ScienceBrief Carbon Cycle updated with IPCC AR6 results and 4C publications, with platform update informed by evaluation

Deliverable 4.1

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Table of Contents

List of tables

List of figures

About 4C

Climate-Carbon Interactions in the Coming Century (4C) is an EU-funded H2020 project that addresses the crucial knowledge gap in the climate sensitivity to carbon dioxide emissions, by reducing the uncertainty in our quantitative understanding of carbon-climate interactions and feedbacks. This will be achieved through innovative integration of models and observations, providing new constraints on modelled carbon-climate interactions and climate projections, and supporting Intergovernmental Panel on Climate Change (IPCC) assessments and policy objectives.

Executive Summary

An evaluation of the ScienceBrief carbon cycle pilot, including new developments implemented within the platform; new content and published outputs; and the impact perceived. The ScienceBrief platform has demonstrated that technology can be used to help scientists keep up with exponential growth of the scientific literature and collaborate to rapidly undertake scientific assessments. Low levels of expert contribution have restricted full assessment of the platform's capability and any further technological developments are not guaranteed to drive better engagement. ScienceBrief offers the potential for widespread outreach and dissemination of science but this is resource intensive. A case is made based on the ScienceBrief experience, to develop a modified technology platform that can support authors of the upcoming IPCC 7th Assessment report.

Keywords

ScienceBrief, technology, scientific assessment, consensus, outreach.

2 Introduction

The ScienceBrief platform is a web application designed to help keep up with science by providing scientists with a means to show (not just tell) the scientific consensus on key topics in the carbon cycle and climate change science. The platform uses modern web-app technologies to maximise collaboration to disseminate the latest scientific understanding. It is an example of an asynchronous-connected technology (see **Table 1**), meaning that it can be used simultaneously by multiple collaborators, without the work of one contributor blocking the work of another. This mode of working is the most efficient among collaborative workflows and is far more efficient than, for example, sending contributions to a lead author to compile. In particular, efficiency is maximised by the scalable nature of the workflow, where the number of contributors collaborating in real-time is not (practically) constrained. The ScienceBrief team recently submitted a paper to the journal npj Climate Action for a themed special collection "*IPCC: dinosaur or dynamo for climate action*". The paper (De-Gol et al., submitted) outlines how, in our opinion, a technology platform like ScienceBrief can be designed and implemented to support authors of the upcoming 7th Assessemt Report of the IPCC.

The rate of scientific publications has grown exponentially in recent decades, outstripping the capacity of individuals to read and absorb information (Nunez-Mir et al., 2016). Prior to the release of the IPCC's sixth assessment report (AR6 WGI, Masson-Delmotte et al., 2021), over 230,000 climate change papers (average 80 per day) were published (see **Figure 1**), with multiple papers per day on specialised topics, such as wildfire (1.4), extreme rainfall (2.7), or drought (9.5). This "big scholarly data"' (Xia et al., 2017) is growing exponentially, meaning a 'comprehensive' assessment is no longer possible with the conventional review processes used in climate science (Berrang-Ford et al., 2021; Callaghan et al., 2020; Minx et al., 2017).

As the scale and speed of scientific publication has increased, more thorough methods for ongoing assessments of scientific developments have been adopted. Literature reviews are the most basic form of scientific synthesis, but they usually follow a narrative style and are not always comprehensive (Haddaway et al., 2020; Pullin & Knight, 2012). Scientific assessments, such as the IPCC, are based on basic literature reviews, complemented by an expert's assessment and a thorough multi-stages review process. In response to bias in literature reviews, more systematic review processes have been developed. Systematic reviews, pioneered by health researchers, are exhaustive, computer-assisted searches of all the literature relating to one research question with specific predetermined inclusion, exclusion, and reporting criteria (Baker & Mace Weeks, 2014). Meta-analyses are a more statistical tool for summarising empirical evidence across many studies. A meta-analysis involves building consensus through integrating the findings from many studies that pose similar questions into one dataset to pool effect sizes (Ahn & Kang, 2018). However, these methods require painstaking work, are usually static analyses, are limited to specific research questions, and are not geared for policy communications.

To maintain relevance, the living systematic review approach was developed to continually integrate emerging evidence (Elliott et al., 2017). Systematic reviews are extremely resource intensive, even for narrowly defined research questions, therefore, machine assisted research can assist by combining human expertise and machine automation in complementary ways (Thomas et al., 2017). A field as diverse as climate change now requires machine automation to systematically synthesise evidence in a timely, transparent and unbiased manner (Berrang-Ford et al., 2021; Callaghan et al., 2020; 2021; Minx et al., 2017), though further development is still required (Thomas et al., 2017).

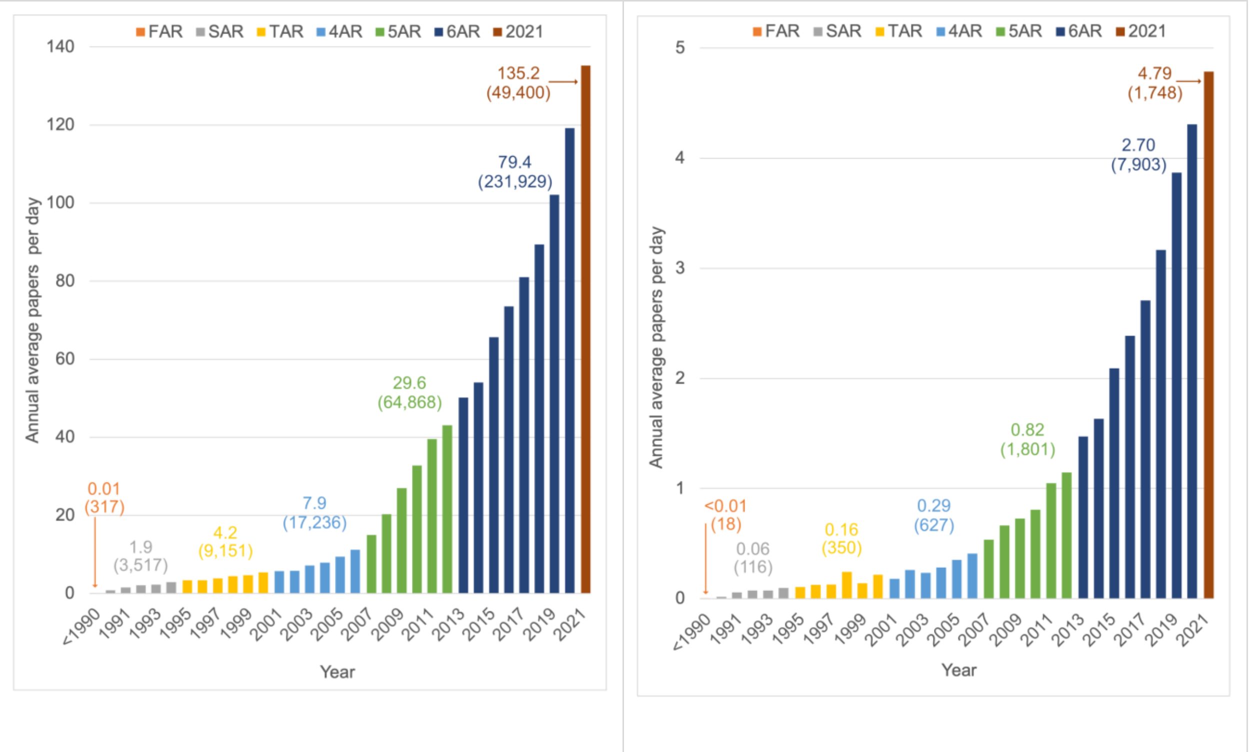


Figure 1. ***Growing number of publications referring to climate change each year, plotted as annual average papers per day. All publications mentioning "climate change" or "global warming" (left), and those mentioning also "extreme rainfall" or "heavy precipitation" (right). Numbers above the bars show daily average (cumulative) papers published for each IPCC assessment cycle. FAR/SAR/TAR/4AR/5AR/6AR = First/Second/Third/Fourth/Fifth/Sixth Assessment Report of the IPCC; Source: ISI Web of Knowledge.***

As reflected by the rapid rise in publications, research in climate change has grown and diversified. Assessment reports that engage a broader group of experts would enrich assessments by providing access to new and potentially more balanced information, for example, through more diverse case studies, or publications in different languages. New asynchronous connected technologies can help to increase equality in expert engagement with the IPCC process, by improving access from the global south and other under-represented regions, and among indigenous people and early career researchers, addressing known biases (Chakraborty & Sherpa, 2021; Rashidi & Lyons, 2021). New technology has the potential to augment, rather than replace, expert's knowledge by distilling literature into easily managed groups of topics, maximising visual encoding.

Asynchronous and connected technology allows the necessary scalability for large numbers of synchronous users to build an assessment collaboratively.

Furthermore, the IPCC and other scientific assessment processes would benefit from the ability to make more frequent, and perhaps even continuous, assessments (Petersen et al., 2015), which could be in response to significant events, new scientific analysis, or socio-political discourse. This would potentially help to address concerns that some parts of IPCC reports escape thorough or consistent review (Palutikof et al., 2023). Focussed updates on specific themes provide scientists with an authoritative voice to respond to misinformation and to reinforce key messages.

As the volume of scientific publications has grown exponentially, developments in technology have been tuned to aid scientific consensus-building. Digital libraries and academic search engines leverage state-of-the-art techniques in information retrieval, recommender systems, and natural language processing to identify tailored, high-quality publications to assist literature reviews (Ammar et al., 2018; Semantic Scholar, 2018; Wu et al., 2015; Xia et al., 2017). Research assistants like elicit.org have enabled automated literature review, but in general, machine learning tasks used for generating paper interpretations such as text summarisation, automated fact-checking, and stance detection are not yet accurate enough for inclusion in public-facing texts or systems (Guo et al., 2021; Ibrahim Altmami & El Bachir Menai, 2022; Wadden et al., 2020). Thus, many tasks in the scientific literature review process still require expert input despite technological advances.

3 Role of technology to enhance scientific assessment process

Recent technological developments could be used to enhance these processes in multiple ways. ScienceBrief for example, leverages technology to help in two specific ways: firstly, by upscaling collaborations to reduce duplication and facilitate concurrent workflows, and second by visualising scientific consensus which helps both integrate information and communicate more broadly.

3.1 Upscaling collaborations to enhance production

Research on scientific workflows has found that, when leveraged effectively, technology tools can be used to increase the speed and effectiveness of collaborations (Cummings & Kiesler, 2005; Dong et al., 2017; Kouzes et al., 1996). Two or more people working on the same task can collaborate either ‘synchronously’ (actions of one worker blocks those of another) or ‘asynchronously’ (non-blocking); and either ‘connected’ and interacting with others, or ‘disconnected’ and working alone). As shown in Table 1, there are consequences for scalability of work depending on which methods are employed.

	SYNCHRONOUS (BLOCKING)	**ASYNCHRONOUS** (NON- BLOCKING)
DISCONNECTED (SEPARATED, INDIVIDUAL, DIVISION OF TASKS)	Draft document exchanged via email	Individuals work alone with coordination through organising central body (e.g. lead author), via email
	Non-scalable, single workflow active at any one time	Scalability depends on efficiency of central body, bottleneck in processing inputs
e.g.	*Journal submission process*	*IPCC*
CONNECTED (CO-LOCATED, TOGETHER, GROUP WORK)	Working together on single document and laptop	Real-time working on different paragraphs of same document
	Scalability depends on efficiency of main contributor, bottleneck in adding inputs	Highly scalable, readily updated
e.g.	*Pair writing*	*Google Docs, ScienceBrief*

Table 1. ***Breakdown of working operation and scalability for differing modes of collaboration*.**

Synchronous disconnected work occurs within a single document exchanged between collaborators i.e. only one person is active at any point in time. Synchronous connected work involves collaboration among multiple co-located contributors, with just the main contributor processing inputs. Asynchronous disconnected work enables multiple people to work concurrently, but there is a bottleneck collecting and distilling work products by e.g. the lead author. Asynchronous connected work is the most efficient mode as people work autonomously, simultaneously and independently. Each worker can see in real-time the actions of others, but are free to work on different sections. Maximising use of asynchronous connected working and development of tools to facilitate such workflows, increases efficiency. Commonly, academic work has utilised the synchronous disconnected mode, working individually and communicating through a lead author. Recently there has been a rapid progression toward connected asynchronous methods using collaborative literature tools (e.g. Google Docs, Figma), but there are still productivity gains possible by developing connected workflows. Based on these concepts, the ScienceBrief platform set itself out to support asynchronous connected and disconnected collaboration workflows to be most efficient.

3.2 Visualising scientific consensus

Past work has demonstrated that effective data visualisations can help experts and the public absorb large amounts of evolving information (Godfrey et al., 2016; Keim et al., 2008). When creating data visualisations for large data sets, presenting data using mental models (e.g. a mind-map) enables the efficient acquisition and distillation of knowledge by supporting cognitive functions (Liu & Stasko, 2010). The way we organise information is crucial to easily discerning patterns or recalling information, and spatially grouping related information can help us make associations more easily (Larkin & Simon, 1987). In particular, there are benefits of interactive visualisations for large datasets as people can filter data more easily and studies have suggested information recall may be higher when people can directly interact with a data source (Godfrey et al., 2016; Pohl, et a., 2012). Visual analytics tools can aid expert assessment of big scholarly data by better representing connections between papers (Felizardo et al., 2010; Felizardo et al., 2012; Stasko et al., 2008). In the context of public communication, visualisations of stances (polarity) between scientific papers on key issues have been used to synthesise how well-supported scientific claims are (Hsiao et al., 2020; Trinquart et al., 2016). Although communicating expert consensus on climate change is vital to improving public support for climate policy (Cook et al., 2013; van der Linden, 2021), visualisations of scientific consensus on climate change are few.

Current organising software (e.g. Endnote, Mendeley) permit easy searching and the addition of colour labels, but do not include data visualisation. Based on the literature, we believe improvements should be made to assist with the organisation, visualisation, and accessibility of literature reviews. The ScienceBrief platform presents one approach to using stance-based data visualisation to communicate scientific consensus to experts and the public.

4 ScienceBrief platform

The aspiration is for the platform to support major scientific assessments, such as IPCC, by streamlining workflows and maximising collaboration. The platform was supported by public research funds and developed by a small team composed of one scientist, developer, and content writer (from 2019), with ad-hoc (unpaid) support from several scientific and technical advisors.

The first phase of ScienceBrief (2017-2019) used a review approach analogous to the IPCC, focussing on the natural carbon cycle. It detailed 17 research areas with a Brief (statement and summary paragraph) outlining the science for that issue. Relevant evidence (published journal papers) was uploaded to the Brief by scientists, which were sifted for their expertise on first registration using a self-declaration coupled with an automated check of home institutions against a list of acceptable academic and research locations. Scientists allocated a score to the evidence indicating the level of agreement with the Brief, which is aggregated to determine the level of scientific consensus (explained below). Additionally, experts could add their own interpretation of a piece of evidence. At this early stage, low levels of engagement by scientists meant the platform's concept could not be demonstrated and impact was very low.

The carbon cycle topic contains 17 Briefs, split temporally into 'paleo reconstructions', 'historical' and 'future projections', with over 300 pieces of evidence uploaded, as outlined in **Table 2**. The climate change science topic comprises 8 Briefs, mostly addressing 'climate change impacts', as well as sections for climate 'understanding' and 'solutions'. This topic has over 1000 pieces of evidence uploaded, around 90% of which also have an interpretation.

TOPIC	PUBLISHED BRIEFS	EVIDENCE	INTERP-RETATIONS	EXPERT CONTRIBUTIONS
Key topics on the Carbon Cycle	17	318	242	20
Critical Issues in Climate Change Science	8	1077	972	13

Table 2. ***Statistics of expert contributions to the ScienceBrief platform, January 2018 - August 2022. Source: ScienceBrief.***

4.1 Technical Developments

Following the early carbon cycle pilot (2018-2019) a user experience audit identified a number of technical platform developments required to streamline the platform and make it more user-friendly and intuitive. In particular, new features were designed to maximise support of cognitive functions and visual appeal. A frequently asked questions (FAQ) page was added to aid users' operation of the site.

4.1.1 Explorer tool

Originally developed as a demo with limited functionality, this visual interface was developed to become the primary mechanism for interacting with evidence and visualising the scientific consensus for a Brief (**Figure 2**). In addition to improving the underlying code to facilitate further development, for example to allow axes to be assigned any dimension of the data, many extra features were implemented. The most noticeable were features to improve the experience on mobile devices. These include the ability to pan and zoom around the map, and the implementation of the "long press" menu (**Figure 3**), such that holding down on a piece of evidence reveals a quick menu at the location of interaction. This vastly increases the efficiency for users interacting with the evidence.

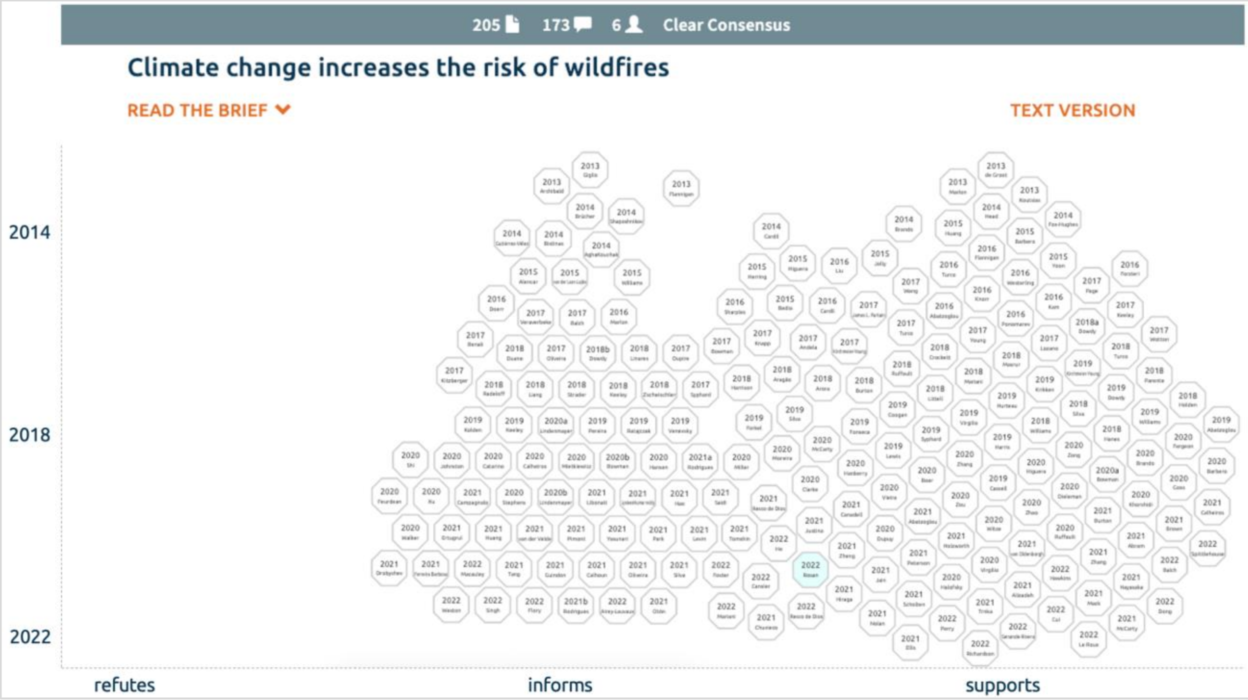


Figure 2. ***Snapshot of the explorer tool that graphically maps evidence by level of agreement with the Brief (x axis) and publication date (y axis). Each octagon symbol is a paper labelled with publication year and lead author name. The consensus ranking ("Clear consensus") for the Brief is shown at the top, as well as the number of pieces of evidence, the number of interpretations added and the number of expert contributors.***

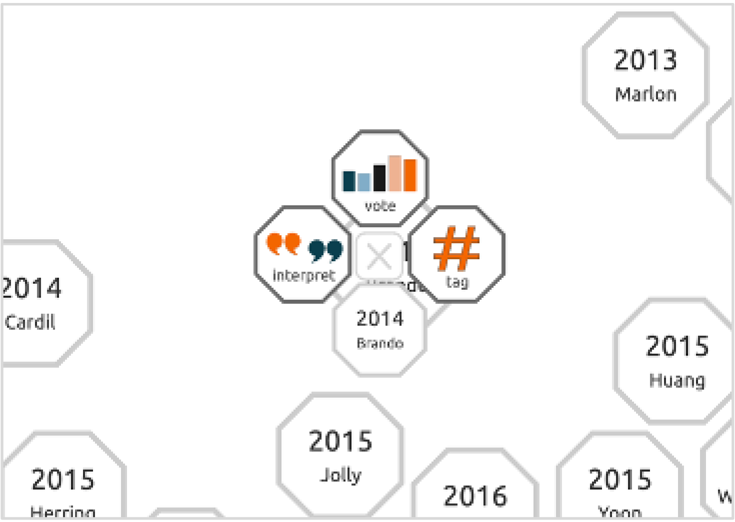


Figure 3. ***Snapshot of the overlay menu that appears on long press within the explorer tool.***

4.1.2 Hashtagging

Feedback from users suggested the original search filtering functionality wasn't returning results in a way that made sense to users. This was updated to include searching over several new fields and displaying data in a way that made intuitive sense. Tagging the data is a powerful way to interact with and classify the evidence and the hashtag feature was developed to allow hashtags to be added at any point (initially this was only possible during uploading of the evidence). The combination of hashtag highlighting and search filtering significantly expanded the data interrogation and data visualisation capabilities of the tool (**Figure 4**). Also in response to user feedback, further development enabled evidence to be highlighted by darker shading where multiple hashtags were applicable to a single piece of evidence.

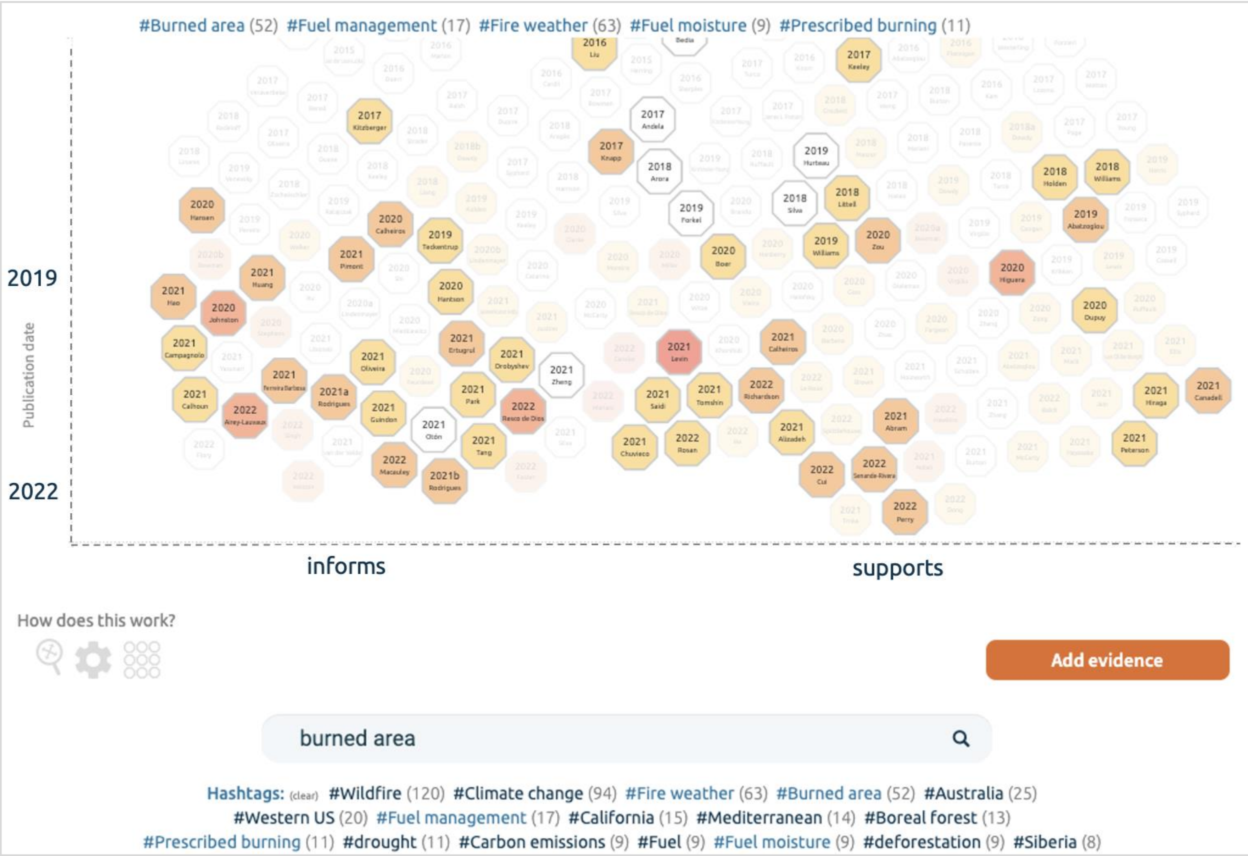


Figure 4. ***Snapshot highlighting evidence by search function and selected hashtags. Transparent evidence does not match the search criteria, while darker shades mean more than one hashtag is applied to a piece of evidence.***

4.1.3 Geotagging

Most Briefs have a geographical range, where evidence may be applicable to a case study country, a regional reanalysis dataset, or perhaps global model output. While this range was originally captured via hashtags, this was later optimised by developing geotags, where locations are selected from a defined list for consistent application. The existence of geotag data enables potential further development of geographic features, including possible integration with spatially aware geographic information systems (GIS) to generate embeddable interactive map views. Though this optional work has not been undertaken.

4.1.4 Consensus score

Initially, ScienceBrief was launched with two measures for evidence: the 'support score' was the mean average of all the votes, and the 'controversy score' was adapted from an algorithm that was once used on the Reddit platform. It became clear that the purpose of the aggregation could be better accomplished if these two measures could be combined into a single measure. It is crucial that the algorithm to aggregate the evidence and distil it into a single point is adequate to the task. After some research, testing, and work with focus groups the following measure has been developed.

Each piece of evidence added to a statement has a number of votes on whether that evidence 'supports', 'informs' or 'refutes' that statement. By taking the average of these votes, weighted by number of votes, we have a score for the whole statement. If a statement is shown to have general support from its evidence, the level of consensus is found by using a weighted standard deviation on votes (discounting 'informs') and then mapping the final value back to a series of categories. The weights given are: 'supports': 1, 'mostly supports': 0.9, 'mostly refutes': 0.1, 'refutes': 0, while categories and their threshold values are shown in **Table 3**.

CONSENSUS LABEL	THRESHOLD
Clear consensus	0 ≤ 0.05
Broad consensus	0.05 ≤ 0.15
Moderate consensus	0.15 ≤ 0.25
No clear consensus	0.25 ≤ 0.35
Controversial	0.35 ≤ 0.45
Highly controversial	0.45 ≤ 0.5

Table 3. U*pdated consensus scoring categories labels and thresholds.*

4.1.5 Platform security

A complete security audit was made of the platform and the libraries. This involved attempting to ascertain weaknesses and gauging the level of any threats coupled with the probability of occurrence. Many security features were implemented, including a live monitoring dashboard, removal of root login, enforced passwordless logins and a full update of the system libraries.

5 ScienceBrief Reviews

The second phase (2020-2021) focused on adding more content of higher public interest. The "*Critical issues in climate change science*" topic focussed on climate change impacts, to help explain the links between climate change and extreme weather events, to aid media, public, and perhaps policy-maker, understanding. To drive scientist's engagement and media coverage, short briefing papers (ScienceBrief Reviews, published under the sub-domain news.sciencebrief.org/reviews) were launched to summarise the evidence. Each review contains key-points in bullet form, providing clear messaging of the latest scientific understanding. Typically 2-4 invited subject experts were invited to co-author Reviews that were peer-reviewed by an independent expert.

In January 2020, an international group of experts used ScienceBrief to quickly publish the 3-page Review "*Climate change increases the risk of wildfires*" (Jones et al., 2020), during 2019-2020 Australian bushfires. Quickly responding to wildfires in western North America, an updated ScienceBrief Review of the same title (Smith et al., 2020) was published in September 2020, addressing newly published evidence. The rapid availability of these reviews, expedited by the platform, enabled a timely response to questions during a period of intense global public interest. In another example, the ScienceBrief on independent expert advisory bodies (Dudley et al., 2021) was developed by a PhD student in just 2 weeks, supported by the ScienceBrief team and her supervisors, and published ahead of important negotiations about this topic in Europe.

ScienceBrief has focussed on summarising and communicating natural science research relevant to the IPCC's Working Group I (WGI). However, the platform can also be applied to social sciences, climate adaptation and climate resilience/solutions research applicable to WGII and WGIII, or indeed, to any discipline with fast-moving, high-stakes research requiring broad consensus.

6 Impact

The ScienceBrief platform and publishing subdomain have attracted a reasonable amount of traffic for certain pages, as detailed in **Table 4**. Although it is difficult to capture the direct impact of ScienceBrief, the correspondence between publications and media coverage provides an indication of plausible influence.

The January 2020 wildfire review was covered globally by over 220 online articles (e.g. Green, 2020; McGrath, 2020a) as well as television news, driving significant traffic (4934 weekly visits) to the platform (**Figure 5a**). The September update was covered by over 135 articles (e.g. McGrath, 2020b) including the World Meteorological Organization (WMO, 2020). Our analysis suggests that these two reviews, together with other expert works, may have contributed to changing the media narrative for wildfire coverage. For example, BBC articles in late-2019 – early-2020 began to mention a "hotter, drier climate" alongside "more frequent and intense fires" (BBC, 2019), which by mid-2021, evolved into the almost systematic use of the sentence "Climate change increases the risk of the hot, dry weather that is likely to fuel wildfires" (BBC, 2021) within BBC wildfire coverage (**Figure 5b**).

The timing of publication determined the strength of media coverage. Subsequent ScienceBrief Reviews, where publication did not coincide with a major event, achieved limited media coverage. However, once published, traffic is seen to peak (**Figure 5b**) after a major event (e.g. cyclone or extreme rainfall), with users searching for information.

CARBON CYCLE	PAGE VIEWS	CRITICAL ISSUES	PAGE VIEWS
Carbon feedbacks	3417	Wildfires	19337
Cumulative CO_2 emissions	766	Tropical cyclones	2144
CO_2 conc. last 800k years	570	Extreme rainfall	1670
Glacial cycle CO_2 conc.	566	Arctic amplification	1128
Historic carbon sinks	231	Heatwaves	644
Ocean sink variability	172	Marine heatwaves	487

SCIENCEBRIEF REVIEW	PAGE VIEWS	DOWNLOADS
Wildfires (Jan 2020)	12765	47
Wildfires (Sep 2020)	4595	105
Tropical Cyclones	5875	401
Expert advisory bodies	451	64
Extreme rainfall	1256	265
Carbon feedbacks	214	23
Arctic amplification	128	49
Marine heatwaves	196	66
Whole collection	119	19

Table 4. ***Statistics of user-engagement with the ScienceBrief platform, January 2018 - August 2022. Source: Google Analytics; Zenodo.***

ScienceBrief Reviews are open access and citable. In addition to publishing on the platform, the document is uploaded to Zenodo.org, providing the document with a digital object identifier (DOI) and permanent open access. An html version and a press release are also published on the ScienceBrief News site, helping to attract media coverage and to aid dissemination on social media channels.

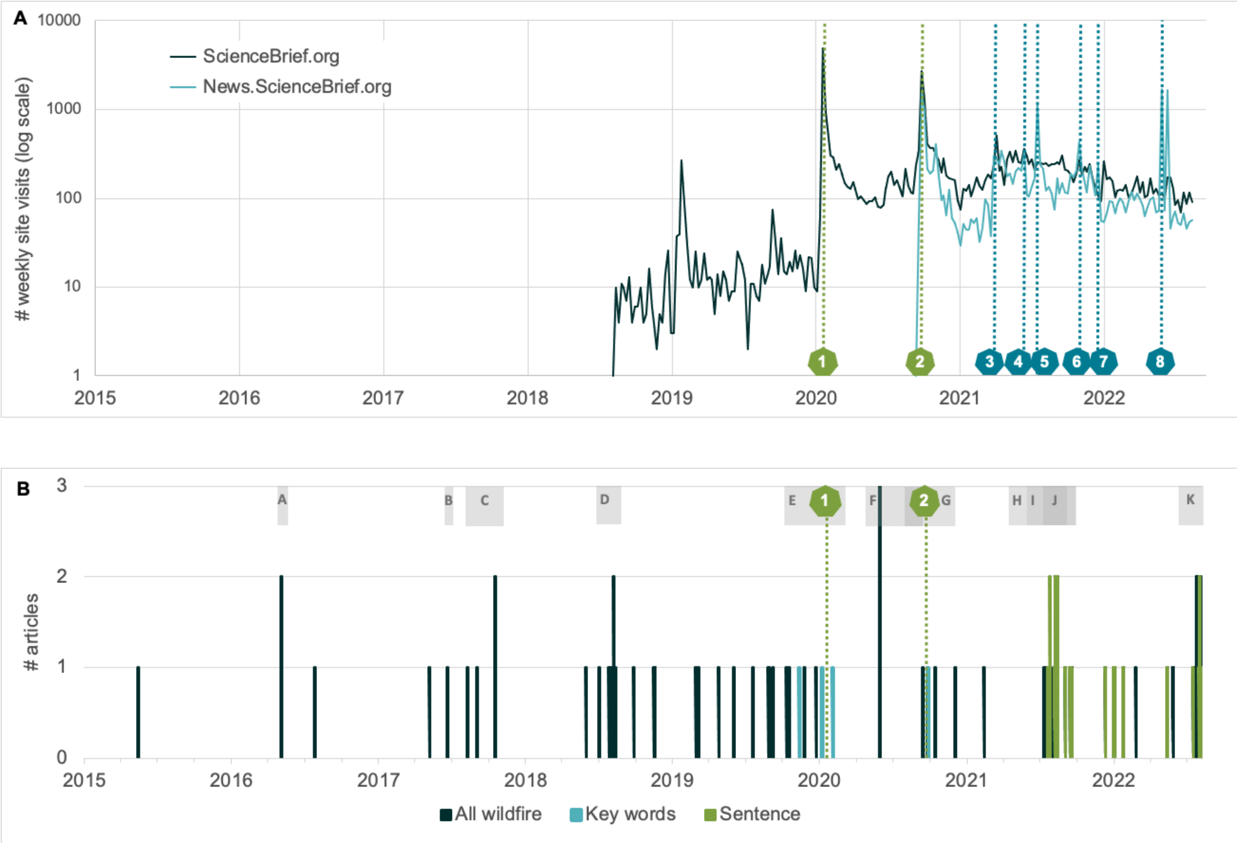


Figure 5. ***Web site visits and mentions of related topics in the media. (A) Time-series of the number of weekly visits to ScienceBrief.org (blue) and News.ScienceBrief.org (orange), Jan 2015 to Aug 2022. Note y-axis log scale. Key events annotated (red): 1 = Wildfires Review published, Jan 2020; 2 = Wildfires Update published and News.ScienceBrief.org launched Sep 2020; (yellow): 3 = Cyclones Review published, Mar 2021; 4 = Extreme rainfall Review published, Jun 2021; 5 = extreme rainfall & flooding in Central Europe, Jul 2021; 6 = multiple Reviews published, Oct 2021;. 7 = COP26, Nov 2021; 8 = European heatwave, Jun 2022. Source: Google Analytics. (B) time-series of the changing narrative of BBC wildfire coverage, 2015-2022. Blue bars show BBC articles mentioning: "wildfires" and "climate change"; yellow bars show articles mentioning key words: "wildfire" and "climate" and "risk"; orange bars show articles mentioning the sentence: "Climate change increases the risk of the hot, dry weather that is likely to fuel wildfires". Grey shading represents major wildfire outbreaks: A. Fort McMurray, Canada, 2016; B. Mediterranean, 2017; C. British Columbia, 2017; D. California, 2018; E. 'Black Summer', Australia, 2019-20; F. Siberia, 2020; G. Western North America, 2020; H. Western North America, 2021; I. Siberia 2021; J. Greece, 2021; K. Europe & Mediterranean, 2022. Key events annotated (red): 1 = Wildfires Review published, Jan 2020; 2 = Wildfires Update published Sep 2020.***

For the COP26 climate summit in Glasgow, we published three new ScienceBrief Reviews, covering carbon sinks, Arctic amplification and marine heatwaves. Unfortunately these reviews received minimal media coverage as they were 'lost in the noise' building up to the start of the much anticipated conference. Shortly after COP26, we published the 'Critical Issues in Climate Change Science Collection' containing all eight ScienceBrief Reviews within one PDF document.

6.1 Data on other platforms

All the public data on ScienceBrief can be downloaded in easy-to-use formats. Upon release of the first wildfire review (Jan 2020) Carbon Brief used data downloaded from the wildfires brief to create a data visualisation, and credited ScienceBrief as the data source. It is hoped that by enriching the data and making it easier to use, ScienceBrief can power more data visualisation in the future.

6.2 Social media and outreach

In addition to giving talks to groups of scientists whenever possible, to develop awareness of ScienceBrief and encourage scientists to contribute evidence, new Briefs are announced on twitter (@sciencebrief) and key papers are tweeted when they are uploaded to a Brief. Newsletters have been sent to those registered on the site, and corresponding authors receive an email inviting their contribution to the platform once their paper is added.

7 Auto-evaluation

Experience with ScienceBrief highlights key potential benefits for assisting in IPCC-style assessment methods. The ScienceBrief platform includes the ability to quickly visualise the scientific consensus for key subjects and highlight any controversies or research gaps. In contrast to a static report, ScienceBrief is updated in real-time to keep up with the science and enable a timely response to key events, emerging science or misinformation. The ScienceBrief platform allows interaction at varying levels of detail, with the Brief, expert interpretations, and ScienceBrief Reviews offering incremental depths of information. Users can also link to the journal paper at source. ScienceBrief enables participation from a broad body of experts from all countries and career stages. Experience with ScienceBrief highlighted a generally low level of engagement by experts, unless specifically recruited to contribute to the process. The number of page visits suggests better uptake by users reading content, than by contributors. Barriers to engagement would need to be addressed by incentivising contributors in different ways, such as specific sollicitations and community recognition for their input. A further challenge was the difficulty attracting co-authors to participate in ScienceBrief Reviews in a timely manner, while demonstrating that timeliness was critical to ensure broad exposure of the scientific insights.

8 Lessons learned

The platform has demonstrated the ability to quickly visualise the scientific consensus for key subjects, highlighting any controversies or research gaps that can be rapidly screened for scientific assessment. Furthermore, ScienceBrief has demonstrated the ability to maintain an up-to-date view of the science underpinning a range of important issues, enabling a timely response to media enquiries and public interest. This helps to combat misinformation. The platform offers great potential to deliver broad outreach and dissemination of science, but to achieve this would require significantly greater resources than have thus far been available.

The ScienceBrief experience illustrates potential future directions for developing and using collaborative technology platforms to assist in global scientific assessments. First, the design of such a platform would need to be engineered to meet the specific needs of the assessment, with a clear structure mapping directly to the chapters of each working group, to ensure evidence is uploaded at the relevant point. Additionally, current guidelines on effective public science communication and policy takeaways should be integrated in the platform.

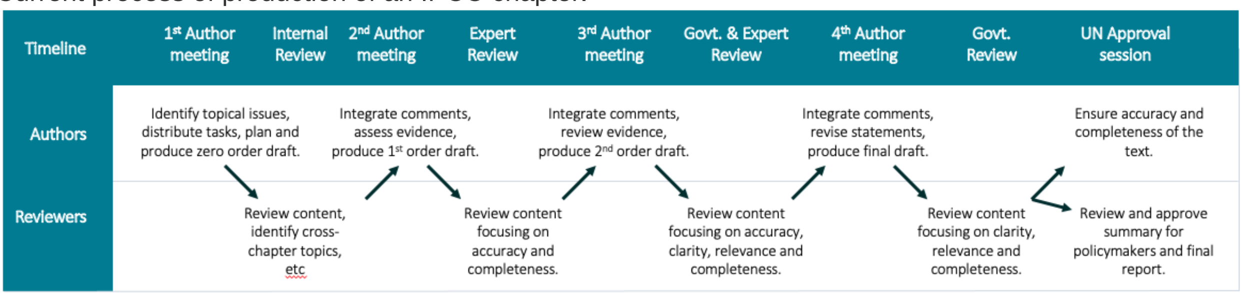
Second, the platform would need to be accompanied by systemic incentive structures to successfully engage experts. Even in instances where technology platforms are novel and meet distinct needs, lack of contributions and few rewards for participation are known to hinder the formation of long-term online communities (Iriberri & Leroy, 2009; Rojo & Ragsdale, 1997). Previous examples show experts can struggle to adopt new technologies that require adjustments to current processes or are time-consuming to learn (van der Eijk et al., 2013). In order to sustain long-term expert contributions, technology platforms must embed incentive structures that are aligned with altruistic goals. These incentives can be grouped into formal processes, such as a call for evidence, or rewards for participation, including additional exposure. Though in the scientific cadre, incentive structures are known to pose significant problems to desirable outcomes like contributing to open science, completing replication studies, or providing quality reviews (Franzoni et al., 2011; Friesike & Schildhauer, 2014; Galiani et al., 2017).

Third, state-of-the-art machine learning and natural language processing techniques could be integrated to lower barriers to expert contribution, increase effectiveness of the platform, and make the platform more self-sustaining. Current capabilities could be enhanced to automatically detect and upload new evidence, and trigger an invitation to experts to add their interpretations. As experts are engaging with the platform, further integration of ML and AI technologies can help to cluster papers with common themes and perspectives, improving the usability of the platform. While ScienceBrief does not currently use extensive machine learning technologies, we implement a workflow for including expert summaries and labels. Finally, while automated text generation is not yet advanced enough to automatically and reliably create summaries or interpretations (Wadden et al., 2020), the platform could suggest interpretations and even stances, which experts can minimally edit. In other high-stakes scenarios, suggest-and-edit models like these have been shown to save time while maximising contributions (Sharma et al., 2022). These developments would be a welcome upgrade to the current ScienceBrief platform.

The use of a collaborative technology platform in global scientific assessments would require a modernisation of the production process within, for example, the IPCC (**Figure 6**). Despite the ambition of IPCC to be open and transparent, the current process is entirely done behind closed walls, with the successive production of intermediate drafts produced by the authors and their review by experts and governments. The use of a technology platform could be introduced after the first iteration among authors, which would focus on identifying topical issues and associated uncertainties and preparing the call for expert's contributions, which would be done openly on the technology platform. The same cycle of iterations as currently can then follow, with the difference that the author's revisions of their main texts would be public and openly scrutinised, and only the executive summaries would remain reviewed behind closed doors. The content of the platform could then also be updated continuously after the IPCC has been published, therefore providing a means by which statements can be kept up to date.

Such a system would have multiple advantages, including a more inclusive process supporting the contributions from early career and scientists from across the world, the easier access of information presented within the core of the reports which is fragmented into small, self-contained documents, and the facilitation of consensus reaching (**Fig. 6**). There are also new risks, including the potential lack of participation, or at the other end the excessive participation of some experts potentially leading to biases. However these risks can be managed with an established vetting system and operational and verification rules. A further challenge comes from the integration of grey literature, which cannot be identified by an automated process. Some provision of manual verification and vetting of the quality of the input evidence would need to be anticipated, but nothing above what is already done in current assessments.

Current process of production of an IPCC chapter.



Proposed process of production of an IPCC chapter using an open collaborative technology platform to enhance expert's collaborations.

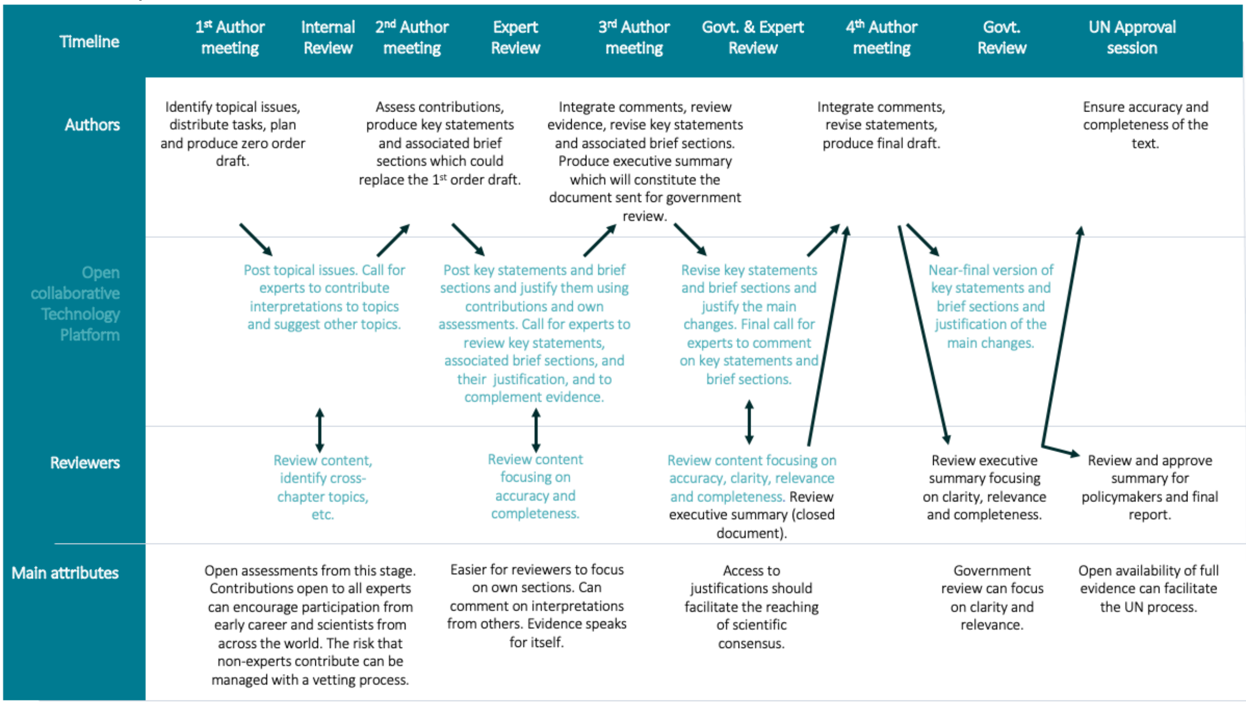


Figure 6. ***Current (top) and proposed (bottom) process of production of an IPCC Chapter. The main attributes of the proposed process are described at the bottom. All processes in teal are publicly visible, whereas those in black, including all current production processes, are closed.***

9 Conclusion

The ScienceBrief carbon cycle pilot has thoroughly tested and further refined a fully functioning technology platform that can support and facilitate rapid scientific assessments. The platform is an asynchronous-connected tool with a focus on visual interfaces, that helps to ameliorate the exponential growth in the scientific literature, which has exceeded the ability of individuals to keep up with science. ScienceBrief is an example of a collaborative technology platform that could benefit global scientific assessments by assisting knowledge extraction from a rapidly expanding and overwhelming scientific literature; engagement of expertise from diverse geographic locations and career stages; and both regular and rapid assessment of scientific consensus on specific topics. Further function development and adjustments targeted to assist in scientific assessment reports, as well as enhanced utilisation by the scientific community would amplify these benefits.

Utilising ScienceBrief, broad outreach and dissemination of science is achievable but resource-intensive, with the original concept of 'crowd-sourced science' contributed by experts, not having been achieved. The input from 4C scientists has been extremely valuable, helping to test the platform and enabling this evaluation; but organic growth to achieve returning or regular expert contributions was not achieved. Further technological development may achieve greater utilisation and enhance the benefits observed, though this is not certain. Future involvement with IPCC assessments would likely require some further development but could potentially deliver far greater expert contributions.

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