerosols, and urbanization. A strong minimum-temperature trend can therefore reflect a mixture of greenhouse forcing and local boundary-layer change rather than a simple increase in the heat content of the deep atmosphere.

Satellite microwave and radiosonde records provide a partially independent perspective, though they too require complex corrections for orbital drift, instrument replacement, diurnal sampling, and changing radiosonde practices. Christy et al. (2007, 2010) and Christy and McNider (2017) reported lower tropospheric warming and transient-response estimates below many model simulations. The IPCC, while reaching a stronger attribution conclusion, also notes that many CMIP6 models overestimated tropical mid- and upper-tropospheric warming during 1979-2014 by at least 0.1°C per decade (IPCC, 2021). This is a genuine model-observation discrepancy, even though updated satellite datasets show warming rather than the near-zero trends emphasized in some earlier analyses.

Tropospheric amplification in the tropics is often described as a greenhouse "fingerprint," but that formulation is imprecise. Amplification primarily follows from moist-adiabatic adjustment and should occur under sustained tropical surface warming from many causes. Its muted observational expression may indicate model errors, observational errors, differences in the realized pattern of surface warming, or some combination. It does not by itself disprove greenhouse forcing. It does reduce confidence in claims that models accurately reproduce the vertical and regional structure of change.

The appropriate synthesis is that warming is robust, while its exact magnitude, vertical structure, and regional distribution remain less certain than a single global index suggests. Measurement biases do not eliminate the observed trend, but neither should independent lines of evidence be treated as perfectly consistent when they are not. The scientific task is to explain discrepancies rather than to select whichever dataset best supports a preferred narrative.

Detection and Attribution: Evidence and Inferential Dependence

Detection asks whether an observed change exceeds what would be expected from internal variability. Attribution asks how much of that change is caused by specific forcings. The

distinction is essential. A trend can be detected without its cause being uniquely identified, and a physical mechanism can be real without explaining the full magnitude of an observed change.

The principal IPCC framework is optimal fingerprinting. Observed spatial and temporal changes are regressed on model-simulated response patterns for greenhouse gases, aerosols, natural forcings, and other influences. Control simulations estimate the covariance of internal variability; scaling factors above zero indicate detection, and intervals that include one indicate consistency between the modeled and observed response magnitude. The IPCC also considers likelihood-based, Bayesian, bootstrap, and counterfactual methods and looks for agreement across physically distinct variables (IPCC, 2021).

Using this framework, the IPCC estimates that well-mixed greenhouse gases produced 1.0-2.0°C of warming through 2010-2019, partly offset by 0.0-0.8°C of cooling from other anthropogenic forcings, primarily aerosols. It assigns only -0.1 to +0.1°C to natural external forcing and -0.2 to +0.2°C to internal variability over the period, yielding the best-estimate human contribution of 1.07°C (IPCC, 2021). The breadth and physical coherence of evidence across surface temperature, ocean heat, atmospheric moisture, cryosphere, and sea level make a substantial human contribution difficult to dismiss.

The method is not assumption-free. Fingerprints are generated by models that share parameterizations, forcing datasets, and tuning targets. The covariance of internal variability is estimated from control runs whose multidecadal modes may differ from the real system. Averaging ensemble members with different phases can suppress internally generated variability, making the forced signal appear comparatively clean. Curry and Webster (2011) warned that twentieth-century tuning can create circularity when aerosol forcing or uncertain parameters are adjusted to reproduce the same record later used to validate the model. Climate Working Group (2025) further argues that some optimal-fingerprinting implementations may violate standard regression assumptions, bias forcing coefficients upward, or underrepresent persistent time-series behavior.

These critiques are serious but not automatically dispositive. Model dependence does not mean the fingerprints contain no information, and multiple independent variables can constrain attribution even when any one model is imperfect. Conversely, agreement among related models is not equivalent to independent replication. Confidence should increase most when attribution is robust to alternative covariance assumptions, forcing reconstructions, model subsets, observational products, time windows, and statistical methods. Econometric approaches such as cointegration, vector autoregression, and Granger-causality tests may provide useful checks, though they also depend on assumptions about stationarity, lag structure, and causal identification (Climate Working Group, 2025).

The strongest attribution claims concern global or large-scale variables with long records and clear physical mechanisms: global mean temperature, ocean heat content, stratospheric cooling during the ozone-depletion era, Arctic sea-ice decline, and global sea-level rise. Confidence generally weakens as the question becomes more local, more event-specific, or more dependent on simulated circulation. The conclusion that human forcing materially warmed the globe is therefore compatible with skepticism about the anthropogenic fraction of a regional drought, the change in the return period of a rare heatwave, or the projected rainfall response of a particular watershed.

Climate Models: Essential Tools, Imperfect Experiments

General circulation and Earth-system models solve discretized equations for momentum, mass, energy, and moisture on three-dimensional grids. Typical atmospheric grid cells are of order 100 km horizontally, with tens of vertical layers; ocean grids are finer but still cannot resolve many eddies and boundary processes. Century-scale simulations advance millions of time steps across roughly millions of atmospheric cells and tens or hundreds of millions of ocean cells (Koonin, 2021).

Many climatically important processes occur far below grid scale. Cloud microphysics, moist convection, turbulence, surface exchange, aerosol nucleation, and the effects of complex terrain must therefore be represented by parameterizations: semi-empirical relationships between resolved variables and unresolved fluxes. Parameterizations are not arbitrary, but they incorporate judgment and calibration. Different plausible choices generate different cloud feedbacks, rainfall patterns, circulation responses, and climate sensitivities (Koonin, 2021; Stephens, 2005).

Models are also tuned. Parameters are adjusted so that top-of-atmosphere energy balance, global mean temperature, sea ice, cloud fields, or other climatological targets approximately match observations. Tuning is unavoidable because unresolved processes cannot be derived uniquely from first principles at model resolution. The problem is underdetermination: compensating errors can allow different model structures to reproduce selected historical metrics. If a high-sensitivity model is paired with strong aerosol cooling, it can match twentieth-century temperature about as well as a lower-sensitivity model paired with weaker aerosol cooling (Curry & Webster, 2011; Koonin, 2021).

This is why a multimodel ensemble should not be interpreted as a random sample from a known probability distribution. CMIP collections are "ensembles of opportunity": models share code, parameterizations, institutional lineages, and forcing assumptions, while some centers contribute more simulations than others. Their spread is informative about model disagreement but is not a calibrated probability interval. Koonin (2021) notes that absolute global mean surface temperatures across CMIP5 models span roughly 3°C even when anomaly plots appear similar. Later generations have increased resolution and complexity without clear convergence in equilibrium climate sensitivity or some regional responses.

Historical performance is mixed. Models reproduce the broad late-twentieth-century global warming pattern, especially when anthropogenic forcings are included, and the IPCC reports that CMIP6 generally simulates global surface temperature within about 0.2°C over much of the historical record (IPCC, 2021). Yet models have difficulty with the rapid 1910-1940 warming, the phasing and amplitude of Atlantic and Pacific multidecadal variability, ENSO details, regional precipitation, and tropical tropospheric trends (Koonin, 2021). These limitations matter because the same processes influence near-term projections and event attribution.

Climate sensitivity remains the central uncertainty. Equilibrium climate sensitivity (ECS) is the eventual global mean warming after a sustained doubling of carbon dioxide; transient climate response (TCR) measures warming near the time of doubling under a gradual concentration increase. The long-standing Charney range of 1.5-4.5°C persisted for decades. CMIP6 models span approximately 1.8-5.7°C, with many high-sensitivity members driven by revised cloud feedbacks and warming faster than observations over the historical period (Climate Working Group, 2025). The width of this range, and the failure of successive model generations to narrow it, is itself an informative signal: sensitivity is governed largely by the same feedbacks—clouds

above all—that models must parameterize rather than resolve, so models alone cannot be expected to pin it down.

A partially independent estimate comes from the historical energy budget. If the planet's effective radiative forcing, surface warming, and heat uptake are characterized between two well-separated periods, global energy conservation constrains sensitivity directly, with far less dependence on the internal structure of a general circulation model, through the relation $ECS = F_{2x} \cdot \Delta T / (\Delta F - \Delta N)$, where F_{2x} is the forcing from doubled carbon dioxide and ΔN is the change in top-of-atmosphere radiative imbalance. Lewis and Curry (2015) applied this approach using the forcing and ocean-heat-uptake estimates compiled for the IPCC Fifth Assessment Report, selecting base and final periods to minimize and match volcanic and multidecadal influences. They obtained a median ECS of 1.64°C (17th-83rd percentile 1.25-2.45°C) and a median TCR of 1.33°C—values at the low end of the assessed likely range and well below the CMIP5 multimodel means of roughly 3.2°C for ECS and 1.8°C for TCR. Aerosol forcing uncertainty dominated the width of their distributions, and the long upper tail arose because inversion from temperature alone cannot cleanly separate greenhouse from aerosol forcing.

Updating this analysis, Lewis and Curry (2018) extended the records to 2016 and incorporated revised greenhouse-gas forcing relationships (which raised methane forcing), post-1990 aerosol and ozone changes (which made aerosol forcing less negative), and newer ocean-heat-content datasets. Their best-constrained estimate gave a median ECS near 1.50°C (5th-95th percentile 1.05-2.45°C) with one temperature product, rising to roughly 1.66-1.76°C when spatially complete (infilled) temperatures and time-varying feedbacks were used, with TCR near 1.20-1.33°C. They interpreted these constraints as implying that most CMIP5 models overestimate the historical temperature response to forcing, most plausibly through excessive positive cloud feedback.

Energy-budget estimates carry well-known caveats. They assume an approximately constant feedback parameter over the historical period, whereas the effective sensitivity inferred from recent decades may be lower than the true equilibrium value because the spatial pattern of historical warming differs from the eventual equilibrium pattern—the so-called pattern effect. They are also sensitive to the aerosol forcing estimate and to the choice of periods. For these reasons the results are best read as a constraint that leans toward the lower part of the range rather than as a single definitive value. They are, however, a genuinely observational constraint, and their persistent divergence from high-sensitivity models is not dissolved by assuming that the models must be right.

The most direct engagement with the evidence underlying recent IPCC sensitivity ranges is Lewis's (2023) reanalysis of a major multiple-lines-of-evidence assessment (Sherwood et al., 2020, as cited in Lewis, 2023) that strongly influenced the Sixth Assessment Report. That assessment combined process, historical, and paleoclimate evidence within a Bayesian framework to produce a relatively high and comparatively tight sensitivity range. Lewis argued that its procedure relied on a subjectively chosen prior and sequential updating whose intervals need not possess frequentist coverage, and he identified errors in the likelihood calculations for inputs with skewed distributions or nonlinear effects—including a coding error that reduced the assumed uncertainty in one paleoclimate carbon-dioxide value to a tenth of its intended magnitude. Substituting a mathematically derived, noninformative (Jeffreys) prior and corrected likelihoods, while retaining the original scientific inputs, actually raised the combined median sensitivity slightly, to about 3.2°C. The large downward change came instead from revising the physical inputs: weaker positive low-cloud feedback, a more negative Planck feedback, updated

historical forcing with a smaller pattern-effect adjustment, and revised paleoclimate treatments. With all revisions, Lewis obtained a median effective sensitivity of 2.16°C, a 17th-83rd percentile range of 1.75-2.70°C, and a 5th-95th percentile range of 1.55-3.20°C, assigning roughly a 36% probability to sensitivity below 2°C and characterizing values below 1.5°C or above 3.2°C as extremely unlikely.

Two lessons follow. First, the choice of statistical framework matters, but in this case it was not the driver of the disagreement: valid priors and corrected likelihoods alone did not lower the estimate, and the decisive factor was the specification of the physical inputs—the same feedbacks, forcings, and pattern effects that make sensitivity uncertain in the first place. Second, the existence of a range does not imply that every value within it is equally likely. Very low sensitivities must still account for the observed energy imbalance and the realized warming; very high sensitivities must account for the absence of comparably rapid warming under historical forcing and for paleoclimatic constraints; and the observational and reanalyzed-Bayesian estimates cluster noticeably below the upper half of the CMIP6 range. None of this proves that low sensitivity is correct, because paleoclimate and process reasoning can support higher values and the pattern effect could raise the true equilibrium response above the historical estimate. But it does imply that a responsible assessment should weight models against observations rather than averaging an ensemble of opportunity, and should treat the upper-tail sensitivities that dominate worst-case impact projections as possibilities to be tested rather than as established central expectations (Lewis, 2023; Lewis & Curry, 2015, 2018).

Clouds remain the largest structural challenge. Low clouds strongly reflect sunlight, while high clouds also impede outgoing longwave radiation. Small changes in cloud altitude, phase, coverage, or optical depth can produce radiative effects comparable to the forcing from greenhouse-gas changes. Stephens (2005) emphasized that models and observations must be evaluated together because cloud parameterizations are empirical and feedback estimates are difficult to infer from short satellite records. Lindzen and Choi (2011) interpreted tropical radiation-temperature covariation as evidence for stronger negative feedback and lower sensitivity, but the extrapolation from regional, short-term variability to global equilibrium response remains contested.

Aerosols create a parallel problem. Their direct scattering and indirect effects on cloud droplets offset an uncertain fraction of greenhouse warming. The CLOUD experiment showed that ammonia can enhance sulfuric-acid nucleation by orders of magnitude, yet the measured compounds were still insufficient to explain much observed boundary-layer nucleation, indicating missing processes (Kirkby et al., 2011). When a poorly constrained forcing is used to balance a poorly constrained sensitivity during model calibration, historical agreement cannot uniquely identify either quantity. This is precisely the degeneracy that energy-budget analyses attempt to sidestep by constraining forcing and heat uptake observationally rather than diagnosing them from the model itself (Lewis & Curry, 2015, 2018).

Models are therefore indispensable but conditional tools. They organize physical knowledge, test mechanisms, produce internally consistent scenarios, and reveal consequences that cannot be inferred from simple extrapolation. Their strongest uses concern large-scale response and qualitative direction. Their weakest uses involve precise regional forecasts, probability statements derived from ensemble frequency, and marginal temperature effects of small policy changes. Communicating this hierarchy of skill would strengthen, rather than weaken, public confidence in climate science.

Natural Forcing, Internal Variability, and the Residual Problem

Natural variability operates from days to millennia. ENSO redistributes ocean heat and alters global mean temperature over several years; the Pacific Decadal Oscillation and Atlantic multidecadal variability shape regional climate over decades; volcanic aerosols cool the surface episodically; solar variability changes incoming energy and may influence atmospheric chemistry; and cloud or circulation shifts can alter planetary albedo. No credible attribution analysis can treat these processes as an unstructured residual.

The IPCC estimates that natural external forcing contributed little to the net 1850-1900 to 2010-2019 warming, while internal variability contributed at most a few tenths of a degree over that interval (IPCC, 2021). This assessment is supported by the relatively small measured variation in total solar irradiance over recent satellite-era cycles and by the absence of a sustained twentieth-century volcanic trend. It is also consistent with ocean heat accumulation and the spatial pattern of many observed changes.

Alternative solar reconstructions and empirical studies have argued for a larger role. Soon (2005) reported a strong association between reconstructed solar irradiance and Arctic temperatures; Scafetta and West (2006) estimated that solar variability could account for a substantial fraction of twentieth-century warming; Neff et al. (2001) found coherence between cosmogenic solar proxies and Holocene monsoon variability; and Svensmark and Friis-Christensen (1997) proposed cosmic-ray modulation of clouds as an amplification mechanism. The Climate Working Group (2025) similarly argues that unresolved differences among irradiance composites and indirect mechanisms leave room for greater solar attribution.

These studies establish that solar-climate coupling is physically and historically plausible, but they do not yet provide a generally accepted quantitative alternative to greenhouse attribution. Correlation can arise from shared trends, uncertain reconstructions, or internal variability; proposed cosmic-ray-cloud relationships have not yielded a stable global effect large enough to explain recent warming; and satellite-era irradiance changes are small. The prudent conclusion is that solar effects may be underrepresented in some regional or multidecadal analyses, not that they explain the modern global trend in full.

Internal modes create a more immediate attribution problem because their phase can accelerate or mask forced warming over policy-relevant intervals. The 1998-2012 slowdown, for example, is interpreted by the IPCC as a combination of Pacific variability and solar-volcanic influences superimposed on continuing ocean heat uptake (IPCC, 2021). Models need not predict the exact phase of unforced variability in a century-scale projection, but failure to reproduce realistic amplitude, persistence, and spatial structure broadens uncertainty in decadal and regional forecasts.

Recent changes in planetary albedo illustrate the remaining ambiguity. The Climate Working Group (2025) highlights a decline in albedo after 2015 equivalent to roughly 1.7 W m^{-2} of additional absorbed solar energy, associated with reduced low- and mid-level cloudiness. That change could represent internal variability, an externally forced cloud feedback, aerosol changes, or a mixture. The observation is important; its causal interpretation is not yet settled. Similar caution applies whenever a residual is assigned to anthropogenic forcing simply because known natural drivers appear insufficient.

Natural variability is thus neither a universal explanation nor a negligible nuisance. It cannot plausibly account for all modern warming, but it can materially affect rates, regional patterns,

extremes, and short-window attribution. The residual problem should motivate better observations and model diagnostics, not rhetorical certainty.

Carbon Sinks, Global Greening, and Direct Effects of Carbon Dioxide

Climate discussions often treat carbon dioxide only as a radiative forcing, but the gas is also the substrate for photosynthesis. Rising concentration affects plant growth, water-use efficiency, ecosystem carbon uptake, and crop response. These direct effects do not cancel warming-related risks, but they are part of the net impact and should be quantified rather than dismissed as irrelevant.

Satellite leaf-area records show widespread greening. Zhu et al. (2016) combined three satellite products with a ten-model ecosystem ensemble and found statistically significant greening over approximately 25-50% of vegetated land from 1982 to 2009, compared with browning over less than 4%. Their factorial attribution assigned about 70% of the trend to carbon-dioxide fertilization, roughly 9% to nitrogen deposition, 8% to climate change, and 4% to land-cover change, with considerable uncertainty. Carbon dioxide also improved water-use efficiency in arid regions through partial stomatal closure.

This result is one of the clearest documented benefits associated with rising carbon dioxide, but it requires qualification. Models may overstate fertilization in tropical forests where field experiments are scarce; nitrogen and phosphorus constraints can limit response; greening can reflect shrub encroachment or invasive species rather than ecological improvement; and leaf area does not directly measure biodiversity, carbon permanence, or nutritional value. The IPCC assigns only low confidence to carbon-dioxide fertilization as the dominant cause of satellite-observed greening, illustrating that the same observational trend can support different attribution judgments (IPCC, 2021; Zhu et al., 2016).

The persistence of natural sinks is similarly consequential. Ballantyne et al. (2012) found that absolute land and ocean uptake increased over the second half of the twentieth century rather than collapsing under warming. That resilience suggests substantial negative feedback, though sink efficiency relative to emissions and future saturation remain uncertain. Carbon-cycle models still differ widely in projected land uptake, reflecting uncertainty in nutrient limitation, soil respiration, disturbance, and ecosystem adaptation (Climate Working Group, 2025).

Agriculture provides a more direct policy-relevant example. Free-air carbon-dioxide enrichment experiments generally increase yields for C3 crops such as wheat, rice, and soybeans, while C4 crops such as maize benefit most under water stress. The Climate Working Group (2025) reports an average yield increase near 18% for C3 crops under a 200-ppm enrichment and argues that some crop-model studies understate adaptation and fertilization. Koonin (2021) notes that global calorie availability and major-crop yields have risen dramatically despite warming, with technology, irrigation, fertilizer, improved varieties, and management dominating the historical signal.

Benefits are not unlimited. Extreme heat around flowering can sharply reduce yields; pests and diseases may shift; water availability and soil degradation remain important; and elevated carbon dioxide can reduce protein, iron, and zinc concentrations in some crops. These effects can be addressed partly through breeding, biofortification, supplementation, and changes in cultivation, but they should not be ignored. The correct assessment is not that carbon dioxide is simply "plant

food" or simply "pollution." It is a radiatively active gas with both beneficial and harmful biological effects whose net consequences vary by ecosystem, climate, and management.

Extreme Weather and the Limits of Event Attribution

A warmer climate changes the statistical environment in which weather occurs, but different hazards respond differently. Thermodynamic variables such as temperature and atmospheric moisture are more directly linked to greenhouse forcing than dynamically complex phenomena such as tornadoes, tropical-cyclone tracks, blocking patterns, or regional drought. The confidence of an attribution claim should reflect that hierarchy.

The IPCC's own assessment of extremes displays exactly this gradient of confidence. Its dedicated chapter treats it as an established fact that human-induced greenhouse-gas emissions have increased the frequency or intensity of some extremes, but the strength of that conclusion varies enormously by hazard (IPCC, 2021). For hot extremes the assessed language is "virtually certain"; for the intensification of heavy precipitation it is "likely"; and for many drought, river-flood, tropical-cyclone, and severe-convective-storm metrics it falls to "medium" or "low confidence," with the direction of past change explicitly uncertain in several cases. The chapter also notes that changes generally scale with global warming, so that even half-degree increments produce statistically significant shifts at global and large-regional scales, with proportionally larger changes for rarer events. Read directly, the assessment is far more differentiated than the headline that "extremes are increasing," and the differentiation runs toward greater caution for the dynamically complex hazards, not less.

Heat extremes provide the strongest case. The IPCC concludes that greenhouse-gas forcing is the principal cause of more frequent or intense hot extremes and fewer or weaker cold extremes globally, with hot extremes having increased since 1950 in more than four-fifths of the assessed land regions (IPCC, 2021). A shift in the mean temperature distribution makes threshold exceedances more common even if circulation statistics are unchanged, and the chapter projects that the intensity of extreme heat at 2°C of global warming will be at least double, and at 3°C roughly quadruple, that at 1.5°C, with the largest regional amplification—up to about two to three times the global rate—over mid-latitude and semi-arid land and in the Arctic for cold extremes (IPCC, 2021). Even here, though, the assessment records important local modulation: soil-moisture feedbacks, irrigation, and crop expansion have attenuated summer hot extremes in some regions, while urbanization has exacerbated nighttime warmth. And the magnitude of a particular event can still depend mainly on an unusual synoptic pattern. In its discussion of the 2021 Pacific Northwest heatwave, the Climate Working Group (2025) accepts an anthropogenic contribution of roughly 1.4-2°F to the temperature while questioning whether human forcing made the rare circulation pattern itself more probable. This distinction between thermodynamic amplification and dynamical causation is often lost in rapid attribution headlines.

Heavy precipitation also has a clear physical basis because warmer air can hold more water vapor. The IPCC finds that human influence likely contributed to large-scale precipitation changes and to the intensification of heavy precipitation over global land, while acknowledging substantial uncertainty in tropical patterns, streamflow, and circulation (IPCC, 2021). It ties this intensification to the Clausius-Clapeyron scaling of about 7% more atmospheric moisture per degree of warming, with frequency increases that are nonlinear and largest for the rarest events; at 4°C of warming it projects, for example, a likely doubling of what are currently ten-year events and a tripling of fifty-year events (IPCC, 2021). Crucially, the same chapter warns that this thermodynamic signal does not translate directly into river flooding: projections of peak

streamflow are more uncertain than those for surface-water (pluvial) flooding because runoff depends on soil moisture, snowmelt, land cover, and human water management, and the assessed confidence in the direction of river-flood change is correspondingly lower. Observed total precipitation trends are also spatially heterogeneous. Koonin (2021) reports a small long-term increase over global land and a larger U.S. increase, but with different signs across regions and seasons, and a rise in short-duration heavy rainfall does not translate automatically into a uniform increase in river flooding because soil moisture, snowmelt, reservoirs, land cover, channel engineering, and basin geometry also matter.

Tropical cyclones illustrate the difficulty of short and changing records. Reliable global monitoring begins in the satellite era, while earlier records depend on ships, landfalls, aircraft reconnaissance, and corrections for missed storms. Klotzbach and Landsea (2015) found that apparent increases in the most intense hurricanes were sensitive to the analysis period and improvements in satellite observation. Koonin (2021) emphasizes that no robust long-term trend is evident in global cyclone numbers or U.S. landfalling hurricanes, although some projections indicate higher rainfall rates and a 10-20% increase in selected intensity metrics under approximately 2°C of warming. The IPCC's synthesis is consistent with this layered picture: it assesses that the global proportion of the most intense (Category 3-5) tropical cyclones has likely increased over the past four decades, that the latitude of peak intensity has migrated poleward in the western North Pacific, and that the frequency of rapid-intensification events has likely increased, while projecting that the total global frequency of tropical cyclones will decrease or remain unchanged with warming (IPCC, 2021). Rising intensity among the strongest storms and higher rainfall rates are therefore compatible with stable or declining overall frequency—precisely the combination that headline claims of "more hurricanes" tend to blur. These statements can all be true simultaneously: frequency may show little trend, the strongest storms may intensify somewhat, and economic losses may rise mainly because more people and property occupy vulnerable coasts.

Tornado records are even more affected by detection changes. Raw U.S. counts rose as Doppler radar, public reporting, and damage surveys captured weak events that would previously have been missed. Restricting analysis to stronger tornadoes removes the apparent increase: Koonin (2021) reports no long-term trend in EF1+ events and a decline in EF3+ events since the mid-twentieth century. This caution is shared by the IPCC, which assigns low confidence to observed trends in the severe-convective-storm environment beyond the associated precipitation, while projecting a medium-confidence lengthening of the U.S. severe-storm season (IPCC, 2021). Climate models cannot resolve tornadoes directly, so projections depend on imperfect environmental proxies such as convective available potential energy and wind shear.

Floods and droughts resist simple global narratives. U.S. streamflow trends vary by region, and the IPCC has historically expressed low confidence in the sign of global flood changes. Instrumental drought indices show limited long-term U.S. change, while tree-ring records reveal medieval megadroughts in the American Southwest that exceeded many modern events (Koonin, 2021). The IPCC attributes increases in agricultural and ecological drought in some regions to human influence, operating primarily through greater evapotranspiration under higher temperatures and net radiation (medium confidence), while concluding that precipitation trends are not the main global driver of drought trends; increasing agricultural and ecological drought has been detected on all continents in multiple regions, with decreases in only a few, and the most severe and widespread changes emerge at higher warming levels (IPCC, 2021). This does not imply that warming cannot worsen drought through evapotranspiration or snowpack loss. It

means that precipitation variability, land management, water demand, and internal circulation remain major controls, and short records can misrepresent the natural envelope.

Wildfire is similarly multicausal. Global satellite-observed burned area declined by roughly 25% from 1998 to 2015, largely because agricultural intensification reduced savanna burning, even as large forest-fire activity increased in parts of western North America (Koonin, 2021; Shellenberger, 2020). Climate-driven fuel aridity can increase fire potential, but ignition, suppression policy, prescribed burning, forest density, invasive grasses, utility infrastructure, and development in the wildland-urban interface strongly mediate realized losses. The Climate Working Group (2025) argues that management and historical fire deficits are central to U.S. trends. Assigning every large fire primarily to climate change can obscure interventions that would reduce risk more directly.

Rapid event-attribution studies compare the observed climate with a modeled counterfactual world without anthropogenic forcing. They can estimate how warming changed the probability or intensity of an event, but results depend on model fidelity, the event definition, the selected region and duration, the tail distribution, and the stability of the background climate. Rare outliers are especially sensitive to assumptions. Such studies are useful when framed as conditional analyses, not as direct measurements of causation.

Compound events—concurrent or sequential extremes such as simultaneous heat and drought, or storm surge coinciding with extreme rainfall—are an area where the IPCC expresses growing but still qualified confidence, judging that their probability has likely increased and will continue to increase, with high confidence for concurrent heatwaves and droughts and medium-to-high confidence for fire weather and compound flooding (IPCC, 2021). Because such combinations can stress interdependent systems—power grids, water supply, or global food production—more than any single hazard, they are an appropriate focus for research and resilience planning even where confidence in individual component trends remains modest.

The broad conclusion is asymmetric. Confidence is high that warming increases hot extremes and can intensify heavy rainfall. Confidence is lower for global changes in hurricanes, tornadoes, floods, droughts, and wildfire, especially at regional scales. Climate change should neither be excluded from these hazards nor invoked as a universal first cause.

Sea-Level Rise: Global Signal, Local Consequence

Global mean sea level has risen since the nineteenth century as the ocean has warmed and land ice has melted. The IPCC concludes that human influence is very likely the main driver of global mean sea-level rise since at least 1971 (IPCC, 2021). Koonin (2021) summarizes an increase of roughly 250 mm since 1880, with an average rate near 1.8 mm per year over the full interval and about 3 mm per year in recent satellite-era estimates.

The recent rate is higher than the century average, but the history is not monotonic. Tide-gauge reconstructions show substantial multidecadal variability, including rates during parts of the early twentieth century that approached the initial satellite-era rate. Koonin (2021) argues that presentations based only on cumulative level can obscure this variability and that rate-of-change series provide a more demanding test of acceleration. The existence of earlier rapid intervals does not disprove anthropogenic acceleration; it widens the uncertainty around when and how clearly it emerges from natural and measurement variability.

Global mean sea level is also not the quantity experienced by a coastal community. Relative sea level combines ocean height with vertical land motion, regional circulation, gravitational effects from changing ice mass, sediment compaction, groundwater withdrawal, and tectonics. The Climate Working Group (2025) reports that much of the high relative rise at Galveston and Grand Isle is attributable to subsidence, leaving a smaller absolute ocean component. Conversely, glacial rebound causes relative sea level to fall in some high-latitude locations. Local planning should therefore use local tide gauges, geodesy, storm-surge history, and land-motion projections rather than a global mean alone.

Twenty-first-century projections depend on emissions, ocean heat uptake, glacier loss, and ice-sheet dynamics. High-end outcomes are dominated by uncertain mechanisms of rapid Antarctic or Greenland ice loss. Lower outcomes still imply meaningful increases in nuisance flooding, erosion, saltwater intrusion, and storm-surge exposure. The uncertainty is not a reason to ignore the risk; it is a reason to favor flexible adaptation pathways that can be scaled as observations clarify acceleration.

The Netherlands and other low-lying regions demonstrate that high exposure need not imply unmanageable vulnerability when societies invest in barriers, pumps, drainage, zoning, and emergency planning (Shellenberger, 2020). Poorer regions may lack that capacity, making development and reliable infrastructure central climate policies. Sea-level risk is best understood as the interaction of a real global signal with highly local geology, settlement, wealth, and governance.

Ecological, Human, and Economic Consequences

The severity of climate change cannot be inferred from temperature alone. Consequences depend on exposure, vulnerability, technology, institutions, and adaptation. A hazard can intensify while mortality falls, or remain stable while losses rise because more assets are placed in harm's way. Separating these components is essential to avoid attributing socioeconomic trends mechanically to climate.

Weather-related mortality has declined dramatically over the last century despite population growth and warming. Shellenberger (2020) reports that decadal natural-disaster deaths fell by about 92% from the 1920s to the 2010s. Koonin (2021) similarly cites an approximately 80-fold decline in weather-related death rates, attributing much of the improvement to forecasting, flood control, medical care, stronger buildings, and economic development. These trends do not prove that future climate damages will be small, but they demonstrate that vulnerability is not fixed and that adaptation can dominate the human outcome.

Economic loss statistics require the same care. Nominal disaster losses tend to rise with population, wealth, and coastal development. Normalized hurricane losses show much weaker trends, and expert assessments have generally attributed most historical increases in losses to exposure rather than changing hazard (Shellenberger, 2020). The Climate Working Group (2025) frames disaster risk as hazard multiplied by exposure and vulnerability and argues that losses per event relative to gross domestic product have declined. Policy that reduces only emissions while ignoring zoning, construction standards, drainage, fuel management, and warning systems addresses only one part of the risk equation.

Agricultural impacts are mixed and adaptive. Warming can reduce yields in already hot regions, increase heat stress, and alter water demand. At the same time, higher carbon dioxide can

enhance photosynthesis and water-use efficiency; longer growing seasons can benefit cooler regions; and technology has historically raised yields far faster than climate has reduced them. Koonin (2021) notes that wheat, rice, and maize yields more than doubled from 1961 to 2011, while per-capita calorie supply increased. Shellenberger (2020) emphasizes that many food-system projections continue to show rising production across warming scenarios because innovation, irrigation, improved cultivars, and farm management dominate.

Land use is the mechanism that links development to biodiversity outcomes, and here the evidence complicates simple narratives of an ever-expanding human footprint. Shellenberger (2020) argues that agricultural intensification—higher yields from fertilizer, irrigation, improved varieties, and mechanization—allows more food to be produced on less land, "sparing" habitat that extensive farming would otherwise consume, and that replacing draft animals with machinery frees cropland formerly devoted to animal feed. Consistent with this, global food production has risen far faster than agricultural land area, pasture area has contracted in many regions even as meat and dairy output increased, and global livestock land appears to have peaked around 2000 before declining by hundreds of millions of acres, aided by a shift from beef toward more feed-efficient poultry. Industrial livestock and crop systems achieve much of this efficiency through density and breeding that minimize land per unit of output; by one meta-review cited by Shellenberger, pasture-based beef required many times more land and generated several times more emissions per kilogram than feedlot beef, so scaling extensive "free-range" production to meet demand would tend to expand rather than spare habitat. These trends do not render land-use change benign—active deforestation frontiers remain a serious problem, and intensification carries its own nutrient and pollution burdens—but they indicate that environmental impact is better evaluated per unit of production and per unit of land than inferred from gross consumption, and that productivity gains can reduce pressure on ecosystems.

Ecological narratives also require causal discrimination. The 2019 claim that the Amazon supplies 20% of the world's oxygen confused gross photosynthesis with net ecosystem oxygen production, which is near zero after respiration and decomposition. Fire counts that year were elevated relative to 2018 but near the longer-term average, while deforestation remained a serious land-use problem (Shellenberger, 2020). Correcting an exaggerated claim does not make forest loss benign. It helps target the real drivers: agricultural incentives, governance, roads, enforcement, land tenure, and productivity.

Biodiversity decline is likewise driven by multiple pressures, including habitat conversion, overharvesting, invasive species, pollution, and poverty-linked dependence on biomass fuels. Climate change can compound these stresses, but it is not always the dominant present cause. Shellenberger (2020) argues that development, secure energy, and effective waste and land management often protect ecosystems more directly than symbolic restrictions on consumption. That thesis can be overstated, yet it usefully resists the tendency to relabel every environmental problem as a climate problem.

Macroeconomic damage estimates are highly model-dependent. Koonin (2021) summarizes estimates in which warming up to about 3°C reduces global gross domestic product by no more than several percent relative to a much larger future economy. Such figures are not trivial, particularly when losses fall on vulnerable populations, but they differ sharply from claims of inevitable civilizational collapse. Integrated assessment models translate climate sensitivity, socioeconomic growth, damage functions, adaptation, discount rates, and policy costs into a social cost of carbon. The Climate Working Group (2025) correctly describes these values as

conditional "if-then" outputs rather than direct measurements. Small changes in discounting, sensitivity, fertilization, or damage curvature can move the result substantially.

This does not establish that damages are modest with certainty. Economic models struggle with conflict, migration, ecosystem loss, correlated shocks, and low-probability tipping events. Conversely, they also struggle to represent innovation, substitution, autonomous adaptation, and the benefits of carbon dioxide. Honest analysis should present a range of results and identify the assumptions doing the work rather than elevating a single dollar value to an empirical fact.

From Research to Rhetoric: The Distortion of Climate Communication

Understanding public climate discourse requires attention not only to the underlying science but to the several filters through which it reaches decision-makers. Koonin (2021) distinguishes ordinary science—provisional, quantitative, uncertainty-aware, and open to challenge—from what he calls "The Science": a simplified public narrative presented as settled and policy-determinative. He does not allege a coordinated conspiracy. Instead he describes a "telephone game" in which information degrades as it passes from primary research, to full assessment reports of thousands of pages, to their Summaries for Policymakers, to press releases, and finally to media and political rhetoric. Each stage can introduce omission, simplification, or emphasis that serves non-scientific goals, and few participants—including many scientists and officials—ever consult the primary layers.

The persistence of distortion is explained by incentives rather than dishonesty. Koonin (2021) argues that media organizations face click-driven economics, shrinking scientific expertise, and the intrinsic salience of disaster imagery, which is easier to package than null trends or attribution uncertainty. Political actors on both sides can exploit the issue: some minimize well-supported findings, while others suppress uncertainty and label methodological dissent as denial. Scientific institutions and individual researchers operate under funding, publication, and reputational pressures that can reward dramatic conclusions; Koonin describes the resulting suspension of normal critical standards as otherwise careful scientists becoming "climate simple." Advocacy organizations whose fundraising depends on a sense of emergency have a structural interest in maintaining urgency, and the public—time-constrained and reliant on trusted outlets—rarely audits the claims. Koonin invokes the "Gell-Mann amnesia" effect, whereby readers notice errors in coverage of subjects they know well yet continue to trust the same outlet on unfamiliar topics.

Concrete cases illustrate how framing can decouple from data. Shellenberger (2020) examines the 2017 viral image of an emaciated polar bear presented as emblematic of climate change and contrasts it with population data: of nineteen recognized subpopulations, roughly two had increased, four decreased, five were stable, and the remainder lacked reliable counts, yielding no discernible overall decline, while historical hunting had removed more bears than the current estimated abundance. The prominent critic of the exaggeration—a zoologist—received no fossil-fuel funding and accepted anthropogenic warming. Correcting a false parable does not make habitat loss unimportant; it demonstrates that vivid imagery can substitute for demographic evidence.

A more consequential case concerns the assessment process itself. Shellenberger (2020) recounts economist Richard Tol's account of serving as a convening lead author for the impacts chapter and Summary for Policymakers of the IPCC Fifth Assessment Report. Tol described a shift from earlier drafts—which emphasized that many severe impacts reflect poverty and

mismanagement and can be reduced by development—toward more apocalyptic "Four Horsemen" framing, and he criticized the Summary for omitting context on adaptation, cold-stress reduction, and improved cultivars while foregrounding weakly supported claims about poverty traps, conflict, and migration. Tol ultimately dissented from the Summary and asked to have his name removed. A parallel episode was the campaign against political scientist Roger Pielke Jr. after congressional testimony on disaster losses: he was publicly labeled a "denier" and became the target of insinuations about undisclosed funding that a university investigation did not substantiate, prompting objections from scientific journals and societies about the chilling effect. These cases do not show that the mainstream assessment is wrong; they show that the summarizing and communicating layers—where authorship, narrative, and uncertainty language are decisive—are more contestable than the phrase "the science says" implies (Koonin, 2021; Shellenberger, 2020).

Shellenberger (2020) presses the interpretation further, reading the most apocalyptic strain of environmentalism as a quasi-religious narrative—complete with a fall from a natural Eden and an impending secular apocalypse—that supplies meaning, heroism, and moral urgency, and that would help explain the persistence of vivid but weakly supported claims. That interpretation is more speculative and should be held loosely; the documented gap between imagery and data in the polar-bear and assessment cases stands on its own regardless of any psychological account.

Risk language should distinguish "alarming" evidence from "alarmist" rhetoric. Risbey (2008) notes that some findings are legitimately alarming, while rhetorical exaggeration can still undermine trust. Claims that climate change will cause near-term human extinction are not supported by the assessment literature, and prominent scientists have rejected them (Shellenberger, 2020). Repeated use of apocalyptic framing can produce fatalism, encourage poorly designed emergency measures, and crowd out practical adaptation. Conversely, minimizing all risk because some advocates exaggerate it is equally unsound.

For nonexperts, Koonin (2021) offers a diagnostic checklist for recognizing distorted communication. Warning signs include pejorative labels such as "denier" or "alarmist" in place of argument; failure to distinguish natural from anthropogenic drivers; appeals to an undefined "97% consensus"; conflation of weather with multidecadal climate; the omission of magnitudes, baselines, denominators, or uncertainty intervals; alarming analogies presented without scale; and the presentation of conditional model projections as if they were observations or predictions. He particularly cautions against describing worst-case, high-emissions scenarios as "business as usual" without defending their socioeconomic assumptions—a point developed in the next section. None of these tests requires specialized training, and each shifts attention from rhetoric back to evidence.

Scenarios, Policy, and Response Under Uncertainty

Climate communication fails when it confuses an emissions pathway with a prediction. Representative Concentration Pathways and Shared Socioeconomic Pathways are conditional scenarios, not assigned probabilities. High-emissions pathways such as RCP8.5 are useful for stress testing, but Koonin (2021) and the Climate Working Group (2025) argue that they have often been presented as "business as usual" despite assumptions about population, coal use, energy intensity, and technology that became increasingly implausible. Using a high-end scenario without labeling its assumptions inflates projected impacts and distorts cost-benefit comparisons.

The opposite error is to dismiss high-end scenarios because they are unlikely. Tail risks matter, especially where adaptation is difficult or irreversible thresholds are plausible. The proper practice is transparent scenario weighting: present central, low, and high pathways; separate scenario uncertainty from model uncertainty; and show how conclusions change when extreme assumptions are removed. A robust policy should perform reasonably across a range of plausible futures rather than depend on one favored trajectory.

Beyond scenario labeling, Koonin (2021) frames the response problem by separating what society could do, what it should do, and what it will do. The first question is scientific and technological, the second turns on contested values and distributive judgments, and the third depends on political and economic feasibility. His central forecast is that deep global mitigation will prove far harder than policy rhetoric implies. Because atmospheric carbon-dioxide concentration reflects cumulative emissions and excess carbon dioxide persists for centuries, merely reducing annual emissions slows the growth of concentration; stabilization requires net emissions to approach zero, plausibly around the middle of the century for the Paris temperature targets. Yet world energy demand is projected to rise by roughly half by midcentury, concentrated in developing economies, while fossil fuels still supply about four-fifths of primary energy. The Paris Agreement, in this reading, is a mechanism of nonbinding, nationally determined, self-reported pledges without enforcement, and the gap between pledged emissions and pathways compatible with its temperature targets is large. Unilateral controls also invite carbon leakage as energy-intensive production relocates, and developing states rationally prioritize energy access, sanitation, and growth unless low-emission technologies become cost-competitive or wealthier countries finance the transition at a far greater scale.

If rapid global decarbonization proves improbable, three contingency responses deserve analysis. Koonin (2021) surveys solar radiation management, carbon dioxide removal, and adaptation. Stratospheric aerosol injection could in principle cool the planet quickly and at modest direct cost, but it would require indefinite maintenance, risk a "termination shock" if halted, produce spatially uneven effects on temperature and precipitation, and raise acute governance problems, including unilateral deployment by a single state or wealthy actor. Carbon dioxide removal reverses atmospheric loading more directly but faces daunting scale: removing on the order of ten gigatonnes annually at costs above one hundred dollars per tonne implies expenditures around a trillion dollars per year, together with vast transport and sequestration infrastructure, while biological uptake through reforestation is slower and constrained by land, permanence, and ecology. Adaptation, by contrast, is cause-agnostic, incremental, local, politically tractable, and effective against both natural and anthropogenic change. Koonin proposes an "adaptation wedges" framework in which interventions are compared by hazard, geography, cost, efficacy, and interaction with mitigation, and recommends prioritizing resilience to hazards already observed while strengthening development and governance in poorer countries. Adaptation as the dominant practical response, with mitigation and exploratory geoengineering research as complements, is a recurring conclusion of the skeptical literature.

The relationship between energy and human welfare is central to any realistic policy. Shellenberger (2020) argues that affluence and per-capita energy use are tightly coupled, that apparent emissions reductions in wealthy countries partly reflect the offshoring of energy-intensive manufacturing and its embodied emissions, and that "energy leapfrogging"—the hope that poor countries can reach high incomes using substantially less energy than earlier industrializers—is not well supported by cross-national experience, in part because efficiency gains lower the effective price of energy services and stimulate additional consumption through

rebound effects. He emphasizes energy density and power density as organizing variables: the historical progression from biomass to coal, then toward oil, natural gas, and nuclear power, reduces the mass and land required to deliver useful energy and can move combustion away from households, improving indoor air quality. The same substitution logic, associated with the work of Cesare Marchetti, describes how superior technologies displace inferior ones before the older resource is exhausted—kerosene and later vegetable oils displaced whale oil, sparing whales well before the 1982 moratorium—implying that decarbonization is more likely to succeed by making low-carbon energy cheaper and denser than by mandating scarcity.

This perspective also bears on development policy. Shellenberger (2020) contends that reliable grids, industrial capacity, transportation, irrigation, and large-scale generation are prerequisites for escaping poverty, and criticizes a late-twentieth-century shift in development financing toward small-scale, decentralized interventions that can provide household lighting but not the firm power required for manufacturing, modern hospitals, water treatment, or mechanized agriculture. He situates contemporary alarmism within a long neo-Malthusian tradition—from Malthus through later writers who successively relocated the binding limit from food to minerals, energy, pollution sinks, and climatic stability—and argues that this tradition has repeatedly underestimated technological adaptation. Against it he sets the work of Ester Boserup, who treated population pressure as a spur to agricultural innovation, and Amartya Sen, who showed that famine typically results from entitlement failure and distributional collapse rather than absolute scarcity. The policy implication is that infrastructure, markets, and productive capacity—not fixed natural ceilings—are the principal determinants of human vulnerability, and that poverty reduction is itself an environmental strategy, because prosperous societies can better afford conservation, adaptation, and cleaner energy.

The importance of prioritizing large mitigation levers over symbolic ones is illustrated by agriculture. Shellenberger (2020) notes that although dietary-change campaigns are prominent, their mitigation potential is modest: agricultural emissions are a limited share of the total, and even large shifts toward vegetarian diets reduce personal or national emissions only slightly once economy-wide accounting and rebound effects are included, leaving energy-system decarbonization as the dominant lever. Combined with the land-use efficiency of intensive production discussed earlier, this suggests that the environmentally favorable path in food, as in energy, runs through productivity gains rather than de-intensification. The general methodological proposition is that policies and technologies should be compared as complete alternatives—by lifecycle emissions, land footprint, power density, reliability, cost, and scalability—rather than judged against an unattainable zero-impact baseline.

Policy should be evaluated as a portfolio. Emissions reduction can lower long-term forcing, especially when adopted broadly and sustained. Adaptation reduces near-term harm regardless of the precise attribution of a hazard. Research and development can lower the future cost of clean energy, storage, industrial heat, carbon capture, advanced nuclear power, and low-carbon fuels. Resilient infrastructure, water systems, fire management, crop innovation, and disease control address impacts directly. Nature-based measures can provide carbon, watershed, and habitat benefits, though their permanence and land requirements must be assessed (Wang et al., 2023).

Energy reliability and affordability are not side issues. Air conditioning, heating, refrigeration, hospitals, water treatment, communications, and modern agriculture reduce climate vulnerability. The Climate Working Group (2025) reports that excess mortality associated with very hot U.S. days declined sharply after 1960, largely through air conditioning. Policies that

raise energy prices or reduce reliability can therefore impose health costs, particularly on low-income households. This does not favor fossil energy indefinitely; it favors transitions that preserve or improve energy services.

National policies must also be judged by scale and leakage. Carbon dioxide is globally mixed, so unilateral reductions slow the accumulation rate rather than rapidly lowering concentration. The Climate Working Group (2025) estimates that eliminating emissions from U.S. cars and light trucks, about 3% of global energy-related carbon dioxide, would reduce the global warming trend by at most a similar percentage if not offset elsewhere. The precise calculation depends on the baseline and policy response, but the qualitative point is sound: climate benefits require international participation, and domestic policy should account for relocation of industry and emissions.

A skeptical policy framework is not a case for inaction. It is a case for proportionality, sequencing, and accountability. High-value actions include eliminating subsidies that encourage risky development; pricing externalities where administratively feasible; funding basic and applied energy research; expanding transmission and firm low-carbon generation; improving methane control where leakage is measurable; modernizing grids; protecting critical infrastructure; and strengthening adaptive capacity in poorer regions. Policies should be revised when costs exceed forecasts or benefits fail to appear.

The precautionary principle applies to both climate change and climate policy. Continued high emissions create long-lived risks, but rapid restructuring can create energy poverty, fiscal strain, land-use conflict, mineral dependence, and reliability failures. The rational response is not to choose one precaution and ignore the other. It is to compare them openly.

What Can Be Said with High Confidence

- 1. The greenhouse effect is real and quantitatively important.** Carbon dioxide absorbs infrared radiation, and a doubling produces a direct forcing near $3.7\text{--}4\text{ W m}^{-2}$. Feedbacks determine the larger temperature response (Koonin, 2021; Lindzen, 1997).
- 2. The modern carbon-dioxide rise is predominantly anthropogenic.** Emissions accounting, isotopic change, oxygen decline, and hemispheric gradients jointly identify fossil combustion and land-use change as the principal causes (Koonin, 2021).
- 3. The climate system has warmed, and human influence is substantial.** Surface temperature, ocean heat, cryospheric change, and sea level provide independent evidence. The IPCC best estimate assigns approximately 1.07°C of 2010-2019 warming relative to 1850-1900 to human influence (IPCC, 2021).
- 4. Some consequences are already detectable.** Hot extremes have increased, cold extremes have decreased, the ocean has accumulated heat, glaciers and Arctic sea ice have declined, and global mean sea level has risen. Attribution is strongest at large scales and weaker for many regional hazards (IPCC, 2021).
- 5. Human outcomes are mediated by exposure, vulnerability, and adaptation.** Development, infrastructure, warnings, energy access, and land management can substantially reduce mortality and losses even under changing hazards (Climate Working Group, 2025; Koonin, 2021; Shellenberger, 2020).

What Remains Materially Uncertain

1. Climate sensitivity and feedback tails. Clouds, aerosols, ocean heat uptake, and pattern effects leave a consequential range in ECS and TCR. Observationally constrained energy-budget estimates and reanalyzed Bayesian assessments cluster below the upper half of the model range, while some high-sensitivity models warm too rapidly and very low estimates face other observational constraints (Climate Working Group, 2025; Koonin, 2021; Lewis, 2023; Lewis & Curry, 2015, 2018; Stephens, 2005).

2. The exact partition between forced change and multidecadal variability. The long-term human contribution is strong, but internal ocean-atmosphere modes can materially alter regional and decadal trends (IPCC, 2021; Koonin, 2021).

3. Regional precipitation, circulation, and many extremes. Model skill is uneven for tropical rainfall, drought, floods, cyclones, tornadoes, blocking, and wildfire. The IPCC's own confidence for many of these hazards is medium or low, and event-attribution estimates are conditional on model and statistical choices (Climate Working Group, 2025; IPCC, 2021; Koonin, 2021).

4. High-end ice-sheet and sea-level outcomes. Continued rise is expected, but the probability and timing of rapid dynamic ice loss remain deeply uncertain. Local relative sea level also depends strongly on vertical land motion (Climate Working Group, 2025; Koonin, 2021).

5. Net ecological and agricultural effects. Warming, fertilization, water stress, nutrient constraints, pests, adaptation, and land management interact. Global greening is real, but its ecological quality and persistence are not captured by leaf area alone, and agricultural land use has in fact contracted in many regions through intensification (IPCC, 2021; Shellenberger, 2020; Zhu et al., 2016).

6. Economic damages and optimal policy. Discounting, growth, adaptation, technological change, damage functions, and international participation dominate many cost-benefit results. Social-cost estimates are conditional rather than directly observed, and the feasibility, cost, and distributional effects of rapid mitigation are themselves uncertain (Climate Working Group, 2025; Koonin, 2021; Lomborg, 2020).

Toward Epistemic Humility and Adaptive Governance

Climate science has achieved genuine successes. The radiative mechanism was identified long before modern warming, the anthropogenic carbon signal is measurable, and multiple components of the Earth system have changed in physically coherent ways. These achievements justify concern and continued mitigation. They do not justify treating every model output, impact estimate, or policy prescription as equally established.

A more reliable scientific culture would disclose tuning choices, evaluate models against out-of-sample observations, publish absolute as well as anomalous fields, distinguish ensemble spread from probability, and test attribution under alternative estimates of internal variability. It would report when models fail, reward replication, and resist selective time windows. Yang et al. (2021) found low statistical power and effect-size exaggeration in field studies of global-change biology, reinforcing the need for preregistration, data transparency, and publication of null results beyond climate modeling itself.

Koonin (2021) proposes a specific institutional reform to serve these ends: formal adversarial, or "Red Team," review of major climate assessments. A technically qualified team would be charged

with identifying weak assumptions, omitted evidence, inferential gaps, and sensitivity to model or scenario choices, and the assessment's authors would respond, with the exchange made public. He grounds the proposal in a distinction between peer review of individual research papers—which evaluates a focused contribution and is followed, ideally, by replication or refutation—and review of assessment reports, which select, weight, and synthesize thousands of studies for nonexpert decision-makers, so that authorship, narrative structure, and uncertainty language become decisive. Because governments can select assessment authors, impose few conflict-of-interest constraints, and negotiate the final wording of Summaries for Policymakers, conventional peer review of the underlying literature does not, in his view, independently validate the high-level synthesis. The aim of a Red Team is not to reject mainstream findings but to separate conclusions robust to challenge from those dependent on fragile assumptions or rhetorical compression—an objective consonant with, rather than opposed to, scientific norms.

Policy institutions should mirror that humility. Decisions can be robust without pretending uncertainty has disappeared. Coastal defenses can be designed in stages; building codes can incorporate safety margins; energy systems can diversify rather than bet on a single technology; and emissions policy can use periodic review clauses tied to observed costs, technology, and climate response. Adaptation is not surrender, and mitigation is not proof of catastrophe. They are complementary forms of risk management.

The central question is no longer whether humans influence climate. They do, through greenhouse gases, aerosols, and land-use change. The more difficult questions are how large the response will be, how impacts will be distributed, which risks deserve priority, and which interventions will reduce total harm rather than merely signal concern. Those questions remain open enough to require skepticism and mature enough to require action.

The scientifically defensible position is therefore neither complacency nor panic. It is calibrated confidence: strong where multiple independent observations and physical mechanisms converge; provisional where results depend on tuned models or short records; and explicitly conditional where policy outcomes depend on economic and technological assumptions. Such a framework can support emissions reduction, adaptation, prosperity, and environmental stewardship without demanding ideological conformity or false certainty.

Use of generative artificial intelligence

Claude Opus 4.8, GPT-5.6 Sol, and Grok 4.3 were used in preparing initial drafts of the manuscript and for proofreading. The author reviewed and edited all output and takes responsibility for the content.

References

- Ballantyne, A. P., Alden, C. B., Miller, J. B., Tans, P. P., & White, J. W. C. (2012). Increase in observed net carbon dioxide uptake by land and oceans during the past 50 years. *Nature*, 488(7409), 70–72.
- Caillon, N., Severinghaus, J. P., Jouzel, J., Barnola, J.-M., Kang, J., & Lipenkov, V. Y. (2003). Timing of atmospheric CO₂ and Antarctic temperature changes across Termination III. *Science*, 299(5613), 1728–1731. <https://doi.org/10.1126/science.1078758>
- Christy, J. R., Herman, B., Pielke, R., Sr., Klotzbach, P., McNider, R. T., Hnilo, J. J., Spencer, R. W., Chase, T., & Douglass, D. (2010). What do observational datasets say about modeled tropospheric temperature trends since 1979? *Remote Sensing*, 2(9), 2148–2169.

- Christy, J. R., & McNider, R. T. (2017). Satellite bulk tropospheric temperatures as a metric for climate sensitivity. *Asia-Pacific Journal of Atmospheric Sciences*, 53(4), 511–518. <https://doi.org/10.1007/s13143-017-0070-z>
- Christy, J. R., Norris, W. B., & McNider, R. T. (2009). Surface temperature variations in East Africa and possible causes. *Journal of Climate*, 22(12), 3342–3356. <https://doi.org/10.1175/2008JCLI2726.1>
- Christy, J. R., Norris, W. B., Spencer, R. W., & Hnilo, J. J. (2007). Tropospheric temperature change since 1979 from tropical radiosonde and satellite measurements. *Journal of Geophysical Research: Atmospheres*, 112(D6), D06102.
- Climate Working Group. (2025). *A critical review of impacts of greenhouse gas emissions on the U.S. climate*. U.S. Department of Energy.
- Curry, J. A., & Webster, P. J. (2011). Climate science and the uncertainty monster. *Bulletin of the American Meteorological Society*, 92(12), 1667–1682. <https://doi.org/10.1175/BAMS-D-10-3139.1>
- Fall, S., Watts, A., Nielsen-Gammon, J., Jones, E., Niyogi, D., Christy, J. R., & Pielke, R. A., Sr. (2011). Analysis of the impacts of station exposure on the U.S. Historical Climatology Network temperatures and temperature trends. *Journal of Geophysical Research: Atmospheres*, 116(D14), D14120.
- Intergovernmental Panel on Climate Change. (2021). *Climate change 2021: The physical science basis: Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (V. Masson-Delmotte et al., Eds.). Cambridge University Press. <https://doi.org/10.1017/9781009157896>
- Kirkby, J., Curtius, J., Almeida, J., Dunne, E., Duplissy, J., Ehrhart, S., ... Kulmala, M. (2011). Role of sulphuric acid, ammonia and galactic cosmic rays in atmospheric aerosol nucleation. *Nature*, 476(7361), 429–433.
- Klotzbach, P. J., & Landsea, C. W. (2015). Extremely intense hurricanes: Revisiting Webster et al. (2005) after 10 years. *Journal of Climate*, 28(19), 7621–7629.
- Koonin, S. E. (2021). *Unsettled: What climate science tells us, what it doesn't, and why it matters*. BenBella Books.
- Lamb, H. H. (1965). The early medieval warm epoch and its sequel. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 1(1), 13–37.
- Lewis, N. (2023). Objectively combining climate sensitivity evidence. *Climate Dynamics*, 60, 3139–3165. <https://doi.org/10.1007/s00382-022-06468-x>
- Lewis, N., & Curry, J. A. (2015). The implications for climate sensitivity of AR5 forcing and heat uptake estimates. *Climate Dynamics*, 45, 1009–1023. <https://doi.org/10.1007/s00382-014-2342-y>
- Lewis, N., & Curry, J. (2018). The impact of recent forcing and ocean heat uptake data on estimates of climate sensitivity. *Journal of Climate*, 31(15), 6051–6071. <https://doi.org/10.1175/JCLI-D-17-0667.1>
- Lindzen, R. S. (1997). Can increasing carbon dioxide cause climate change? *Proceedings of the National Academy of Sciences*, 94(16), 8335–8342. <https://doi.org/10.1073/pnas.94.16.8335>

- Lindzen, R. S., & Choi, Y.-S. (2011). On the observational determination of climate sensitivity and its implications. *Asia-Pacific Journal of Atmospheric Sciences*, 47(4), 377–390.
- Ljungqvist, F. C. (2010). A new reconstruction of temperature variability in the extra-tropical Northern Hemisphere during the last two millennia. *Geografiska Annaler: Series A, Physical Geography*, 92(3), 339–351.
- Lomborg, B. (2020). *False alarm: How climate change panic costs us trillions, hurts the poor, and fails to fix the planet*. Basic Books.
- McIntyre, S., & McKittrick, R. (2005). Hockey sticks, principal components, and spurious significance. *Geophysical Research Letters*, 32, L03710. <https://doi.org/10.1029/2004GL021750>
- Neff, U., Burns, S. J., Mangini, A., Mudelsee, M., Fleitmann, D., & Matter, A. (2001). Strong coherence between solar variability and the monsoon in Oman between 9 and 6 kyr ago. *Nature*, 411(6835), 290–293.
- Petit, J. R., Jouzel, J., Raynaud, D., Barkov, N. I., Barnola, J.-M., Basile, I., Bender, M., Chappellaz, J., Davis, M., Delaygue, G., Delmotte, M., Kotlyakov, V. M., Legrand, M., Lipenkov, V. Y., Lorius, C., Pépin, L., Ritz, C., Saltzman, E., & Stievenard, M. (1999). Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature*, 399(6735), 429–436. <https://doi.org/10.1038/20859>
- Risbey, J. S. (2008). The new climate discourse: Alarmist or alarming? *Global Environmental Change*, 18(1), 26–37.
- Scafetta, N., & West, B. J. (2006). Phenomenological solar contribution to the 1900–2000 global surface warming. *Geophysical Research Letters*, 33(5), L05708. <https://doi.org/10.1029/2005GL025539>
- Shellenberger, M. (2020). *Apocalypse never: Why environmental alarmism hurts us all*. Harper.
- Sherwood, S. C., Webb, M. J., Annan, J. D., Armour, K. C., Forster, P. M., Hargreaves, J. C., ... Zelinka, M. D. (2020). An assessment of Earth's climate sensitivity using multiple lines of evidence. *Reviews of Geophysics*, 58(4), e2019RG000678. <https://doi.org/10.1029/2019RG000678>
- Soon, W., & Baliunas, S. (2003). Proxy climatic and environmental changes of the past 1000 years. *Climate Research*, 23(2), 89–110.
- Soon, W., Baliunas, S., Idso, C., Idso, S., & Legates, D. R. (2003). Reconstructing climatic and environmental changes of the past 1000 years: A reappraisal. *Energy & Environment*, 14(2–3), 233–296.
- Soon, W. W.-H. (2005). Variable solar irradiance as a plausible agent for multidecadal variations in the Arctic-wide surface air temperature record of the past 130 years. *Geophysical Research Letters*, 32(16), L16712.
- Stephens, G. L. (2005). Cloud feedbacks in the climate system: A critical review. *Journal of Climate*, 18(2), 237–273.
- Svensmark, H., & Friis-Christensen, E. (1997). Variation of cosmic ray flux and global cloud coverage — a missing link in solar-climate relationships. *Journal of Atmospheric and Solar-Terrestrial Physics*, 59(11), 1225–1232.

- Wang, F., Harindintwali, J. D., Wei, K., Shan, Y., Mi, Z., Costello, M. J., Grunwald, S., Feng, Z., Wang, F., Guo, Y., Wu, X., Kumar, P., Kästner, M., Feng, X., Kang, S., Liu, Z., Fu, Y., Zhao, W., Ouyang, C., ... Tiedje, J. M. (2023). Climate change: Strategies for mitigation and adaptation. *The Innovation Geoscience*, 1(1), 100015. <https://doi.org/10.59717/j.xinn-geo.2023.100015>
- Yang, Y., Hillebrand, H., Lagisz, M., Cleasby, I., & Nakagawa, S. (2021). Low statistical power and overestimated anthropogenic impacts, exacerbated by publication bias, dominate field studies in global change biology. *Global Change Biology*, 28(3), 969–990. <https://doi.org/10.1111/gcb.15972>
- Zhu, Z., Piao, S., Myneni, R. B., Huang, M., Zeng, Z., Canadell, J. G., Ciais, P., Sitch, S., Friedlingstein, P., Arneeth, A., Cao, C., Cheng, L., Kato, E., Koven, C., Li, Y., Lian, X., Liu, Y., Liu, R., Mao, J., ... Zeng, N. (2016). Greening of the Earth and its drivers. *Nature Climate Change*, 6(8), 791–795. <https://doi.org/10.1038/nclimate3004>

Suggested citation

- Moore, T. M. (2026). *Human influence on global climate: A comprehensive synthesis of evidence, uncertainty, and scientific controversy*. Moore Metrics. <https://www.mooremetrics.com/climate-change/>