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COMMENTARY

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This article is commentary on Weiss et al. (2022), https://doi.org/10.1029/2021PA004361

Toward New and Independent Constraints on Global Mean Sea-Level Highstands During the Last Glaciation (Marine Isotope Stage 3, 5a, and 5c)

Tamara Pico[1]

[1]Earth & Planetary Sciences, UC Santa Cruz, Santa Cruz, CA, USA

Key Points:

- Weiss et al. use planktic oxygen isotopes (δ^{18}O) infer flooding and exposure of the Karimata Strait (Indonesia) over the last glacial cycle
- New sea-level constraints are contextualized within ongoing debates about global ice volumes during the last glaciation phase
- Past ocean circulation offers new insight into glacial-interglacial sea-level change

Correspondence to:

T. Pico,
tpico@ucsc.edu

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Abstract

Estimates of ice volume over the last 120 ka, from marine isotope Stage (MIS) 5d (~110 ka) through MIS 3 (60–26 ka) are uncertain. Weiss et al. (2022, https://doi.org/10.1029/2021PA004361) offer an innovative new constraint on past sea level using the oxygen isotopes (δ^{18}O) of planktic (surface and thermocline dwelling) foraminifers to infer the salinity of the Sulu Sea in the Indo-Pacific Ocean and assess flow through the Karimata Strait (Indonesia) over the last glaciation. Based on the timing of Karimata Strait flooding, the study concludes that local relative sea level in the Karimata Strait was $>-8 \pm 6$ m during MIS 5c (~100 ka) and $>-12 \pm 6$ m during MIS 5a (~80 ka), relative to present. For MIS 3, a maximum possible relative sea level of -16 ± 6 m is determined. Here, these results are placed into the context of current knowledge of last glacial sea-level change and the implications for climate forcings and feedbacks (e.g., global average surface temperature and greenhouse gases) and ice sheet growth are discussed. By tracing past ocean circulation patterns that are modulated by the depth of shallow straits such as the Karimata Strait, Weiss et al. (2022, https://doi.org/10.1029/2021PA004361) provide independent constraints on local sea level, which are essential for improving global mean sea level reconstructions on late Pleistocene glacial-interglacial cycles.

Main Text

Despite the importance of quantifying how ice sheets will respond to ongoing and future climate change, little is known about variations in ice sheet size, or even global sea level, in response to large temperature changes across most of the last glacial cycle (120,000 years ago to today). Knowledge of how ice sheets respond to climatic warming is critical, as ice sheet behavior during past climate variations informs understanding of the nature and resilience of the Earth's climate system (Dutton et al., 2015). Ice volume variations through the last glacial cycle are a direct and sensitive measure of climate change. However, the magnitude and timescale of global sea-level fluctuations prior to the Last Glacial Maximum (LGM; 26,000 years ago; 26 ka (Clark et al., 2009)) are uncertain (Cutler et al., 2003; Lambeck & Chappell, 2001; Siddall et al., 2008). Determining global ice volume during ice expansion is challenging, as sea-level rise during the last deglaciation destroyed or submerged ancient coastlines and advancing ice sheets obscured prior ice extent (Dyke et al., 2002; Stokes et al., 2015). Yet, knowledge of global sea-level change across the glaciation phase is critical for understanding ice sheet behavior associated with changes in atmospheric and oceanic temperatures, greenhouse gases, and other climate forcings/feedbacks.

Past global ice volume variations have been estimated from the oxygen isotope (δ^{18}O) composition of benthic and planktic foraminifer tests preserved in marine sediments (K. M. Grant et al., 2014; Siddall et al., 2008) and geological markers of relative sea level, including erosional and constructional terraces, sedimentary facies, and fossilized corals (de Gelder et al., 2022; Dumitru et al., 2019; G. R. Grant et al., 2019; Hibbert et al., 2016; Lambeck & Chappell, 2001; Medina-Elizalde, 2013; Yokoyama et al., 2000). However, ice volume inferences from foraminiferal oxygen isotopes (δ^{18}O) are complicated by local variations in seawater δ^{18}O, ocean temperature, post depositional calcium carbonate diagenesis/dissolution, and uncertainties in the mean δ^{18}O of past ice sheets (Raymo et al., 2018; Siddall et al., 2008; Spratt & Lisiecki, 2016; Waelbroeck et al., 2002), which may introduce tens of meters of uncertainty to global mean sea level (GMSL) estimates. Moreover, geological sea level records are limited, difficult to date, and influenced by glacial isostatic adjustment (GIA), tectonics, and other processes of vertical displacement (Dutton et al., 2015; Lambeck et al., 2014; Rovere, 2016).

(Weiss et al., 2022) offer a new constraint on sea level over the last glacial cycle based on planktic (surface and thermocline) foraminifer δ^{18}O, which they use to reconstruct salinity in the Sulu Sea to track the flow of South China Sea waters through the Karimata Strait. These data indicate times of surface water flow through

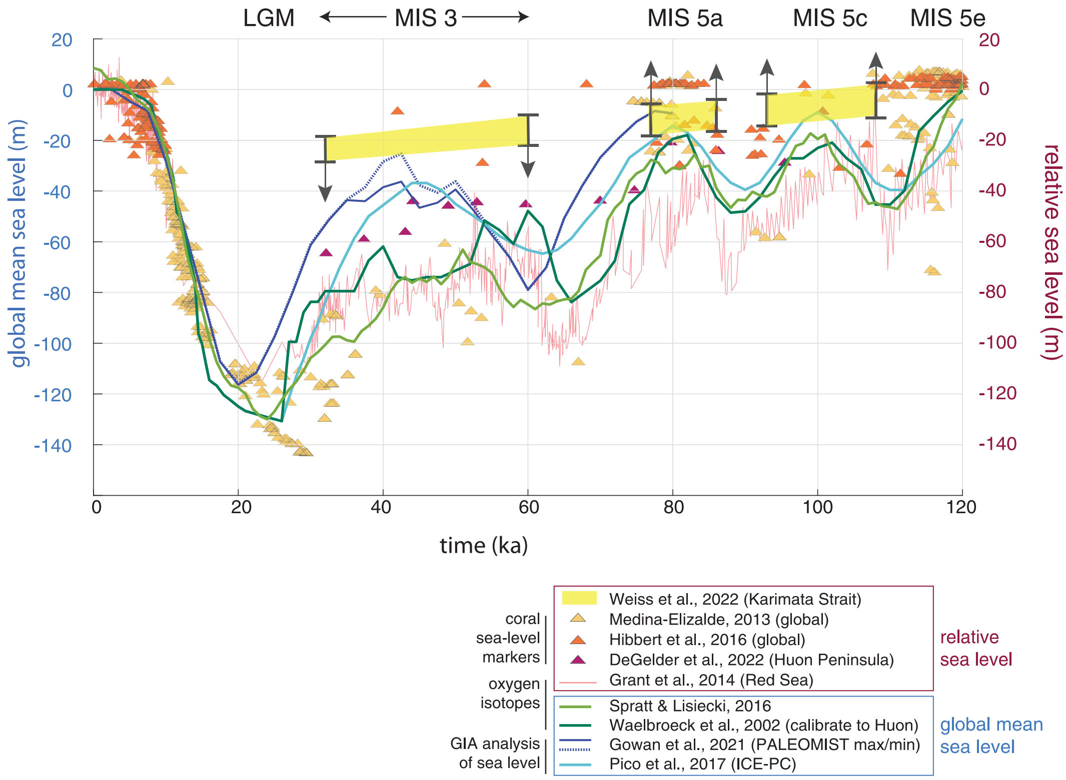

Figure 1. | Global mean sea level estimates (lines) compared with relative sea level observations (triangles) based on corals, foraminifer oxygen isotopes, and glacial isostatic adjustment (GIA) analyses. Yellow bars indicate relative sea levels in the Karimata Strait inferred by Weiss et al. (2022). Black arrows represent maximum and minimum sea level estimates. Only passive margin sites are included from the Hibbert et al. (2016) database.

the Karimata Strait, which enables Weiss et al. (2022) to establish the timing of shallow (present day sill depth = 36 m) Karimata Strait flooding over the last ice age. These data provide a new constraint on regional relative sea level (yellow bars and black arrows; Figure 1).

Estimates of global ice volume and the associated GMSL changes during the first half of the last glaciation (e.g., marine isotope stage (MIS) 5d (~110 ka) through MIS 3 (60–26 ka)) are not yet well constrained. For example, estimates of GMSL during MIS 3 (e.g., between 45 and 35 ka) range from −80 to −20 m, a difference of ~60 m (Figure 1). By the LGM lowstand, GMSL estimates range between −115 and −130 m (Austermann et al., 2013; Yokoyama et al., 2000), indicating that global ice volume may have increased rapidly in the 15 kyrs before the LGM. Understanding the nature of ice growth and associated GMSL fall between late MIS 3 and the LGM is essential for understanding the forcings and feedbacks involved in glacial-interglacial climate change. Traditionally, the sawtooth pattern of late Pleistocene glacial-interglacial cycles, as revealed by deep-sea foraminifer δ^{18}O, indicate rapid deglaciations followed by relatively slow glaciations and, by extension, slow steady global sea-level fall (Cheng et al., 2009; Emiliani, 1955). The rapid global sea-level fall between late MIS 3 and the LGM challenges this paradigm.

Weiss et al. (2022) provide new insight into relative sea levels during MIS 3 (60–26 ka), MIS 5a (~80 ka), and MIS 5c (~100 ka). New data indicate that the Karimata Strait was flooded during MIS 5a and MIS 5c, but subaerial during MIS 3. The authors constrain minimum local sea level to >−8 ± 6 m during MIS 5c and >−12 ± 6 m during MIS 5a. During MIS 3, the authors argue for a maximum local sea level of −16 ± 6 m. Uncertainties are based on regional tectonic subsidence estimates that suggest subsidence rates on the order of 0.2–0.3 m/ky (Sarr et al., 2019) and glacial isostatic adjustments from nearby sites in Papua New Guinea (Creveling et al., 2017).

Local Karimata Strait sea level estimates during MIS 3, MIS 5a, and MIS 5c relative sea level highstands are consistent with previous estimates that, in combination with GIA modeling, indicate that GMSL reached −8.5 ± 4.6 m during MIS 5a, and −9.4 ± 5.3 during MIS 5c (Creveling et al., 2017). Further, Weiss et al.'s (2022) novel flooding/exposure record constrains the timing of transitions between MIS 5a and 5c highstands and MIS 5b and 5d lowstands. During MIS 3, Weiss et al. (2022) present a maximum local sea level estimate that is consistent with MIS 3 GMSL estimates higher than −40 m (Figure 1; Pico et al., 2016; Gowan et al., 2021).

While the authors are unable to resolve the spread in the estimates of MIS 3 sea level, Weiss et al. (2022) highlight discrepancies between geologic- and oxygen isotope-based estimates of GMSL. The highest GMSL estimates, based on correcting relative sea level records for GIA (Gowan et al., 2021), are ~40 m higher than those estimated from benthic δ^{18}O records (Waelbroeck et al., 2002). The reason for this disagreement is not fully understood and a variety of factors may influence absolute values. Scaling benthic foraminifer δ^{18}O records to global ice volumes requires estimates of local temperature and salinity, as well as knowledge of global continental ice sheet distribution and δ^{18}O composition (Waelbroeck et al., 2002). Benthic δ^{18}O stacks may blend local signals deep-ocean temperature and salinity (Spratt & Lisiecki, 2016) and are often scaled to global ice volumes based on continental ice sheet extent at the LGM (Mix, 1992). Further, the duration of sea-level highstands may influence their presence in benthic foraminifer δ^{18}O records. For example, millennial-scale GMSL highstands may not be recorded in benthic foraminifer δ^{18}O stacks because they occur on timescales shorter than those of ocean mixing (Skinner & Shackleton, 2005). Furthermore, challenging chronologies are often associated with MIS 3 relative sea level markers as this time interval lies at the edge of reliable radiocarbon dating and luminescence-based ages are complicated to interpret (Dalton et al., 2019; Miller & Andrews, 2019).

Ultimately, MIS 3 GMSL uncertainty challenges the paradigm of a sawtooth interglacial to glacial cycle. During MIS 3, global temperatures were likely similar to those at the LGM (Snyder, 2016), yet global ice volumes may have been smaller, suggesting non-linear forcings between global temperatures, radiative forcing, and ice growth. If the GMSL was closer to −40 m (Batchelor et al., 2019; Dalton et al., 2022; Pico et al., 2017, 2018), then continental ice sheets may have grown rapidly in the 15 kyr before the LGM, suggesting that we must reassess our understanding of climate feedbacks between temperature, greenhouse gases, and ice volume.

Weiss et al. (2022) track the relative flow of South China Sea waters into the Sulu Sea via the Karimata Strait, which is a unique approach to reconstructing past sea level that establishes the timing of transitions between highstands and lowstands over the last glacial cycle. Their study suggests that tracing past ocean circulation patterns modulated by the depth of shallow straits can offer an independent constraint on local sea level, which can then be used to estimate GMSL over glacial-interglacial cycles.

Data Availability Statement

No new data is used in this manuscript. Datasets included here publicly available (de Gelder et al., 2022; Gowan et al., 2021; Hibbert et al., 2016; K. M. Grant et al., 2014; Medina-Elizalde, 2013; Pico et al., 2017; Spratt & Lisiecki, 2016; Waelbroeck et al., 2002; Weiss et al., 2022).

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