On an error in defining temperature feedback: a scientist's guide

Monckton of Brenchley *et al.* (2018)

An elementary and grave error of physics first perpetrated 123 years ago (Arrhenius 1896, 1906) and since perpetuated by climatologists (e.g. Charney+ 1979; Hansen 1984; Schlesinger 1985) drove the excessive predictions of up to 10 K global warming per CO_2 doubling (e.g. Armour 2017; Friedrich+ 2016; Johansson+ 2015; Murphy+ 2009; Forest+ 2006; Andronova & Schlesinger 2001) that have until now provided the pretext for misplaced worldwide concern about climate change. After correction, there will be about 1.2 K global warming per CO_2 doubling – small, slow, harmless and beneficial.

The chief unknown quantity in climate sensitivity studies was the feedback system-gain factor – the ratio of equilibrium temperature (after feedback has acted) to reference temperature (before feedback acts). Till now, the system-gain factor was thought to multiply the 1.04 K reference sensitivity (before feedback) to doubled CO_2 (Andrews+ 2012) by $\mathbf{3.25}$ [2, 4.5]. Thus, climate models currently predict that equilibrium sensitivity (after feedback) will be $\mathbf{3.4}$ [2.1, 4.7] K per CO_2 doubling. Murphy+ (2009) goes so far as to say 10 K cannot be ruled out. These excessive global-warming estimates have changed little since Charney+ (1979) predicted equilibrium sensitivity of $\mathbf{3.0}$ [1.5, 4.5] K, the interval adopted by IPCC (1990, 2013).

In mainstream control theory, first formalized in the early 20[th] century (e.g. Black 1934, Bode 1945), responses to feedback arise not only from perturbations in the state of a dynamical object like climate but from the entire input signal, which in climate includes the 255 K reference temperature that would have obtained at the Earth's surface in 1850 before any significant anthropogenic perturbation (and before any temperature feedbacks acted). Observed equilibrium temperature (after feedbacks had acted) was 287 K.

Climatologists had, however, erroneously assumed that feedback responses arose only when the climate was perturbed. In effect, they forgot the Sun is shining. The variant system-gain equation they used to study the influence of feedback on temperature constituted the difference between two equilibrium states of the mainstream system-gain equation that models feedback in all dynamical systems. Climatology's variant equation is correct as far as it goes, but it is incomplete. In effect, the emission temperature and the influence of the pre-industrial greenhouse gases are subtracted out. Therefore, unlike the mainstream equation, the variant equation cannot reliably derive the correct system gain factor. Restoring the Sun's warmth permits a simple but reliable derivation of the system gain factor for 1850: $287/255 = \mathbf{1.129}$.

A similar calculation may be done for 2011. Reference sensitivity to the $2.29\ \mathrm{W\,m^{-2}}$ net anthropogenic forcing to 2011 (IPCC 2013, fig. SPM.5) was $\mathbf{0.7\ K}$. Observed warming was 0.75 K (Morice+ 2012), but, allowing for a $0.6\ \mathrm{W\,m^{-2}}$ radiative imbalance (Smith+ 2015) that may have delayed the full warming, a further 0.25 K may be imagined, giving $\mathbf{1\ K}$ presumed equilibrium warming from 1850-2011. Then the system gain factor for 2011 is $(287 + \mathbf{1})/(254 + \mathbf{0.7}) = \mathbf{1.129}$, the same as in 1850. Thus, any non-linearity in individual feedbacks is overwhelmed by the feedback response to reference temperature 254 K, which is 375 times the feedback response to the 0.7 K anthropogenic reference warming to 2011.

True equilibrium sensitivity to doubled CO_2, is $\mathbf{1.129}$ times the 1.04 K reference sensitivity to doubled CO_2: i.e., just $\mathbf{1.17}$ **K.** This value is about a third of the models' mid-range estimate, a quarter of their high-end estimate and less than one-eighth of the extreme estimates imagined by some authors.

Even using climatology's variant equation, the system gain factor for 2011 is $\mathbf{1.02/0.68 = 1.5}$, giving 1.04 x $\mathbf{1.5 = 1.55\ K}$ equilibrium sensitivity. Yet models had baselessly predicted up to 4.7 K.

Feedbacks, though mentioned more than 1000 times in the *Fifth Assessment Report* (IPCC 2013), will thus add little to the 1 K reference sensitivity to doubled CO_2 concentration. They can be altogether ignored with little error. Though Lord Stern, in his 2006 government review of climate economics, had bizarrely based his case for mitigation of global warming on an imagined 1 in 10 chance that global warming would end the world by 2100 (Dietz+ 2007), there will be only $\mathbf{1.17}$ [1.08, 1.25] K warming per CO_2 doubling, and about the same warming from all anthropogenic sources by 2100 – far too little to cause harm.

A scientific summary with more details of the physics underlying this result is overleaf.

On an error in defining temperature feedback: the physics

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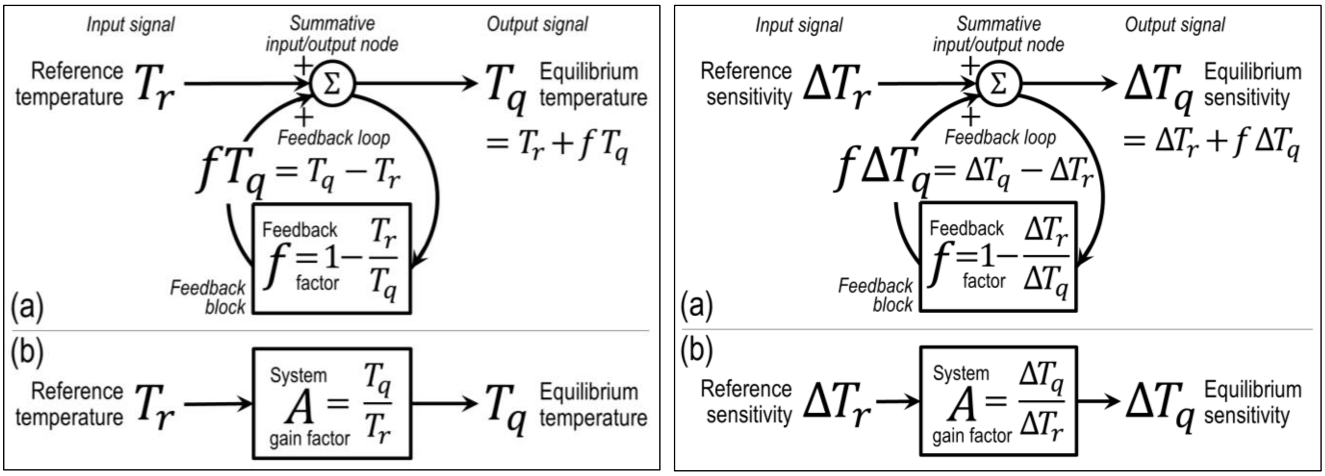
Abstract: In any dynamical system, feedback responds to the entire absolute input signal, not merely to perturbations. Hitherto, however, climatology has used a variant system-gain equation that omitted from the input signal in the temperature-feedback loop not only the emission temperature but also the warming from pre-industrial non-condensing greenhouse gases. Using control theory's mainstream equation, the system gain factors for 1850 and 2011 are found identical at $\mathbf{1.129}$ rather than the current 3.25, reducing the 2 σ interval of Charney sensitivities from 3.35 [2.1, 4.7] K to just $\mathbf{1.17}$ [1.09, 1.25] K.



FIGS. 1 (left) and **2** (right) Block diagrams for Eqs. (1, 2). The feedback loop diagrams (a) simplify to the system-gain diagrams (b).

Control theory's mainstream system-gain equation, Eq. (1), whose block diagram is Fig. 1 (left above), models feedback in all dynamical systems. In climate, $T_r, \Delta T_r, T_q, \Delta T_q$ are, respectively, reference temperature and sensitivity (before feedbacks act) and equilibrium temperature and sensitivity (after feedbacks have acted). The feedback factor $f\ (= 1 - T_r/T_q)$ is the fraction of equilibrium temperature represented by the temperature response to feedback. The system-gain factor A is defined as T_q/T_r.

Two surface temperature equilibria, for 1850 (Eq. 1.1) and 2011 (Eq. 1.2), were input to the mainstream equation to derive the feedback factors f_1, f_2 and system-gain factors A_1, A_2 for these two years and then to derive Charney sensitivity ΔT_{q2}.

$\boldsymbol{T_q = T_r/(1-f) \coloneqq T_r A}$	**Mainstream equation (generic)**	**(1)**
$T_{q1} = T_{r0} + \Delta T_{r0} + f T_{q1} = T_{r1} + f T_{q1} = T_{r1}/(1-f_1) \coloneqq T_{r1}\,A_1$	Mainstream equation for 1850	(1.1)
$T_{q2} = T_{r1} + \Delta T_{r1} + f T_{q2} = T_{r2} + f T_{q2} = T_{r2}/(1-f_2) \coloneqq T_{r2}\,A_2$	Mainstream equation for 2011	(1.2)

Climatology's variant equation, Eq. (2) (block diagram at Fig. 2), relies on perturbations, not on absolute temperatures. In Eq. (2), which constitutes the difference between two instances of the mainstream equation, reference temperature T_{r2} is subtracted out:

$T_{q3} = (T_{r2} + \Delta T_{r2})A;$	Mainstream equation for 2xCO₂	(1.3)
$T_{q2} = (T_{r2} \qquad)A;$	Mainstream equation for 2011	(1.2)
$\boldsymbol{\Delta T_{q2} = (\qquad \Delta T_{r2})A.}$	**Variant equation for 2xCO₂**	**(2)**

Equilibrium 1 (1850): In Eq. (1.1), reference temperature T_{r1} is the sum of emission temperature T_{r0} and the warming ΔT_{r0} from pre-industrial non-condensing greenhouse gases. Without those gases, albedo α would be 0.418 (Lacis 2010) against 0.298 today (deWitte 2017). Then, assuming today's insolation $S_0 = 1364.625$ W m^2 (Mekaoui 2010), emission temperature T_{r0} at the surface without pre-industrial non-condensing greenhouse gases would be $[S_0(1-\alpha)/4\sigma]^{¼} = 243.25$ K in the Stefan-Boltzmann equation.

From the 30 W m^{-2} CO_2 forcing to date (Schmidt+ 2010), of which 1.68 W m^{-2} represented 73% of net anthropogenic warming from all sources to 2011, the net pre-industrial greenhouse-gas forcing ΔQ_0 to 1850 was $(30 - 1.68)/0.73$, or 38.6 W m^{-2}. Where the Planck parameter λ_P is 0.3 K W^{-1} m^2 (Schlesinger 1985), $\Delta T_{r0} = \Delta Q_0 \lambda_P = 11.55$ K. Reference temperature $T_{r1}\ (= T_{r0} + \Delta T_{r0})$ in 1850 was 254.8 K, while equilibrium temperature T_{q1} was today's 288.4 K (ISCCP 2018) less the 0.85 K observed warming from 1850-2017 (HadCRUT4), i.e., 287.55 K. Therefore, in 1850 the system-gain factor A_1 was 287.55/254.8. or $\mathbf{1.129}$.

Equilibrium 2 (2011): In Eq. (1.2), anthropogenic forcing ΔQ_1 to 2011 was 2.3 W m^{-2} (IPCC 2013, fig. SPM.5), implying period reference sensitivity $\Delta T_{r1} = \Delta Q_1 \lambda_P = \underline{0.68\text{ K}}$. The radiative imbalance ΔQ_{im} to 2010 was 0.6 W m^{-2} (Smith+ 2015). Warming ΔT_{obs} to 2011 was 0.75 K (Morice+ 2012); ΔT_{q1} in 2011 was then $\Delta T_{\text{obs}} \Delta Q_1/(\Delta Q_1 - \Delta Q_{\text{im}})$, or $\underline{1.02\text{ K}}$. The system-gain factor A_2 was $(T_{q1} + \Delta T_{q1})/(T_{r1} + \Delta T_{r1}) = (287.55 + \underline{1.02})/(254.8 + \underline{0.68}) = T_{q2}/T_{r2} = 288.57/255.48 = \mathbf{1.129}$, very close to A_1 in 1850.

Equilibrium 3 (2xCO₂): In the CMIP5 models (Andrews 2012), mean forcing ΔQ_2 from 2xCO₂ is 3.466 W m^{-2}. Then reference sensitivity $\Delta T_{r2} = \Delta Q_2 \lambda_P = 3.464(0.3) = 1.04$ K to doubled CO_2. In Eq. (2), Charney sensitivity $\Delta T_{q2} = 1.04(\mathbf{1.129}) = \mathbf{1.17}$ **K.**

Empirical verification: Ten authoritative estimates of net industrial-era anthropogenic forcing were compared with period surface temperature trends. Charney sensitivity was not the 3.37 K currently imagined. It was $\mathbf{1.17}$ **K** in each of the ten cases.