Holocene Temperatures and Sea Level Changes

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Introduction

At the end of the last Ice Age, global temperatures increased significantly and ushered in an interglacial period known as the Holocene. According to Pielou (1991), the interglacial is now more than half over, with temperatures having peaked about 10,000 years ago.

On the basis of a variety of "proxy" indicators (parameters which allow estimates of climate change), there is much evidence for the early Holocene peak. Below are some examples of evidence about climate based on proxy indicators (courtesy co2science.org):

1. Based on studies of latitudinal displacements of terrestrial vegetation (Bernabo and Webb, 1977; Wijmstra, 1978; Davis et al., 1980; Ritchie et al., 1983; Overpeck, 1985) and vertical displacements of alpine plants (Kearney and Luckman, 1983) and mountain glaciers (Hope et al., 1976; Porter and Orombelli, 1985), it has been concluded (Webb et al., 1987; COHMAP, 1988) that mean annual temperatures in the Midwestern United States were about 2 °C warmer 8,000 years ago than temperatures of the past few decades (Bartlein et al., 1984; Webb, 1985).

2. At about the same time, summer temperatures in Europe were 2 °C warmer than present (Huntley and Prentice, 1988), as was the case in New Guinea (Hope et al., 1976), and temperatures in the Alps were as much as 4 °C warmer (Porter and Orombelli, 1985; Huntley and Prentice, 1988).

3. In the Russian Far East, temperatures are also reported to have been from 2 °C (Velitchko and Klimanov, 1990) to as much as 4-6 °C (Korotky et al., 1988) higher than at present; while the mean annual temperature of the Kuroshio Current between 22 and 35 °N was 6 °C warmer (Taira, 1975), and the southern boundary of the Pacific boreal region was positioned 700 to 800 km north of its present location (Lutaenko, 1993).

4. A 10,000-year temperature history graphical representation of the mean global air temperature that results from the amalgamation of these several records, as prepared by the Intergovernmental Panel on Climate Change (Houghton et al., 1990), shown in Figure 1, indicates that temperatures during the Holocene maximum were warmer than those of the past few decades for a period of time on the order of several thousand years.

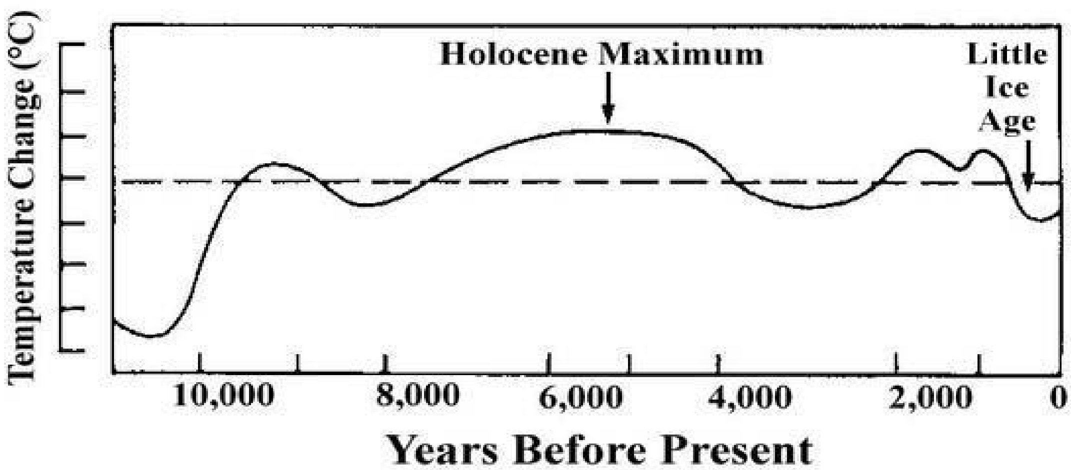

Figure 1. 10,000-year temperature history graphical representation of the mean global air temperature that results from the amalgamation of these several records, as prepared by the Intergovernmental Panel on Climate Change (Houghton et al., 1990)

In addition to exhibiting temperatures that were significantly warmer than those of today, the first half of the Holocene also produced several regions of significantly enhanced precipitation. The hyper-arid core of the Sahara, for example, was much more mesic at this time and contained many lakes (Fabre and Petit-Marie, 1988; Petit-Marie, 1991). The summer monsoon migrated northward by some 600 kilometers (Ritchie and Haynes, 1987), helping to create the extensive groundwater deposits of that region (van Zinderen Bakker and Coetzee, 1980) and giving life to ecosystems that supported crocodiles, giraffes, elephants and gazelles (Crowley and North, 1991). Increased monsoon moisture was seen in Saudi Arabia, Mesopotamia, and the Rajastan Desert of India (Bryson and Swain, 1981), causing far-reaching effects on those areas.

This warmer period has customarily been referred to as the Holocene Climatic Optimum (MacCracken et al., 1990; Ciaia et al., 1992; Lutaenko, 1993; Lambin et al., 1996) because the warmer (and in many cases, wetter) conditions are thought to have been beneficial to society and ecosystems. Further, during this period the world experienced "the rise of human civilization, based on the development of agriculture (Whyte, 1995)."

Air Temperatures

Many researchers have studied Holocene climate patterns. Below are synopses of a few studies from different parts of the world.

ShuYun, et al (2007) conducted a study using a high-resolution pollen record of the past 13,000 years from Huguangyan Maar Lake in China. The results indicated that the vegetation and environment changes in southern China during the Holocene showed that:

1. “pollen percentage of trees and shrubs reached 56% during the early Holocene (11600–7800 cal yr BP [calendar years before present]), of which the pollen percentage of tropical trees reached a maximum at 9500-8000 cal ~~a~~ yr BP, reflecting a hot and wet environment;
2. “during the mid-Holocene (7800–4200 cal yr BP), the pollen percentage of montane coniferous trees and herbs increased, while the percentage of tropical-subtropical trees decreased, indicating lower temperature and humidity;
3. “in the late Holocene spanning from 4200 to 350 cal yr BP, the pollen percentage of herbs and montane conifer increased significantly, indicating a marked decrease of temperature and humidity.”

The pollen data revealed that “the time period 9500–8000 cal yr BP in southern China represents a climatic optimum for the Holocene characterized by hot and wet conditions.”

Viau, et al (2006) constructed “A mean continental July temperature reconstruction based on pollen records from across North America” which “quantifies temperature variations of several timescales for the past 14,000 cal yr BP.” They found that “temperatures increased nearly 4°C during the late glacial, reaching maximum values between 6000 and 3000 cal yr BP, after which mean July temperatures decreased.” During the Holocene, “climate in North America appears to have varied periodically every ∽1100 years rather than the ∽1500 year cycle found during the last glacial period. Coherence at frequencies between 900 and 1100 years between land, ice, and ocean records suggests a common forcing associated with widespread surface impacts during the Holocene.”

In the Arctic, according to Kaufman, et al (2004), “Paleoclimate inferences based on a wide variety of proxy indicators provide clear evidence for warmer-than-present conditions at 120 [proxy] sites. At the 16 terrestrial sites where quantitative estimates have been obtained, local HTM temperatures (primarily summer estimates) were on average 1.67 ± 0.8°C higher than present (approximate average of the 20th century), but the warming was time-transgressive across the western Arctic. As the precession-driven summer insolation anomaly peaked 12–10 ka (thousands of calendar years ago), warming was concentrated in northwest North America, while cool conditions lingered in the northeast. Alaska and northwest Canada experienced the HTM between ca 11 and 9 ka.” Figures 2 and 3 (Kaufman, et al, 2004) show examples of their results for Canada and Greenland-Iceland, respectively.

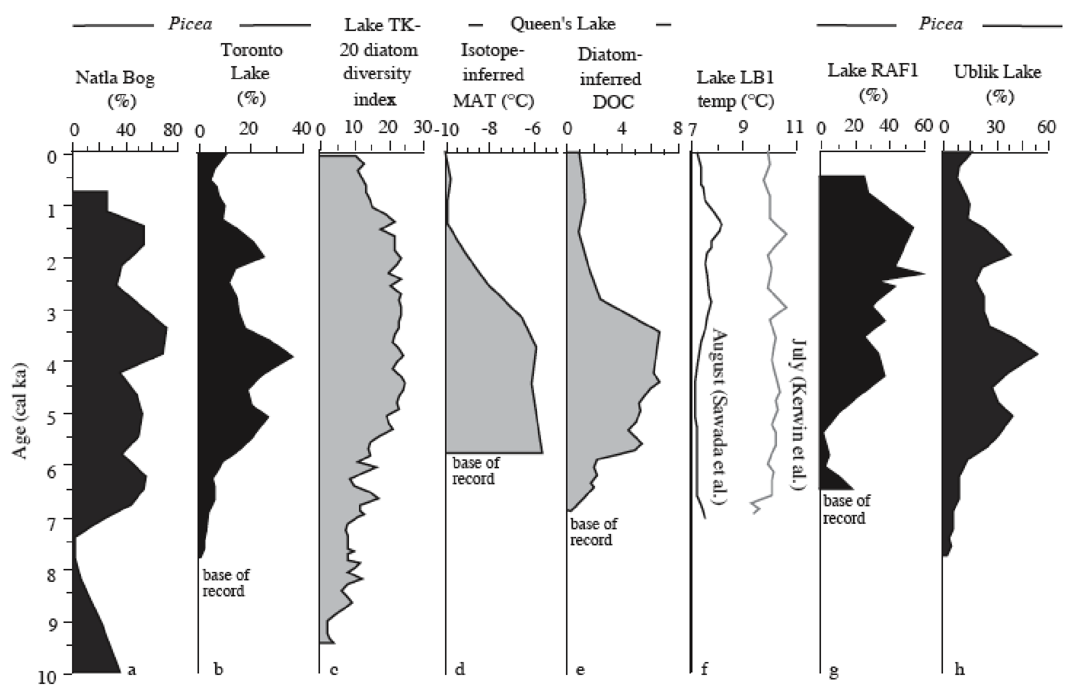

Fig. 2 (from Kaufman, et al, 2004). Selected records of the Holocene Thermal Maximum (HTM) from northern continental Canada. Palynological records of tree expansion in the treeline zone are presented in black to accentuate the regionally asynchronicity of expansion. (a) Picea pollen percentage, Natla Bog, Mackenzie Mountains, NWT; (b) Picea pollen percentage, Toronto Lake, NWT; (c) Diatom species diversity calculated using Hill’s N2 diversity index, Lake TK-20; (d) Isotope-inferred change in mean annual temperature (MAT), Queen’s Lake, NWT; (e) Diatom-inferred dissolved organic carbon (DOC), Queen’s Lake, NWT; (f) Pollen-inferred temperature, Lake LB1, Quebec, showing August and July temperature estimates; (g) Picea pollen percentage, Lake RAF1, northern Quebec; (h) Picea pollen percentage, Ublik Pond, northern Labrador.

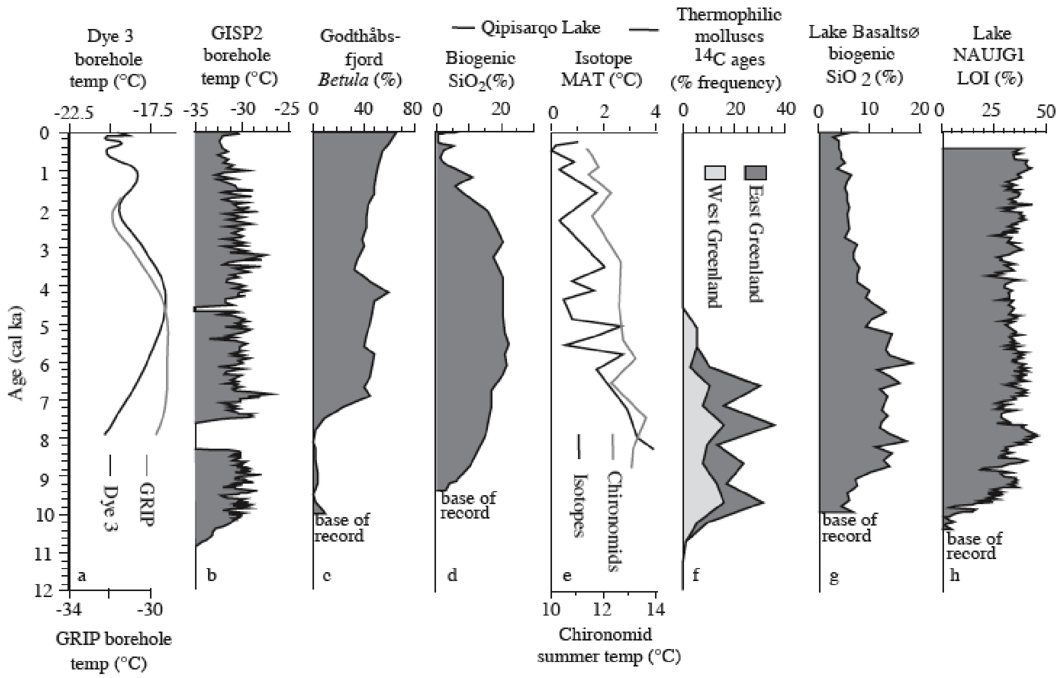

Fig. 3 (from Kaufman, et al, 2004). Selected records of the Holocene Thermal Maximum (HTM) from Greenland and Iceland. (a) Temperatures inferred from inverse-modeled borehole temperatures at Dye 3, southwest Greenland, and Summit (GRIP), central Greenland; (b) Isotope-inferred temperature calibrated using borehole temperature, GISP2, central Greenland; (c) Betula pollen percentage, Godth(absfjord); (d) Biogenic silica, Qipisarqo Lake, southwest Greenland; (e) Mean annual temperature (MAT) inferred from the oxygen-isotope composition of chironomids, and summer lake-water temperature inferred from chironomid assemblage transfer function, Qipisarqo Lake; (f) Occurrence of thermophilic mollusc shells based on frequency distribution of 14C ages (bin size=500 yr) for: (1) east Greenland (67.271.0 N latitude, 52.571.5 W longitude, n 1/4 77), and (2) west Greenland (72.171.5 N latitude, 24.371.3 W longitude, n 1/4 26); (g) Biogenic silica, Lake Basalts; (h) Loss-on-ignition (LOI), Lake.

Sea Surface Temperatures (SSTs)

SSTs have varied much less than have land temperatures due to the ocean's very large thermal inertia. Nonetheless, significant variations characterize SST history, generally mirroring air temperature changes.

According to Sachs (2007), "Climate of the last 11,000 years, the Holocene, is usually described as warm and stable. Benchmark temperature records from central Greenland ice cores show none of the large, abrupt variations that characterized the prior 100,000 years of glacial climate. Nor do they show any substantial trend, indicating at most 1 – 3°C of cooling. Here we show that the slope waters east of the United States and Canada cooled 4 – 10°C during the Holocene. Declining insolation, increasing convection in the Labrador Sea, and equatorward shifting of the Gulf Stream path may have caused the cooling."

SSTs for the last 12,000 years from three Atlantic sampling sites in the Atlantic are shown in Figure 4. The peak Holocene temperatures occurred 10-12,000 years ago.

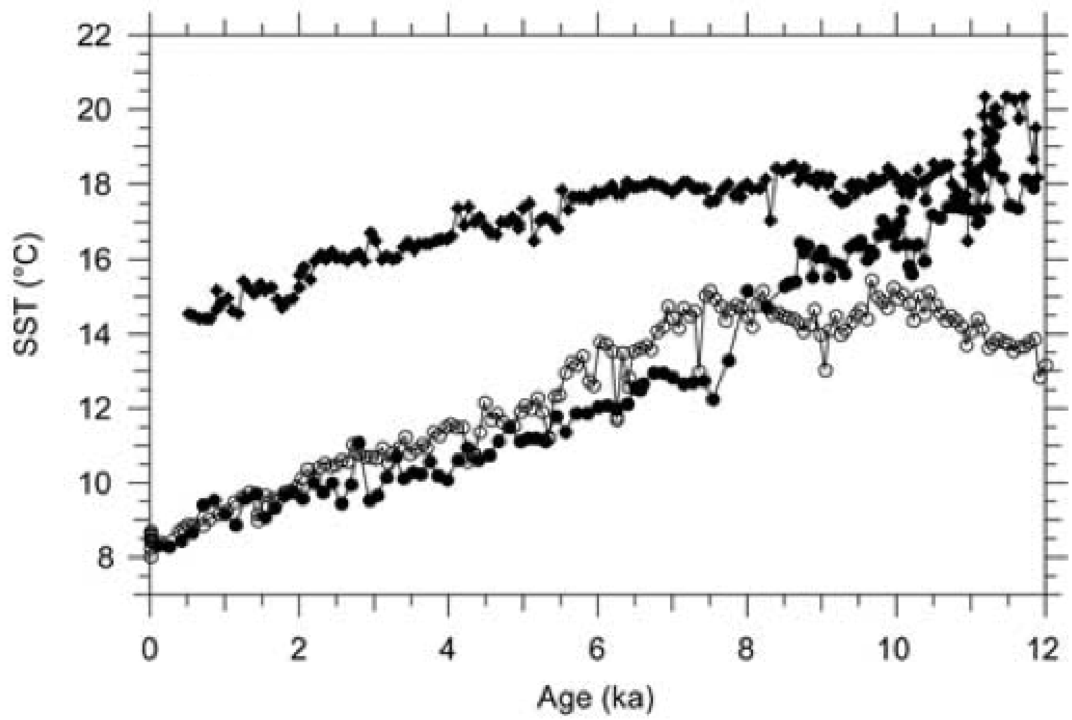

Figure 4. Alkenone sea surface temperatures (SSTs) on an age scale in the Virginia Slope (36°N, 74°W, 1049 m) (diamonds), Scotian Margin (43°N, 62°W, 250 m) (open circles) , and Laurentian Fan (43°N, 54°W, 3975 m) (solid circles), from Sachs (2007).

Tropical Pacific SSTs have also declined, according to Stott et al (2004), who say, "little is known about the variability of the coupled ocean–atmosphere system on timescales of centuries to millennia. Here we combine oxygen isotope and Mg/Ca data from foraminifers retrieved from three sediment cores in the western tropical Pacific Ocean to reconstruct Holocene sea surface temperatures and salinities in the region. We find a decrease in sea surface temperatures of 0.5°C over the past 10,000 yr." Figure 5, from that paper, illustrates this.

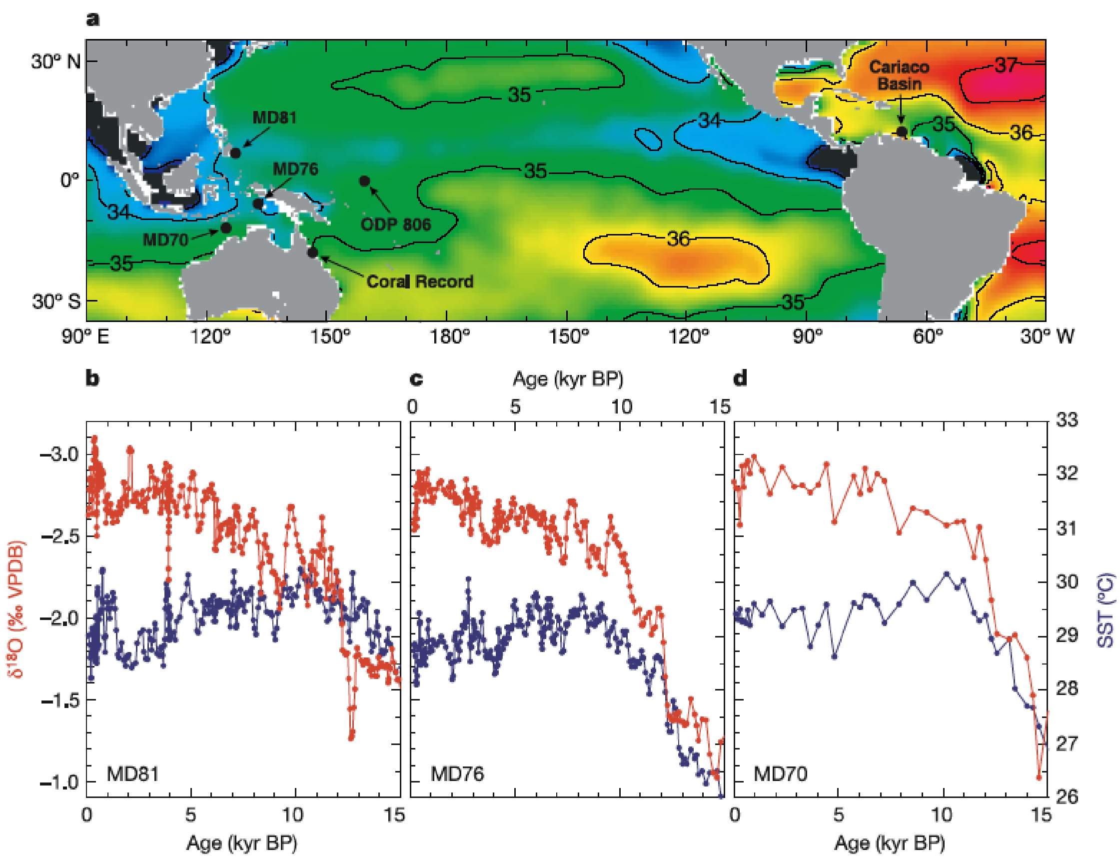

Figure 5, from Stott et al. (2004). Western tropical Pacific marine sediment core locations and corresponding climate records. a, Map of mean annual surface salinities in the tropical Pacific, illustrating the location of IMAGES MD core locations from which the oxygen isotope (red in b–d) and Mg/Ca–paleo SST records (blue in b–d) were generated for this study. b–d, Results from individual sites: b, MD81; c, MD76; d, MD70. The data from sites MD81 and MD76 have been smoothed with a 3-point running mean.

Sea Level

Unlike air and sea surface temperatures, which peaked thousands of years ago and have declined since, sea levels have shown steady increases since the last ice age, when they were more than 100 meters lower than today's.

Figure 6 shows long-term rise over the last 20,000 years, at a resolution of tens of meters. Evident is a relatively steady rise from 14,000 to 8,000 years ago, with the rate of rise leveling off in recent millennia.

Figure 7 shows the last 8,000 years, at a resolution of meters. At this scale, very little rise has occurred over the last 2,000 years.

In Figure 8, estimated sea level rise since 1880 is shown. A steady, near-linear rise is shown, averaging about 2 mm per year.

Figure 9, from Holgate (2007), shows sea level rise over the last century. According to Holgate, “The rate of sea level change was found to be larger in the early part of last century (2.03 ± 0.35 mm/yr 1904–1953), in comparison with the latter part (1.45 ± 0.34 mm/yr 1954–2003).”

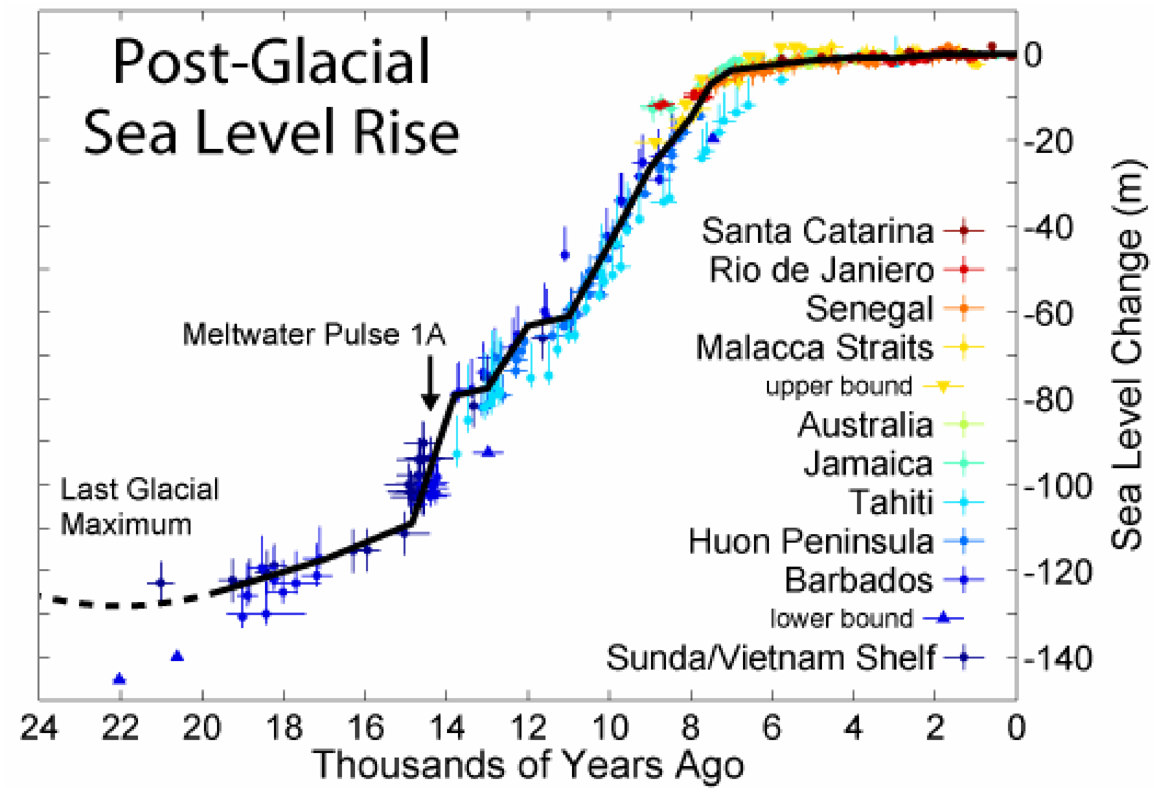

Figure 6. Sea level rise since the end of the last Ice Age (Global Warming Art)

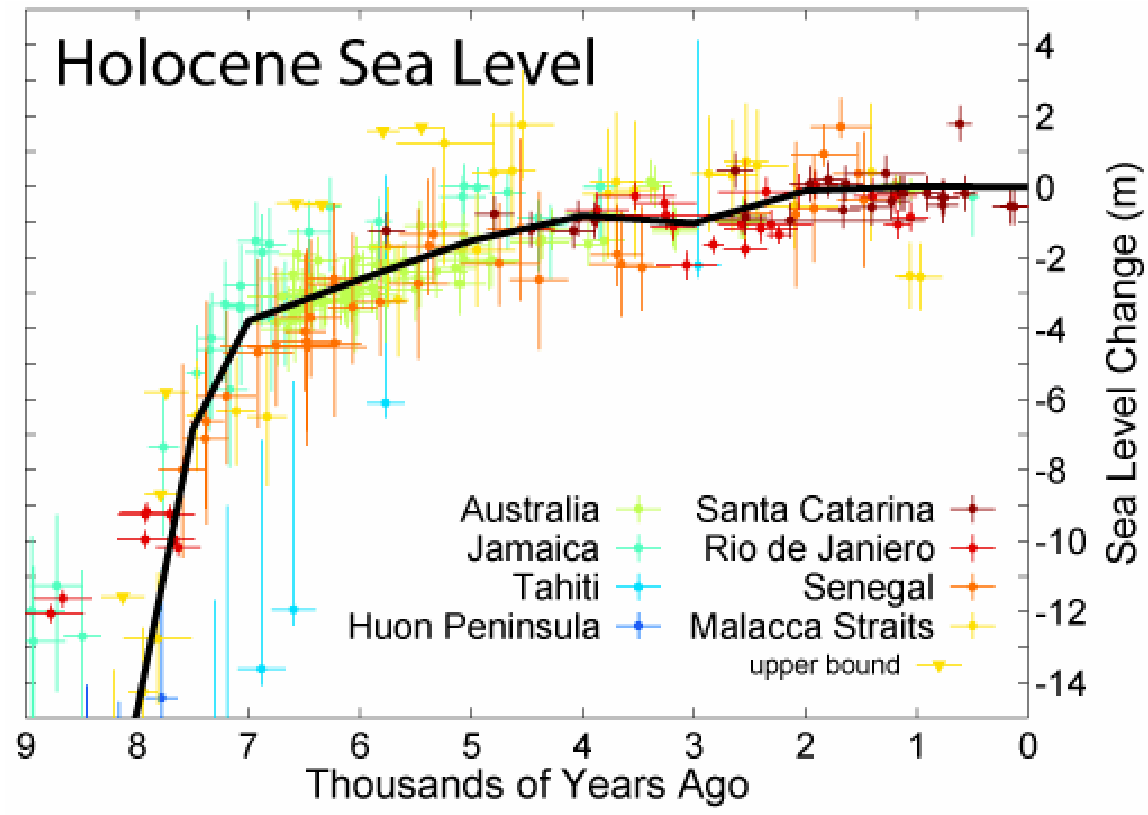

Figure 7. Sea level rise over the last 8,000 years (Global Warming Art)

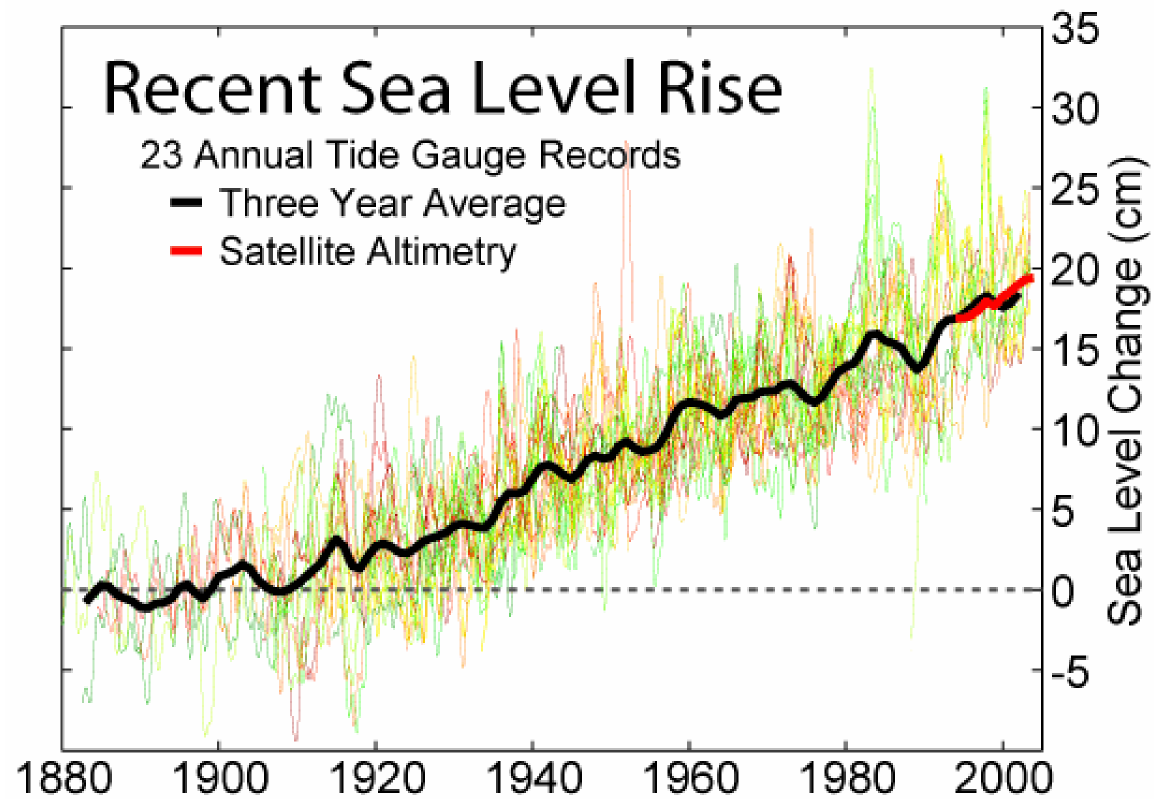

Figure 8. Sea level rise since 1880 (Global Warming Art)

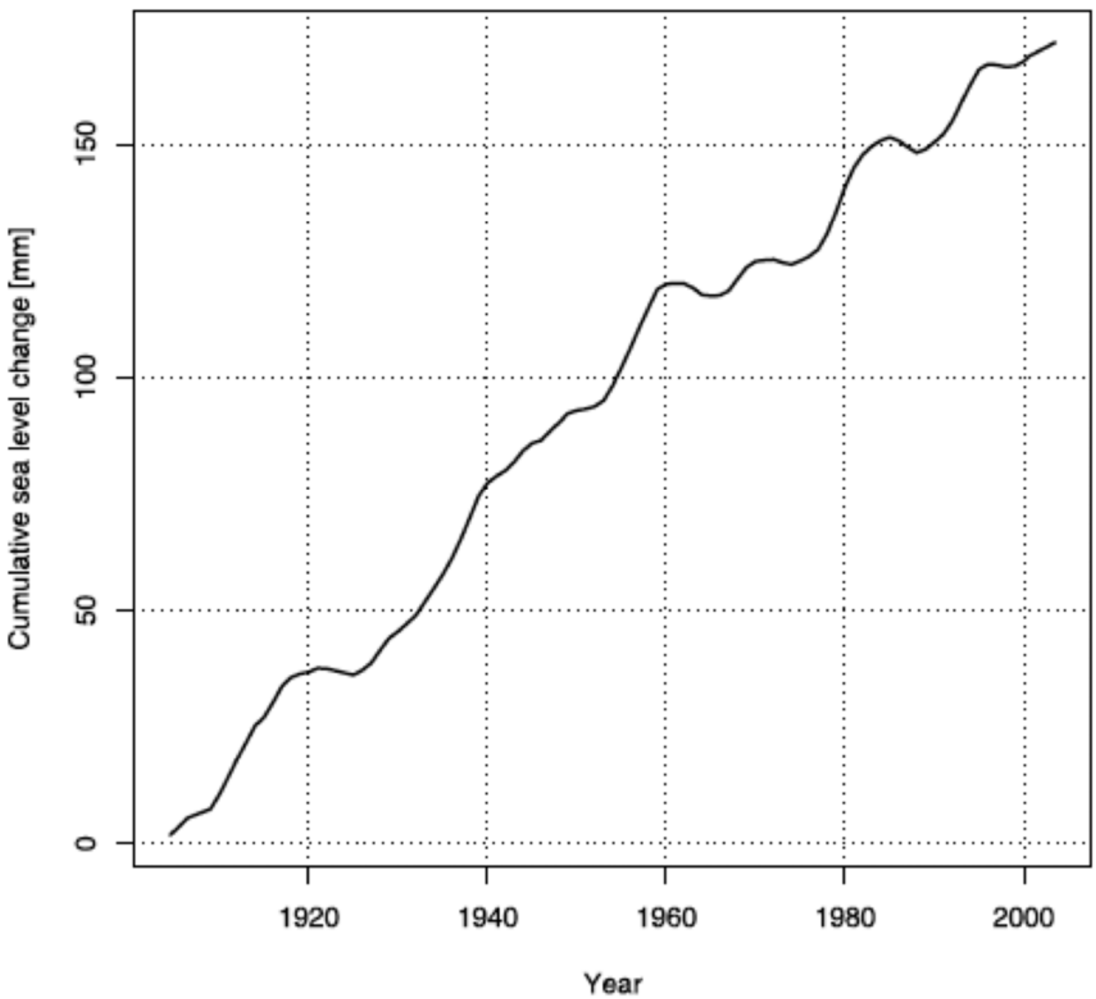

Figure 9. Mean sea level rise from nine tide gages over the period 1904-2003 based on the decadal trend values from 1907-1999 (Holgate, 2007)

Conclusions

There is ample evidence that air and sea temperatures were significantly higher than present conditions approximately 10,000 years ago. Some researchers see this as evidence for an inexorable movement toward the next ice age (see, for example, Pielou, 1991). Recent temperature rises are rather insignificant compared to these longer-term variations.

Sea level rise does not show the same type of behavior as the air and sea temperatures. Rather, there has been a continuous rise in sea level since the last glacial maximum ended. However, the rate of rise had dropped steadily over the last several thousand years, and shows signs of continued decline over the last hundred.

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