Sources of Variation in Climate Sensitivity Estimates

GC33H-1453

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Misdefinition

PROBLEM *Lack of CO2 data constraining TCR's PDF*

The bulk of the interest in climate sensitivity is arguably for its applicability to centennial climate forecasts. Equilibrium climate sensitivity is clearly out of the question for that application, which leaves transient climate response, TCR, as the IPCC's only applicable definition of climate sensitivity. (The IPCC also defines TCRE, transient climate response to a teratonne increase in carbon *emissions*, but climate sensitivity is customarily understood in terms of response to radiative forcing rather than emissions.)

TCR is hard to estimate because it is defined for a behavior of CO2 for which we have no prior experience, namely a compound annual growth rate (CAGR) of 1%. Climate models estimate their parameters as probability density functions (PDFs) calculated iteratively from other PDFs using Bayes' theorem, starting from priors constrained by empirically obtained relations between geophysical parameters. The difficulty for TCR is that the only relations we've seen between CO2 and climate are for much lower CAGRs, and there seems to be no universally accepted way to bridge that data gap.

SOLUTION *A small modification to TCR's definition*

We propose a simple modification of TCR, which we call *Prevailing* Climate Response. We replace the 1% CAGR of CO2 with a 2% CAGR for *anthropogenic* CO2 defined as the excess CO2 over the natural background of 280 ppm. (This is essentially a simplification of D. Hofmann's law of 2010 [1].)

ADVANTAGES *Three justifications for this modification*

(i) PCR is a far better fit than TCR to RCP8.5 to 2060, one of the scenarios we are very interested in, as Figure 1 makes clear. (The abrupt climate change forecast by RCP8.5 for 2070 is very interesting.)

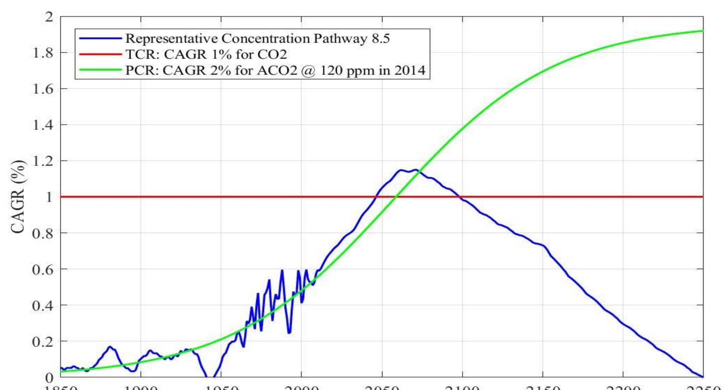

Fig. 1. CAGR of CO2 for RCP8.5 TCR, and PCR, 1850-2250

(ii) We have excellent data constraining PCR from past centuries, as illustrated by Figure 2.

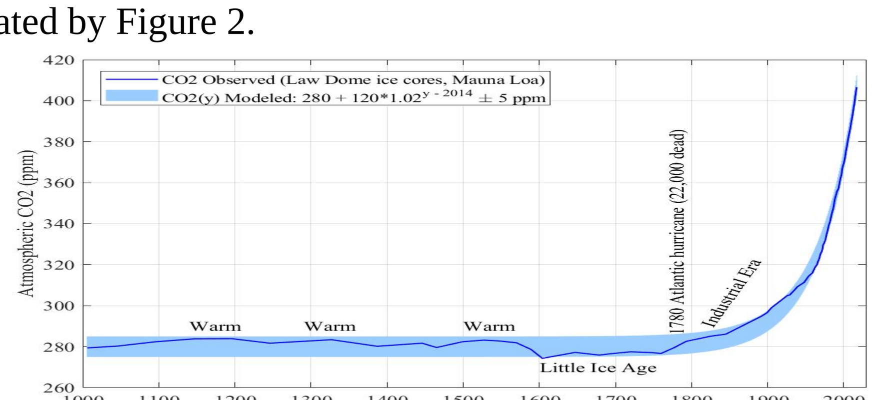

Fig. 2. CO2 1006-2017: observed (Law Dome, Mauna Loa) vs. PCR

(iii) The extreme straightness of log2(CO2 – 280) as seen in Figure 3 makes it likely that estimates of PCR will remain good until that curve starts to bend down, about whose timing we know nothing whatsoever.

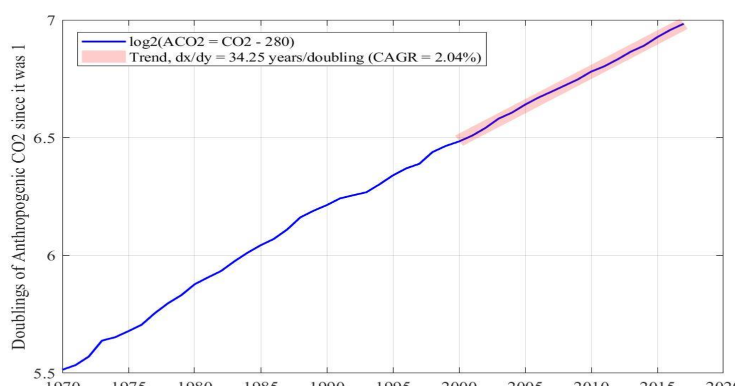

Fig. 3. Logarithm of Anthropogenic CO2

Mistakes

PROBLEM *PCR seems no better than TCR in practice*

Some authors have understood climate sensitivity to mean simply the response of climate to a doubling of CO2 without the ECS requirement of waiting until the response equilibrates (and so implicitly assuming effective or real-time climate sensitivity), and without the TCR requirement that CO2 rise at 1% a year during the warming (and so implicitly assuming the prevailing behavior of CO2 on which to base the response). Figures 1-3 show this to be equivalent to PCR.

Loehle and Scafetta (2011) [2] obtained a warming induced by CO2 of 0.66 C/century, based on fitting CO2 rising at the TCR CAGR of 1% to HadCRUT3's rise in temperature during the period 1943-2010. Since it takes 0.7 of a century for CO2 to double at that rate, this would be a PCR of 0.66*0.7 = 0.462 C/doubling. Fig. 4 duplicates their method exactly in MATLAB.

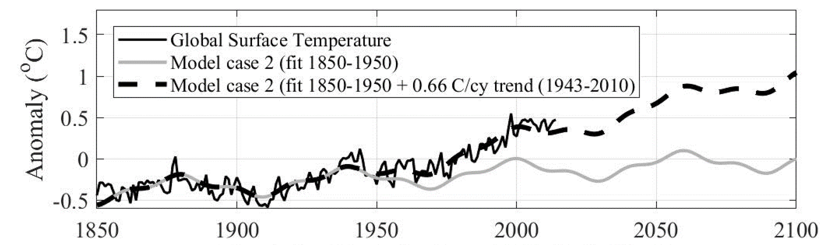

Fig. 4. Loehle & Scafetta 2011 (their Fig 5)

S. Lovejoy (2014) [3] obtained a far larger PCR of 2.33 C by a more plausible method, namely to plot GISTEMP against log2(CO2) instead of against time. (We obtained 2.32 when we duplicated it in MATLAB as per Fig. 5.)

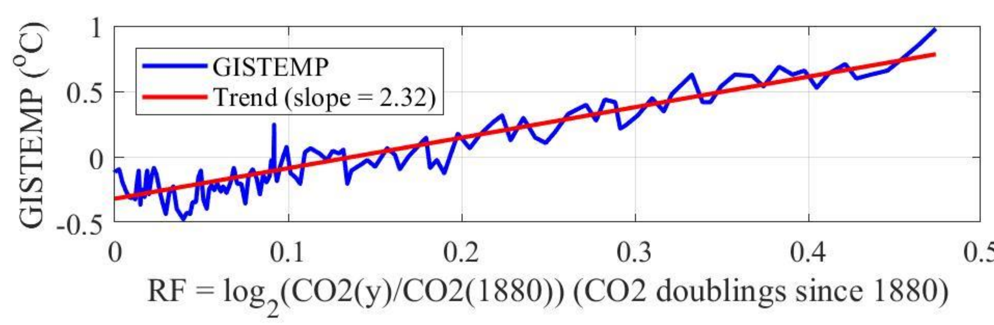

Fig. 5. Lovejoy's method: GISTEMP vs. log2(CO2/CO2(1880))

One might infer from this wide range that PCR does no better than TCR as a notion of climate sensitivity that can be reliably estimated.

SOLUTION *Simple mistakes that are easily fixed*

Both estimates make elementary mistakes in estimating PCR as respectively too low and too high.

(i) L&S's mistake is to relate warming during 1943-2010 to TCR's 1% CAGR for CO2 instead of that for CO2 during that period.

(ii) Lovejoy makes two mistakes. First is his assumption that global warming is entirely attributable to CO2 when in fact total solar irradiance TSI increased during 1900-1950, a period in which CO2 increased relatively little. Second, when the CO2 data is uniformly distributed in time its logarithm concentrates more of those datapoints in the left half of the plot, exaggerating the Sun's contribution by a factor of about two.

When the appropriate corrections are made, the respective estimates of L&S and Lovejoy converge to the neighborhood of 1.8 C/doubling. The correction for L&S is simply to use the correct CO2 data. For Lovejoy it suffices to detrend GISTEMP by the likely influence of solar irradiance and then resample GISTEMP to create datapoints spread evenly along the radiative-forcing x-axis, easily done with MATLAB's interp1 function.

Misattribution

PROBLEM *Climate is too noisy to estimate PCR accurately*

We saw this already with Lovejoy's method, which not only attributed the 1900-1950 rise in TSI to CO2 but then doubled that error by concentrating much of the data into where the CO2 was not changing much. We infer that *multiple* linear regression fitting both CO2 *and* TSI to HadCRUT4 is essential to avoid Lovejoy's overestimate of PCR. The blue curve in Figure 6 shows the residual after this fitting.

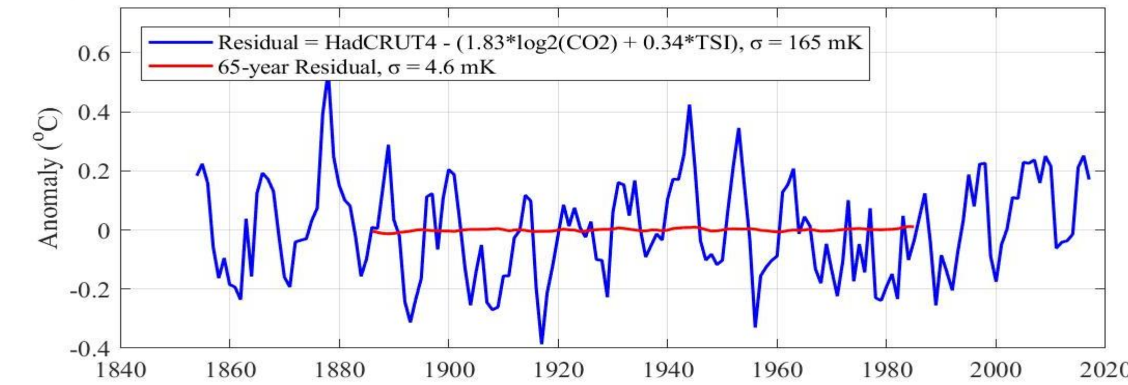

Fig. 6. HadCRUT4 detrended by RF and TSI, unsmoothed and smoothed

This residual is quite noisy, with a standard deviation σ of 165 millikelvin (mK). This gives a quantitative sense in which "climate is always changing", and also raises doubts as to the quality of the fit: the noise could well be masking considerable uncertainty.

Applying a 65-year moving average filter to this residual yields the red curve, whose σ of 4.6 mK is dramatically lower. The significance of this huge decrease is that, with the exception of changes due to CO2 and TSI, we can now say "climate is always changing *quickly*", namely with all event durations and oscillation periods shorter than 65 years.

While some decrease is to be expected, such a large decrease is remarkable. We can get insight into how filtering the residual brought its σ down by a factor of 16 by comparing (i) what we would have obtained if we had omitted TSI from the above fit, with (ii) TSI itself, after smoothing both to a 65-year moving average. (This is recent TSI reconstructed from group numbers, ^{10}Be deposits, etc.)

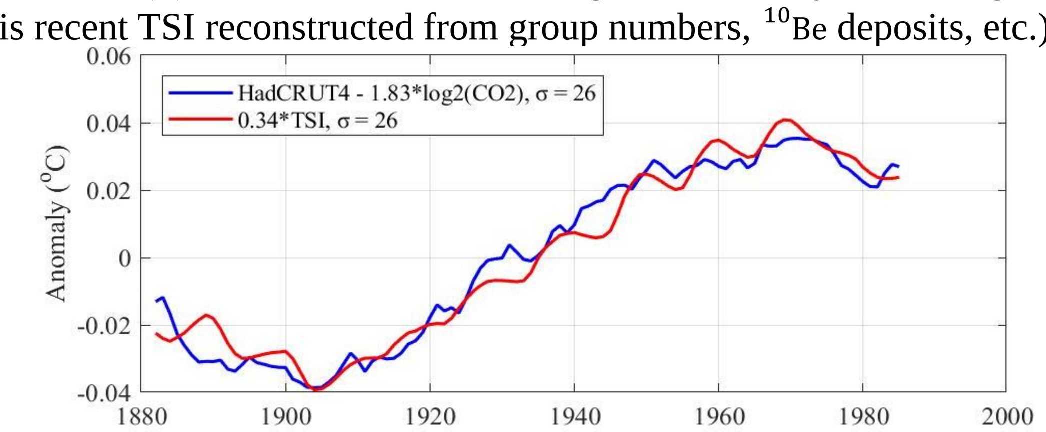

Fig 7. Climate less CO2 vs. TSI, filtered to 65 years

Both turn out to have a σ of 26 mK. This is more typical of what is obtained when modeling data with one signal when other signals are present: they naturally contribute to the residual.

What we infer in this case is that TSI is essentially the *only* other signal present! All other contributors to climate varied too rapidly to survive the 65-year filter.

The next plot shows that we still haven't fully solved our attribution problem.

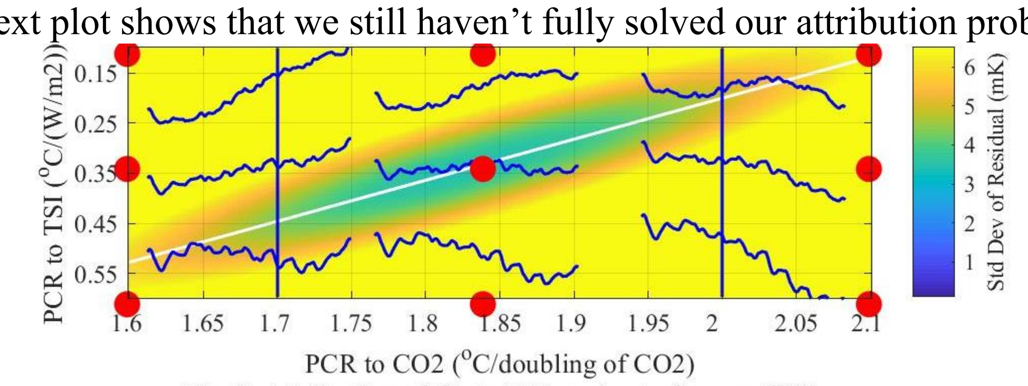

Fig. 8. Attribution of Global Warming to Sun vs. CO2

It shows σ for the smoothed residual for various coefficient pairs, and the residual shape at each red dot. At (x,y) = (1.7, 0.45) and (2.0, 0.20) we still have essentially the same good fit. We must therefore limit our confidence to PCR in the range 1.7-2.0.

Mitigation

PROBLEM *What if we fall off the straight line in Fig. 3?*

There is no apriori geophysical reason why climate sensitivity should be well-defined. The concept is at best an article of faith of both climate science and climate denial, the latter because it provides ideology-neutral language for debating climate change authoritatively.

What we *have* shown here is that the concept of climate sensitivity defined as exponentially rising *anthropogenic* CO2 in place of exponentially rising CO2 has shown remarkable stability between 1850 and now provided we confine attention to 65-year climate.

It seems very likely to us that this would also hold of exponentially rising CO2. The difference is that whereas we have copious data concretely supporting this for PCR we have no experience to date of CO2 rising at 1% a year, or for that matter at any constant CAGR as Figs. 1-3 make plain. Estimates of TCR are therefore much more speculative than of PCR. If even after great care we were not able to improve our estimate of PCR to better than the range 1.7-2.0, it is hardly reasonable to expect a comparably narrow range for TCR when we have no relevant data to constrain the priors for estimating a good PDF for TCR.

With 168 years of data in hand and only 82 more years in this century, if all significant climate factors continue along their trajectories to date, "business as usual", allowing Figures 3 and 6 to be projected forward 50 or perhaps even 100 years, we should expect ACO2 to increase from today's 130 ppm to $130*1.0204^{82}$ = 680 ppm by 2100. That plus 280 comes to 960 ppm, constituting log2(960/410) = 1.23 doublings of CO2 . With PCR in the range 1.7-2.0, that entails a further rise during this century between 1.23*1.7 ~ 2.1 degrees and 1.23*2 ~ 2.5 degrees.

This however does not refer to the year 2100 itself but only to the likely average over a 65-year window in that vicinity. On the bright side, about half of those years are likely to be colder. More ominously the other half are likely to be hotter. **What we can't say right now is which years will be which, we only know their average with any confidence,** *as a sort of uncertainty principle for climate.*

All this is predicated on ACO2 continuing to rise with a CAGR of about 2%. If by some miracle Earth's inhabitants are able to reduce that CAGR significantly, the business-as-usual assumption is no longer satisfied.

What then? Well, vegetation draws down some 120 PgC (GtC) per year, which climate change supposedly has increased by a further 3 PgC. This may reflect plants' appreciation of CO2 rising from 280 to 400 ppm and onwards. If we reduced the CAGR of ACO2 to 0% it seems extremely unlikely that the plants would notice. More likely they would continue to try to catch up. The rise and fall of the vegetable kingdom involves significant hysteresis, whence we can't rule out that plants could pull us back into an ice age, though how soon would take some clever biology!

Conclusions

We traced the wide variations in TCR to a paucity of available climate data that is not obvious how to fix. We proposed PCR as a modification of TCR much better supported by extant climate data. We traced the wide variations in previous estimates of PCR to easily fixed elementary mistakes. We identified confounding of solar irradiance and radiative forcing as an obstacle to further improvements in PCR. And we showed that mitigation beneficial to the planet could however be detrimental to estimation of PCR, for example by allowing plant drawdown to catch up.

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References

[1] Hofmann, D.J., J.H. Butler and P.P. Tans (2010). A new look at atmospheric carbon dioxide, Atmospheric Environment 2009 Vol.43 No.12 pp.2084-2086

[2] Loehle, C. and N. Scafetta. 2011. Climate Change Attribution Using Empirical Decomposition of Historical Time Series. *Open Atmospheric Science Journal* **5**:74-86.

[3] Lovejoy, S. (2014), Clim.Dyn., DOI10.1007/s00382-014-2128-2

Abstract

We identify four main sources of variation in present and future estimates of climate sensitivity, namely misdefinition, mistakes, misattribution, and mitigation.

Equilibrium Climate Sensitivity and Transient Climate Response are hard to estimate because the future behaviors of CO2 for which each is defined do not correspond in a straightforward way to their historical values used to constrain the probability density functions to which climate models aim to converge. The extant approaches to dealing with this discontinuity vary greatly with widely varying results.

Some authors have informally used a different notion of climate sensitivity based directly on the observed relations. but again with wide variation in some cases. Finding this surprising, we investigated two extremes, respectively 0.46 and 2.33 C per doubling. We found elementary mistakes in both that when corrected greatly narrowed that range.

Thus narrowed, we explored the prospects for defining climate sensitivity in a way that could improve confidence in climate projections. While good, these prospects are limited by potential misattribution of past climate to radiative forcing vs. solar irradiance, and by a mechanism by which mitigation can compromise those prospects, namely the possibility that the vegetable kingdom could violate Le Chetalier's Principle to an extreme degree.