A Probabilistic Assessment of the WAIS and Greenland Contributions to Sea Level during the Last Interglacial

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The Last Interglacial (LIG) stage, also known as the Eemian, is a partial analog for the near-future Earth under low-end global warming scenarios. Ice core data indicate that, during the LIG, Arctic and Antarctic temperatures were 3-5ºC warmer than today, comparable to the Arctic warming expected to accompany 1-2ºC of global warming. While the global mean temperature anomaly is uncertain, sea-surface temperatures in the equatorial Pacific and Atlantic were about 2ºC warmer than pre-Industrial levels. These warmer temperatures may have been the product of changes in orbital forcing.

Numerous data suggest that LIG sea level was a few meters higher than at present; based on a small set of data, the Intergovernmental Panel on Climate Change 2007 assessment report estimated 4 to 6 m above modern sea level. Greenland ice core evidence has been interpreted by some as suggesting that the extent of the Greenland Ice Sheet was significantly reduced, a possible cause of higher sea levels, but this evidence remains contested. Identifying the sources, if any, of meltwater contributing to elevated sea level can help constrain the hazard posed by future ice sheet melt.

The patterns of local sea level rise produced by ice sheet melt depend upon the meltwater source. Melting ice sheets cause changes in the position of the sea surface (the geoid), the deformation of the lithosphere, the orientation of Earth's spin axis, and the position of shorelines, as well as triggering a long-term isostatic response from the mantle. The resulting geographical patterns raise the prospect of fingerprinting meltwater sources, though also complicate the task of reconstructing global sea level from local indicators. In order to place better constraints on global sea level and make a first attempt at identifying Last Integlacial meltwater sources, we have constructed a database of LIG sea level indicators from 42 geographically-widespread localities and developed a novel statistical approach for their analysis. Our approach couples Gaussian process regression of spatio-temporal variability in sea level and ice sheet volume with Markov Chain Monte Carlo simulation of geochronological uncertainty.

Our results indicate a 95% probability that global sea level peaked during the Last Interglacial above 6.6 m, a 67% probability that it exceeded 8.0 m, and only a 33% probability that it exceeded 9.4 m. Because the current methodology requires us to approximate the bounded probability distribution for ice sheet volumes with Gaussian distributions, inferences about ice sheet volumes must be viewed cautiously. We can, however, say with 95% confidence that both Northern Hemisphere and Southern Hemisphere ice volumes reached levels 2.5 m equivalent sea level smaller than today, though not necessarily at the same time. Within the uncertainties of our projections, we can make no significant statement about which ice sheet shrunk to a greater extent.

The current version of our statistical model employs a prior distribution for individual ice sheet volumes that, like the prior distribution for sea level, is a function of time. The next version of the model will instead employ a prior distribution for ice sheet volumes that is a function of global sea level. As a consequence, it should be better able to account for bounds on ice sheet volumes (e.g., that it is impossible for the Greenland Ice Sheet to be less than about 7 m equivalent sea level smaller than today) and thus improve our ability to attribute meltwater sources.