On the Hemispheric Origins of MWP1b

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Abstract

Antarctica has been proposed as the dominant source of the meltwater that entered the oceans during Meltwater Pulse 1b (MWP1b) that occurred approximately 11,500 years ago. The deglaciation of heavily glaciated fjords off the coast of Antarctica at approximately this time has provided support for this hypothesis. Further support for this scenario was provided by the fact that the highly non-monotonic relative sea level histories recorded at sites on the coast of Scotland, which had been heavily glaciated at last glacial maximum, could be explained by the inter-hemispheric sea level teleconnection associated with a significant deglaciation of Antarctic ice sheets at this time. That the magnitude of grounded ice loss from Antarctica at MWP1b time was adequate to provide the necessary RSL rise along the coast of Scotland has not been demonstrated. Furthermore, there exist implicit suggestions to the effect that a significant contribution to MWP1b must have also been delivered to the oceans by the abrupt northern hemisphere warming that occurred at the end of the Younger Dryas (YD) cold reversal, which also occurred approximately 11,500 years ago. This warming event occurred due to the rapid intensification of the Atlantic Meridional Overturning Circulation (AMOC) when it recovered after the YD. We present a fingerprinting analysis of the contribution of all major ice sheets to MWP1b using the ICE7G_NA (VM7) model of ice loading history and find that the best agreement between calculated sea level curves and observations is obtained with a minimal Antarctic contribution.

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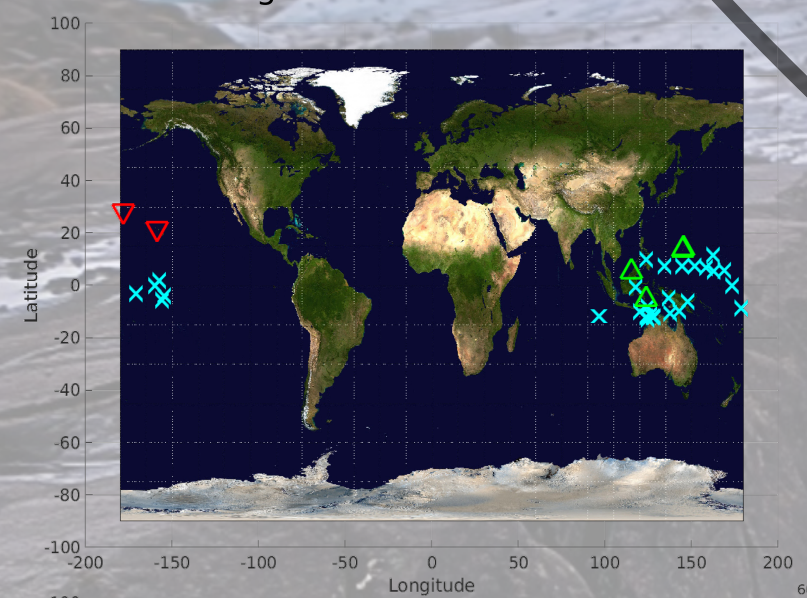
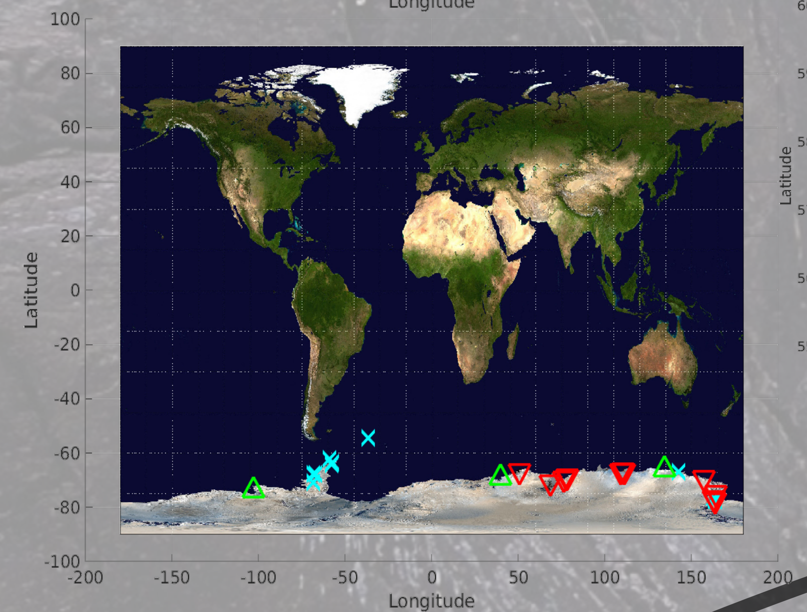
Introduction

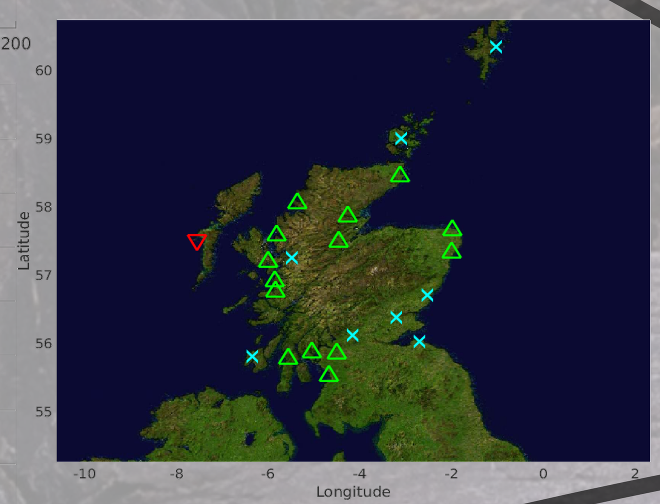
Antarctica has been proposed as the dominant source of the meltwater that entered the oceans during Meltwater Pulse 1b (MWP1b) that occurred approximately 11,500 years ago[1]. The deglaciation of heavily glaciated fjords off the coast of Antarctica at approximately this time has provided support for this hypothesis.[2] Further support for this scenario was provided by the fact that the highly non-monotonic relative sea level histories recorded at sites on the coast of Scotland, which had been heavily glaciated at last glacial maximum, could be explained by the inter-hemispheric sea level teleconnection associated with a significant deglaciation of Antarctic ice sheets at this time. That the magnitude of grounded ice loss from Antarctica at MWP1b time was adequate to provide the necessary RSL rise along the coast of Scotland has not been demonstrated. Furthermore, there exist implicit suggestions that a significant contribution to MWP1b can be sourced to the Laurentide ice sheet,[3] delivered to the global oceans by the abrupt northern hemisphere warming that occurred at the end of the Younger Dryas (YD) cold reversal[4], which also occurred approximately 11,500 years ago. This warming event occurred due to the rapid intensification of the Atlantic Meridional Overturning Circulation (AMOC) when it recovered after the YD. We present a fingerprinting analysis of the contribution of all major ice sheets to MWP1b using the ICE7G_NA (VM7) model of ice loading history and find that the best agreement between calculated sea level curves and observations is obtained with a minimal Antarctic contribution. Additionally, by altering the ice loading history, we hope to recover the mid-Holocene Pacific highstand.[5]

Locations

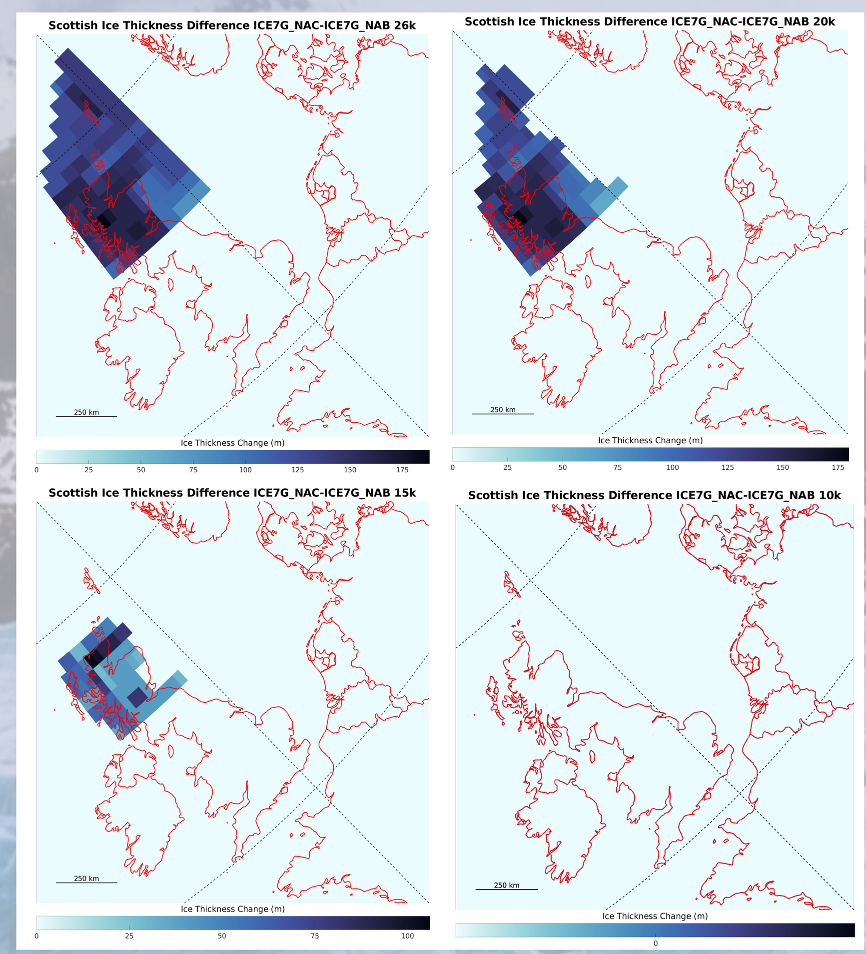
The effect of alterations to the ice-loading history on calculated relative sea levels were compared against observations in three geographical areas: the equatorial Pacific, the Antarctic coast, and Scotland. In these figures, a blue x indicates that there was little change, a green arrow indicates and improvement, and a red arrow indicates a degradation.

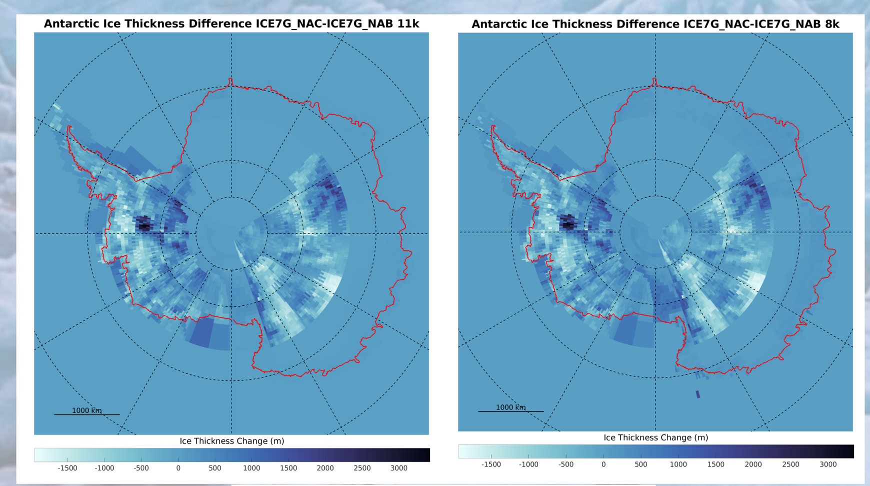


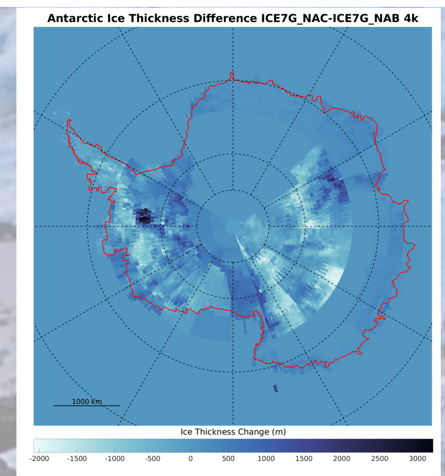


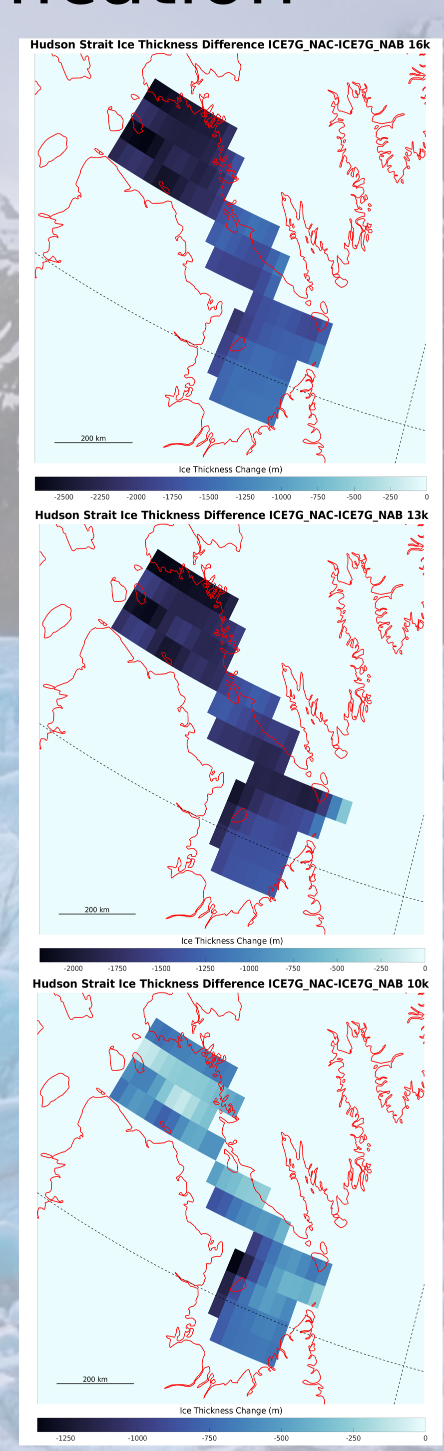


Loading History Modification



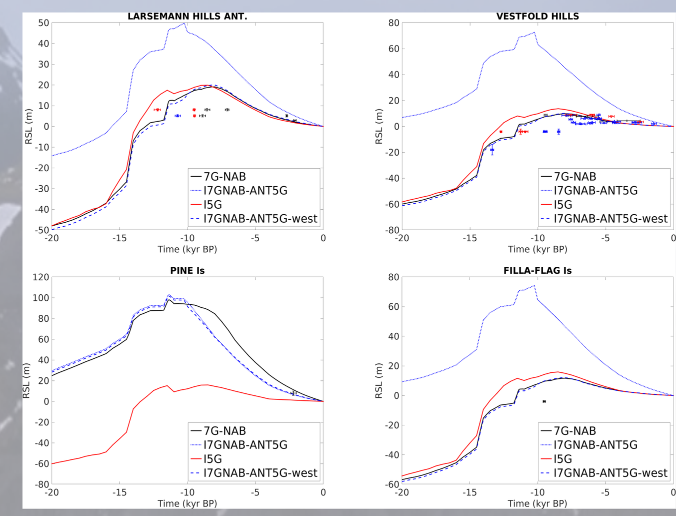


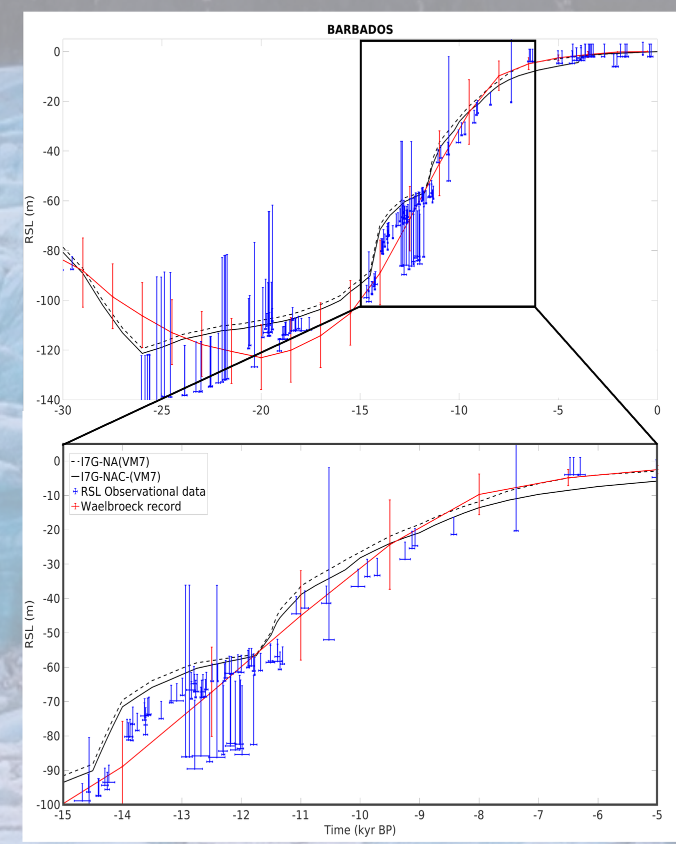


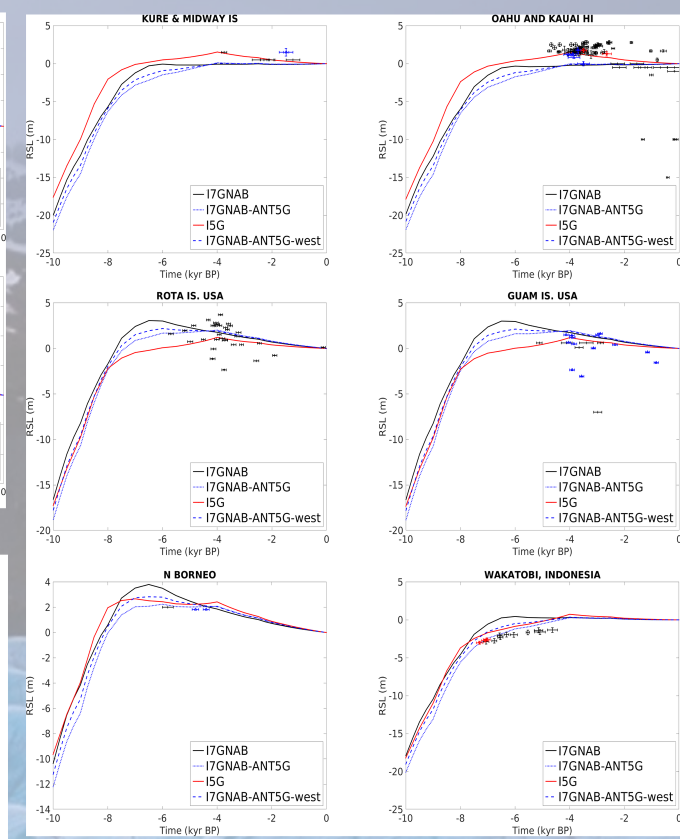


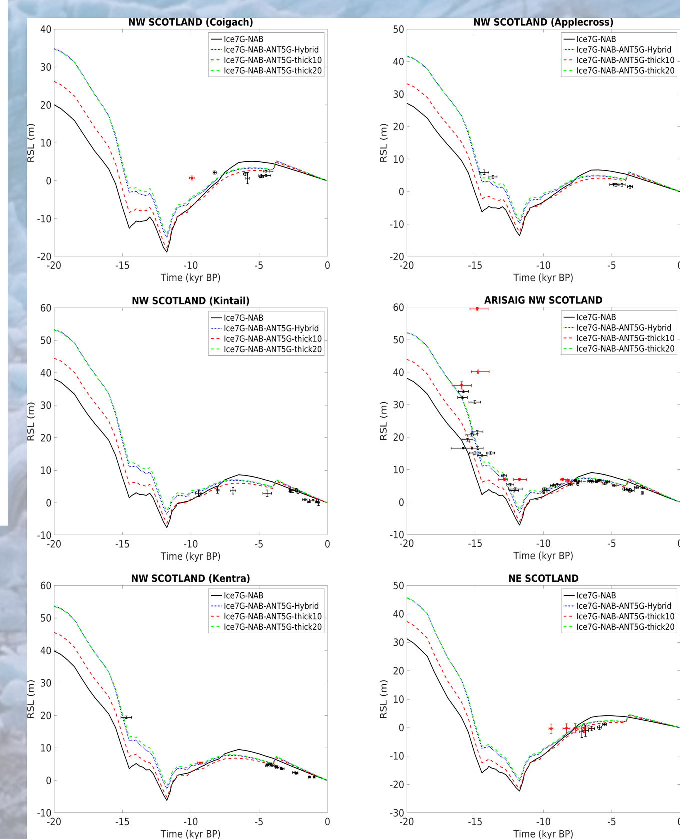
Above are three snapshot timeseries of the ice thickness differences between ICE-7G_NAC and ICE-7G_NAB. In Scotland, ice thickness was simply increased by 20% between LGM and modern day. The rightmost series depict the Hudson Strait, in which a simple version of H1 was implemented, with ice being permanently removed by 16ka. Bottom left the changes ot Antarctica are depicted. The Western Antarctic ice sheet and the Interior of the Eastern Antarctic ice sheet were reverted to their values from ICE-5G and then paused in evolution between 10k and 4k. Additionally, the contribution from Antarctica during MWP1b was halved.

Sea Level Curves









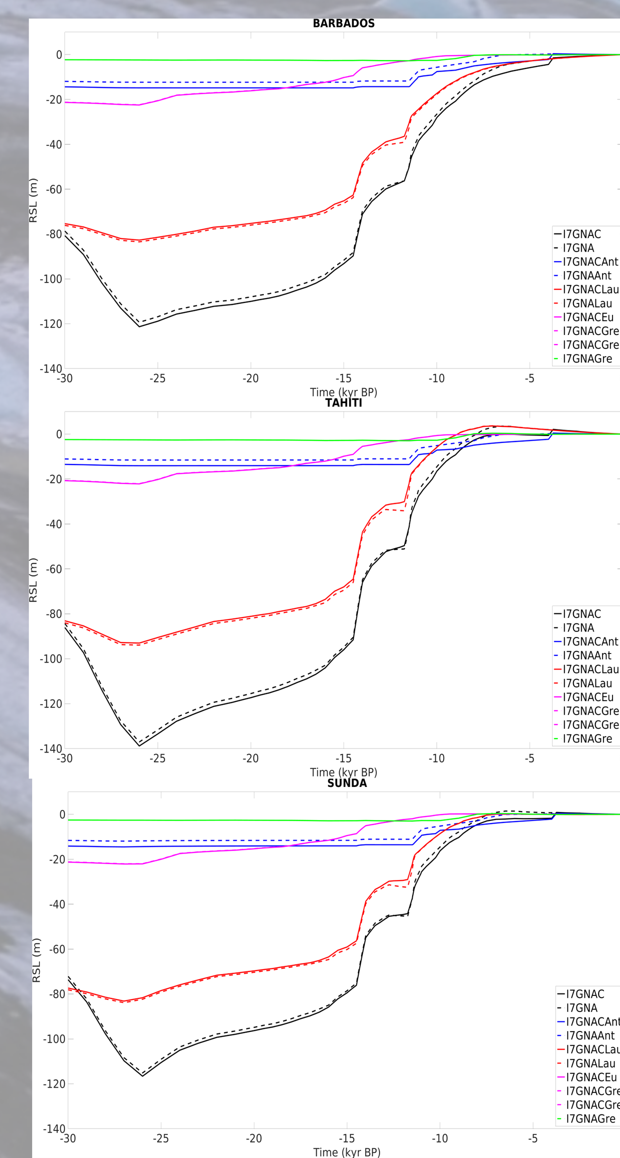
Sea level curves for various intermediate ice loading histories are presented in four regions and compared to observational data. "West" indicates that the East Antarctic coast was left as it is in ICE-7G_NAB. For the scottish sea level curves, "Thick%" indicates that the Scottish ice sheet was thickened between LGM and deglaciation by that percentage. At top left, the sea level curves are presented for the Antarctic coast. At top right, those for the Equatorial Pacific are presented, and below that, select locations from Northern Scotland are shown. Finally, at bottom left, the sea level curves at Barbados are presented.

Results

After applying the series of changes to the ice loading history described previously, individual sea level curves were computed at a number of locations, described in the Location Section. A comparison was made ebtween different intermeidate versions of the modified ice loading history and earlier versions, such as ICE-5G. In the eastern Pacific locations, our modifications have pertially recaptured the mid Holocene Pacific highstand, though there is a notable misfit at the most northern sites of Hawaii and Midway. The alterations did not produce unreasonable misfits in Antarctica, but this was only attained by leaving the coast of Eastern Antarctica unchanged. The Scottish sea level curves are much improved by the combination of changes to the Antarctic loading history and the local thickening of the Scottish ice sheet. At all North western locations, the degree of non-monotonicity is reduced and the over estimate of relative sea level height in the Holocene is substantially improved. The alterations also improve the agreement between model and observation at the key site of Barbados. There is a slight degradation of fit in the later section of the RSL history, but a large increase between MWP1a and MWP1b. The final analysis that was conducted was a fingerprinting of the contributions to MWP1b from all major trerrestrial ice sheets. It was found that a model in which the Laurentide is the dominant source of meltwater accurately fits the observations, and that no large contribution from Antarctica is required. This analysis was conducted at three key sites: Barbados The Sunda Shelf and Tahiti. The modifications ajdusted the total sea level rise at each site down by 2-3 meters, which more accurately fits the observations.

Finger Printing

In this analysis, each of the major terrestrial ice sheets was isolated, for both ICE7G and ICE7GNAC. The contribution of each ice sheet to eustatic RSL from 30 ka to modern is plotted at three separate locations, Barbados, Tahiti and the Sunda Shelf. The table gives the numerical values of the plots between 11 ka and 11.75 ka.



Sea Level Relative to Modern (m)

	Barbados		Tahiti		Sunda Shelf	
Ice Loading History	I7GNAC	I7G	I7GNAC	I7G	I7GNAC	I7G
Base model	17.6499	19.9209	21.8601	25.9137	18.6365	22.2978
Laurentide	11.9804	13.8965	16.0815	19.7842	13.747	17.0393
Antarctica	4.3639	4.7356	4.3579	4.7309	4.2127	4.5925
Europe	1.0084	1.0061	0.9843	0.9819	0.9737	0.9717
Greenland	0.1491	0.1489	0.2059	0.2047	0.1969	0.1957
Total	**17.5018**	**19.7871**	**21.6296**	**25.7017**	**19.1303**	**22.7992**

Conclusions

By adjusting down the Antarctic contribution to MWP1b and shifting the sea level rise associated to later in the Holocene, a higher degree of agreement between calculated and observed RSL was achieved. In particular, the replacement of the west Antarctic iceloading history from ICE7G_NA with that from ICE5G along with a thickening of the Scottish ice sheet by 15% recaptured the desired mid-Holocene Pacific highstand in all but the two most northern sites and improved the agreement between model and observation at Antarctic and Scottish sites. Furthermore, this altered ICE7G model accurately produces the required sea level without a significant Antarctic contribution, leading to the intriguing possibility that the Laurentide ice sheet was the dominant source of both MWP1a and MWP1b. As the Laurentide ice sheet is already implicated in Heinrich events and the Younger Dryas, the most recent transition from glacial to interglacial climate may have been primarily mediated by the Laurentide ice sheet.

Future Work

A number of additional alterations are required to further improve the agreement between the predicted RSL from the ICE7G model and those observed in various locations. A few exmaples of these are introducing Heinrich events into the ice loading history and fine tuning the ice loading history of the Laurentide ice sheet. The failure of a reasonable ice loading hostory to recapture the well documented mid holocene Pacific highstand at Midway and Oahu raises the possibility that a spherically symmetric viscosity model for the Earth's interior is insufficient to fully describe the observations. As these two sites are both volcanic, a future viscosity model could include a correction term for these locations. Additional future work will involve compiling all of these alterations into the next iteration of the ICEG model series.

Citations

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Acknowledgements

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