the approval. The statements in the First Order Draft of the SPM were still long and cluttered with jargon and numbers. In the process of preparing the Final Draft of the SPM, the headline statements were continuously refined, taking into account the many review comments and ensuring consistency with ongoing revisions in the SPM and the main report. The most significant step in the improvements, however, happened at an intensive preparatory meeting by the author team just before the WGI approval plenary. In that meeting, during which the final government comments were taken into account and revisions of the SPM draft were discussed, the language of the headline statements was streamlined and cut in length by another 30% — down to just 922 words. At the approval plenary, a mere 26 words were added, indicating that the statements as proposed by the authors had reached a very high level of acceptance.

Most importantly, the headline statements, as an integral element of the SPM drafts, underwent the same multistage expert and government review as all of the other text of the WGI SPM. For instance, the simple headline sentence: "Human influence on the climate system is clear."[4] was iterated many times among the authors until finally an agreement was reached and this statement could be presented to the IPCC plenary. The statement, as the high-grade distillate of detailed assessment findings that are elaborated in a section of the SPM and an entire chapter of the main report, was approved unchanged and in consensus by all governments.

It is interesting to note that the score of the SYR SPM headline statements is just over half that of the WGI SPM score, but still higher than that of both the WGII and WGIII SPMs, as well as of the full SYR SPM. Had this element been an agreed standard for all WG SPMs, and had the construction of headline statements been given higher priority during the writing of the SYR, it may have substantially raised the level of comprehension of these SYR statements and certainly made them more accessible than a complex scientific paper.

We agree with Barkemeyer *et al.*[1] that further improvement is possible with regard to the readability of top-level documents by IPCC. However, progress must also be made in the application of analysis and metrics that measure text complexity in relation to the IPCC reports. Alternative, more sophisticated modes of technical analysis already exist[6]. For instance, using a 'familiarity score', measuring the average occurrence of words in quality newspapers, would provide valuable information on general comprehension. The information required to determine this score could be derived from existing and readily available large and comprehensive databases of word frequencies in contemporary English such as Word frequency data (http://www.wordfrequency.info). In any case, more detailed linguistic tests should be employed to provide useful assistance in the future production of IPCC headline statements.

But even the simple scores illustrated in Fig. 1 highlight the significant improvement in the accessibility of IPCC key conclusions. Some of the most evocative WGI SPM headline statements, such as the one quoted above, have been used by the media unaltered. In such cases, the collective voice of the scientists — approved verbatim by the governments — was carried in an unfiltered manner by the media to the public. This avoided the danger of increasingly emotive and opinionated coverage in the popular media as highlighted by Barkemeyer and colleagues[1]. IPCC headline statements were also quoted in decision documents of the UN Framework Convention on Climate Change[7], opening a direct channel for scientific knowledge into the policymaking process. This demonstrates their utility and suggests that they should become a standard element of all top level products of the IPCC in the new assessment cycle. ❐

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Thomas F. Stocker[1,2] and Gian-Kasper Plattner[1,3]
[1]Climate and Environmental Physics, Physics Institute, University of Bern, Sidlerstrasse 5, 3012 Bern, Switzerland. [2]Oeschger Centre for Climate Change Research, University of Bern, Falkenplatz 16, 3012 Bern, Switzerland. [3]Swiss Federal Research Institute WSL, Zürcherstrasse 111, 8903 Birmensdorf, Switzerland.

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CORRESPONDENCE:

Technological change and climate scenarios

To the Editor — Clark *et al.*[1] consider the consequences of twenty-first-century climate policy and present scenarios for the effects of anthropogenic carbon emissions on a 10,000-year timescale. Unfortunately, however, their scenarios are underpinned by the implicit and unrealistic assumption of *ceteris paribus* (all else being equal) with respect to technology, echoing the field's publications more generally.

Although Clark *et al.*[1] recognize the potential importance of large-scale capture and storage of airborne carbon, their use of language in general does not adequately reflect the implausibility of the 'all else being equal' assumption. Declarations such as "the ultimate return to pre-industrial CO_2 concentrations will not occur for hundreds of thousands of years" and "the CO_2 released during this century will commit Earth and its residents to an entirely new climate regime" are made with unwarranted confidence, and without appropriate caveats.

Today many environmental problems seem intractable because remediation would require the manipulation of the physical world at a scale and/or with a precision that is prohibitively expensive. In the specific case of the carbon and climate problem, carbon dioxide removal (CDR) geoengineering in the form of direct air carbon capture and storage (DACCS) at the gigaton scale would require trillions of US dollars using current technology[2,3]. To render the problem tractable, costs would need to fall by a factor of a million or more. To observers not familiar with the accelerating nature of technological progress, it might seem reasonable to assume that DACCS will therefore not be feasible for thousands of years. But at least one technological pathway to a million-fold cost reduction for megaprojects of this scale (and much else besides) is already clear: intelligent machine labour, a technology that lies only decades away[4].

The prospect of technological progress does not at all diminish the severity of any form of environmental degradation or the urgency with which mitigation and adaptation action are called for. The carbon and climate problem is a crisis today, regardless of what tomorrow may bring. Moreover, the risk of 'mitigation obstruction' and complacency associated with the anticipation of geoengineering 'techno-fixes' remains a legitimate concern[5–8]. Likewise, the risks — both known and unknown — of all forms of geoengineering warrant rigorous evaluation (see for example, refs 9,10). Nevertheless, the question of whether CDR geoengineering will be feasible in the relatively near future must not be conflated with the question of whether it is desirable. And the fact that CDR geoengineering may indeed become feasible far sooner than many people imagine only underscores the importance of starting to evaluate its desirability now.

Scenarios such as those presented by Clark *et al.*[1] may, just like 'business as usual', provide instructive baselines for comparison. Nevertheless, any scenario that claims or implies itself to be a realistic forecast rather than a prospective counterfactual one must include an open-eyed accounting of the technological changes that current research across the engineering and computer science disciplines suggests we are very likely to see over the remainder of this century. ❐

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Adam Dorr
Luskin School of Public Affairs, University of California, 337 Charles E. Young Drive East, Los Angeles, California 90095, USA.
e-mail: adamdorr@ucla.edu

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CORRESPONDENCE:

Improving estimates of Earth's energy imbalance

To the Editor — Earth is gaining energy owing to increasing concentrations of greenhouse gases and the large thermal inertia of the oceans[1]. This gain is difficult to measure directly because it is the small difference between two much larger components of Earth's energy budget — the amount of incoming solar radiation absorbed and the total thermal infrared radiation emitted to space. With over 90% of Earth's energy imbalance (EEI) being stored in the ocean, the most accurate way to determine it is to measure increases in ocean temperatures (along with increases in land temperatures, decreases in ice mass, and increases in atmospheric temperature and moisture)[1]. Although the observed net uptake of ocean heat energy is robust over decades, measurement biases and changes in sampling over time have made assessing year-to-year changes difficult[2].

We previously estimated[3] the EEI at 0.58 ± 0.38 W m^{-2} (expressed here in terms of average heat uptake applied over Earth's surface area with 5–95% confidence intervals). This *in situ* estimate was made from 2005 (the year the Argo array of profiling floats achieved sparse near-global coverage) to 2010 by combining observed ocean heat uptake over 0–1,800 m with published estimates of energy uptake by the deeper ocean, lithosphere, cryosphere, and atmosphere. It was used to anchor satellite-observed EEI from the Clouds and the Earth's Radiant Energy System (CERES), which, although stable over time, is not sufficiently accurate in absolute value to determine EEI at the required level. Year-to-year variations of 0–1,800 m ocean heat uptake and CERES EEI were correlated at 0.46. Here, we update our calculations (Fig. 1), and find a net heat uptake of 0.71 ± 0.10 W m^{-2} from 2005 to 2015 (with 0.61 ± 0.09 W m^{-2} taken up by the ocean from 0–1,800 m; 0.07 ± 0.04 W m^{-2} by the deeper ocean[4]; and 0.03 ± 0.01 W m^{-2} by melting ice, warming land, and an increasingly warmer and moister atmosphere[1]). In addition to a remarkable quartering of uncertainty, owing to improved sampling by the Argo array over time (Fig. 1), the correlation between year-to-year rates of 0–1,800 m ocean heat uptake[5] and the latest release of CERES EEI is a much-improved 0.78. This striking agreement between two completely independent measures of EEI variability bolsters confidence in both of these complementary climate observation systems, and provides valuable insights into climate variability.

Argo recognizes the imperative to improve its coverage of the global oceans, with a plan to sample the bottom half of the ocean volume[6], where significant changes in deep[7] and bottom[8] water circulation and properties have been observed in recent decades, in addition to expansions into marginal seas and the climatically vital seasonal ice-covered oceans, where ocean warming may melt sea ice, decreasing Earth's albedo[9] and undermine the marine terminations of ice sheets, raising the sea level[10]. If supported, making Argo truly global, coupled with continued satellite observations, will also better allow us to monitor changes in EEI, and hence to refine and initialize global climate projections and predictions that are so vital to societal adaptation in a rapidly changing world. ❐