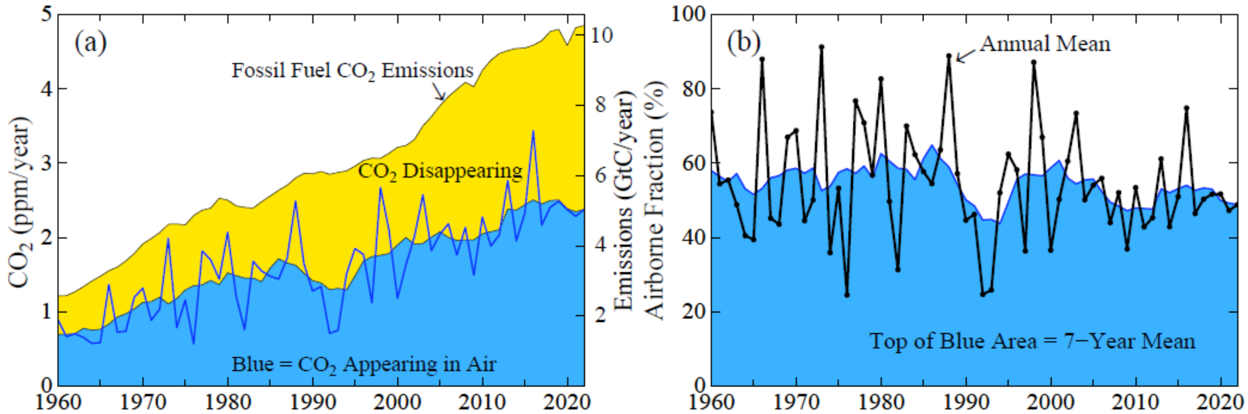

Fig. 1. Fossil fuel emissions divided into portions appearing in the annual increase of airborne CO_2 and the remainder, which is taken up by the ocean and land (1 ppm CO_2 ~ 2.12 GtC).

Good News for Young People About Climate Change and a Thank You

28 December 2023

James Hansen, Makiko Sato, Pushker Kharecha

Abstract. Our climate research and analysis places comparable emphasis on paleoclimate information, global climate modeling, and modern observations of ongoing global change. Despite our findings[1] that climate sensitivity is greater than the canonical estimate of 3°C equilibrium warming for doubled CO_2 and that global warming is accelerating, let us end the year with some real-world good news.

Betsy Taylor, President of the Board[2] of Climate Science, Awareness and Solutions (CSAS.inc), asked if we had any good news to counter pessimism from our findings that climate sensitivity is 4.8°C ± 1.2°C, much higher than the 3°C best estimate of the Intergovernmental Panel on Climate Change (IPCC), and that global warming is accelerating due to reduction of human-made aerosols.[1]

We proffer new evidence of nature's ability to help clean up human pollution of the climate system, specifically nature's ability to rapidly absorb a large part of the CO_2 that humanity injects into the air by burning fossil fuels. There has long been a "carbon cycle" mystery, a "missing carbon sink." Fossil fuel emissions are known quite accurately, shown by the upper curve in Fig. 1a, increasing by about a factor of four from ~2.5 GtC (gigatons of carbon) in 1960 to ~10 GtC in the last few years. However, the amount of carbon (C) appearing in the air is not much more than half (blue area in Fig. 1) of the fossil fuel emissions, and that fraction has even decreased over the past few decades.

The "problem" was that the most expert estimates for the ocean and terrestrial "sinks" for increased atmospheric CO_2 did not add up to the magnitude of the disappearing CO_2 (yellow area in Fig. 1), especially after estimates were included for the additional carbon source from deforestation. Resolution of this problem, in part, is provided by the new paper of Wang et al. (2023).[3] They use data-driven analysis of the carbon, oxygen and phosphorus cycles in the ocean, accounting for all known export pathways for carbon, and obtain greater advective-diffusive downward transport of biological carbon than that found in more conventional global climate modeling. The upshot is that the deep ocean may provide a little more help in taking up excessive atmospheric CO_2 than most models have been indicating. This does not alter conclusions in our paper *Global Warming in the Pipeline*,[1] which uses empirical carbon cycle data. Fig. 1 above is Fig. 26 in *Pipeline*.

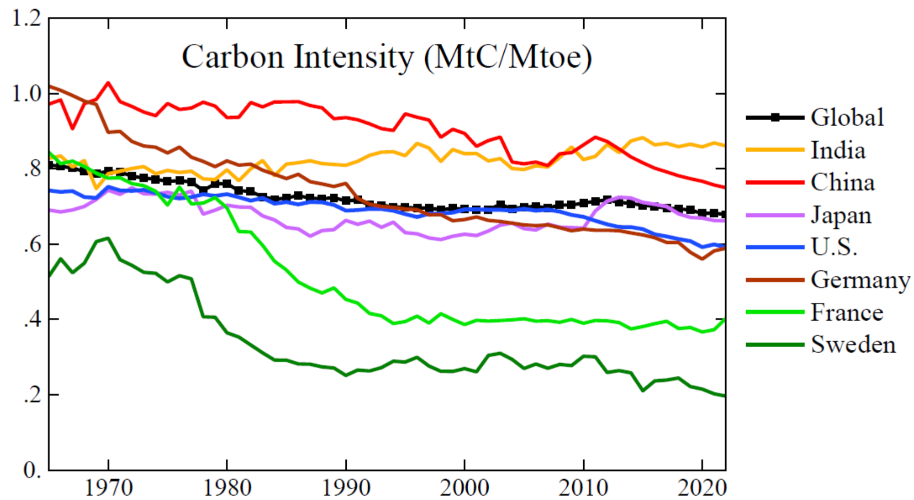

Fig. 2. Carbon intensity (carbon emissions per unit energy use) of several nations and the world. Mtoe = megatons of oil equivalent. Data sources (Hefner *at al*.[4] and Energy Institute[5]).

The world has made progress in reducing the carbon intensity of its energy, i.e., carbon emissions per unit energy use (Fig. 2). Over the past half century, the carbon intensity has declined from a bit less than 0.8 to a bit less than 0.7. We compare the carbon intensity of various nations (Fig. 2) as that helps reveal how effective different energy policies are. Fig. 2 is Fig. 32 in the energy policy section of the *Pipeline* paper.

The progress in reducing carbon intensity is welcome, but small compared to the task at hand. Global carbon emissions are the product of carbon intensity and energy use, and global energy use is still rising, as much of the world is in the process of raising their living standards. Fig. 3 is a new figure made by Makiko Sato, which compares fossil fuel emissions to emissions in 1997, the year of the Kyoto Protocol. Global emissions have increased about 50 percent since 1997 and show no signs of the very steep decrease that would be needed to keep global warming below 2°C. Although nations with emerging economies and nations that are just beginning to develop economically have the largest growth rates, their contribution to climate change is smaller than that of the mature economies, especially on a per capita basis, as shown by several graphs in *Pipeline*.

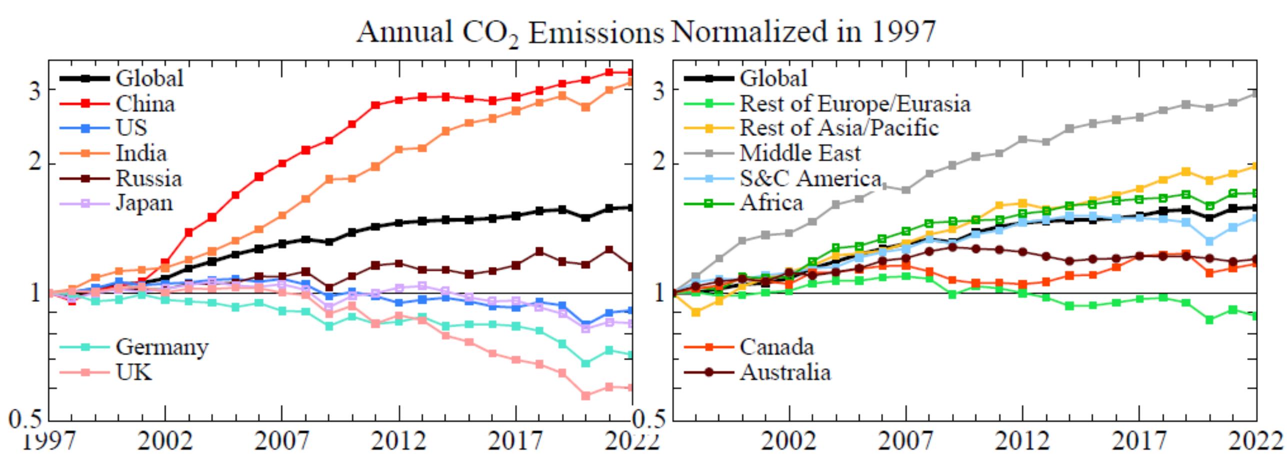

Fig. 3. Global, national and regional fossil fuel CO_2 emissions relative to emissions in 1997.

We are especially grateful for the unusual level of support that we received in 2023, which made it possible for us to finish the *Pipeline* paper, a 2+ year project. Specifically, we were able to hire Isabelle Sangha, whose contributions were essential to complete the Cenozoic section of the paper (in an upcoming communication we will explain why the Cenozoic analysis is important for understanding climate change and implications for policy; Isabelle is now in a Ph.D. program at Cambridge University) and Joe Kelly, who is helping us investigate cloud feedbacks in climate models and in the real world.

Clouds are a great challenge, because of their role as both a climate feedback and a climate forcing. Our inference of high climate sensitivity implies that clouds provide a large, amplifying, climate feedback. However, cloud changes also provide the mechanism by which aerosol changes cause a large climate forcing. This complicates the task of quantifying both the cloud feedback and the aerosol climate forcing.

Our expectation for 2024 is that continued unusual global warming will provide empirical evidence of the strong acceleration of global warming. Our goal is to complete work that helps provide understanding of ongoing climate change and actions that are needed to avoid unacceptable consequences for young people and future generations.

We are grateful for the wonderful support that we received in 2023 as delineated in section 2.6 of our recent communication ("A Miracle Will Occur" Is Not Sensible Climate Policy).[6] We hope for continued support in 2024, which will be a challenging year because Makiko Sato will be retiring in late 2024 and we need to continue her remarkable work in obtaining, updating, and helping us understand the huge number of data sets that are needed to analyze climate change. We apologize for failure to send out thank you letters to supporters as we have been without a local program coordinator for some time. Eunbi Jeong continues to work with us part-time from Korea, via CSAS.inc, but work at a distance places limitations on some activities.

Contributions to our work are equally useful to CSAS at Columbia University or CSAS.inc; both are 501(C3) non-profits. CSAS at Columbia supports people with University appointments while CSAS.inc supports all other costs without overhead. Instructions for donations are at:
CSAS-Columbia University: https://csas.earth.columbia.edu/giving
CSAS.inc: https://www.climatescienceawarenesssolutions.org/donate

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[1] Hansen J, Sato M, Simons L *et al*. Global warming in the pipeline. *Oxford Open Clim Chan* 2023;3(1):kgad008, doi.org/10.1093/oxfclm/kgad008
[2] Board of Directors for Climate Science, Awareness and Solutions.inc
[3] Wang WL, Fu W, Le Moigne FAC et al. Biological carbon pump estimate based on multidecadal hydrographic data. *Nature* 2023;624:579-85
[4] Hefner M, Marland G, Boden T *et al.* Global, Regional, and National Fossil-Fuel CO_2 Emissions, Research Institute for Environment, Energy, and Economics, Appalachian State University, Boone, NC, USA. https://energy.appstate.edu/cdiac-appstate/data-products (20 August 2023, date last accessed)
[5] Energy Institute. 2023 Statistical Review of World Energy (20 August 2023, date last accessed)
[6] Hansen J, Kharecha P, Sato M. "A Miracle Will Occur" Is Not Sensible Climate Policy. 07 December 2023.