Proceedings of the International CLINTEL Prague Science Conference

An Error of Temperature Feedback Analysis

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Vol. 4.3 (2024)

ISSN 2703-9072

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pp. 21-26

After correcting an error that arose in 1984 when climatologists borrowed, misunderstood and misapplied feedback formulism from control theory in engineering physics, global warming will continue (till hydrocarbon reserves are exhausted) at the net-beneficial 0.15 K decade^{-1} observed rate, half the long-predicted but erroneous 0.3 K decade^{-1} midrange rate.

Keywords: Climate sensitivity, temperature feedback, control theory, emission temperature

Submitted 2024-11-20, Accepted 2024-11-23. https://doi.org/10.53234/scc202412/12

1. Introduction

Equilibrium doubled-CO_2 sensitivity (ECS: final warming after a forcing equivalent to doubling CO_2) is projected to fall on 3 [2 to 5] K (Charney 1979; IPCC 2021), of which only ~1 K is direct warming by (or reference sensitivity RCS to) a doubled-CO_2-equivalent forcing. Uncorrected feedback response, an additional, indirect warming engendered by a direct temperature, was accordingly thought to fall on 2 [1 to 4] K, representing as much as 67% [50% to 80%] of ECS. Thus, IPCC (2013) mentions the word "feedback" 1100 times, and IPCC (2021) 2500 times.

By the water-vapor feedback, directly-warmed air may carry more water vapor, a greenhouse gas, amplifying a direct temperature. At midrange, all other sensitivity-relevant feedbacks (Bates 2016), chiefly lapse-rate, cloud and albedo, broadly self-cancel (*e.g.*, IPCC 2013, table 9.5).

Temperature feedbacks respond at any moment to the entire reference temperature then present. The 269 K current reference temperature R_2 comprises 260 K emission temperature R_0, 8 K reference sensitivity (NRS) ΔR_1 to natural greenhouse gases and 1 K reference sensitivity ΔR_2 to all anthropogenic ghg forcing since 1850 (equivalent to 1 K reference sensitivity RCS to doubled CO_2 alone). R_0, which thus exceeds all other temperature signals by orders of magnitude, is the true input signal to the feedback loop, but is universally omitted. Instead, its large feedback response is in effect added to, and miscounted as part of, the small feedback response to the 1 K RCS ΔR_2. IPCC (2021, p. 2222) incompletely defines "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."

The resultant error is universal in climatology. Hansen (1984) first deployed control theory in deriving ECS, but omitted the 260 K emission temperature R_0 and took reference doubled-CO_2 sensitivity (RCS) ΔR_2 as 1.2–1.3 K and ECS ΔE_2 as ~4 K, thereby assuming that the feedback variables responded solely to RCS and concluding that the uncorrected closed-loop-gain factor A_2 [misidentified *ibid.* as the "feedback factor"] was 4 / 1.25, or 3–4:

> "Our 3D global climate model yields a warming of ~4 C for doubled CO_2. This indicates a net feedback factor [actually a closed-loop gain factor] of … 3–4."

Though the error is grave, the interdisciplinary divide has delayed its detection. Without it, dangerous warming becomes unlikely: the world is warming at a rate half the long-standing 0.3 K decade^{-1} midrange projection (*e.g.*, IPCC 1990). The error explains why the ~3 K breadth of the projected ECS interval is as broad today as in Charney (1979) and IPCC (1990).

2. Results by the corrected feedback method

In a feedback amplifier, at time t ($t = 0$ at emission temperature; $t = 1$ in 1850; $t = 2$ in 2024 following the observed 2xCO_2-equivalent anthropogenic forcing by all sources since 1850), the input signal or setpoint R_0 enters a feedback loop, around which the signal passes infinitely via the $\mathbf{G_2}$ open-loop gain block and the $\mathbf{H_2}$ feedback block to yield the output signal E_2 (Fig. 1).

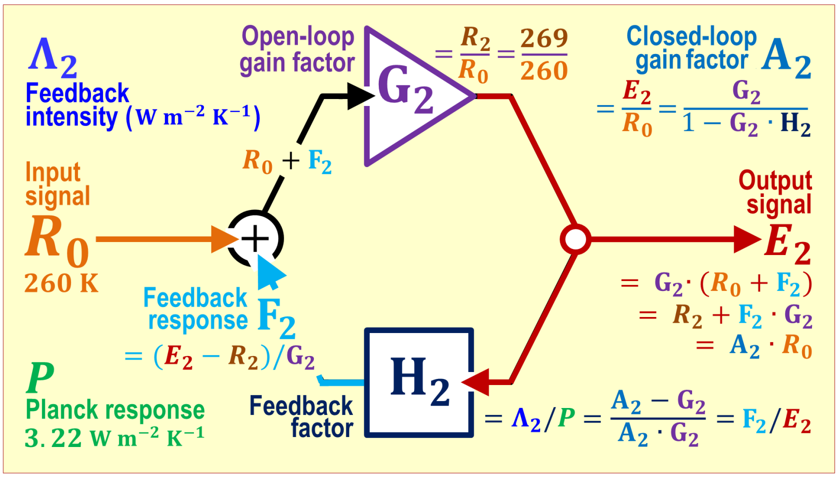

Figure 1. *Block diagram showing principal temperature-feedback equations at time* $\boldsymbol{t} = 2$

Feedback variables (feedback intensity Λ_2; feedback factor $\mathbf{H_2}$; closed-loop gain factor A_2) are not *italicized*: uncorrected $\lambda_2, \mathbf{h_2}, a_2$ are lowercase; corrected $\Lambda_2, \mathbf{H_2}, A_2$ are UPPERCASE.

> **Feedback intensity** Λ_2, the originating feedback variable, in W m^{-2} K^{-1} of the output signal (equilibrium temperature E_2), is the sum of the short-acting (sensitivity-relevant) water-vapor, lapse-rate, surface-albedo and cloud feedback intensities (IPCC 2021).

> **The feedback factor** $\mathbf{H_2}$ (unitless) is the ratio of Λ_2 to the 3.22 W m^{-2} K^{-1} Planck response P (*ibid.*); of feedback response F_2 to E_2; and of $(\mathbf{A_2} - \mathbf{G_2})$ to $\mathbf{A_2} \cdot \mathbf{G_2}$.

> **The closed-loop gain factor** A_2 (unitless) is equal to E_2 / R_0, and to $\mathbf{G_2} / (1 - \mathbf{G_2} \cdot \mathbf{H_2})$.

On doubling CO_2 since 1850 (Fig. 1), the true feedback factor $\mathbf{H_2}$, the operant in the feedback loop, responds to the entire reference temperature R_2, the 269 K sum of the 260 K R_0, the 8 K NRS ΔR_1 and the 1 K RCS ΔR_2. The open-loop gain factor $\mathbf{G_2}$ is the ratio 1.0346 of R_2 to R_0.

In electronic feedback amplifiers, one may introduce a differencer permitting the $\mathbf{H_2}$ feedback block to act more upon the direct-gain signals than upon the input signal. No such differencer exists in climate. Therefore, since $\mathbf{G_2}$ barely exceeds unity, $\mathbf{H_2}$ and thus Λ_2 respond in close proportion to the amplitudes of the three components R_0, ΔR_1 and ΔR_2 that sum to R_2.

The Sun, via R_0, thus drives 96% of feedback response F_2, a fact hitherto overlooked in climate science. That fact permits derivation of the 0.235 [0.225 to 0.255] $\mathrm{W\,m^{-2}\,K^{-1}}$ interval (Eq. 1) of corrected feedback intensities Λ_2 that would yield the long-projected [2 to 5] K ECS ΔE_2. The derivative $dE_2/d\Lambda_2$, equal to $d(\Delta E_2)/d\Lambda_2$, is then of order 100 K $(\mathrm{W\,m^{-2}\,K^{-1}})^{-1}$ (Fig. 2 *left*).

$$\begin{aligned}\Lambda_2 \;=\; P\cdot\mathbf{H_2} \;=\; P\cdot\frac{\mathrm{F}_2}{E_2} \;=\; P\cdot\frac{E_2-R_2}{E_2\cdot\mathbf{G_2}} \;&=\; P\cdot\frac{(E_1+\Delta E_2)-R_2}{(E_1+\Delta E_2)\cdot(R_2/R_0)}\\ &=\; 3.22\cdot\frac{(288+\Delta E_2)-269}{(288+\Delta E_2)\cdot(269/260)}.\end{aligned} \qquad (1)$$

To constrain ECS to within 1 K by feedback analysis, Λ_2 must be derived to 0.01 $\mathrm{W\,m^{-2}\,K^{-1}}$ precision. Given the large published uncertainties in feedback intensities (none can be measured directly), as well as in process understanding, such fine precision is in practice unattainable.

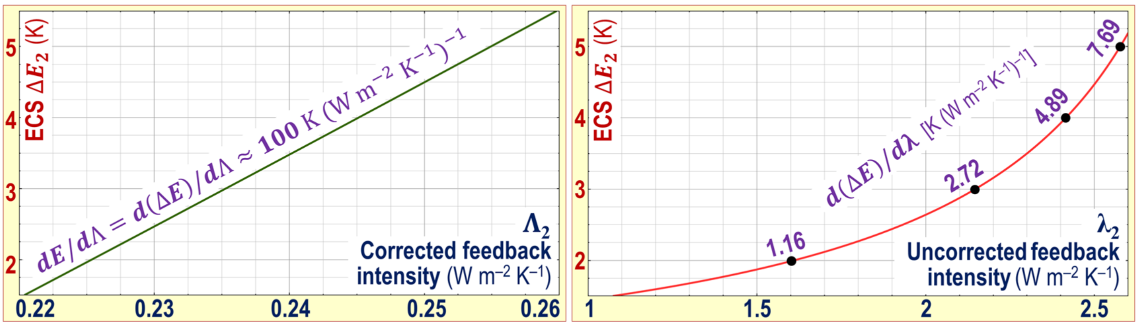

Figure 2. *ECS on [2 to 5] K against corrected (left) and uncorrected (right) feedback intensity*

3. Results by the uncorrected feedback method

The uncorrected method (Eq. 2) neglects emission temperature R_0. Feedback intensity λ_2 falls on 2.1 [1.6 to 2.6] $\mathrm{W\,m^{-2}\,K^{-1}}$, similar to the 2.1 [1.4 to 2.7] $\mathrm{W\,m^{-2}\,K^{-1}}$ found by adding the 3.22 $\mathrm{W\,m^{-2}\,K^{-1}}$ Planck response $|P|$ to the –1.16 [–1.81 to –0.51] $\mathrm{W\,m^{-2}\,K^{-1}}$ feedback intensities in IPCC (2021, table 7.10); and see Roe (2009). Since the calming effect of R_2 is absent, the uncorrected derivative $d(\Delta E_2)/d\lambda_2$ accelerates (Fig. 2 *right*) with λ_2, which is excessive.

$$\lambda_2 \;=\; P\cdot\mathbf{h_2} \;=\; P\cdot\frac{\Delta\mathrm{F}_2}{\Delta E_2} \;=\; P\cdot\frac{\Delta E_2-\Delta R_2}{\Delta E_2} \;=\; P\cdot\left(1-\frac{\Delta R_2}{\Delta E_2}\right) \;=\; 3.22\cdot\left(1-\frac{1}{\Delta E_2}\right). \qquad (2)$$

4. The corrected and uncorrected feedback methods compared

Table 1. *Results*

ECS ΔE_2	K	1	2	3	4	5
Corrected Λ_2	$\mathrm{W\,m^{-2}\,K^{-1}}$	0.215	0.225	0.235	0.245	0.255
Derivative $dE_2/d\Lambda_2$	$\mathrm{K\,(W\,m^{-2}\,K^{-1})^{-1}}$	99.76	100.45	101.15	101.84	102.54
Uncorrected λ_2	$\mathrm{W\,m^{-2}\,K^{-1}}$	0.00	1.61	2.15	2.42	2.58
cf. IPCC (2021): implicit λ_2	$\mathrm{W\,m^{-2}\,K^{-1}}$	—	*1.41*	*2.06*	—	*2.72*
Derivative $d(\Delta E_2)/d\lambda_2$	$\mathrm{K\,(W\,m^{-2}\,K^{-1})^{-1}}$	0.23	1.16	2.72	4.89	7.69

Table 1 compares results by both methods. Substituting the 2.06 [1.41 to 2.72] $\mathrm{W\,m^{-2}\,K^{-1}}$ uncorrected feedback intensities λ_2 (IPCC 2021) for Λ_2 in the corrected system-response equation (Eq. 3) treats λ_2 as responding not only to 1 K RCS but also to 8 K NRS and 260 K emission temperature R_0. ECS would then fall on 500 [200 to 1800] K, illustrating the large effect of the order-of-magnitude overstatement of feedback intensity when R_0 is neglected.

$$\Delta E_2 = E_2 - E_1 = R_0 \cdot \mathrm{A}_2 - E_1 = R_0 \cdot \frac{\mathbf{G_2}}{1 - \mathbf{G_2} \cdot \mathbf{H_2}} - E_1$$
$$= \frac{R_2}{1 - (R_2/R_0) \cdot (\Lambda_2/P)} - E_1 = \frac{269}{1 - (269/260) \cdot (\Lambda_2/3.22)} - 288. \quad (3)$$

A priori, the many thermostatic processes in climate (*e.g.*, ocean heat capacity, thermal inertia of ice or earlier tropical afternoon convection with warming) render it le Châtelier-unlikely that feedback intensity is time-variant in the industrial era, in which event ECS is ~1.1 K.

If, however, time-variance is present, uncertainties in process understanding and in in individual feedback intensities rule out constraint of Λ_2 to within 0.01 $\mathrm{W\,m^{-2}\,K^{-1}}$, so that feedback analysis is unsuitable for constraint of ECS.

After correcting the error, the hypersensitivity of ECS even to very small time-variance in Λ_2 compounds a grave, established defect in the general-circulation models.

Frank (2019) showed that propagation of the published uncertainty in just one initial condition, the global annual mean cloud fraction, renders any ECS projection falling within a ±15 K uncertainty envelope valueless. Since all current projections by diagnosis of feedback variables from models' outputs (*e.g.*, Vial 2013) fall within that envelope, they are merely speculative.

In the electronic feedback circuits for which control theory was originally developed, the AC open-loop gain and feedback signals may exceed the small DC input by orders of magnitude, and the input may be blocked and discarded, so that neglect thereof in taking the derivative entails little or no error.

In climate, however, the 260 K emission temperature R_0 exceeds the 8 K NRS ΔR_1 and the 1 K RCS ΔR_2 by two orders of magnitude and the 0.1 K feedback response $\Delta \mathrm{F}_2$ by three. For this reason, feedback analysis cannot reliably constrain ECS. Other methods are required.

5. Methods independent of feedback analysis

Four methods independent of feedback analysis, each informed by mainstream data, cohere in yielding ECS on [1 to 2] K rather than on the current [2 to 5] K (Charney 1979; IPCC *passim*).

a) If the current closed-loop gain factor A_2 is invariant at 1.1 as in 1850, ECS is $\sim\mathbf{1.1\ K}$.

b) Anthropogenic greenhouse-gas forcing since 1850 is 3.6 W m^{-2} (NOAA 2024), similar to projected forcing by doubled CO_2, while observed period warming was ~1.1 K. Assuming no unrealized warming in the pipeline from pre-existing emissions (significant unrealized warming being unlikely after correcting the error), ECS is again $\mathbf{1.1\ K}$.

c) Though 0.3 [0.2 to 0.5] K decade^{-1} warming and 3 [2 to 5] K ECS are predicted (IPCC 1990, 2021), in the third of a century since 1990 only [0.15 to 0.2] K decade^{-1} is observed (Spencer 2024; Morice 2021). Thus, *pro rata,* observationally-derived ECS falls on $[\mathbf{1.5\ to\ 2}]\ \mathbf{K}$.

d) The energy-budget method (Gregory 2004; Bates 2016; Lewis 2014, 2018) generally shows appreciably less ECS than the defective feedback analyses compromised by the error. Deploying mainstream climate data in the simplified energy-budget equation from Lewis, *op. cit.*, via a billion-trial Monte Carlo process yields ECS on $\mathbf{1.3}\ [\mathbf{0.9\ to\ 2}]\ \mathbf{K}$.

6. Verification

John Whitfield, a control engineer, built a feedback amplifier to emulate temperature feedback, confirming that feedbacks respond to the entire reference temperature. A national laboratory of physics thereupon constructed its own apparatus, with which it conducted 23 experiments providing confirmation of that result (which is anyway inherent in the feedback equations).

7. Consequences of the error

The input signal to the climate-feedback loop is understated by two orders of magnitude, feedback intensity is overstated by an order of magnitude and projected global warming is overstated by a factor 2–3.

Feedback analysis is valueless for constraint of ECS, due to the small amplitude, narrow interval, observational immensurability and unknown time-variance of true feedback intensity.

Temperature is hypersensitive even to minuscule changes in corrected as well as in uncorrected feedback intensity (though feedback intensity is proving time-invariant).

Methods independent of feedback analysis yield only 1 to 2 K warming to 2100, implying only 1 to 2 K ECS and swinging the risk-reward ratio against climate action.

8. Conclusion

After correcting the error, the mild warming that may legitimately be expected is more likely to do good than harm. 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. Adaptation, to the limited extent necessary, is the rational economic choice. Mitigation inexpensive enough to be affordable will be ineffective; mitigation expensive enough to be effective will be as unaffordable as it is now unnecessary.

Guest editor: Stein Storlie Bergsmark

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