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Short Communication

Quantifying the consensus on anthropogenic global warming in the literature: A re-analysis

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ABSTRACT

A claim has been that 97% of the scientific literature endorses anthropogenic climate change (Cook et al., 2013. Environ. Res. Lett. 8, 024024). This claim, frequently repeated in debates about climate policy, does not stand. A trend in composition is mistaken for a trend in endorsement. Reported results are inconsistent and biased. The sample is not representative and contains many irrelevant papers. Overall, data quality is low. Cook's validation test shows that the data are invalid. Data disclosure is incomplete so that key results cannot be reproduced or tested.

1. Introduction

Cook et al. (2013) argue that 97% of the published literature on climate change supports the position that climate change is real and largely human-made. The paper attracted worldwide media attention and was downloaded overt 146,000 times in the first 10 months since publication. The current paper reconsiders the evidence put forward by Cook et al. (2013).

The estimate by Cook et al. (2013) was preceded by those of Anderegg et al. (2010b), Doran and Zimmerman (2009), Oreskes (2004), Rosenberg et al. (2010), studies which led to a discussion of the value of "consensus" in science and policy (Anderegg et al., 2010a; Bray, 2010; Grundmann, 2007; O'Neill and Boykoff, 2010; Poortinga et al., 2011; Schulte, 2008). I will not revisit that discussion here, noting that consensus has no academic value (although the occasional stock take is valuable for teaching and guiding future research) and limited policy value. Cook et al. (2013) has been praised (Reusswig, 2013)[1]. and criticized (Legates et al., 2013). Legates et al. tried and failed to replicate part of Cook's abstract ratings, showing that their definitions were inconsistently applied. Montford (2013) notes that Cook's consensus is rather shallow—that carbon dioxide is a greenhouse gas, and that humans have played some role in observed climate change (Andrews et al., 2012; Hegerl et al., 2007; Randall et al., 2007; Rohling et al., 2012; Annan and Hargreaves, 2011).

In this paper, I focus on the technical aspects of Cook et al. (2013). After presenting the survey and comparing it to the accepted standards in Sections 2 and 3 discusses the representativeness of the sample, the biases, data errors, classification errors, and the trend in the measured consensus. Section 4 recaps the discussion in more accessible language. Section 5 concludes.

2. Materials and methods

The method of Cook et al. (2013) was as follows. A query on "global climate change" or "global warming" to the Web of Science returned 12,465 abstracts. Only articles in English published between 1991 and 2011 were included. After cleaning, 11,944 abstract remained. The abstracts were assessed by a team of 24 volunteers, recruited through *Skeptical Science*. Raters were not independent.[2] Unusually, Cook and his co-authors all rated abstracts; John Cook also administered the survey. Abstracts were rated on a 1–7 scale ranging from an explicit, quantified endorsement of anthropogenic climate change (rating of 1)

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[1] The editor of *Environmental Research Letters* has commended Cook et al. for their "the excellent data collection, analysis and scholarship" ⟨http://blogs.berkeley.edu/2013/05/29/the-story-of-a-presidential-tweet/⟩.

[2] ⟨http://rankexploits.com/musings/2013/i-do-not-think-it-means-what-you-think-it-means/⟩.

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to an explicit, quantified rejection (rating of 7). Abstracts were rated twice, and re-rated if the initial ratings disagreed.

Cook et al. adjusted the dissensus rate from 2% to 3% as follows. After three rounds of rating, 1000 of the 7970 papers rated a 4 (i.e., no position taken) were reassessed as 4a (no position) or 4b (expressed uncertainty about rejection or acceptance). In the subsample of 1000, 5 papers were rated 4b; this number was scaled up to an estimate of 40 ratings of 4b for the entire sample of 7970 papers. In deviation from best practice (Mohler et al., 2008), no survey protocol was published; it is therefore not known whether the 4th rating was an ad hoc addition, which would invalidate the result.

Some of Cook's data are available: year of publication, title, journal, authors, classification, 1st and 2nd rating, 3rd and 4th rating (if applicable), reconciled rating, and author rating. More information—specifically, rater ID, time of rating, survey protocol, and lab notes – was requested in vain, in contrast to best practice[3] and journal policy.[4] John Cook refused to run diagnostic tests on the withheld data.

3. Results

The methods used in the current paper are discussed together with the results.[5]

3.1. Representativeness

The sample includes almost 12,000 papers. The population of papers on climate change is much larger. Cook et al. do not test the representativeness of their sample. They searched for papers on “global climate change” or “global warming”. In current usage, “climate change” means “global climate change”, unless otherwise specified. Replicating their query in May 2013, I find 13,458 papers.[6] They found 12,465 in May 2012.[7] Dropping the “global” in “global climate change”, I find 53,359 papers. That is, 75% of the population (or rather, a larger sample) was excluded.

There are large differences between the disciplinary composition of the larger sample and the smaller sample ($\chi^2_{108} = 4076$; $p < 0.001$; Fig. S1). The narrower query undersamples papers in meteorology (by 0.7%), geosciences (2.9%), physical geography (1.9%) and oceanography (0.4%), disciplines that are particularly relevant to the causes of climate change. This likely introduces a bias against endorsement.

Many papers by the most 100 prolific researchers (in the larger sample) were omitted. Some authors were disproportionally disenfranchised ($\chi^2_{98} = 289$; $p < 0.001$; Fig. S2). Although 25% of papers in the larger sample are in the smaller sample, only 20% of papers by the most prolific authors are included. The narrower query undersampled the most active scholars, who tend to support anthropogenic climate change.

Only 17 of the 50 (34%) most cited papers in the larger sample are included in the smaller sample (Fig. S3). The narrower query oversampled the most influential papers, which tend to support anthropogenic climate change.

Cook et al. used the Web of Science. I posed the same queries to Scopus, a data source with similar functionality but wider coverage. Scopus returned 20,772 papers, 54% more than the Web of Science. Scopus uses fewer disciplines, so I aggregated the Web of Sciences disciplines to the Scopus ones. The disciplinary distribution of the smaller sample is again not representative for the larger sample ($\chi^2_{22} = 2457$; $p < 0.001$; Fig. S4). Earth and planetary sciences, the most relevant papers, are oversampled. This introduces a bias towards endorsement.

Geophysical Research Letters is the most prominent journal in the query to both databases. However, Scopus returns 728 papers and the Web of Science 334. This is because the latter only considers the title, abstract and keywords, whereas the former uses meta-data too. Apparently, in more specialized journals, authors do not include a reference to “global climate change” or “global warming” but rather use more specific words. Scopus adds higher level keywords and thus retrieves such papers, whereas the Web of Science does not.

The Web of Science is more exclusive than Scopus. Young journals and obscure journals are better represented in Scopus. Such journals tend to be kinder on heterodox material. However, this pro-establishment bias of the Web of Science is dominated by its omission of meta-data, which leads to the exclusion of more technical papers in more specialized journals.

Overall, though, Cook et al. both undersample and oversample papers that are likely to endorse anthropogenic climate change. Their sample is unrepresentative, but the direction of the bias is unknown.

3.2. Signs of bias

Twelve volunteers rated on average 50 abstracts each, and another 12 volunteers rated an average of 1922 abstracts each. Fatigue may have been a problem,[8] with low data quality as a result (Lyberg and Biemer, 2008).

Rater IDs and times of rating are not available. It is not possible to test whether individual raters systematically deviate from the average. It is not possible to test whether raters deviated from the study protocol to reduce the time burden.

I run consistency tests on the 24,273 abstract ratings; abstracts were rated between 1 and 5 times, with an average of 2.03. I computed the 50-, 100- and 500-abstract rolling standard deviation, first-order autocorrelation – tests for fatigue – and rolling average and skewness – tests for drift. I bootstrapped the data 10,000 times to estimate the 95% confidence intervals.[9] Table 1 summarizes the exceedence frequencies.

The rolling averages suggest that the rating varied with different stages of the rating process. Rolling averages are outside their 95% confidence interval far too often (Figs. S5–S7). Earlier ratings appear biased towards greater endorsement of the hypothesis of anthropogenic climate change; later ratings tended towards greater rejection, with a reversion towards endorsement at the very end. The results for skewness too indicate drift. Some parts of the sample, and particularly the last ratings, show more negative skew than would be expected by chance (Figs. S14–S16).

The results for skewness may be due to undue clustering of rates. The average distances between individual ratings and groups of ratings is well within the expected range (Fig. S17).

[3] Cf. (Singer, 2008), ⟨http://www.aapor.org/Best_Practices1.htm⟩, and ⟨http://www.amstat.org/committees/ethics/index.html⟩.

[4] ⟨http://authors.iop.org/atom/help.nsf/0/F18C019D6808524380256F630037B3C2?⟩OpenDocument.

[5] Data and code for the current paper are at ⟨http://www.sussex.ac.uk/Users/rt220/consensus.html⟩.

[6] Restricting the search to the Science Citation Index yields 12,308 papers.

[7] 27 papers from 2011 were added to the Web of Science since May 2012. Paper IDs run from 1 to 12,876. The number of unaccounted papers (521, 931 or 1487) is large relative to the number of dissenting papers (78). I have not been able to reconstruct why Cook excluded these papers from his sample.

[8] Indeed, one of the raters, Andy S, worries about the “side-effect of reading hundreds of abstracts” on the quality of his ratings. See ⟨http://rankexploits.com/musings/2013/i-do-not-think-it-means-what-you-think-it-means/⟩.

[9] I could have assumed stationarity and bootstrapped the data once rather than for each of the 24,273 ratings. The result would have been the same: as shown in the graphs, the bootstrap is indeed stationary; 10,000 bootstraps is enough for convergence.

However, the minimum and maximum distances are not as expected (Figs. S18–S19). Particularly, ratings "7" (rejection without quantification) are further apart and closer together than can be explained by chance, while ratings "6" are more evenly spaced than would be expected.

The data should be homoskedastic but are not. Rolling standard deviations are occasionally too small or large, and more frequently so than would be expected by chance alone (Figs. S8–S10). This may be because, in part of the sample, too many abstracts were rated near the mean. First-order autocorrelation should be zero, but it is not (Figs. S11–S13). In parts of the sample, ratings are consistently above average – suggesting that unduly long sequences of abstracts were rated neutral (4).

3.3. Data quality

3.3.1. Abstract ratings

There are two duplicate records among the 11,944 abstracts, and one case of self-plagiarism. Of these three identical abstracts, two were rated differently. The authors of the sampled papers also rated their work. Seven authors (including me) have disagreed with their papers' rating[10] Legates et al. (2013) find that 23 (out of 64) abstracts were incorrectly rated "1".

According to Cook, every abstract was rated twice; in fact, 33 abstracts were seen by only one rater. Cook reports "disagreement" on "33% of endorsement ratings". If errors are random, 18.5% of abstracts were incorrectly rated. That implies that 0.6% of abstracts were identically but incorrectly rated. About half of the discrepancies were solved by reconciliation; the rest was referred to a third rater.[11]. Assuming the same error rate in reconciliation and re-rating, 6.7% of ratings are wrong.

Reconciliations and reratings were biased towards a rejection of the hypothesis of anthropogenic climate change ($\chi_3^2 = 62$; $p < 0.001$; Fig. S20). However, the number of endorsements far exceeds the number of rejections. Therefore, applying the same correction to the 6.7% incorrectly rated abstracts, the consensus rate falls from 98% to 91%.

3.3.2. Paper ratings

Cook's Table 5 shows that paper ratings are different from abstract ratings ($\chi_2^2 = 316$; $p < 0.001$). The dissensus rate is 1% for abstracts (that were also rated as papers) and 3% for papers. Furthermore, the subsample of abstracts that were also rated as papers is not representative for the whole sample ($\chi_2^2 = 22$; $p < 0.001$). Cook emphasizes that the consensus rates in the paper ratings and the abstract ratings are similar. A similar result in an unrepresentative subsample invalidates the finding. Indeed, the dissensus rate is 2% for all abstracts and 4% for the bias-corrected sample of papers.

Data for 2136 out of 2142 paper ratings were released by Cook. The authors of the remaining 6 papers could be identified as they have a unique combination of abstract rating and publication year. Only 23 of the 11,494 papers have a unique abstract rating and year. Of these, 7 endorse anthropogenic climate change (rating 1–3); the paper ratings of 4 of the 7 were not released. The remaining 16 of the 23 reject anthropogenic climate change (rating 5–7); the paper ratings of 2 of the 16 were not released. These numbers further underline that the subsample of authors who rated their papers is not representative for the whole sample of abstract ratings ($\chi_1^2 = 18$; $p < 0.001$).

[10] ⟨http://www.populartechnology.net/2013/05/97-study-falsely-classifies-scientists.html⟩.

[11] According to Cook; in fact, 167 abstracts were seen by 2 additional raters, and 5 by 3 additional ones.

No less that 63% of abstract ratings differ from the paper ratings, 25% differ by more than 1 point, and 5% by more than 2 points; 0.7% of ratings were rejections in one case and endorsement in the other (Fig. S21). Overall agreement is low: $\kappa_0 = 10\%$; with linear, quadratic, cubic and quartic weights, $\kappa_1 = 16\%$, $\kappa_2 = 22\%$, $\kappa_3 = 26\%$ and $\kappa_4 = 26\%$.

3.4. Classification errors

Most of the papers selected by Cook focus on the impacts of climate change or on climate policy. Impacts are independent of the causes of climate change. One could argue that impact papers should be rated as neutral or not at all. Emission reduction policy presumes a human influence on climate. However, a paper on, say, carbon taxes cannot be taken as evidence for global warming. The author is a tax expert and, the author's opinions on the causes of climate change are arguably irrelevant. Policy papers should be rated as neutral or not at all.

Table 2 shows the number of papers by rating and subject. 34.6% of papers that should have been rated as neutral were in fact rated as non-neutral. Of those, 99.4% were rated as endorsements.

Table 3 shows the consensus rate, the number of papers that support the hypothesis of anthropogenic climate change over all papers that take a position. For the whole sample, the ratio is 98.0% (out of 3974 papers). Implicit endorsements may be in the mind of the reader only. The explicit consensus rate is 97.6% (out of 1010 papers).

Table 3 splits the sample into papers on impacts and mitigation and papers on methods and palaeoclimate. The consensus rate is much higher in impacts and mitigation (99.4% and 98.6%) than in methods and palaeoclimate (92.8% and 94.4%). The overall consensus rate is driven by papers that are not about the causes of climate change.

If methods and palaeoclimate papers are misrated in the same proportion as impacts and mitigation papers, then the consensus rate is 89.9% (all endorsements) and 93.8% (explicit endorsements only).

These results should be interpreted with care. Cook reports that 67% of papers do not take a position. Moving the papers on impacts and mitigation to 'neutral', 93% do not take a position. Correcting for misclassification, 95% of surveyed papers are silent on the hypothesis of anthropogenic climate change.

3.5. Trends

Cook et al. argue that the level of endorsement of the hypothesis of anthropogenic climate change has increased over time. See Fig. 1. There is indeed an upward trend ($p = 0.052$). Fig. 1 also shows the consensus rates for impacts and mitigation, and for methods and palaeoclimate. There is no upward trend in either ($p = 0.249$ and $p = 0.342$). The level of endorsement in impact and mitigation is much higher than in methods and palaeoclimate. The share of impact and mitigation in all abstracts has grown over time ($p = 0.00003$). The apparent trend in consensus is thus a trend in composition rather than in endorsement.

4. Discussion

Cook et al. claim that 97% of the literature endorses the hypothesis that climate change is real and largely caused by human activity. Although they surveyed a large number of abstracts, most of these are not on the narrow subject of what causes climate change. Theirs is not a consensus on the causes of climate change, but rather a vote of confidence by the broader

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Table 1
One-sided deviations outside the 95% confidence interval for four indicators (average, standard deviation, first-order autocorrelation, skewness) for rolling windows of alternative widths (50, 100, 250 abstracts).

	50-Abstract		100-Abstract		500-Abstract	
	< 2.5%	> 97.5%	< 2.5%	> 97.5%	< 2.5%	> 97.5%
Average	6.4	4.9	7.8	6.9	10.7	13.0
Standard deviation	4.9	4.0	5.6	4.7	12.2	7.6
Autocorrelation	5.3	2.7	6.4	2.6	8.0	3.3
Skewness	1.5	6.1	1.4	7.6	0.0	25.5

Table 2
Abstracts by subject and rating.

Subject\rating[a]	1	2	3	4	5	6	7
Impacts	12	316	907	4528	8	5	4
Mitigation	20	418	1474	1471	1	2	0
Methods	28	161	391	1359	42	7	5
Palaeoclimate	4	27	138	612	3	1	0

[a] (1) Explicit endorsement with quantification; (2) explicit endorsement without quantification; (3) implicit endorsement; (4) no position; (5) implicit rejection; (6) explicit rejection without quantification; (7) explicit rejection with quantification.

Table 3
Levels of endorsement[a].

	All (%)	Explicit (%)
All papers	98.0	97.6
Impacts + mitigation	99.4	98.6
Methods + palaeoclimate	92.8	94.4
Methods + palaeoclimate corrected[b]	89.9	93.8

[a] The level of endorsement is defined as the number of papers in columns 1, 2 and 3 in Table 1 over the number of papers in columns 1, 2, 3, 5, 6, and 7. Explicit endorsement omits columns 3 and 5.

[b] The correction is based on the assumption that methods and paleoclimate papers were misrated in the same proportions as impacts and mitigation papers.

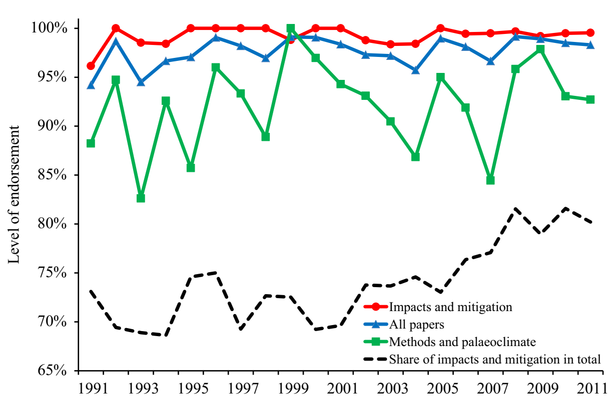

Fig. 1. Levels of endorsement in all papers, papers on impacts and mitigation, and papers on methods and palaeoclimate; and the share of impacts and mitigation papers in total.

climate research literature in the narrower literature on the attribution of climate change.

Cook's estimate of a 97% consensus was thus probably inflated by self-selection. Researchers who think that climate change is real and anthropogenic are more likely to study climate impacts and climate policy than those who are unconvinced. Besides, it is customary in academic publications to embrace the consensus on issues that are peripheral to the actual contribution of the paper. Furthermore, the chance of publishing a paper on the impacts of climate change or on climate policy falls if it argues that climate change is not real or not anthropogenic.

Removing irrelevant papers, I find that, rather than 3%, up to 10% of papers explicitly disagree with the hypothesis that climate change is real and largely anthropogenic.

Cook et al. report a time trend towards greater endorsement. This, however, is due to an increase in the number of papers that are not on the causes of climate change.

Although Cook et al. survey a large number of papers, the number of published papers is larger still. The sampled papers are not representative of larger samples of papers, and probably not representative of the population either. Cook's sample statistics are just that. No conclusion can be drawn about the level of consensus in the wider literature. The sampling strategy may have worked in favour or against the measured consensus on the hypothesis of anthropogenic climate change.

The data reported by Cook et al. show signs of error: Taking their ratings at face value (Legates et al., 2013), 7% of the ratings are wrong, and biased towards endorsement of the hypothesis of anthropogenic climate change. Furthermore, the rating data show inexplicable patterns, revealing an inconsistent survey instrument (or worse). Cook et al. failed to report that their data fail their own validation test.

The full data-set would shed further light on possible causes of these problems but is unavailable. Cook has refused to release such diagnostic tests as the ratings profiles of individual raters, and the histogram of times between ratings.

5. Conclusion and policy implications

The conclusions of Cook et al. are thus unfounded. There is no doubt in my mind that the literature on climate change overwhelmingly supports the hypothesis that climate change is caused by humans. I have very little reason to doubt that the consensus is indeed correct. Cook et al., however, failed to demonstrate this. Instead, they gave further cause to those who believe that climate researchers are secretive (as data were held back) and incompetent (as the analysis is flawed).

It will take decades or longer to reduce carbon dioxide emissions to zero—the only way to stabilize its atmospheric concentration. During that time, electoral fortunes will turn. Climate policy will not succeed unless it has broad societal support, at levels comparable to other public policies such as universal education or old-age support. Well-publicized but faulty analyses like the one by Cook et al. only help to further polarize the climate debate.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.enpol.2014.04.045.

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