How fast are the oceans warming?

Observational records of ocean heat content show that ocean warming is accelerating

By Lijing Cheng, John Abraham, Zeke Hausfather, Kevin E. Trenberth

Ocean warming is a key indicator of climate change, with implications for sea level rise, ocean circulation, and regional weather patterns. Recent studies have shown that ocean warming has accelerated in recent decades, with implications for global climate systems.

Since then, the research community has made substantial progress in improving long-term OHC records and has identified several sources of uncertainty in prior measurements and analyses. In AR5, all OHC time series were corrected for biases in expendable bathythermograph (XBT) data that had not been accounted for in the previous report (AR4). But these correction methods relied on very different assumptions of the error sources and led to substantial differences among correction schemes. Since AR5, the main factors influencing the errors have been identified, helping to better account for systematic errors in XBT data and their analysis.

Several studies have attempted to improve the methods used to account for spatial and temporal gaps in ocean temperature measurements. Many traditional gap-filling strategies introduced a conservative bias toward low-magnitude changes. To reduce this bias, Domingues et al. (10) used satellite altimeter observations to complement the sparseness of in situ ocean observations and update their global OHC time series since 1970 for the upper 700 m. Cheng et al. (2) proposed a new gap-filling method that used multimodel simulations to provide an improved prior estimate and error covariance. This method allowed propagation of information from data-rich regions to the data gaps (data are available for the upper 2000 m since 1940). Ishii et al. (6) completed a major revision of their estimate in 2017 to account for the previous underestimation and also extended the analysis down to 2000 m and back to 1955. Resplandy et al. (11) used ocean warming outgassing of O₂ and CO₂ which can be isolated from the direct effects of anthropogenic emissions and CO₂ sinks, to independently estimate changes in OHC over time after 1991.

These recent observation-based OHC estimates show highly consistent changes since the late 1950s (see the figure). The warming is larger over the 1971-2010 period than reported in AR5. The OHC trend for the upper 2000 m in AR5 ranged from 0.20 to 0.32 W m⁻² during this period (4). The three more contemporary estimates that cover the same time period suggest a warming rate of 0.36 ± 0.05 (6), 0.37 ± 0.04 (10), and 0.39 ± 0.09 (2) W m⁻². [Note that the analysis in Domingues et al. (10) is combined with that in Levitus et al. (12) for 700 to 2000 m to produce a 0 to 2000 m time series.] All four recent studies (2, 6, 10, 11) show that the rate of ocean warming for the upper 2000 m has accelerated in the decades after 1991 to 0.55 to 0.68 W m⁻² (calculations provided in the supplementary materials).

Multiple lines of evidence from four independent groups thus now suggest a stronger observed OHC warming. Although climate model results (see the supplementary materials) have been criticized during debates about a “hiatus” or “slowdown” of global mean surface temperature, it is increasingly clear that the pause in surface warming was at least in part due to the redistribution of heat within the climate system from Earth surface into the ocean interiors (13). The recent OHC warming estimates (2, 6, 10, 11) are quite similar to the average of CMIP5 models, both for the late 1950s until present and during the 1971-2010 period highlighted in AR5 (see the figure). The ensemble average of the models has a linear ocean warming trend of 0.39 ± 0.07 W m⁻² for the upper 2000 m
Past and future ocean heat content changes

Annual observational OHC changes are consistent with each other and consistent with the ensemble means of the CMIP5 models for historical simulations pre-2005 and projections from 2005–2017, giving confidence in future projections to 2100 (RCP2.6 and RCP8.5) (see the supplementary materials). The mean projected OHC changes and their 90% confidence intervals between 2081 and 2100 are shown in bars at the right. The inset depicts the detailed OHC changes after January 1990, using the monthly OHC changes updated to September 2018 [Cheng et al. (2)], along with the other annual observed values superposed.

Updated OHC estimates compared with ARS. The three most recent observation-based OHC analyses give ocean warming rates (depths from 0 to 2000 m) for 1971 to 2010 that are closer to model results than those reported in ARS. This increases confidence in the model projections (see the supplementary materials for more detail). The error bars are 90% confidence intervals.

2.6 scenario, the models project an ocean warming (0 to 2000 m) of 1037 zettajoules (ZJ) (~0.40 K) at the end of the 21st century (mean of 2081–2100 relative to 1991–2005); this pathway is close to the Paris Agreement goal of limiting global warming to well below 2°C. For the RCP8.5 scenario, a business-as-usual scenario with high greenhouse gas emissions, the models project a warming of 2020 ZJ (~0.78 K). This level of warming would have major impacts on ocean ecosystems and sea level rise through thermal expansion; 0.78 K warming at 2100 is roughly equal to a sea level rise of 30 cm. This is in addition to increased sea level rise caused by land ice melt.

The fairly steady rise in OHC shows that the planet is clearly warming. The prospects for much higher OHC, sea level, and sea-surface temperatures should be of concern given the abundant evidence of effects on storms, hurricanes, and the hydrological cycle, including extreme precipitation events (3, 15). There is a clear need to continue to improve the ocean observation and analysis system to provide better estimates of OHC, because it will enable more refined regional projections of the future. In addition, the need to slow or stop the rates of climate change and prepare for the expected impacts is increasingly evident.

REFERENCES AND NOTES


ACKNOWLEDGMENTS

This study is supported by the National Key R&D Program of China (2017YFA0603202). The National Center for Atmospheric Research (NCAR) is sponsored by the National Science Foundation. We thank the climate modeling groups (listed in table S1) for producing and making available their model output, and we acknowledge J. Fasullo for calculating OHC in CMIP5 models and making the data available to the authors. Institute of Atmospheric Physics data and the CMIP5 time series are available at http://www.sciencemag.org/content/363/6423/suppl/DC1. This study is supported by the National Key R&D Program of China (2017YFA0603202). The National Center for Atmospheric Research (NCAR) is sponsored by the National Science Foundation. We thank the climate modeling groups (listed in table S1) for producing and making available their model output, and we acknowledge J. Fasullo for calculating OHC in CMIP5 models and making the data available to the authors. Institute of Atmospheric Physics data and the CMIP5 time series are available at http://www.sciencemag.org/content/363/6423/suppl/DC1. This study is supported by the National Key R&D Program of China (2017YFA0603202). The National Center for Atmospheric Research (NCAR) is sponsored by the National Science Foundation. We thank the climate modeling groups (listed in table S1) for producing and making available their model output, and we acknowledge J. Fasullo for calculating OHC in CMIP5 models and making the data available to the authors. Institute of Atmospheric Physics data and the CMIP5 time series are available at http://www.sciencemag.org/content/363/6423/suppl/DC1.
How fast are the oceans warming?
Lijing Cheng, John Abraham, Zeke Hausfather and Kevin E. Trenberth

Science 363 (6423), 128-129.
DOI: 10.1126/science.aav7619

ARTICLE TOOLS
http://science.sciencemag.org/content/363/6423/128

SUPPLEMENTARY MATERIALS
http://science.sciencemag.org/content/suppl/2019/01/09/363.6423.128.DC1

REFERENCES
This article cites 14 articles, 1 of which you can access for free
http://science.sciencemag.org/content/363/6423/128#BIBL

PERMISSIONS
http://www.sciencemag.org/help/reprints-and-permissions

Use of this article is subject to the Terms of Service