

Karina von Schuckmann¹, Lijing Cheng^{2,28}, Matthew D. Palmer³, James Hansen⁴, Caterina Tassone⁵, Valentin Aich⁵, Susheel Adusumilli⁶, Hugo Beltrami⁷, Tim Boyer⁸, Francisco José Cuesta-Valero^{7,27}, Damien Desbruyères⁹, Catia Domingues^{10,11}, Almudena García-García⁷, Pierre Gentile¹², John Gilson¹³, Maximilian Gorfer¹⁴, Leopold Haimberger¹⁵, Masayoshi Ishii¹⁶, Gregory C. Johnson¹⁷, Rachel Killick³, Brian A. King¹⁰, Gottfried Kirchengast¹⁴, Nicolas Kolodziejczyk¹⁸, John Lyman¹⁷, Ben Marzeion¹⁹, Michael Mayer^{15,29}, Maeva Monier²⁰, Didier Paolo Monselesan²¹, Sarah Purkey⁶, Dean Roemmich⁶, Axel Schweiger²², Sonia I. Seneviratne²³, Andrew Shepherd²⁴, Donald A. Slater⁶, Andrea K. Steiner¹⁴, Fiammetta Straneo⁶, Mary-Louise Timmermans²⁵, Susan E. Wijffels^{21,26}

AN IMPERATIVE TO MONITOR EARTH'S ENERGY IMBALANCE

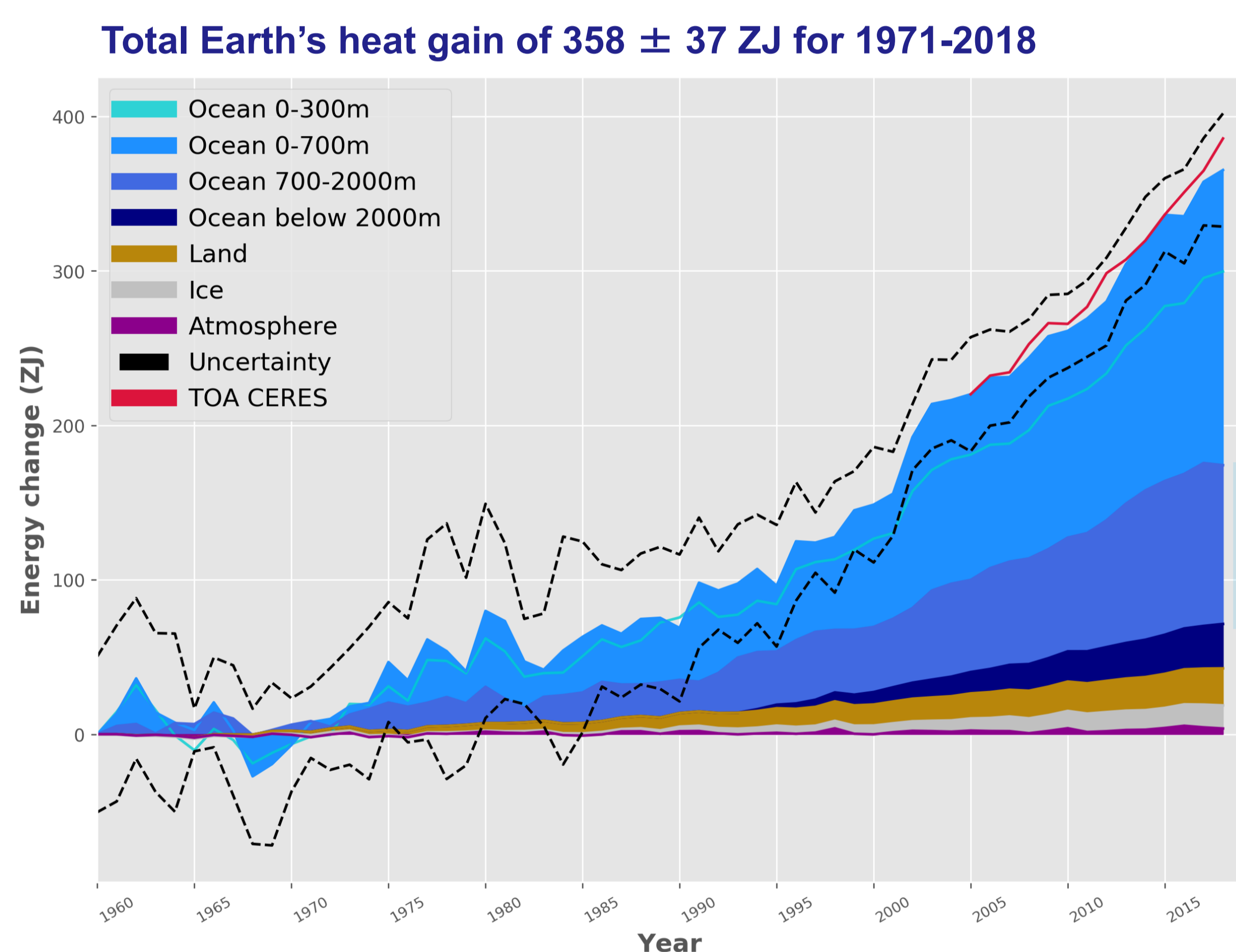
Earth's Energy Imbalance (EEI) is the most critical number defining the prospects for continued global warming and climate change. The EEI arises from alterations in the composition of the atmosphere which traps excess energy in the Earth system. The Earth is in radiative imbalance, with less energy exiting the top of the atmosphere than entering, since at least about 1970 and the Earth has gained substantial energy over the past 4 decades.

This study is a Global Climate Observing System (GCOS) concerted international effort to update the Earth heat inventory, and presents an updated assessment of ocean warming estimates, and new and updated estimates of heat gain in the atmosphere, cryosphere and land over the period 1971-2018.

EARTH SYSTEM INVENTORY : HEAT STORED IN THE CLIMATE SYSTEM FROM A POSITIVE EARTH ENERGY IMBALANCE

The knowledge of where and how much heat is stored in the different Earth system components from a positive EEI is of fundamental importance to unravel the current status of climate change, as well as to better understand and predict the implications of climate change, which are fundamental concerns for society.

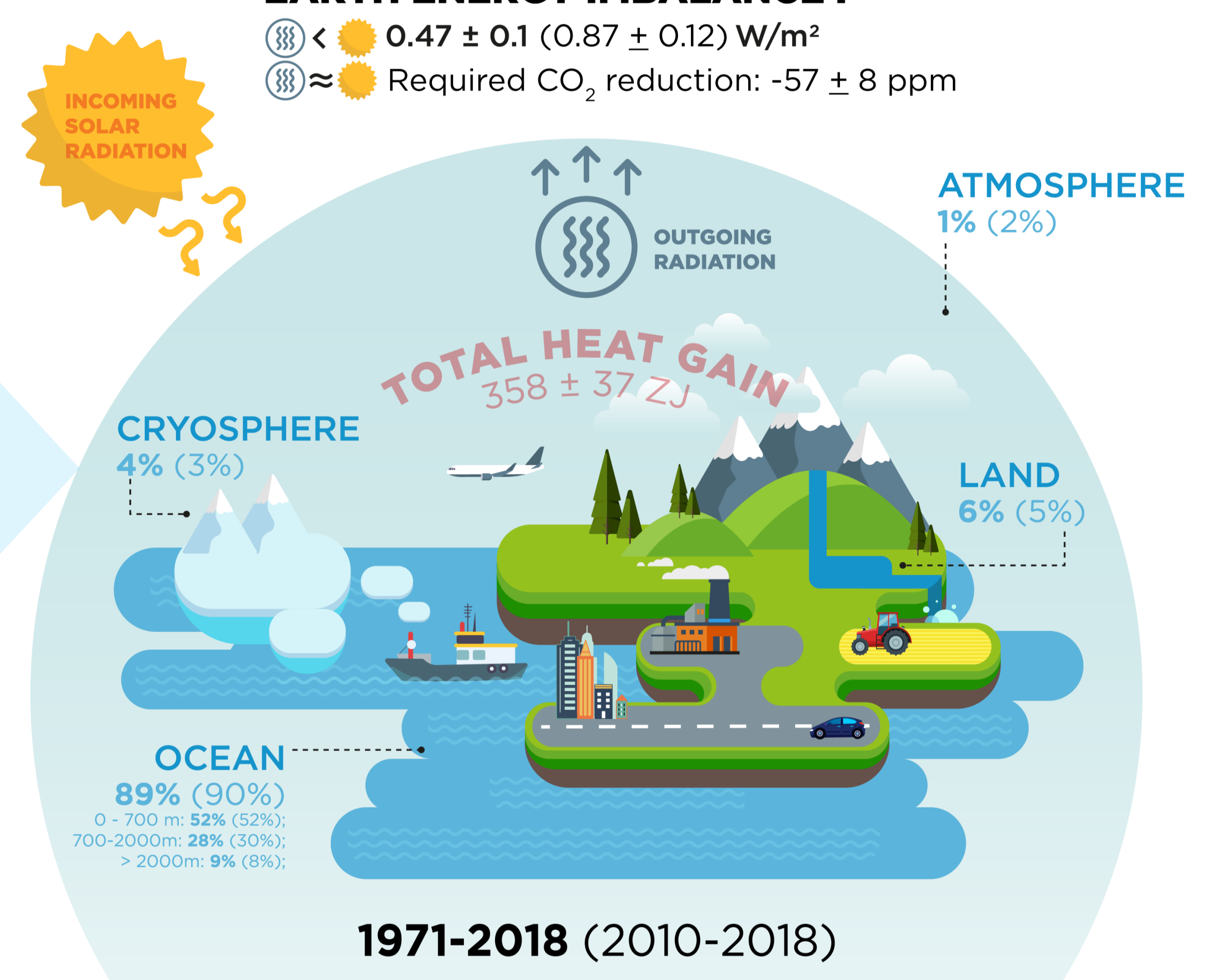
About 90% of this accumulated heat goes into heating the ocean, (4%) into melting of ice, (6%) heating the land and (1%) heating the atmosphere.



equivalent to a heating rate (i.e. the EEI)

EARTH ENERGY IMBALANCE :

$\text{INCOMING SOLAR RADIATION} < \text{OUTGOING RADIATION}$
 0.47 ± 0.1 (0.87 ± 0.12) W/m^2
Required CO_2 reduction: -57 ± 8 ppm



KEY MESSAGES

For the period **1971-2018**, the EEI amounts to $0.47 \pm 0.12 \text{ W/m}^2$ – thus continues at a comparable rate as reported in IPCC AR5.

Our results also show that **EEI is not only continuing, it is increasing**: the EEI amounts to $0.87 \pm 0.12 \text{ W/m}^2$ during 2010-2018.

Stabilization of climate, the goal of the universally agreed UNFCCC in 1992 and the Paris agreement in 2015, **requires that EEI be reduced to approximately zero to achieve Earth's system quasi-equilibrium.**

The amount of CO_2 in the atmosphere would need to be reduced from 410 ppm to 353 ppm to increase heat radiation to space by 0.87 W/m^2 , bringing Earth back towards energy balance.

This simple number, **EEI, is the most fundamental metric that the scientific community and public must be aware of**, as the measure of how well the world is doing in the task of bringing climate change under control, and **we call for an implementation of the EEI into the global stocktake** based on best available science.

Continued quantification and reduced uncertainties in the Earth heat inventory can be best achieved through the **maintenance of the current global climate observing system, its extension into areas of gaps in the sampling**, as well as to **establish an international framework for concerted multi-disciplinary research of the Earth heat inventory** as presented in this study.

¹Mercator Ocean International, France

²Institute of Atmospheric Physics, Chinese Academy of Sciences, China

³Met Office Hadley Centre, UK

⁴Columbia University Earth Institute, USA

⁵WMO/GCOS, Switzerland

⁶Scripps Institution of Oceanography, UCSD, San Diego, CA, USA

⁷Climate & Atmospheric Sciences Institute, St. Francis Xavier University, NS, Canada

⁸NOAA's National Centers for Environmental Information

⁹Ifremer, University of Brest, CNRS, IRD, Laboratoire d'Océanographie Physique et Spatiale, France

¹⁰National Oceanographic Centre, UK

¹¹ARC Centre of Excellence for Climate Extremes, University of Tasmania, Hobart, Tasmania, Australia

¹²Earth and Environmental Engineering in the School of Engineering and Applied Sciences, Columbia University, USA

¹³University of California, USA

¹⁴Wegener Center for Climate and Global Change and Institute of Physics, University of Graz, Austria

¹⁵Department of Meteorology and Geophysics, University of Vienna, Austria

¹⁶Department of Atmosphere, Ocean and Earth System Modeling Research, Meteorological Research Institute, Japan

¹⁷NOAA, Pacific Marine Environmental Laboratory, USA

¹⁸University of Brest, CNRS, IRD, Ifremer, Laboratoire d'Océanographie Physique et Spatiale, IUEM, France

¹⁹Institute of Geography and MARUM-Center for Marine Environmental Sciences, University of Bremen, Germany

²⁰CELAD/Mercator Ocean International, France

²¹CSIRO Oceans and Atmosphere, Hobart, Tasmania, Australia

²²Polar Science Center, Applied Physics Laboratory, University of Washington, Seattle, USA

²³Institute for Atmospheric and Climate Science, ETH, Switzerland

²⁴Center for Polar Observation and Modeling, University of Leeds, UK

²⁵Department of Earth and Planetary Sciences, Yale University, New Haven, USA

²⁶Woods Hole Oceanographic Institution, Massachusetts, United States

²⁷Environmental Sciences Program, Memorial University of Newfoundland, NL, Canada

²⁸Center for Ocean Mega-Science, Chinese Academy of Sciences, Qingdao, China, 266071

²⁹European Centre for Medium-Range Weather Forecasts, Reading, UK