# An error of temperature-feedback formulism and its consequences


## ABSTRACT

FEEDBACK FORMULISM borrowed from control theory is universally misapplied in deriving climate sensitivity. Though in electronic feedback amplifiers the DC input is often small enough to be ignored without error, in climate the overwhelmingly predominant 255 K emission temperature must not be, but was hitherto, omitted from the input to the temperature-feedback loop. In effect, its large feedback response was added to (and miscounted as part of) the actually small feedback response to anthropogenic warming. By that grave control-theoretic error, feedback response was hitherto thought to constitute as much as 2 [1 to 4] K, or 67% [50% to 80%], of the long-projected 3 [2 to 5] K equilibrium doubled-$CO_2$ sensitivity (ECS). However, at the 1850 equilibrium, feedback response comprised only 7.7% of global temperature, implying only 1.2 K ECS. Allowing for subsequent time-variance, a feedback factor 0.09 would yield 2 K ECS, while 0.10 would yield 5 K: but no precision so fine as 0.01 is attainable, vitiating all ECS projections via feedback formulism, hitherto the standard method. After correcting the error, mitigation is unnecessary.


## 1. Introduction

Feedback formulism in control theory is applicable to all feedback-moderated dynamic systems, from electronic circuits and rockets to climate. Temperature-feedback response, an indirect additional temperature signal engendered by a direct or reference temperature and proportional thereto, was hitherto thought to contribute 67% [50% to 80%] of the projected 3 [2 to 5] K equilibrium sensitivity (ECS) forced by a doubled-$CO_2$-equivalent anthropogenic enrichment of the atmosphere with radiatively-active gases. Accordingly, the word "feedback" is mentioned 1100 times in IPCC (2013) and 2500 times in IPCC (2021).

The principal temperature feedback process is the water-vapor feedback, "an even more powerful absorber of terrestrial radiation" than $CO_2$ (Charney 1979). Directly-warmed air may carry more water vapor, itself a radiatively-active gas, amplifying a direct warming. At midrange, all other short-acting and thus sensitivity-relevant feedback intensities (Bates 2016), chiefly the lapse-rate, cloud and albedo intensities, broadly self-cancel (*e.g.*, IPCC 2013, table 9.5). However, the present result requires no knowledge of individual feedback intensities.

Arrhenius (1896, 1906) first sought to allow for water-vapor feedback in deriving ECS, the standard climate-sensitivity metric. However, control theory, the theory of feedback amplification, would not be formalized until Black (1934) and Bode (1945).

## 2. Initial conditions

**Time-subscripts** $t$ are **0** *ab initio*; **1** in 1850; **2** at present.

**Net inbound flux density** $Q_0$ at top of atmosphere (Eq. 1) is found from 1363.5 W m$^{-2}$ total solar irradiance $S$ (DeWitte 2016) and current Earth albedo $\alpha$, equal to 0.293 (Stephens 2015).

$$Q_0 \;\equiv\; S \cdot (1-\alpha)\,/\,4 \;=\; \mathbf{241\ W\ m^{-2}}. \tag{1}$$

**The Stefan-Boltzmann constant** σ (Eq. 2) is the constant of proportionality between $Q_0$ and emission temperature $R_0$ (defined next) for $\pi$ the circumference-diameter ratio, $k$ the Boltzmann constant, $h$ Planck's constant, and $c$ lightspeed *in vacuo* (Rybicki 1979).

$$\sigma \;\equiv\; 2\cdot\pi^5\cdot k^4\,/\,(15\cdot h^3\cdot c^2) \;=\; \mathbf{5.6704\ x\ 10^{-8}\ \ W\ m^{-2}\ K^{-4}}. \tag{2}$$

**Emission temperature** $R_0$ is derived in the Stefan-Boltzmann equation (3). So predominant is $R_0$ that the present result would scarcely be affected even if, after allowing for Hölder's inequalities between nonlinear integrals by integrating emission temperatures derived for all solar zenith angles via Eq. (3), $R_0$ were appreciably less than shown.

$$R_0 \equiv [Q_0 / \sigma]^{0.25} = \mathbf{255\ K} \Rightarrow dR / dQ = (4 \cdot \sigma \cdot R_0^3)^{-1} = R_0 / (4 \cdot Q_0). \quad (3)$$

**The Planck response** $P_t$ (Eq. 4), the scaling factor between surface temperature $T_t$ and $Q_0$, replaces $R_0$ by $T_t$ in the derivative $dR/dQ = R_0/(4 \cdot Q_0)$ of Eq. (3). Roe (2009) justifies thus treating $P_t$ as part of the sensitivity reference system, not as a negative feedback. Then the product of $P_t$ and any direct or reference forcing $\Delta Q_t$ is a reference sensitivity, while the product of $P_t$ and the net aggregate feedback intensity $\Lambda_t$ is the unitless feedback factor $\mathbf{H}_t$.

$$P_2 \equiv T_2 / (4 \cdot Q_0) = 289 / (4 \cdot 241) = \mathbf{0.300\ K\ W^{-1}\ m^2}. \quad (4)$$

***In 1850,* natural reference sensitivity (NRS)** $\Delta R_1$ was 10 K (Schmidt 2010).
**Reference temperature** $R_1$ was the **265 K** sum of the 255 K $R_0$ and 10 K NRS $\Delta R_1$.
**The open-loop gain factor or direct-gain factor** $\mathbf{G_1}$ was the ratio $\mathbf{1.039}$ of $R_1$ to $R_0$.
**The 288 K equilibrium temperature** $E_1$ was equal to $\mathbf{G_1} / (R_0 + \mathrm{F}_1)$, where –
**The 22.1 K feedback response** $\mathrm{F}_1$, equal to $(E_1 - R_1) / \mathbf{G_1}$, was only 7.7% of $E_1$.

***At present,* doubled-$CO_2$ forcing** $\Delta Q_2$ (CMIP6 mean: Zelinka 2020) is $\mathbf{3.52\ W\ m^{-2}}$.
**The 1.052 K reference doubled-$CO_2$ sensitivity (RCS)** $\Delta R_2$ is equal to $\Delta Q_2 / P_2$.
**The 266 K reference temperature** $R_2$ is the sum of $R_1$ and ~1 K RCS $\Delta R_2$, so that –
**The closed-loop gain factor (or direct-gain factor)** $\mathbf{G_2}$ is the ratio $\mathbf{1.043}$ of $R_2$ to $R_0$.

**Feedback variables** are not *italicized*. Normative variables $\Lambda_2, \mathbf{H_2}, \mathrm{A}_2, \mathrm{F}_2$ (formulism a) and $\Lambda_2^*, \mathbf{H_2^*}, \mathrm{A}_2^*, \mathrm{F}_2^*$ (b) are UPPERCASE. Defective variables $\lambda_2, \mathbf{h_2}, \mathrm{a}_2, \Delta\mathrm{f}_2$ (c) are lowercase.

**Net aggregate feedback intensity** $\Lambda_2$, the originating feedback variable, in W m$^{-2}$ per Kelvin of present-day reference temperature $R_2$ (or of equilibrium temperature $E_2$) is the sum of the short-acting, sensitivity-relevant feedback intensities (IPCC 2021, table 7.10). Here, however, no knowledge of individual feedback intensities is needed.

**The feedback factor** $\mathbf{H_2}$ (unitless) is equal to $\Lambda_2 \cdot P_2$ and to $(E_2 - R_2)/ (E_2 \cdot \mathbf{G_2})$.
**The closed-loop gain factor** $\mathrm{A}_2$ (unitless) is equal to $E_2 / R_0$ and to $\mathbf{G}_2 / (1 - \mathbf{G}_2 \cdot \mathbf{H}_2)$.
**Feedback response** $\mathrm{F}_2$ (in Kelvin) is equal to $\mathbf{H}_2 / E_2$ and to $(E_2 - R_2) / \mathbf{G}_2$.

**Three feedback formulisms** will be considered: (a) the normative control-theoretic formulism; (b) a simplified normative formulism; and (c) the defective formulism used in climatology.

## 3. The error of control-theoretic physics in climatology

Present-day reference temperature $R_2$ is the 266 K sum of 255 K emission temperature $R_0$ (Eqs. 1–3) and two direct-gain or *perturbation* signals: the 10 K NRS $\Delta R_1$ and the 1 K RCS $\Delta R_2$. Net aggregate feedback intensity $\Lambda_2$, the originating temperature-feedback variable in today's climate, necessarily acts in response to the entire reference temperature $R_2$, and in close proportion to the amplitude of each of the components therein.

By a grave error of control-theoretic physics, however, all sensitivity studies omit the input signal $R_0$ from the temperature-feedback loop, though $R_0$ exceeds all other temperature signals by two orders of magnitude. They also omit the 8 K natural-gain signal, NRS $\Delta R_1$, which exceeds the 1 K anthropogenic direct-gain signal, RCS $\Delta R_2$ by an order of magnitude. Instead, they treat RCS as though it were the input signal to the temperature-feedback loop.

In effect, then, the feedback responses $F_0$ to emission temperature $R_0$ and $\Delta f_1$ to NRS $\Delta R_1$ are added to, and miscounted as part of, the actually small feedback response $\Delta f_2$ to RCS $\Delta R_2$. Thus, Hansen (1984), the earliest authority explicitly to deploy control theory in deriving feedback response and hence ECS, introduced the control-theoretic error by taking RCS $\Delta R_2$ as 1.2–1.3 K and ECS $\Delta E_2$ as 4 K. Feedback variables were treated as though they responded solely to RCS, with the implication that the defective closed-loop-gain factor $a_2$ [misidentified *ibid.* as the "feedback factor"] was $\Delta E_2 \,/\, \Delta R_2$, the ratio of ECS to RCS.

> "Our … model yields a warming of ~4 C for doubled $CO_2$. This indicates a net [defective closed-loop gain factor $a_2$] of … 3–4."

Yet the normative closed-loop gain factor $A_2$ was 1.129, implying $< 1.2$ K ECS (Eq. 5).

$$A_2 \equiv E_2 \,/\, R_0 = 288/255 \quad \Rightarrow \quad \Delta E_2 \equiv \Delta R_2 \cdot A_2 = 1.052 \cdot 1.129 < \mathbf{1.2\ K}. \qquad (5)$$

Likewise, IPCC (2021, p. 2222) [*author's emphases*] misdefined "climate feedback" as –

> "An interaction in which a *perturbation* in one climate quantity causes a *change* in a second, and the *change* in the second ultimately leads to an additional *change* in the first. A negative feedback is one in which the initial *perturbation* is weakened by the *changes* it causes; a positive feedback is one in which the initial *perturbation* is enhanced. The initial *perturbation* can either be externally forced or arise as part of internal variability."

Incomplete definitions such as these, and the resultant error, are universal in climatology (e.g. Hansen 1984; Schlesinger 1988; IPCC 1990–2021; Ruddiman 2001; Bony 2006; Soden 2006; Bates 2007, Roe 2009; Goosse 2010; Lacis 2010, 2013; Schmidt 2010; Lindzen 2011; Knutti 2015; Dufresne 2015; Prentice 2015; Sherwood 2015, 2020; Ye 2015; Baboo 2018; Heinze 2019; AMS 2020; Schmittner 2021; Visconti 2023; FutureLearn 2024; UCAR 2025).

Interdisciplinary compartmentalization has inhibited detection of the error, by which the defective feedback response $\Delta f_2$ to $1\,K$ RCS $\Delta R_2$ was thought to fall on $2\,[1\ to\ 4]\,K$, representing $67\%$ $[50\%\ to\ 80\%]$ of projected ECS $\Delta E_2$ on $3\,[2\ to\ 5]\,K$ (e.g., Charney 1979; IPCC passim), implying a defective feedback factor $\boldsymbol{h_2}$ falling on the interval $0.67\ [0.5\ to\ 0.8]$.

## 4. Theory

*a. Formulism (a): The normative control-theoretic temperature-feedback amplifier*

The equations shown in the normative (a) temperature-feedback amplifier block diagram (Fig. 1) obtain at the operating point at time $t = 2$ once the short-acting feedbacks have acted and temperature has resettled to equilibrium. The input signal, the 255 K emission temperature $R_0$, enters the feedback loop at the summative $(+)$ input node, whence the sum of $R_0$ and the feedback factor $F_t$ is sent to the direct-gain block. There, $F_t$ is multiplied by the open-loop gain factor $\mathbf{G}_t$, the ratio of $R_t$ to $R_0$ (Eq. 6), to become the output signal, equilibrium temperature $E_t$ (Eq. 7), itself the product of $R_0$ and the closed-loop gain factor $A_t$ (Eq. 8). Next, the signal passes to the feedback block, where it is multiplied by the feedback factor $\mathbf{H}_t$ (Eq. 9), itself the product of feedback intensity $\Lambda_t$ and the Planck response $P_t$, to form the feedback response $F_t$ (Eq. 10).

*NB*: Here, for simplicity and clarity, a net-positive feedback intensity and feedback factor is taken as implying a net-positive feedback response.

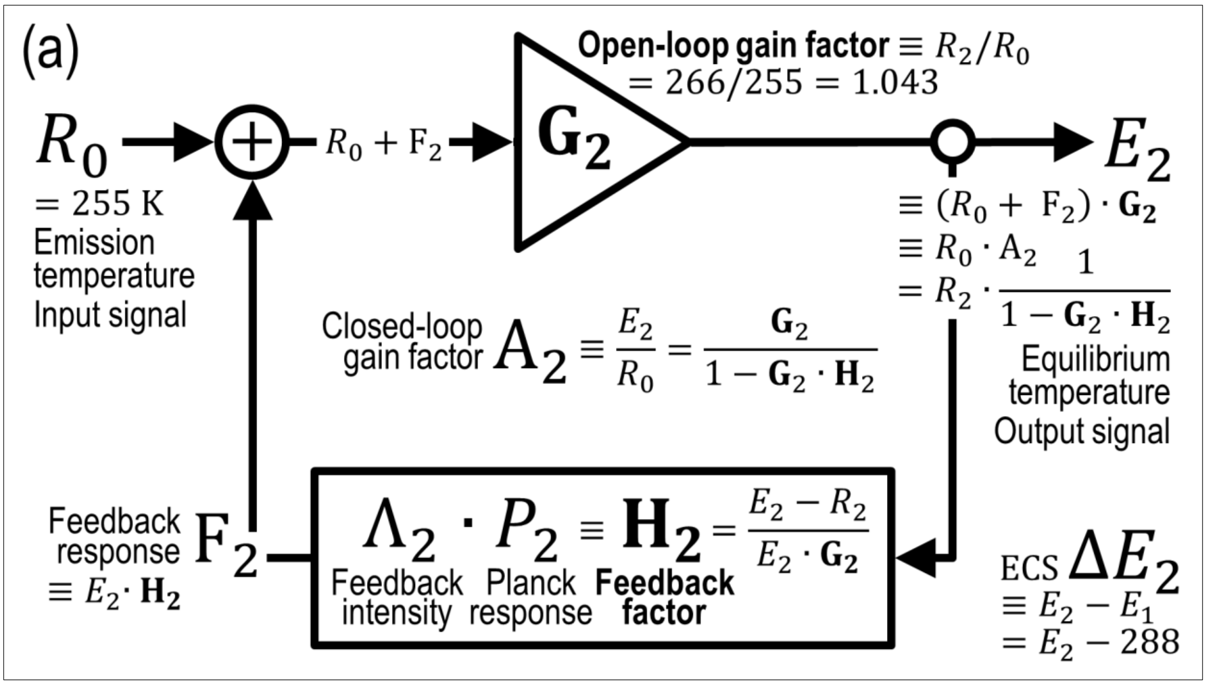


Fig. 1. Normative control-theoretic temperature-feedback amplifier (a) at time $t = 2$.

Eqs. (6–10), then, are the definitional equations of the temperature-feedback amplifier.

$$\mathbf{G}_t \equiv R_t \;/\; R_0; \tag{6}$$

$$E_t \equiv (R_0 + \mathrm{F}_t) \cdot \mathbf{G}_t; \tag{7}$$

$$\mathrm{A}_t \equiv E_t \;/\; R_0; \tag{8}$$

$$\mathbf{H}_t \equiv \Lambda_t \cdot P_t; \tag{9}$$

$$\mathrm{F}_t \equiv E_t \cdot \mathbf{H}_t. \tag{10}$$

The following expressions for $\mathrm{F}_t, \mathbf{H}_t, \mathrm{A}_t, E_t$ (Eqs. 11–14), derived from the above definitional equations (6–10), are relevant hereto:

$$E_t \equiv (R_0 + \mathrm{F}_t) \cdot \mathbf{G}_t = R_t + \mathrm{F}_t \cdot \mathbf{G}_t$$

$$\Rightarrow \qquad \mathrm{F}_t = (E_t - R_t) \;/\; \mathbf{G}_t; \tag{11}$$

$$\wedge \qquad \mathrm{F}_t \equiv E_t \cdot \mathbf{H}_t$$

$$\Rightarrow \qquad \mathbf{H}_t = (E_t - R_t) \;/\; (E_t \cdot \mathbf{G}_t). \tag{12}$$

$$E_t \;/\; \mathbf{G}_t = R_0 + \mathrm{F}_t = R_0 + E_t \cdot \mathbf{H}_t$$

$$\Rightarrow \qquad \mathbf{G}_t \cdot R_0 = E_t \cdot (1 - \mathbf{G}_t \cdot \mathbf{H}_t);$$

$$\wedge \qquad \mathrm{A}_t \equiv E_t \;/\; R_0$$

$$\Rightarrow \qquad \mathrm{A}_t = \mathbf{G}_t \;/\; (1 - \mathbf{G}_t \cdot \mathbf{H}_t). \tag{13}$$

$$E_t \equiv R_0 \cdot \mathrm{A}_t = R_0 \cdot \frac{\mathbf{G}_t}{1 - \mathbf{G}_t \cdot \mathbf{H}_t} = R_t \cdot \frac{1}{1 - \mathbf{G}_t \cdot \mathbf{H}_t} = \sum_{k=0}^{\infty} R_t \cdot (\mathbf{G}_t \cdot \mathbf{H}_t)^k$$

$$= R_t \cdot (\mathbf{G}_t \cdot \mathbf{H}_t)^0 + R_t \cdot (\mathbf{G}_t \cdot \mathbf{H}_t)^1 + R_t \cdot (\mathbf{G}_t \cdot \mathbf{H}_t)^2 + \ldots + R_t \cdot (\mathbf{G}_t \cdot \mathbf{H}_t)^\infty. \tag{14}$$

Equilibrium temperature $E_t$ (Eq. 14) is the sum of an infinite Archimedean geometric progression of first term $R_t$ and common ratio $\mathbf{G}_t \cdot \mathbf{H}_t$, the product of the direct-gain and feedback-gain factors, subject to the convergence criterion $(\mathbf{G}_t \cdot \mathbf{H}_t < 1) \in \mathbb{R}$, which is amply satisfied given that emission temperature $R_0$ predominates in reference temperature $R_t$. As the temperature signal circulates infinitely around the feedback loop, on each pass through the gain and feedback blocks the signal is incremented by the product of $R_t$ and a successively greater power of $\mathbf{G}_t \cdot \mathbf{H}_t$. Today, on each pass $\mathbf{G}_2 \cdot \mathbf{H}_2$ acts on $R_2$, the sum of $R_0, \Delta R_1$ and $\Delta R_2$.

*b. Formulism (b): The simplified* normative control-theoretic feedback amplifier*

Since the open-loop gain factor $\mathbf{G}_2$ in the normative feedback formulism (a) (Fig. 1) barely exceeds unity, with little error one may omit the $\mathbf{G}_2$ gain block and replace the input signal $R_0$ by the 264 K reference temperature $R_2$ (Fig. 2b). Since $\mathbf{G}_2$ is omitted in climatology [or sub-optimally replaced with a forcing-to-temperature converter, and then with a temperature-to-forcing back-converter in the feedback block], the simplified normative formulism (b) (Fig. 2b) facilitates direct comparison with the defective climatological formulism (c) (Fig. 2c). Feedback parameters in formulism (b) are indicated by asterisks. Equilibrium temperature $E_2$ becomes the sum of $R_2$ and the feedback response $\mathrm{F}_2^*$, for $\mathrm{F}_2^*$ the product of $E_2$ and the feedback factor $\mathbf{H}_2^*$, itself the product of feedback intensity $\Lambda_2^*$ and the Planck response $P_2$; and the closed-loop gain factor $\mathrm{A}_2^*$, the ratio of $E_2$ to $R_2$, is also the reciprocal of $(1 - \mathbf{H}_2^*)$.

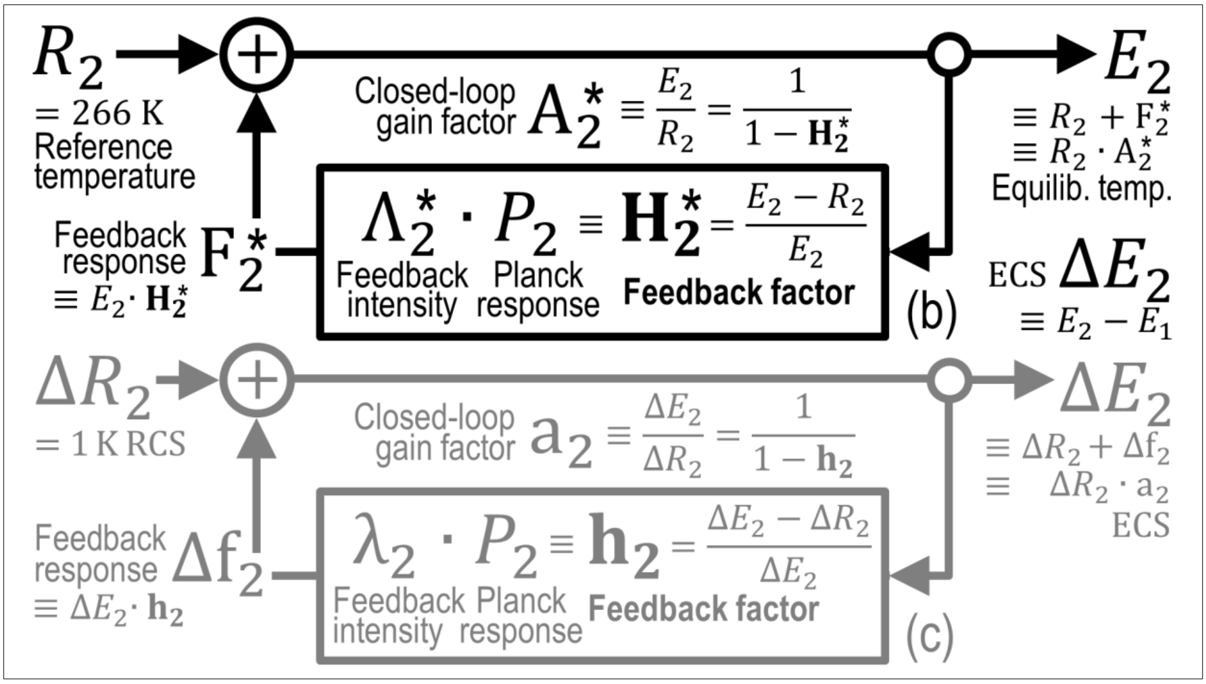


Fig. 2. (b) Simplified* control-theoretic feedback amplifier; (c) Defective feedback amplifier.

*c. Formulism (c): The defective feedback amplifier universal in climatology*

In climatology, the 1 K RCS $\Delta R_2$, a gain signal, is taken as the sole input to the feedback loop (Fig. 2c). Thus, the $\mathbf{G}_2$ gain block is omitted (or replaced by a converter with a forcing $\Delta Q_2$ as the input). Erroneously, neither the 255 K emission temperature $R_0$ nor the 10 K natural reference sensitivity $\Delta R_1$ is represented in the defective temperature-feedback loop. Instead, deltas replace absolute quantities: ECS $\Delta E_2$ replaces the output signal, equilibrium temperature $E_2$; the product $\mathbf{h}_2$ of defective feedback intensity $\lambda_2$ and the Planck response $P_2$ replaces the feedback factor $\mathbf{H}_2^*$; $\Delta \mathrm{f}_2$, the product of $\Delta E_2$ and $\mathbf{h}_2$, replaces the feedback response $\mathrm{F}_2^*$; and $\mathrm{a}_2$, the reciprocal of $(1 - \mathbf{h}_2)$, replaces the closed-loop gain factor $\mathrm{A}_2^*$.

In control theory the DC input signal is often neglected where it is small compared with the AC gain and feedback signals. However, in climate the input signal predominates and must be kept.

Currently, the feedback responses $\mathrm{F}_0$ to the input signal (emission temperature $R_0$) and $\Delta\mathrm{F}_1$ to the natural direct-gain signal (NRS $\Delta R_1$), together comprising $> 99.5\%$ of total feedback response, are omitted and are, in effect, miscounted as though they were part of the actually small feedback response $\Delta\mathrm{F}_2$ to RCS $\Delta R_2$; and linearization about the present state of the climate is then unsuccessfully attempted by way of a first-order Taylor-series expansion.

Since defective $\lambda_2$ and $\mathbf{h_2}$ are excessive by an order of magnitude, the defective closed-loop gain factor $\mathrm{a}_2$ (and hence the defective ECS $\Delta E_2$) is excessive by a factor 2–5.

## 5. Results

*a. Feedback variables implicit in currently-projected ECS*

Table 1 derives feedback variables (Eqs. 16abc–19abc) implicit in projected [2 to 5] K ECS. The interval of $\Lambda_2$ that would yield [2 to 5] K ECS is 0.27 [0.26 to 0.29] W m$^{-2}$ K$^{-1}$ (Eq. 18a), requiring derivation of $\Lambda_2$ to an unattainable 0.01 W m$^{-2}$ K$^{-1}$ precision.

| $\Delta E_2$ | | ECS | 2 K | 3 K | 4 K | 5 K | (IPCC 2021) | (Eq.) |
|---|---|---|---|---|---|---|---|---|
| $E_2$ | $\equiv$ | $E_1 + \Delta E_2$ | 290 K | 291 K | 292 K | 293 K | Equilibr. temp. | (15) |
| a) $\mathrm{A}_2$ | $\equiv$ | $E_2 \,/\, R_0$ | 1.14 | 1.14 | 1.15 | 1.15 | Closed-loop gain factor (unitless) | (16a) |
| b) $\mathrm{A}_2^*$ | $\equiv$ | $E_2 \,/\, R_2$ | 1.09 | 1.09 | 1.10 | 1.10 | | (16b) |
| c) $\mathrm{a}_2$ | $\equiv$ | $\Delta E_2 \,/\, \Delta R_2$ | 2.00 | 3.00 | 4.00 | 5.00 | | (16c) |
| a) $\mathbf{H_2}$ | $\equiv$ | $(E_2 - R_2) \,/\, (E_2 \cdot \mathbf{G_2})$ | 0.08 | 0.08 | 0.09 | 0.09 | Feedback factor (unitless) | (17a) |
| b) $\mathbf{H_2^*}$ | $\equiv$ | $(E_2 - R_2) \,/\, E_2$ | 0.08 | 0.09 | 0.09 | 0.09 | | (17b) |
| c) $\mathbf{h_2}$ | $\equiv$ | $(\Delta E_2 - \Delta R_2) \,/\, \Delta E_2$ | 0.50 | 0.67 | 0.75 | 0.80 | | (17c) |
| a) $\Lambda_2$ | $\equiv$ | $\mathbf{H_2} \,/\, P_2$ | 0.26 | 0.27 | 0.28 | 0.29 | Feedback intensity (W m$^{-2}$ K$^{-1}$) | (18a) |
| b) $\Lambda_2^*$ | $\equiv$ | $\mathbf{H_2^*} \,/\, P_2$ | 0.28 | 0.29 | 0.30 | 0.31 | | (18b) |
| c) $\lambda_2$ | $\equiv$ | $\mathbf{h_2} \,/\, P_2$ | 1.58 | 2.17 | 2.46 | 2.63 | | (18c) |
| $\lambda_2$ | | *IPCC (2021, table 7.10)* | *–1.81* | *–1.16* | —— | *–0.51* | | (19d) |
| $+\lvert P_2^{-1}\rvert$ | | *ibid.* | +3.40 | +3.22 | —— | +3.00 | | (19e) |
| $= \lambda_2$ | | *cf.* Eq. (18c) | 1.59 | 2.06 | —— | 2.49 | | (19f) |
| | | | | | | | | |
| $\dfrac{d(\Delta E)}{d\Lambda}$ | | $\mathbf{G_2} \cdot P_2 \cdot R_2 / (1 - \mathbf{G_2} \cdot P_2 \cdot \Lambda_2)^2$ | 99 | 100 | 100 | 101 | Derivative $\left(\dfrac{\mathrm{K}}{\mathrm{W\,m^{-2}\,K^{-1}}}\right)$ | (20a) |
| | | $P_2 \cdot R_2 \,/\, (1 - P_2 \cdot \Lambda_2^*)^2$ | 95 | 95 | 96 | 97 | | (20b) |
| | | $P_2 \cdot \Delta R_2 \,/\, (1 - P_2 \cdot \lambda_2)^2$ | 1.1 | 2.6 | 4.6 | 7.1 | | (20c) |

**Table 1.** Results by a) the normative; b) the simplified* normative; c) the defective method

The derivatives of the system-response curve of ECS $\Delta E_2$ on [2 to 5] K against net aggregate feedback intensity are obtained in Eqs. 20abc. The derivative $d(\Delta E)/d\Lambda$ (Eqs. 20ab) of the normative system-response curve is of order 100 K per unit of feedback intensity $\Lambda_2$, demonstrating the extent to which temperature is hypersensitive to time-variance in $\Lambda_2$.

In Eqs. (21–22), feedback intensities are derived directly from projected ECS and *vice versa*.

Feedback intensities $\Lambda_2, \Lambda_2^*, \lambda_2$ implicit in projected ECS $\boxed{\Delta E_2}$

$$\Lambda_2 = \left(\frac{1}{\mathbf{G_2}} - \frac{R_0}{E_1 + \boxed{\Delta E_2}}\right) / P_2 \quad = \quad \left(\frac{255}{266} - \frac{255}{288 + \boxed{\Delta E_2}}\right) / 0.3. \tag{21a}$$

$$\Lambda_2^* \approx \left(1 - \frac{R_2}{E_1 + \boxed{\Delta E_2}}\right) / P_2 \quad \approx \quad \left(1 - \frac{266}{288 + \boxed{\Delta E_2}}\right) / 0.3. \tag{21b}$$

$$\lambda_2 = \left(1 - \Delta R_2 / \boxed{\Delta E_2}\right) / P_2 \quad = \quad \left(1 - 1/\boxed{\Delta E_2}\right) / 0.3. \tag{21c}$$

ECS $\Delta E_2$ derived from feedback intensities $\boxed{\Lambda_2, \Lambda_2^*, \lambda_2}$

$$\Delta E_2 = \frac{R_2}{1 - \mathbf{G_2} \cdot P_2 \cdot \boxed{\Lambda_2}} - E_1 \quad = \quad \frac{266}{1 - 1.0353 \cdot 0.3 \cdot \boxed{\Lambda_2}} - 288. \tag{22a}$$

$$\Delta E_2 \approx R_2 / (1 - P_2 \cdot \boxed{\Lambda_2^*}) - E_1 \quad \approx \quad 266 / (1 - 0.3 \cdot \boxed{\Lambda_2^*}) - 288. \tag{22b}$$

$$\Delta E_2 = \Delta R_2 / (1 - P_2 \cdot \boxed{\lambda_2}) \quad = \quad 1 / (1 - 0.3 \cdot \boxed{\lambda_2}). \tag{22c}$$

*b. The response curve of ECS against normative $\Lambda_2$ (Fig. 3a)*

The response curve of ECS against normative $\Lambda_2$ on [0.26 to 0.29] W m$^{-2}$ K$^{-1}$, of interval breadth only 0.03 W m$^{-2}$ K$^{-1}$ (Fig. 3a; Eq. 18a), is very close to linear. Visibly, constraint of ECS via derivation of $\Lambda_2$ is untenable, particularly given the 1.3 W m$^{-2}$ K$^{-1}$ breadth of the published interval of uncertainty in net aggregate feedback intensity (IPCC 2021, table 7.10).

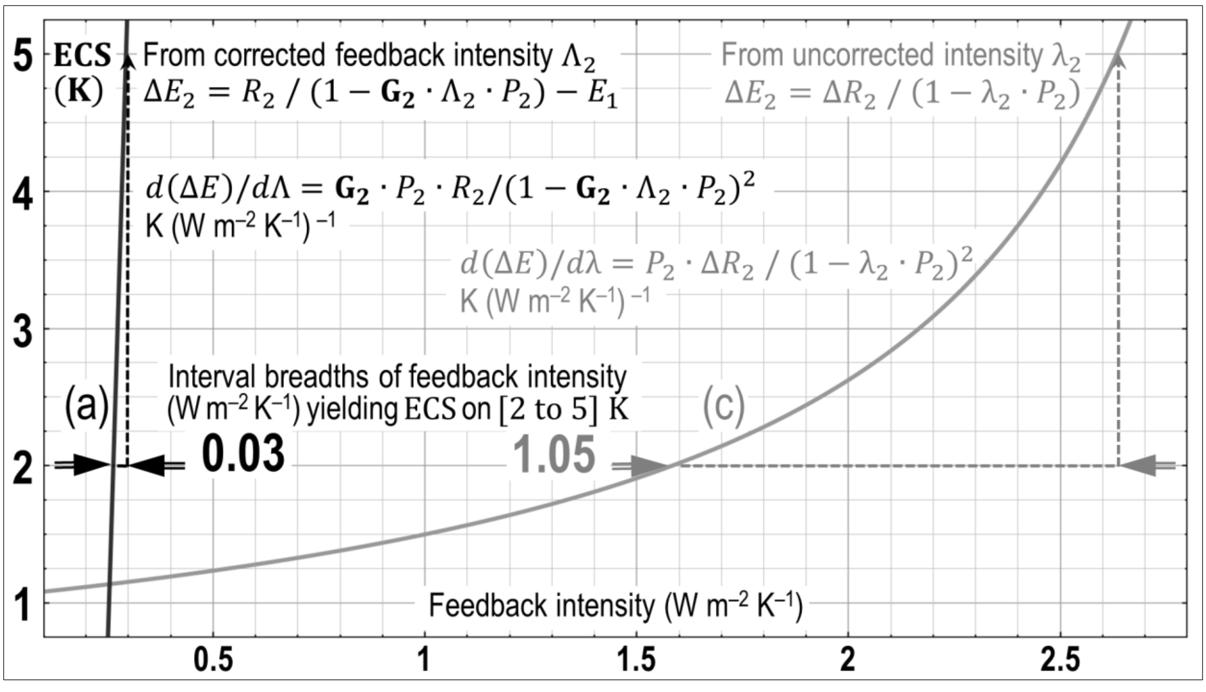


**Figure 3.** Response curve of ECS against (a) normative and (c) defective feedback intensities.

*c. The response curve of ECS against defective $\lambda_2$ (Eqs.18c, 22c)*

The defective response curve of ECS against $\lambda_2$ on $[1.58 \text{ to } 2.63]\ \mathrm{W\,m^{-2}\,K^{-1}}$ (Eq. 18c) is rectangular-hyperbolic: the derivative $d(\Delta E)/d\lambda$ (Eq. 20c) rapidly steepens with $\lambda_2$ (Fig. 3c). Therefore, even if it were acceptable to overlook the control-theoretic error, the defective feedback formulism cannot constrain ECS without an unattainably precise knowledge of $\lambda_2$. To illustrate the amplitude of the error, if defective $\lambda_2$ were input to the normative system-response equation (22a), ECS would fall not on [2 to 5] K but on $[239 \text{ to } 1223]$ K.

In electronic feedback circuits, where the AC open-loop gain and feedback signals often exceed the small DC input signal by orders of magnitude, the input signal may be discarded with little error. In climate, however, there exists no differencer permitting the feedback factor $\mathbf{H_2}$ to respond more to RCS $\Delta R_2$ than to NRS $\Delta R_1$ or to emission temperature $R_0$. Inanimate feedback processes cannot distinguish between 1 K of RCS, of NRS or of emission temperature. Since $\mathbf{G_2} \approx 1$, at any time $t$ they must respond in close proportion to each Kelvin of each of the three components in the entire reference temperature $R_2$.

For this reason, in temperature-feedback amplification it is impermissible to neglect any of the three components in $R_2$. In particular, the $255$ K emission temperature $R_0$ erroneously omitted from the input signal to the temperature-feedback loop exceeds the input signal RCS $\Delta R_2$ in the defective feedback formulism (c) by 2 orders of magnitude, so that $R_0$ cannot be omitted from the input to the temperature-feedback loop without large error. So predominant is $R_0$ that, where it is omitted from the input to the temperature-feedback loop, attempted linearization around the present state of the climate becomes meaningless.

*d. Propagation of uncertainty in general-circulation models' time-step algorithms*

Where $R_0$ is transmitted into the feedback loop (Figs. 1, 2b), the hypersensitivity of ECS even to minuscule time-variance in normative feedback intensity $\Lambda_2$ compounds an established defect in the general-circulation models. The interdisciplinary divide between climatology and statistics has inhibited modelers from taking due account of propagation of uncertainty in through the models' typically hourly time-steps, over decades to centuries, in just one initial condition, the global cloud fraction, renders any ECS projection falling within a $\pm 15$ K uncertainty envelope merely speculative (Frank 2019). All current projections by diagnosis of feedback variables from models' outputs (*e.g.*, Vial 2013) fall within that broad envelope of uncertainty. Since all such projections are further compromised by the control-theoretic error, they are valueless *a fortiori*. Since feedback formulisms (a), (b), (c) cannot reliably constrain ECS, other methods, rooted in observation rather than in general-circulation models' outputs sent to a feedback-amplifier algorithm, must be deployed.

*e. Observational derivations of ECS*

Four observational methods independent of feedback formulism cohere in yielding ECS on [1 to 2.5] K rather than on the [2 to 5] K *e.g.*, in Charney (1979) and IPCC (*passim*) –

a) The energy-budget method (Gregory 2004; Lewis & Curry 2014, 2018) depends not on feedback formulism but on observation. It generates lesser ECS values than the projections overstated in consequence of the control-theoretic error: at midrange, typically $< \mathbf{2\ K}$.

b) *A priori*, the many thermostatic processes in climate (such as ocean heat capacity, thermal inertia of ice or earlier tropical afternoon convection with warming) render it le Châtelier-unlikely that feedback intensity $\Lambda_t$ is time-variant in the industrial era, particularly since the anthropogenic perturbation RCS is small, in which event ECS is as derived in Eq. (5) from the data for the 1850 equilibrium: *i.e.*, $< \mathbf{1.2\ K}$.

c) Anthropogenic forcing by radiatively-active gases since 1850 is $3.2 \text{ W m}^{-2}$ (NOAA 2024), coincidentally close to projected effective doubled-$CO_2$ forcing (ERF) $\Delta Q_2$. Observed warming since 1700 is of order 1.6 K (Jarvis 2024). Assuming no unrealized warming from pre-existing emissions (significant unrealized sub-centennial-scale warming being unlikely after correcting the control-theoretic error), ECS is $\mathbf{1.6}$ **K**.

d) Though 0.3 [0.2 to 0.5] K decade$^{-1}$ transient warming and 3 [2 to 5] K ECS are projected (Charney 1979; IPCC 1990, 2021), since 1979 only 0.15–0.25 K decade$^{-1}$ is observed (Spencer 2025; Morice 2012, 2021). Thus, *pro rata*, ECS falls on $\mathbf{1.5}$**–**$\mathbf{2.5}$ **K**.

*f. Verifications*

**a) Test apparatus:** John Whitfield, a control engineer, constructed a feedback amplifier to emulate temperature feedback and confirm that feedbacks must respond to the input signal (also known in electronics as the setpoint) as well as to any subsequent perturbations thereof.

**b) A national laboratory of physics** thereupon constructed its own apparatus, with which it conducted 23 experiments confirming that feedback processes must respond to any sufficiently substantial input signal – a fact that is in any event inherent in the control-theoretic equations governing feedback amplifiers.

**c) The absent 'hot spot':** Models misrepresent the altitudinal profile of water-vapor feedback. Though by the Clausius-Clapeyron relation the air may carry $7\% \text{ K}^{-1}$ more water vapor at industrial-era temperatures (Wentz 2007), specific humidity is rising at that rate only in the boundary layer (Kalnay 1996), where, however, non-radiative transports limit its influence and its spectral lines are near saturation. As humidity increases, only the far wings add to infrared absorption (Harde 2017), which in any event varies quasi-logarithmically with specific humidity. In the mid-troposphere, specific humidity has declined since 1948 (Kalnay *op. cit.*), while nearly all general-circulation models project that warming should increase it.

Though models thus project a "hot spot" at 200–300 mb in the tropics warming at twice the surface rate (*e.g.*, IPCC 2007**,** fig. 9.1c; Lee 2007), declining specific humidity at that pressure altitude (Kalnay *op. cit.*; Paltridge 2009) explains its absence from nearly all datasets (e.g., Lanzante 2006, fig. 5.7E) and explains a mid-troposphere warming rate 30% of models' mean projection (Spencer 2025). The hot spot being absent, the water-vapor feedback is well below models' current projections, coherent with the present result.

## 6. Discussion

Emission temperature, the true input signal to the temperature-feedback loop, exceeds RCS, the defective input signal, by two orders of magnitude. Feedback intensity acts in response not only to the anthropogenic direct-gain signal RCS (as was hitherto thought) but also to the natural direct-gain signal NRS and, above all, to the predominant emission temperature.

After correction, the slope of the system-response curve of ECS against feedback intensity may readily be derived by multivariate calculus, as in Eqs. 20ab. Since the normative response curve (Fig. 3a) is already close to linear, linearization by way of a first-order Taylor-series expansion is unnecessary. The difficulty lies not in deriving the slope of the curve at the point corresponding to a given value of net aggregate feedback intensity but rather, given the large uncertainties in the underlying data and the hypersensitivity of global temperature to time-variance in net aggregate feedback intensity, in constraining that feedback intensity itself.

Though the interval breadth of projected feedback intensities is $1.3 \text{ W m}^{-2} \text{ K}^{-1}$ (IPCC 2021, table 7.10), the normative feedback intensity for 1850 (the ratio of the feedback factor 0.077 to the then Planck response $0.299 \text{ K W}^{-1} \text{ m}^2$) was $0.257 \text{ W m}^{-2} \text{ K}^{-1}$; and the interval that would yield the long-projected [2 to 5] K ECS today is $[0.264 \text{ to } 0.294] \text{ W m}^{-2} \text{ K}^{-1}$.

Even the normative feedback formulism, then, cannot constrain ECS due to the small amplitude, narrow interval, observational immensurability, large uncertainty and unknown time-variance of net aggregate feedback intensity.

Since feedback processes act on a reference signal greater by orders of magnitude than the 1 K RCS hitherto adopted as the input signal to the feedback loop, equilibrium temperature is hypersensitive even to very small time-variance in feedback intensity: for each $1\ \mathrm{W\ m^{-2}\ K^{-1}}$ increase in feedback intensity, ECS would be expected to increase by $\sim 100$ K. However, since feedback intensity is proving time-invariant in the industrial era, as is to be expected in a near-thermostatic system, the hypersensitivity of temperature to feedback intensity is not proving problematic. Observationally-derived midrange feedback response since 1850 is approximately half of RCS and thus one-third of ECS, not two-thirds as was hitherto thought.

The 3 K projected ECS interval breadth has not changed since Charney (1979) and IPCC (1990): but fear of "tipping points" is an artefact of the error, arising from the shape of the defective rectangular-hyperbolic system-response curve across the interval of overstated ECS projections (Fig. 3c), and is contradicted by the observed near-thermostasis of the climate system in the industrial era. Moreover, where significant time-variance in feedback intensity is assumed, the linearity of observed temperature response to $CO_2$ forcing (Jarvis 2024) is inconsistent with the defective formulism (c) (Fig. 3c).

Due to the error, feedback intensity was hitherto overstated by an order of magnitude. Consequently, projected [2 to 5] K ECS was overstated by a factor 2. Methods independent of feedback formulism, and thus free of the control-theoretic error, yield only 1–2.5 K warming to 2100. Upon correction, climate risk is significantly reduced, since dangerous warming ceases to be near-certain and becomes ever less likely as transient global warming continues at a net-beneficial rate little more than half of the long-standing 0.3 K decade$^{-1}$ midrange projection that has prevailed since IPCC 1990.

# 7. Conclusion

Correcting the control-theoretic error in climatology by which the predominant emission temperature was universally omitted from the input to the climate-feedback loop removes the apparently overriding, error-driven imperative to replace coal, oil and gas with far costlier and less reliable (and, in many Western nations, already wastefully overbuilt) wind and solar generation, which must in any event be backed up at all times by thermal generation at wasteful, continuously-spinning reserve.

While coal, oil and gas reserves endure, the West may safely retain thermal generation for competitiveness, energy security and affordability, even as China and Russia, India and Pakistan rapidly expand it in the East (Shaw 2023; Chaganti Singh 2023; APP 2023; Statista 2023). Adaptation (if needed) is the rational economic choice; and, given the growing security as well as terms-of-trade threats posed by the West's near-unilateral transition to net zero, it is also the strategic imperative.

After correction of the control-theoretic error herein identified, mitigation inexpensive enough to be affordable will be ineffective, especially if it remains near-unilateral, while mitigation expensive enough to be effective will be as unaffordable as it is now unnecessary.

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*Data Availability Statement.*

Supplemental matter providing a history of the control-theoretic error and a national laboratory's report confirming the present result is available from the author.

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