Appendix: Global Holocene Climatic Optimum Temperatures

The issue of Holocene temperatures has become controversial. While the Holocene Hypsithermal or Climatic Optimum (HCO, ~ 9800-5700 BP) is well characterized in the Northern Hemisphere as 1-5°C warmer than the bottom of the LIA depending on latitude, much less information exists regarding the tropical and Southern areas. Marcott et al. (2013), take the view that the HCO was 0.7°C warmer than the bottom of the LIA, and such low temperature variability for the Holocene rests on tropical warming of 0.4°C from the HCO, and Southern area cooling of just 0.4°C.

At the core of the issue rests the question if current temperatures are outside registered bounds for Holocene temperatures. The cryosphere clearly indicates that glaciers all over the world were significantly more reduced during the HCO than at present (Koch et al., 2014), and the biology generally agrees as the extension of species such as the water chestnut and the pond turtle were then north of their present European climatic limits, and the treeline has not reached its HCO maximum latitude or altitude in Sweden (Kullman, 2001), Canada (Pisaric et al., 2003), Russia (MacDonald et al., 2000), the Alps (Tinner et al., 1996), or Colombia (Thouret et al., 1996).

The non-tropical Southern Hemisphere cooling is well documented in the many glaciers from the Southern Andes and New Zealand reviewed by Porter (2000), that demonstrates that Southern Hemisphere glaciers were smaller during the HCO, and that the early Neoglacial advance culminated between 5400-4900 BP. In Southern Africa Holmgren et al. (2003) have shown persistent Holocene cooling since 10,000 yr BP. In Antarctica Masson et al. (2000), identify an early Holocene optimum at 11,500-9,000 BP followed by a secondary optimum at 7,000-5,000 BP. Shevenell et al. (2011), show that the Southern Ocean has cooled by 2-4°C at several locations in the past 10-12 kyr. If anything, the cooling of just 0.4°C proposed by Marcott et al. (2013) for the Southern 30-60°S region appears an underestimation or perhaps a minimum value. At Southern latitudes, the HCO cannot be explained by summer insolation changes, and large-scale reorganization of latitudinal heat transport has instead been invoked. A higher obliquity could also be partially responsible.

However it is in the tropical areas where Marcott et al. (2013) becomes more controversial. The fossil coral Sr/Ca record at the Great Barrier Reef, Australia, shows that the mean SST ~ 5350 BP was 1.2°C warmer than the mean SST for the early 1990s (Gagan et al., 1998). At the Indo Pacific Warm Pool, the warmest ocean region in the world, Stott et al. (2004) find that SST has decreased by ~ 0.5°C in the last 10,000 years, a finding confirmed by Rosenthal et al. (2013), that demonstrate a decrease of 1.5-2°C for intermediate waters. East African lakes show temperatures peaking towards the end of the HCO, followed by a general decrease of 2-3°C towards the LIA (Berke et al., 2012). Tropical glaciers at Peru (Huascarán) and Tanzania (Kilimanjaro) display their highest $d\ ^{18}O$ values (warmest) at the HCO, followed by a general decline afterwards (Thompson et al., 2006). The position that the tropics have experimented a warming since the HCO appears to be based in great part on marine alkenone proxies, however many alkenone records are from upwelling areas that present high sedimentation rates, but often display inverted temperature trends, and even worse, they generally do not agree with Mg/Ca proxies. Leduc et al. (2010) attempt to resolve the discrepancy between these two paleothermometry methods and note that none of the seven Mg/Ca records available for the East Equatorial Pacific have exhibited monotonous warming during the Holocene. They attribute the discrepancy to the alkenone method not being representative of a mean-annual temperature signal, but capturing only the winter season and thus responding mainly to changes in insolation during that season. This explanation brings the divergent alkenone records in agreement with the rest of the marine and land tropical records that display a tropical cooling since the HCO. If we estimate this cooling in the 0.5-1°C range it is clear that Marcott et al. (2013) are underestimating global Holocene cooling and therefore HCO global temperatures.

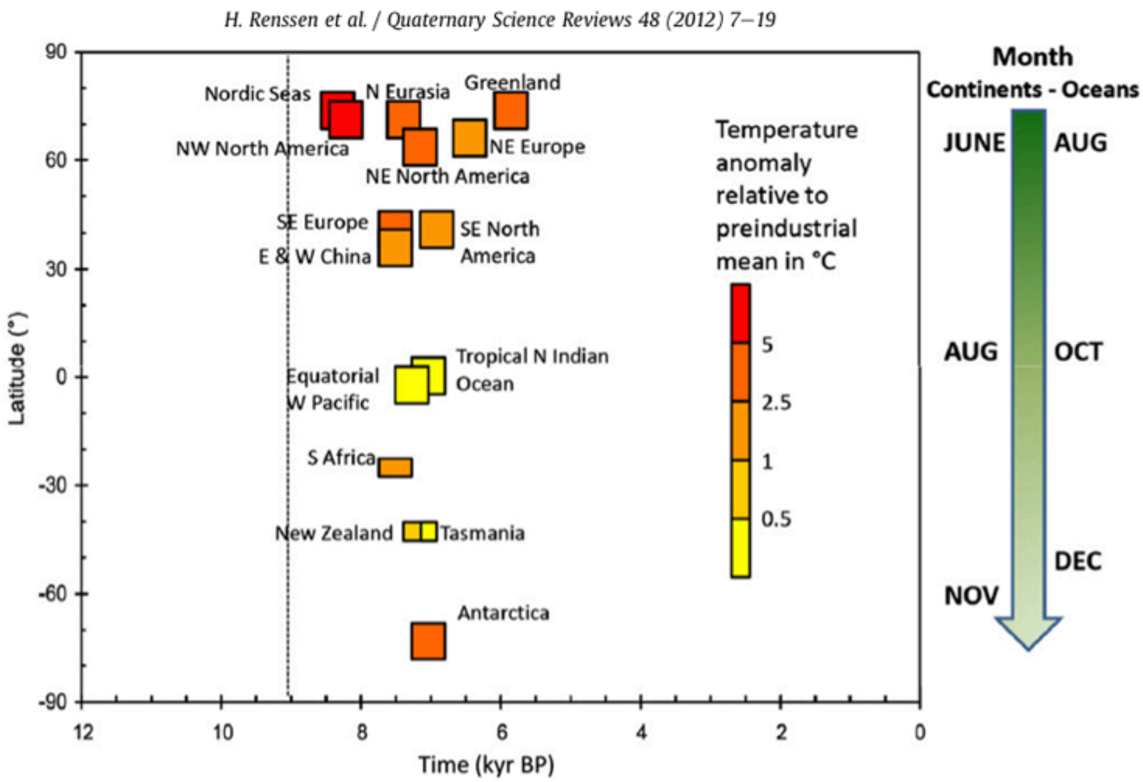

Figure A1. Summary of main characteristics (Holocene timing, intensity and seasonal timing) of the simulated maximum positive temperature deviation from pre-industrial levels, shown as a function of latitude (vertical axis) and time (horizontal axis). The Holocene timing for the different regions is given with a 500-year range (as indicated by the width of the boxes). The green arrow at the right summarizes the seasonal timing of the maximum temperature deviation for the different latitudes. Source: Renssen et al., 2012.

My estimate of ~ 1.2°C global temperature decrease between average HCO temperatures and the bottom of the LIA is therefore consistent with global proxies, glaciological changes, biological evidence, and with model reconstructions (Renssen et al., 2012; figure A1), that also disagree with Marcott et al., 2013 by showing warming in the tropical areas during HCO with respect to pre-industrial temperatures.

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