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ASSOCIATIONS BETWEEN MAJOR GREENHOUSE GAS RADIATIVE FORCING COMPONENTS AND GLOBAL ANNUAL SURFACE TEMPERATURE ANOMALY VARIATIONS

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Abstract:

This analysis examines whether associations between major greenhouse gas forcing components and global surface temperature persist when annual levels are replaced by annual changes. NOAA forcing estimates and NASA GISTEMP temperature anomalies provide 15 annual observations covering 2010 to 2024 and 14 annual differences. Descriptive statistics and Pearson correlations compare carbon dioxide, methane, and nitrous oxide forcing with contemporaneous temperature anomalies. Level correlations are positive at 0.849, 0.842, and 0.843, respectively, but decline to 0.310, 0.136, and 0.117 for annual changes. Temperature decreases in four annual transitions despite increases in every forcing component throughout the observation window. These findings distinguish shared movement across annual conditions from weaker correspondence between annual increments, without identifying independent causal contributions. The empirical contribution is a consistent comparison across three forcing components within the same global observation window. The analysis clarifies the temporal interpretation of associations within planetary energy balance reasoning. International climate reporting should distinguish persistent radiative influence from annual temperature fluctuations and state explicitly whether indicators represent levels or changes.

Key Words: Greenhouse Gas Forcing; Global Surface Temperature; Temporal Aggregation; First Differences; Pearson Correlation.

1. Introduction:

Rising greenhouse gas forcing and fluctuating annual surface temperatures create an interpretive challenge for climate monitoring: persistent warming influence does not imply a uniform temperature increase each year. Distinguishing these temporal patterns matters when institutions communicate annual climate observations and assess whether short periods represent sustained change. The Intergovernmental Panel on Climate Change 2021 situates observed surface warming within a system shaped by radiative forcing, internal variability, and heat exchange among climate components. This framework establishes why the relationship between greenhouse gas forcing and temperature must be interpreted at the temporal scale represented by the evidence. Planetary energy balance provides the physical foundation for examining this relationship. Increased greenhouse gas abundance alters atmospheric absorption and the balance between incoming and outgoing energy, creating a warming influence on the climate system. Carbon dioxide, methane, and nitrous oxide contribute through distinct absorption characteristics, while overlapping spectral effects influence their calculated forcing. Etminan et al. 2016 demonstrate that these physical properties affect forcing estimates, particularly for methane. Consequently, emissions, atmospheric concentrations, radiative forcing, and surface temperature represent different stages of the climate process and cannot be treated as interchangeable measures. This analysis focuses specifically on published forcing estimates and observed temperature anomalies.

The temperature response also depends on how energy moves through the climate system. Hansen et al. 2011 explain that ocean heat uptake influences the timing of surface adjustment to planetary energy imbalance. Kosaka and Xie 2013 demonstrate through climate modelling that tropical Pacific surface conditions can modify global temperature evolution alongside continued radiative forcing. Together, these findings distinguish the physical warming influence of greenhouse gases from the expectation of immediate annual temperature correspondence. They provide a basis for examining annual levels and annual changes separately, while reserving causal explanations for designs that directly represent the relevant processes. Measurement choices further shape interpretation. Global surface temperature anomalies combine observations across land and ocean environments into an aggregate departure from a reference average. Hansen et al. 2010 show that observational coverage and the treatment of spatially incomplete records affect estimates of global temperature change. Lenssen et al. 2019 extend the assessment of uncertainty associated with measurements, coverage, and processing in GISTEMP. These contributions establish the value of the global anomaly while clarifying that a complete annual series remains an observational estimate. This analysis retains the published GISTEMP version 4 annual anomalies and their reference period rather than constructing an alternative temperature indicator.

The closest literature addresses complementary but distinct questions. Marvel et al. 2016 examine how responses to individual forcings affect climate sensitivity estimates, while Richardson et al. 2016 investigate differences between climate model responses and estimates derived from Earth's energy budget. Medhaug et al. 2017 show how temporal definitions, observational choices, and variability influence interpretations of apparent changes in warming rates. These papers establish that forcing response, measurement, and temporal representation matter. They do not, by themselves, determine the descriptive correspondence between each of the three forcing components and temperature in the matched annual observations examined here. The bounded empirical question is how that correspondence differs between levels and annual increments over 2010 to 2024. This study aims to describe how carbon dioxide, methane, and nitrous oxide forcing correspond with global annual surface temperature anomalies, and how those relationships change when expressed as annual differences. The analysis combines NOAA forcing estimates with NASA temperature anomalies for 15 global calendar years. It examines each forcing component separately through descriptive statistics and Pearson correlations, then applies the same comparisons to 14 annual changes. The design

provides a consistent comparison within one observation window and preserves the distinction between variation across annual states and variation between consecutive years. Its analytical scope is descriptive association rather than independent attribution of warming to individual gases.

The findings identify positive level correlations exceeding 0.84 for all three forcing components, alongside weaker annual change correlations ranging from 0.117 to 0.310. This contrast makes temporal representation central to the interpretation of the observed relationships. The contribution is an explicit comparison across three physically distinct components using the same outcome, period, and transformation. It qualifies the information conveyed by strong level correlations without treating weaker annual correspondence as evidence against greenhouse warming. For climate reporting, the evidence supports presenting forcing levels, temperature anomalies, and annual changes as distinct indicators, with their temporal definitions stated clearly. The global aggregation makes this interpretive lesson relevant to international monitoring, while providing no basis for country specific comparisons or policy effect estimates.

2. Theory Conceptual Framework and Research Questions Development:

This analysis draws on planetary energy balance theory to examine the relationship between major greenhouse gas forcing components and global annual surface temperature anomalies from 2010 to 2024. Increased atmospheric absorption of radiation alters the balance between incoming solar energy and outgoing terrestrial energy. Surface warming contributes to restoring that balance, while ocean heat uptake influences the timing of the response. Hansen et al. 2011 establish the physical connection between radiative forcing, planetary energy imbalance, and temperature adjustment. This mechanism provides a theoretical expectation of warming under increased greenhouse gas forcing, without implying that temperature must increase in every calendar year. The conceptual framework connects three observed forcing estimates with one observed temperature series. Carbon dioxide, methane, and nitrous oxide forcing represent distinct components of major greenhouse gas radiative forcing, measured in watts per square metre. Global annual surface temperature anomaly represents the temperature outcome, measured in degrees Celsius relative to the 1951 to 1980 average. The forcing components remain separate measured variables rather than indicators of an estimated latent construct. The framework expresses theoretically motivated associations between each component and temperature. It does not treat those associations as independently identified causal effects.

Carbon dioxide forcing captures the additional radiative influence associated with increased atmospheric carbon dioxide. Greater forcing strengthens the warming influence on the climate system, but the annual temperature response also reflects heat redistribution and other sources of variability. Hansen et al. 2010 demonstrate that substantial annual temperature fluctuations can coexist with sustained global warming. Accordingly, this analysis distinguishes the descriptive association between forcing and temperature levels from the correspondence between their annual changes. The first captures movement across the observation period, while the second examines whether larger annual forcing increments coincide with larger annual temperature changes.

Research question 1: How do carbon dioxide forcing and global annual surface temperature anomaly vary together in levels and annual changes from 2010 to 2024?

Methane forcing represents a second radiative contribution whose magnitude depends on its absorption characteristics and interactions with other atmospheric gases. Etminan et al. 2016 show that incorporating methane absorption of solar radiation changes its estimated forcing and that overlapping absorption affects the calculation of individual gas contributions. This evidence supports examining methane through its published forcing estimate rather than treating concentration, emissions, and forcing as interchangeable measures. A warming influence is physically expected, but the contemporaneous association with annual surface temperature remains an empirical question within the available observation period.

Research question 2: How do methane forcing and global annual surface temperature anomaly vary together in levels and annual changes from 2010 to 2024?

Nitrous oxide forcing provides the third measured component. Its theoretical connection with temperature follows the same energy balance mechanism, although a common physical mechanism does not imply identical annual statistical relationships across gases. The observed surface response depends on the combined forcing environment and the evolving distribution of heat within the climate system. Richardson et al. 2016 demonstrate that estimates connecting radiative forcing with temperature response depend on observational coverage, measurement definitions, and forcing uncertainty. This analysis therefore examines the correspondence between nitrous oxide forcing and temperature without interpreting their descriptive relationship as a separate estimate of climate sensitivity.

Research question 3: How do nitrous oxide forcing and global annual surface temperature anomaly vary together in levels and annual changes from 2010 to 2024?

The temperature construct is an estimated global average derived from spatially distributed observations. Lenssen et al. 2019 identify measurement uncertainty, changing observational coverage, and processing choices as contributors to uncertainty in the GISTEMP temperature record. This analysis retains the published annual anomaly as its outcome and uses the 15 matched annual observations and 14 annual changes already available in the dataset. The research questions permit descriptive resolution through temporal patterns, observed ranges, and correspondence between increases and decreases. They impose no requirement that every association be positive or that annual changes reproduce the relationship visible in levels.

3. Data:

This analysis combines global annual greenhouse gas forcing estimates with surface temperature anomalies for 2010 to 2024.The data procedures establish provenance, define the analytical sample, document variable construction, and support descriptive comparisons of levels and annual changes.

3.1 Data Sources, Population, and Sample Construction:

The dataset combines two public institutional sources. The National Oceanic and Atmospheric Administration Global Monitoring Laboratory supplies annual effective radiative forcing estimates through its Annual Greenhouse Gas Index data table. The selected series identifiers are CO2, CH4, and N2O. These columns measure forcing contributions in watts per square metre rather than atmospheric concentrations or the dimensionless greenhouse gas index. The National Aeronautics and Space Administration Goddard Institute for Space Studies supplies the temperature outcome through GISTEMP version 4. The selected

series is the global annual land and ocean temperature anomaly, identified by the January through December annual mean column. Hansen et al. 2010 describe the integration of meteorological station observations and sea surface temperature records underlying the global temperature measure. The empirical structure is a single global annual time series. The observational unit is one calendar year, with 15 observations covering 2010 through 2024 inclusive. Geographical coverage is global, and no industrial sector defines eligibility. Forcing values are published annual estimates, while temperature values are annual averages relative to the 1951 to 1980 reference period. Neither measure represents an annual emissions flow. The target population comprises global calendar years within the stated observation window. The accessible sampling frame comprises those years represented in both source extracts. Selection retains every eligible year, without sampling countries, monitoring stations, or individual atmospheric measurements. All 15 years satisfy the inclusion rule and contain all four analytical variables. Table 1 documents the resulting sample.

Table 1: Sample construction

Stage	Global Units	Annual Observations	Reason or Rule
Eligible forcing extract	1	15	Published CO2, CH4, and N2O forcing estimates for 2010 to 2024
Eligible temperature extract	1	15	Published global annual anomalies for the same years
Records excluded during matching	0	0	Every eligible year appears in both extracts
Merged annual sample	1	15	One record per calendar year with four complete measures
Records removed for missing values or duplication	0	0	No missing analytical values or duplicate years
Final descriptive levels sample	1	15	All matched annual observations retained
Observations unavailable for annual differencing	1	1	The first year has no preceding observation within scope
Final annual changes sample	1	14	Changes calculated for 2011 to 2024

The supplied workbook records extraction and release metadata separately from observation years. The retained figures are retrospective historical estimates rather than a reconstruction of information available during each calendar year. GISTEMP version 4 is identified explicitly; the forcing extract is identified by its source table and column names. Public download access required no credentials. A separate redistribution licence was not independently verified.

3.2 Data Integration, Cleaning, and Quality Assurance:

Integration uses calendar year as the sole merge key. Both sources contain global annual observations, so the intended relationship is one forcing record to one temperature record for each year. The consolidated workbook contains 15 distinct years, with no unmatched years, duplicate year identifiers, or increase in observations after integration. Calendar alignment requires no fiscal year adjustment or conversion from monthly to annual frequency because the published annual series are used directly. The completeness check covers all 60 analytical values across the four variables. Every variable has 15 valid observations and zero missing values. No observations were imputed, interpolated, replaced with zero, or supplemented from another dataset. Published numeric values remain unchanged. The forcing series retain three decimal places, and the temperature series retains two decimal places. Annual changes were independently checked against consecutive observations in the level's worksheet. All 56 calculated changes agree with their underlying annual differences. No additional observations were introduced to construct the first difference, which preserves the observation boundary and leaves 14 usable annual changes. No threshold-based outlier deletion, trimming, or winsorisation was applied. All published extremes remain in the analytical sample. The checks establish temporal uniqueness, completeness, numeric consistency, and agreement between stored formulas and source values. They do not constitute independent remeasurement of the underlying atmospheric or temperature records. The source estimates incorporate provider processing and historical revisions. Lenssen et al. 2019 identify observational coverage, measurement changes, and processing choices as sources of uncertainty in GISTEMP. Accordingly, numerical completeness is distinguished from absence of measurement uncertainty. No additional source adjustment or cleaning change was introduced after inspecting the descriptive statistics.

3.3 Variable Measurement, Construction, and Validation:

The explanatory construct is represented by three separate published forcing components. Carbon dioxide, methane, and nitrous oxide forcing are measurement informed physical estimates rather than direct radiation readings or interchangeable measures of emissions. Etminan et al. 2016 demonstrate that gas absorption characteristics and overlapping spectral effects influence calculated forcing. This analysis uses the supplied forcing estimates without recalculating atmospheric radiation or substituting concentration values. The outcome is the published global annual surface temperature anomaly. Higher values indicate a warmer annual global surface relative to the temperature reference period. Table 2 defines the observed and calculated measures.

Table 2: Variable dictionary

Variable or Indicator	Analytical Role	Definition and Construction	Source and Identifier	Unit and Frequency	Transformation and Direction	Missing Value Rule	Coverage and Limitation
Calendar year	Temporal identifier	Published observation year	Year field in both extracts	Calendar year	No transformation	No missing years	15 consecutive years
Carbon	Explanatory	Published effective radiative	NOAA AGGI	W/m²,	Published level; higher	All values	2010 to 2024; physical

Variable or Indicator	Analytical Role	Definition and Construction	Source and Identifier	Unit and Frequency	Transformation and Direction	Missing Value Rule	Coverage and Limitation
dioxide forcing	component	forcing associated with carbon dioxide relative to preindustrial abundance	table, CO2	annual	values indicate greater forcing	available	estimate
Methane forcing	Explanatory component	Published effective radiative forcing associated with methane relative to preindustrial abundance	NOAA AGGI table, CH4	W/m², annual	Published level; higher values indicate greater forcing	All values available	2010 to 2024; physical estimate
Nitrous oxide forcing	Explanatory component	Published effective radiative forcing associated with nitrous oxide relative to preindustrial abundance	NOAA AGGI table, N2O	W/m², annual	Published level; higher values indicate greater forcing	All values available	2010 to 2024; physical estimate
Surface temperature anomaly	Outcome	Published annual global temperature departure from the 1951 to 1980 average	NASA GISTEMP version 4, annual mean column	°C, annual	Published level; higher values indicate warmer conditions	All values available	2010 to 2024; global observational estimate
Annual forcing changes	Descriptive transformation of each forcing component	Current annual forcing less preceding annual forcing	Calculated separately from CO2, CH4, and N2O	W/m², annual change	Positive values indicate increased forcing	First year excluded	14 changes; published rounding limits precision
Annual temperature change	Descriptive transformation of the outcome	Current anomaly less preceding annual anomaly	Calculated from GISTEMP annual anomalies	°C, annual change	Positive values indicate warming relative to the preceding year	First year excluded	14 changes; represents annual movement rather than a trend estimate

Equation 1 defines the implemented transformation:

$$\Delta x_t = x_t - x_{t-1}.$$

Here, Δx_t denotes the annual change in a selected measure, x_t denotes its value in year t, and x_{t-1} denotes its value in the preceding year. Equation 1 applies separately to each of the four measures. These differences are absolute changes in the original units, not percentage changes. Table 3 reports descriptive statistics calculated from the retained annual levels. Standard deviations use the sample convention.

Table 3: Descriptive statistics for annual levels

Measure	Valid Observations	Mean	Standard Deviation	Median	Minimum	Maximum
Carbon dioxide forcing, W/m²	15	2.0886	0.1524	2.0920	1.8570	2.3330
Methane forcing, W/m²	15	0.5398	0.0162	0.5380	0.5190	0.5670
Nitrous oxide forcing, W/m²	15	0.2024	0.0147	0.2010	0.1800	0.2260
Surface temperature anomaly, °C	15	0.8827	0.1896	0.8900	0.6100	1.2800

The three forcing components increase throughout the retained period, whereas temperature displays both increases and decreases. Their separate physical meanings therefore remain distinct from their statistical independence. Verification identifies pairwise correlations above 0.990 among the forcing levels, indicating substantial redundancy for simultaneous statistical attribution. No composite index or latent measurement model was constructed.

3.4 Analytical Framework, Identification, and Reproducibility:

The implemented framework is descriptive and observational. Its analytical target is the temporal correspondence between each forcing component and global temperature, examined through annual levels and absolute annual changes. Summaries include valid counts, means, sample standard deviations, medians, minima, and maxima. The analysis does not estimate a regression baseline, conditional effect, or causal parameter. The available variation comes from changes across calendar years within one global series. The 15 observations are temporally ordered rather than independent experimental units. Common trends and strong correlations among the forcing components prevent the descriptive comparisons from identifying separate contributions to observed warming. Richardson et al. 2016 show that estimates linking forcing and temperature response depend on observational definitions and forcing uncertainty, reinforcing the distinction between descriptive correspondence and a physically identified response parameter.

Annual differencing provides a complementary description of shorter temporal movements. It uses 14 observations because the initial year has no preceding observation within scope. This transformation does not establish exogeneity, remove every form of temporal dependence, or resolve omitted influences. No inferential significance tests, alternative temperature datasets, or model robustness exercises were implemented. The interpretation also respects the distinction between radiative forcing and immediate surface adjustment. Hansen et al. 2011 explain that ocean heat uptake influences the timing of temperature responses to planetary energy imbalance. Consequently, an annual temperature decrease alongside rising greenhouse gas forcing does not independently contradict the underlying warming mechanism. The supplied workbook preserves the annual observations, calculated changes, variable definitions, source identifiers, and construction formulas. Independent verification reproduced every annual difference and confirmed complete coverage. Consistent calendar alignment and unchanged measurement units make the descriptive calculations reproducible, while the recorded source vintages identify the historical estimates used.

4. Methods:

4.1 Research Design and Analytical Scope:

This analysis uses a descriptive observational design to examine contemporaneous relationships between three greenhouse gas forcing components and global annual surface temperature anomalies. The unit of analysis is the global calendar year. The analytical quantities are the Pearson correlations between each forcing component and temperature, calculated

separately for annual levels and annual changes. These comparisons address whether correspondence across annual conditions also appears in movements between consecutive years. The sample construction in Table 1 provides 15 annual observations covering 2010 to 2024. Useful variation arises from changes across years within a single global series. The analysis compares continuous measurements without a treatment group, comparison group, or intervention. Correlations describe unadjusted linear association within the retained observation window. The interpretation distinguishes temporal correspondence from causal attribution. Common trends, dependence between consecutive years, and strong overlap among the forcing components can influence the observed correlations. The design therefore does not identify independent contributions to warming or estimate temperature responses to isolated changes in individual gases.

4.2 Measurement Alignment and Temporal Transformation:

Table 2 defines the four analytical measures, their units, and source identifiers. Each published forcing component is paired with the temperature anomaly for the same calendar year. Annual observations receive equal weight. The analysis preserves the original measurement scales and uses the published annual temperature average rather than reconstructing it from monthly observations. Two temporal representations are examined. The levels comparison uses all 15 observations. The annual changes comparison applies Equation 1 separately to each measure, subtracting the preceding annual value from the current value. This produces 14 matched changes covering 2011 to 2024. The initial year contributes to the calculation of the first change but cannot itself supply a change without an observation outside the study window. Annual differences retain the original units. They represent absolute changes rather than percentage growth rates or departures from an estimated trend. Both representations use the same underlying source series, although their observation counts differ mechanically. Differencing changes the descriptive question from correspondence between annual states to correspondence between annual increments; it is not treated as proof that temporal dependence or common influences have been removed.

4.3 Descriptive Estimation and Association Measurement:

The analytical sequence begins with valid observation counts, arithmetic means, sample standard deviations, medians, minima, and maxima. Additional comparisons calculate endpoint differences, average annual changes, and the number of positive and negative temperature changes. These summaries characterise the observed window without interpreting an endpoint difference as an estimated trend. Pearson correlation measures the direction and strength of contemporaneous linear correspondence. Its interpretation follows Schober et al. 2018, who distinguish correlation from causal explanation and emphasise matching the coefficient to the relationship being examined. Here, Pearson correlation is used as a descriptive numerical summary, without distribution based significance testing.

$$r_{ab} = \frac{\sum_{t=1}^{n}(a_t - \bar{a})\,(b_t - \bar{b})}{\sqrt{\sum_{t=1}^{n}(a_t - \bar{a})^2 \sum_{t=1}^{n}(b_t - \bar{b})^2}}$$

In Equation 2, r_{ab} denotes the Pearson correlation between two selected series; a_t and $b_t$denote their paired observations; $\bar{a}$ and $\bar{b}$denote their arithmetic means; tindexes matched observations; and ndenotes the number of pairs. For the principal comparisons, one series represents a forcing component and the other represents temperature. The coefficient is calculated using 15 pairs for levels and 14 pairs for annual changes. Equation 2 is applied separately to each forcing and temperature pair. Pairwise correlations among the three forcing levels are also calculated to assess overlap in their temporal information. Coefficient magnitudes are interpreted comparatively rather than classified through universal thresholds. A stronger correlation is not interpreted as a larger physical contribution. The calculations use Python version 3.12.14 and its standard library. The statistics module supplies mean, sample standard deviation, median, and correlation functions. The minimum and maximum functions identify observed bounds. Sample standard deviations use the number of observations less one as the denominator. Calculations retain numerical precision internally, with rounding applied only when presenting results.

4.4 Verification, Sensitivity, and Replicability:

Verification checks the chronological sequence, uniqueness of year identifiers, numeric completeness, and alignment of observations. All four measures contain values for every retained year. No imputation, interpolation, zero substitution, trimming, or winsorisation is performed. Published extreme observations remain in the sample. The stored annual changes are independently recalculated from the levels and compared with the workbook values. This check covers all 56 differences across four measures and confirms exact numerical agreement. The descriptive outputs are generated from the retained observations without manual alteration of individual values. The comparison between levels and annual changes assesses sensitivity to temporal representation. It does not establish robustness to alternative datasets, observation windows, omitted influences, or measurement uncertainty. Pairwise forcing correlations assess information overlap; they are not used to remove components or select a multivariable specification.

No confidence intervals or significance probabilities are calculated because the implemented analysis describes the selected historical observations without specifying an inferential model for temporal dependence. Accordingly, coefficient differences are reported as descriptive contrasts rather than statistically established differences. Regression residual diagnostics and predictive validation are outside the implemented analytical procedure. Replication uses the annual observations and construction formulas preserved in the supplied workbook. Sorting by year, applying Equation 1, and calculating the stated summaries and Equation 2 reproduces the reported descriptive outputs. The methodological contribution is a consistent comparison across measures and temporal representations using established procedures, rather than a new estimator or identification design.

2. Findings:

This analysis examines how carbon dioxide, methane, and nitrous oxide forcing correspond with global annual surface temperature anomalies. The findings distinguish associations across annual levels from correspondence between annual changes. The three research questions are resolved through descriptive statistics and contemporaneous correlations for 2010 to 2024. The analytical sample contains 15 global annual observations with complete coverage of all four variables. Annual differencing

produces 14 observations covering 2011 to 2024. No observations were imputed or removed because of missing values or extreme values. Forcing is measured in watts per square metre, while temperature anomalies are measured in degrees Celsius relative to the 1951 to 1980 average. The forcing variables represent published physical estimates rather than emissions or atmospheric concentrations. This distinction follows the measurement framework examined by Etminan et al. 2016.

Table 4: Descriptive characteristics of annual levels and changes

Measure	Mean Annual Level	Sample Standard Deviation	Median	Minimum	Maximum	Mean Annual Change
Carbon dioxide forcing, W/m²	2.0886	0.1524	2.0920	1.8570	2.3330	0.0340
Methane forcing, W/m²	0.5398	0.0162	0.5380	0.5190	0.5670	0.0034
Nitrous oxide forcing, W/m²	0.2024	0.0147	0.2010	0.1800	0.2260	0.0033
Surface temperature anomaly, °C	0.8827	0.1896	0.8900	0.6100	1.2800	0.0400

Table 4 identifies sustained increases in all three forcing components alongside greater annual variability in temperature. Carbon dioxide forcing increased from 1.857 to 2.333 W/m², methane forcing from 0.519 to 0.567 W/m², and nitrous oxide forcing from 0.180 to 0.226 W/m². The temperature anomaly increased from 0.72°C to 1.28°C between the initial and final years, an endpoint difference of 0.56°C. This difference describes the observed endpoints rather than an estimated warming trend. The reported standard deviations measure variation across years, not uncertainty in the underlying measurements. Lenssen et al. 2019 distinguish such measurement uncertainty from the temporal variation represented in the GISTEMP series.

Table 5: Descriptive associations between forcing and temperature

Research Question	Forcing Component	Pearson Correlation in Annual Levels	Pearson Correlation in Annual Changes	Descriptive Resolution
Research question 1	Carbon dioxide	0.849	0.310	Positive correspondence in levels; weaker correspondence in annual changes
Research question 2	Methane	0.842	0.136	Positive correspondence in levels; limited correspondence in annual changes
Research question 3	Nitrous oxide	0.843	0.117	Positive correspondence in levels; limited correspondence in annual changes

For research question 1, carbon dioxide forcing has a positive correlation of 0.849 with the annual temperature anomaly. The corresponding correlation between annual changes is 0.310. Thus, years with higher carbon dioxide forcing generally coincide with warmer global conditions across the observation window, but larger annual forcing increments show substantially weaker correspondence with annual temperature increases. The evidence supports positive descriptive association at both temporal representations, with a clear reduction in strength after differencing. For research question 2, methane forcing has a level correlation of 0.842 with temperature, compared with 0.136 for annual changes. Methane forcing increased in every annual transition, yet temperature declined in four transitions. The positive relationship across levels therefore does not imply that annual methane increments closely track annual temperature movements. The largest methane forcing increment, 0.006 W/m² in 2022, coincided with a temperature increase of 0.04°C. The largest temperature increase, 0.28°C in 2023, coincided with a smaller methane forcing increment of 0.004 W/m². These observations resolve the question through positive level correspondence and limited annual change correspondence.

For research question 3, nitrous oxide forcing has a level correlation of 0.843 with temperature and an annual change correlation of 0.117. Its forcing increments occupy a narrow published range from 0.002 to 0.004 W/m². Within that range, temperature changes extend from a decline of 0.16°C to an increase of 0.28°C. Nitrous oxide forcing therefore shares the direction of the overall temperature movement without closely matching its annual fluctuations. The small variation in forcing increments and their published rounding also constrain interpretation of the change correlation. Across all three comparisons, the principal distinction concerns temporal scale. Level correlations cluster between 0.842 and 0.849, whereas annual change correlations range from 0.117 to 0.310. Carbon dioxide displays the strongest descriptive correspondence under both representations, although the small differences between level correlations do not establish a meaningful ranking of independent warming contributions.

Temperature increased in ten annual transitions and decreased in four, despite increases in every forcing component throughout all 14 transitions. The temperature declines occurred in 2011, 2017, 2018, and 2021. The largest decline occurred in 2021, when all three forcing components still increased. This coexistence of rising forcing and fluctuating annual temperature is consistent with the distinction between sustained warming and annual variability documented by Hansen et al. 2010. Differencing changes the substantive interpretation of the observed relationships. The level comparisons describe shared movement across the observation period, while annual differences reveal incomplete contemporaneous alignment. They do not measure delayed thermal responses or identify the processes responsible for individual temperature fluctuations. Hansen et al. 2011 explain why planetary energy imbalance and ocean heat uptake can separate the timing of forcing changes from surface temperature adjustment. The present findings remain consistent with that distinction without estimating those mechanisms.

The forcing components themselves are highly correlated. Their pairwise level correlations are 0.991 for carbon dioxide and methane, 0.998 for carbon dioxide and nitrous oxide, and 0.995 for methane and nitrous oxide. Consequently, their similar correlations with temperature cannot be interpreted as three independent estimates of influence. Richardson et al. 2016 demonstrate that estimating climate response requires attention to forcing uncertainty and observational definitions, reinforcing the narrower interpretation warranted by these descriptive results. The three research questions yield a consistent answer: each forcing component corresponds positively with temperature across annual levels, while correspondence becomes weaker when measured through annual changes. The observed contrast establishes sensitivity to temporal representation. It does not establish separate causal contributions, statistical significance, or predictive performance.

6. Discussion:

Strong correspondence across annual levels can coexist with weak correspondence between annual changes. Table 5 demonstrates this distinction across all three greenhouse gases: level correlations exceed 0.84, while correlations calculated using Equation 1 are substantially smaller. This analysis therefore contributes a consistent comparison of temporal representations within the same global observation window. Its contribution concerns how the measured relationship changes with transformation, rather than establishing a new physical mechanism. Medhaug et al. 2017 show that interpretations of surface warming depend on temporal definitions, variability, and observational choices. The present comparison makes that interpretive dependence explicit for three forcing components over 2010 to 2024. Higher forcing levels accompany warmer conditions, but this correspondence does not imply that annual forcing increments closely determine annual temperature movements. The divergence between sustained forcing increases and fluctuating temperature sharpens the distinction between radiative influence and immediate surface response. Table 4 records positive average annual changes in all forcing components, while the annual differences underlying Table 5 include four temperature declines. These observations show that contemporaneous temperature movement is not a direct annual readout of greenhouse gas forcing. Kosaka and Xie 2013 demonstrate through climate modelling that tropical Pacific conditions can influence global surface temperature despite continuing radiative forcing. That evidence provides a physical context for the observed divergence, without identifying the cause of individual fluctuations in this analysis. The interpretive advance is to separate evidence of shared movement across years from evidence about the timing and transmission of temperature responses.

The component comparison also changes how apparent dominance should be interpreted. Carbon dioxide has the largest forcing level in Table 4 and the strongest annual change correlation in Table 5, but these characteristics measure different properties. A larger forcing contribution describes the magnitude of a published physical estimate; a larger correlation describes closer statistical correspondence within the selected observations. Neither provides a decomposition of observed warming. Marvel et al. 2016 demonstrate that climate responses depend on the efficacy of individual forcings, making correlation rankings an unsuitable substitute for physical attribution. The near identical level correlations across the three gases further indicate that their shared temporal movement limits differentiation. This analysis consequently preserves the distinction between component magnitude, temporal association, and temperature response rather than combining them into a single claim of pathway dominance. The principal analytical constraint is the concentration of information in a short, strongly trending global series. Pairwise forcing correlations above 0.990 show that the three component histories provide limited independent variation. Equation 1 changes the question from correspondence between annual states to correspondence between annual increments, explaining why Table 5 yields different interpretations without either representation being intrinsically incorrect. Schmidt et al. 2014 show that reconciling warming patterns requires attention to forcing histories and internal variability. Here, the practical implication is narrower: common movement should remain visible in reporting, and weak annual change correspondence should not be presented as evidence against the physical warming influence of greenhouse gases. The findings clarify an identification boundary that numerical completeness alone cannot resolve.

The international relevance follows from the global measurement scale rather than from comparisons between national economies. Tables 4 and 5 concern a shared planetary outcome and cannot establish differences between advanced and emerging economies. Their useful implication for international climate reporting is to present forcing levels, temperature anomalies, and annual changes as distinct indicators. The Intergovernmental Panel on Climate Change 2021 situates surface warming within an interacting climate system, supporting interpretation across multiple indicators and temporal scales. Climate monitoring organisations should therefore accompany annual temperature updates with the observation period and transformation used, and avoid treating a single annual decline as a reversal of sustained forcing. This analysis adds an explicit comparison across the three gases, showing why communication and interpretation must distinguish persistent radiative influence from contemporaneous annual correspondence.

7. Conclusion and Implications:

Global climate interpretation depends on distinguishing persistent warming influence from annual temperature fluctuations. This analysis shows that three radiative contributions share strong correspondence with warmer annual conditions, while their annual increments exhibit weaker correspondence with immediate surface changes. The contribution lies in comparing these temporal representations consistently within a common global observation window. The evidence clarifies the difference between shared movement and contemporaneous response, refining how descriptive associations should inform interpretation of planetary energy balance. It establishes neither independent causal contributions nor conditional interactions. For climate monitoring organisations, the practical implication is to report annual conditions alongside changes between consecutive years and to explain what each representation measures. Reporting routines should preserve measurement units, reference periods, and observation windows so that readers can distinguish persistent patterns from temporary departures. Policymakers should avoid treating isolated annual cooling as evidence that sustained warming influence has reversed, or strong correlations as sufficient grounds for attributing separate contributions. These distinctions support more disciplined interpretation of climate indicators across international reporting systems. Their social value lies in clearer public communication: separating observed fluctuations from sustained pressures can reduce misleading claims and improve understanding without implying that a short descriptive record resolves the processes governing climate change.

The short annual record provides a focused foundation for extending the comparison across longer periods and alternative temperature datasets. Strong overlap among the explanatory series motivates designs that distinguish shared trends from independent information. Published rounding also warrants examining higher precision observations where available. Future research could assess sensitivity across observation windows, represent temporal dependence, and investigate delayed responses using additional physical measurements. Such extensions would clarify whether the observed contrast between levels and annual changes persists across datasets and periods, while reserving causal interpretation for designs that explicitly identify the relevant processes.

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