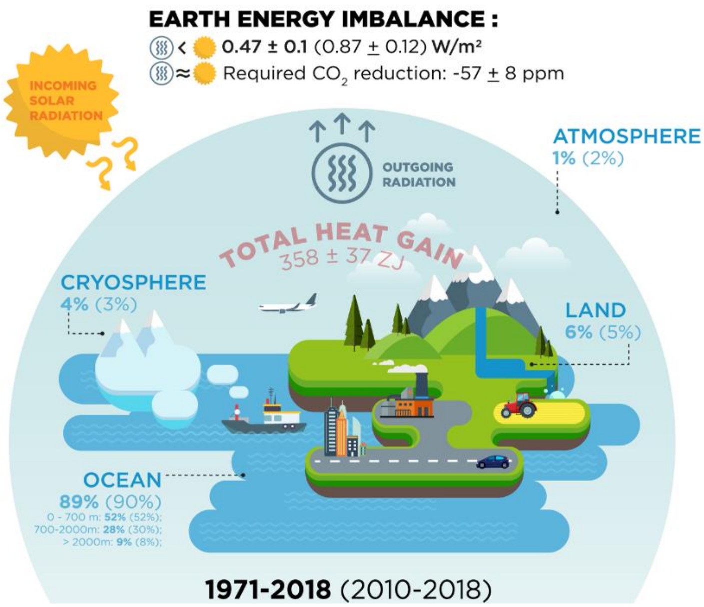

Fig. 1. **Boldface** numbers for period 1971-2018, lightface for 2010-2018.

Sentinel for the Home Planet

7 September 2020

James Hansen

The single number that best characterizes the status of Earth's climate, Earth's energy imbalance, will be updated today in a paper[1] by Karina von Schuckmann and 37 co-authors. As long as Earth continues to absorb more solar energy than the planet radiates to space as heat, global temperature will continue to rise. The new paper finds that Earth's energy imbalance increased during the past decade, with implications for the burden being left for young people. Stabilizing climate requires that humanity reduce the energy imbalance to approximately zero. That task has become more difficult during the past several years.

Two numbers, atmospheric CO_2 amount and global surface temperature, have received special prominence, and they deserve attention. However, this third number, Earth's energy imbalance, is perhaps the most important. CO_2 is just one of the forcings that drive climate change, even if the dominant one. Earth's energy imbalance incorporates the effect of CO_2 and all other forcings, including some, such as human-made aerosols, that are poorly measured at best.

Earth's energy imbalance will be our guide during the next several decades as we work to restore a healthy climate for future generations. It deserves greater attention.

Karina von Schuckmann has become perhaps the world's leading expert in monitoring Earth's energy imbalance, in some sense analogous to Dave Keeling monitoring atmospheric CO_2. Measuring Earth's energy imbalance is a lot harder though, it requires a whole team of experts. We might call Karina, with her team of colleagues, the "sentinel for the home planet."

Karina was the first person I called following a long conversation with legal scholar Mary Wood in 2010. Explanation for why I called a young scientist I did not know – a German post-doc working in a French oceanographic institute – reveals some key issues in climate science.

Mary Wood was intent on making the case that the government has an obligation to leave a sustainable world for future generations. She was aware of a paper in which several colleagues and I concluded that it was necessary to reduce atmospheric CO_2 to some level less than 350 ppm to maintain a hospitable climate on the long run. Could we make that conclusion firm enough to stand up in court, and could we define a realistic pathway to stabilize climate?

Accurate knowledge of Earth's energy imbalance was essential for both of those objectives.

Just prior to the conversation with Mary Wood I read a paper[2] by von Schuckmann, Gaillard and Le Traon with the innocuous title "Global hydrographic variability patterns during 2003-2008." But within the paper there was a graph of what seemed to be the most reliable data until then of the increasing heat storage in the ocean.

I must back up more than a decade to explain why this paper was the one I had been waiting for. In the 1990s Carolyn Harris and I initiated a summer program, the Institute on Climate and Planets (ICP) at the Goddard Institute for Space Studies (GISS). We brought in students and teachers of New York City high schools and students and professors of colleges of the City University of New York to work with NASA scientists on what we called Research Education.[3] We wanted to spur diversity in NASA, which was dominantly white and male, and aid teaching of science. A brief discussion of the ICP program by several of its graduates is available.

We divided ICP participants into six or seven teams. My team, with about 10 total members, was dubbed "Pinatubo" the first two years, when we focused on analyzing the climate impact of the 1991 volcanic eruption of Mount Pinatubo in the Philippines. We changed the name to "Forcings and Chaos" after our research interests expanded. Our team's principal publication[4] also included as co-authors people who provided data or other assistance to our study.

The Forcings and Chaos team aimed to quantify the roles of climate forcings and chaotic (unforced) variability in interannual to decadal climate change. We chose the 18-year period 1979-1996 because of availability of NASA measurements of solar irradiance and stratospheric aerosols. These data let us define accurately the natural climate forcings by the Sun and volcanoes, and include these with the well-known forcing by human-made greenhouse gases.

Our approach was to make multiple climate simulations with the GISS global climate model (GCM), adding in the forcings one-by-one. For a given set of forcings we ran the model five times with slightly perturbed initial atmospheric conditions; the five runs provided a measure of unforced climate variability that arises because of the chaotic behavior of fluid dynamics.[5]

Volcanic aerosols, especially from the large Pinatubo eruption in 1991, imparted an easily recognized signature on simulated atmospheric and surface temperature. However, the model did not match the observed strong global warming trend for surface temperature during 1979-1996, if the model was driven only by the changes of known forcings within that period. Annual increases of atmospheric GHGs added a forcing of about 0.04 W/m^2 each year, but the warming effect of the GHGs was nearly offset by the cooling from volcanic aerosols.

However, the global warming trend was matched well when we added a "disequilibrium forcing" of +0.65 W/m^2, which was presumed to be a residual effect of increasing GHGs prior to 1979. We concluded that our results were evidence for an Earth energy imbalance of about that magnitude, at least 0.5 W/m^2. This energy imbalance arises because of the great heat capacity (thermal inertia) of the ocean and the changing composition of the atmosphere: Earth has not yet come to equilibrium with the changing atmosphere.

Such a large energy imbalance, if it were correct, implied that continued global warming was almost certain on decadal time scales. The imbalance was much larger than the magnitude of solar cycle variability of insolation. Barring unusual circumstances such as multiple large volcanic aerosol injections, each decade should be warmer than the prior decade.

However, the inferred imbalance was a model result. We needed reliable monitoring of real-world energy imbalance. Most of the excess energy goes into the ocean, whose large thermal inertia is the cause of the planetary energy imbalance, so the simple requirement is precise monitoring of the ocean's heat content.

Simple in principle. Difficult in practice. Many measurements of ocean temperature had been made over time, but the data must be very accurate. If the same instrument, or even the same type of instrument, were used for all the measurements, we could tolerate a systematic error. However, multiple instrument types were used, and they were not always well calibrated.

Moreover, the global ocean is very large. Many places were unmeasured and analyses often assumed that if there was no measurement, there was no change in the heat content.

Oceanographers realized that a better system was needed, and they began an international cooperation to develop a global fleet of thousands of "Argo floats." These floats periodically dive to a depth of 2 km, measuring the profile of ocean temperature and salinity. At the surface, they radio their measurements to a satellite. By the middle of the first decade of the 21st century global deployment of floats was sufficient for an improved analysis of ocean heat content.

The paper by von Schuckmann, Gaillard and Le Traon that I read in early 2010 was the first analysis of Argo data that I had seen. They included a graph of increasing ocean heat content in the upper two km of the ocean during 2003-2008.

When I called Karina in 2010 I asked if she would help prepare the paper that Mary Wood had requested, for a lawsuit on behalf of young people. She agreed enthusiastically, even though, she noted, she might be a little preoccupied, as she was getting close to the birth of her first child.

We decided to first carry out a climate analysis based on an update of the Argo data through 2010 and the global temperature record for the past century. In our paper[6] we concluded that Earth's energy imbalance was about 0.6 W/m^2 during the period 2005-2010, which was a period of solar minimum irradiance. Despite the solar minimum, there was 0.6 W/m^2 more solar energy absorbed by Earth than heat radiation returned to space. [That amount of energy, I pointed out in a TED talk, is equivalent to the energy in exploding 400,000 Hiroshima atomic bombs per day, every day of the year. Most of that energy is warming the ocean.]

In our paper we noted that observed global warming and observed ocean heat uptake together placed a strong constraint on the net global climate forcing, if we assumed a climate sensitivity of 3°C or higher for climate sensitivity to doubled atmospheric CO_2 as implied by paleoclimate studies. In turn, because the greenhouse gas climate forcing was well known, we could infer the climate forcing by atmospheric aerosols.

Our paper concluded that the aerosol climate forcing in 2010 was -1.6 ± 0.3 W/m^2. We also inferred that many ocean models at that time tended to mix heat too efficiently from the surface ocean into the deeper ocean, leading to unrealistically large heat uptake by the ocean in many global climate models and an underestimate of the negative climate forcing by aerosols.

In a later paper,[7] using Karina's analysis for ocean heat uptake during 2005-2015, we concluded that Earth's energy imbalance was 0.75 ± 0.25 W/m^2 during that 11-year period.

The new paper being published today by von Schuckmann and 37 co-authors concludes that the energy imbalance in 2010-2018 has increased to 0.87 ± 0.12 W/m^2.

That imbalance must be reduced approximately to zero for the sake of stabilizing climate.

The authors note that one way to achieve energy balance would be to reduce atmospheric CO_2, presently at about 410 ppm, by 57 ± 8 ppm. That reduction of CO_2 would increase Earth's heat radiation to space by 0.87 ± 0.12 W/m^2, thus leaving Earth at energy balance with global temperature close to its present value, which is about 1.2°C above the preindustrial level. This is consistent with an earlier suggestion[8] that the initial target for CO_2 should be about 350 ppm, if we wish to aim for stable shorelines and avoid other climate problems.

As expected, this initial target has not changed much. However, the task of achieving the target is now more difficult. The required reduction of greenhouse gases is larger, and the time that we have to achieve the reduction, even though uncertain, is certainly shorter.

Could we not, instead, reduce other greenhouse gases? We suggested in our *Young People's Burden* paper[7] that there is potential in other greenhouse gases to reduce climate forcing by as much as a few tenth of 1 W/m^2. However, we are in the process of doing no such thing.

Methane (CH_4), in principle, should present the best possibility to rapidly reduce climate forcing, because the lifetime of a methane molecule is only of the order of 10 years. If we reduce the sources, the atmospheric methane amount will decline rapidly. However, in reality, at least in part due to "fracking," methane has resumed its growth.

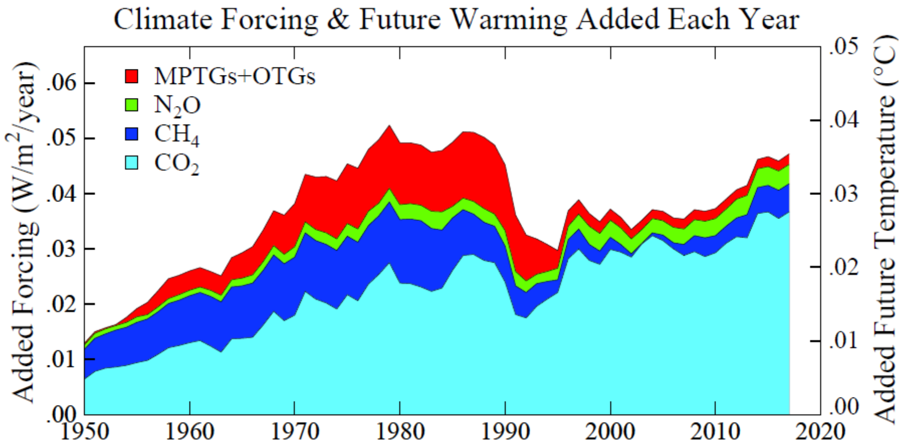

Fig. 2. Greenhouse gas climate forcing annual growth rate (5-year running mean). Annual addition to eventual global warming (right scale) is based on climate sensitivity 3°C for 2×CO_2.

Figure 2 shows that the greenhouse gas climate forcing is still growing by more than 0.04 W/m^2 per year. The growth rate has even accelerated in the past decade, which is consistent with the increase of Earth's energy imbalance.

The most disconcerting fact is the seeming absence of understanding by governments of what action is required to achieve climate stabilization, and the certain absence of any plan to achieve that action. As long as the price of fossil fuels does not include their costs to humanity, the climate problem will not be solved. This situation is disconcerting because economists agree that the required actions make sense, independent of concerns about climate change.

It is still possible that at least one of the great economic powers – the United States, China or the European Union – might adopt an across-the-board (oil, gas, coal) rising carbon fee. The fee could then be imposed on a near-global basis via border duties on products from countries without an equivalent fee.

Economic studies show that such a carbon fee would cause rapid phasedown of CO_2 emissions without damaging economies, if the funds collected are distributed uniformly to the public. This procedure is anti-regressive, because wealthy people have a large carbon footprint. About 70 percent of the public would receive more in their dividend than they pay in increased prices for fossil fuels and products made using fossil fuels.

When governments eventually understand the implications of the climate science, the world will begin to pay more attention to the key metrics: CO_2, temperature and Earth's energy imbalance. The last of these is, by far, the most difficult to measure. I have no doubt that the Sentinel for the Home Planet will continue to provide updates for Earth's energy imbalance, but she cannot manufacture accurate data without appropriate measurements.

Governments need to support and enhance the Argo float program. It is particularly important to enhance data collection in the Southern Ocean, where it abuts Antarctic ice. It has become clear that, because governments have been slow to understand and deal with climate change, it will be necessary to take remedial actions for the sake of young people and future generations.

Karina von Schuckmann photo: Teresa Bellina

Such actions are feasible and can be safe for humanity and nature, but they need to be guided by appropriate data. That's a story for another day.

The embargo time is 10 AM CEST Monday 7 September. Karina's contact is karina.von.schuckmann@mercator-ocean.fr The journal, Earth Systems Science Data, is announcing publication of the paper as follows:

> Earth System Science Data (ESSD) announces first publication of a comprehensive Earth Energy Imbalance (EEI, von Schuckmann et al, https://doi.org/10.5194/essd-12-2013-2020) that reports energy (heat) accumulating in ocean, ice, land and atmosphere. This group of more than 30 researchers from scientific institutions around the world tracked and quantified global heat distributions over the past 58 years (1960-2018) to answer the urgent question 'where does the heat go?'. Starting from a heat accumulation of 358 ± 37 zettajoules (10^{21} joules) driven by input of greenhouse gases inducing a positive EEI of 0.47 ± 0.1 W/m^2, the authors identify 89% going into the ocean, 6% warming the land, 4% melting of grounded and floating ice, and 1% warming the atmosphere. The authors show clearly that, due to large heat capacity, the ocean dominates the Earth energy inventory. The results also show that EEI not only continues, it increases: the EEI amounted to 0.87 ± 0.12 W/m^2 during 2010-2018. Stabilization of climate, the goal of UNFCCC since 1992 emphasized by the Paris agreement of 2015, requires that EEI be reduced to approximately zero to restore Earth's system quasi-equilibrium. These results indicate that the amount of CO_2 in the atmosphere would need to be reduced from today's value of 410 ppm to roughly 350 ppm to increase heat radiation to space by 0.87 W/m^2, bringing Earth back towards energy balance. This single number, the EEI, serves as a fundamental metric to allow the scientific community and the public to assess how well the world responds to the task of bringing climate change under control. Assembling this global Earth's heat inventory required careful analysis of decades of high-quality climate observations from around the planet, observations combined with concerted international multidisciplinary collaboration that - in the authors' view - should continue. In particular, this research benefited from long-term attention by the Global Climate Observation System (GCOS). These authors make all data and calculations freely and openly available through the Copernicus open access journal ESSD which collaborated in this case with the World Data Center for Climate at Deutsche Klimarechenzentrum.

You can sign up for our monthly global temperature updates here.

You can sign up for my other Communications here.

I opened a Twitter account @DrJamesEHansen, (https://twitter.com/drjamesehansen), but I am focusing mainly on finishing the book.

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