Sea-level Changes

Yusuke Yokoyama[1,2], Tezer M Esat[3,4], Kurt Lambeck[4], and Jun'ichi Okuno[5]

1. Ocean Research Institute, University of Tokyo
2. Institute of Biogeosciences, Japan Agency for Marine-Earth Science and Technology
3. Australian Nuclear Science and Technology Organization
4. Research School of Earth Sciences, Australian National University
5. National Institute of Polar Research

Abstract

Sea-level is an integral component of the studies related to changes in the earth's climate. It reflects the mean state of the earth's climate and is a direct measure of the global ice sheet volume. Climate change arises from complex interactions between the cryosphere, the oceans, the atmosphere and the lithosphere; yet full understanding of its' detailed workings remain elusive. Therefore, reconstructions of the magnitude and timing of sea-level movements can provide clues to the complex mechanisms of global climate change. In general, sea-level change follows the waxing and waning of large continental ice sheets. However, globally, the signals are not uniformly distributed due to glacio-hydro-isostatic adjustments (GIA) of solid Earth and the changing gravitational potential of the ice sheets. Observations from sites far distant from former ice sheet regions, far-field, are suitable for reconstructing the timing and magnitude of global ice volume. In contrast, sea-level data from sites close to the former ice sheets, near field, provide information on the melting history of individual ice sheets. Hence, we propose to drill both far- and near- field sites, facilitated through IODP projects, to trace the total magnitude and sources of melt-water inputs to the oceans as the impacts of global climate change depend on both of these parameters.

Background

One of the main concerns of the current ongoing debate on global warming is the potential for rises in sea-level due to the melting of mountain glaciers; and over the rest of the century, the likely accelerated melting of either or both of the Greenland ice sheet and the Antarctic ice sheet. In particular, the West Antarctic Ice sheet (WAIS) which is currently held in place by grounded ice may be disrupted due to increased buoyancy as sea levels rise from the melting of northern hemisphere ice sheets. The Intergovernmental Panel for Climate Changes (IPCC) predicts a sea-level rise of as much as one meter during the next century (IPCC AR4, 2007). The current estimates of sea-level rise are within the upper end of the uncertainties in the IPCC projections. The uncertainties in the sea-level projections are large as ice sheet dynamics are poorly understood and have not been included explicitly in the IPCC reports. Empirical approaches using paleo sea-level records such as coral reefs as proxy bench-marks can provide better constraints. This is so, because, previous glacials and interglacials include examples of lower sea-levels as well as colder temperatures than the present. In particular, ice sheets responses for different climate backgrounds remain uncertain due to the difficulties of establishing reliable geophysical ice models that take account of the basal conditions of the ice sheets. Studies of previous glacial-interglacial transitions, as well as the rapid millennial to centennial sea-level oscillations during the glacial periods may reveal the degree of sensitivity of sea-level changes to variations in temperature. In addition, the timing of the glacial sea-level changes can constrain the phase relationship between temperature change and ice sheet response (e.g. Yokoyama et al., 2000; Kawamura et al., 2007).

Coupled Far- and Near-field sea-level studies for understanding climate and ice sheet response

Last ice age climate is characterized by millennial scale fluctuations between warm and cold states. Greenland ice cores were first to reveal large magnitude, rapid temperature variations ranging over as much as 5 to 10 degrees C, called Dansgaard-Oeschger (DO) events. Corresponding warm and cold episodes were also discovered in Antarctic ice cores and the possibility of a thermal sea-saw relationship, between the two hemispheres, has been considered. North Atlantic sediment cores showed periodic ice rafted debris layers that corresponded to even colder sea surface temperatures (SST) called Heinrich events (HE). It appeared that successive DO cycles led progressively to cooler cold periods and presumably to the growth of the northern hemisphere ice sheets. The ice sheets eventually collapsed thereby triggering periods of very cold temperatures (HE) in the North Atlantic. It was postulated that the presence of large numbers of melting icebergs may have weakened or stopped North Atlantic Deep Water formation, reducing the transport of heat to northern latitudes. Original predictions of glaciological models for the ice discharge predicted minimal sea-level rises of no larger than a few meters. We have dated last ice age coral terraces at Huon Peninsula, Papua New Guinea. The shoreline is ringed by coral terraces that formed during episodes of rapid sea-level rise when corals constructed large, discrete structures while trying to keep close to sunlight. The terraces were subsequently uplifted due to continuous tectonic movement. Uranium series ages of four prominent Huon Peninsula last glacial (MIS3) coral terraces coincide with the timing of major North Atlantic climate reversals at intervals of 6000-7000 yr between 30,000 yr and 60,000 yr ago. Terrace elevations, when combined with the rate of uplift indicate 10-15m high sea-level excursions at these times. We attribute the growth of the terraces directly to sea-level rises arising from ice-calving episodes from major North Atlantic ice-sheets and probably from the Antarctic ice-sheet that precipitated extremes of cold climate and the Heinrich events in the North Atlantic. These periods are associated with major discharges of land-based ice, up to 20% of the mass of the Laurentide ice sheet, and enhanced concentrations of ice-rafted debris in deep-sea cores. In turn, the ages of the Huon terraces provide absolute timing for the HE and can be used as a calibration for the ice core data. The ages of Huon MIS3 terraces correspond to HE-3, HE-4, HE-5 and HE-5a. The magnitude of sea-level rises derived from the dating of Huon terraces were originally considered to be impossibly high. However, they have since been confirmed by salinity analyses of forams from Red Sea cores which also indicate the involvement of the Antarctic ice sheet. The West Antarctic Ice Sheet (WAIS) is thought to be the main candidate for this but more recently the East Antarctic Ice Sheet has also been considered as a possible source based on IRD records as well as 10Be dating of coastal mountains. Similar work can potentially extend to periods prior to the last glacial. Ice core records from Antarctica reveal persistent millennial scale fluctuations in climate. IRD in South Atlantic sediments also show Heinrich type events. However, quantitative studies of sea-level change and of ice sheet fluctuations coupled to global climate variability have not been undertaken and, hence, future IODP work should target these issues in future expeditions.

Future topics of investigation

The relationships between the last ice age climate and sea-levels have been relatively well understood, in particular, as reflected in total ice volume fluctuations and the timing of climate changes. However, the particular mix of sources contributing to specific sea-level changes are not well understood. For example, the largest magnitude change in sea-level during the last deglaciation is called melt water pulse 1a amounting to as much as 20 m of sea-level. However, the proposed involvement of the Antarctic ice sheet in this episode is still debated. Sea-level observations at far-field sites coupled with GIA modeling can point to possible sources of the melt-water. Also, organic geochemical approaches in polar region sediment cores can provide direct fingerprints to melt-water sources. Outcomes from empirical sea-level evidence can indeed constrain global climate models and a sophisticated computational climate model, of coupled general atmosphere-ocean circulation (AOGCM) can , in principle, predict the Greenland and Antarctic ice sheet behavior in a globally warming climate.

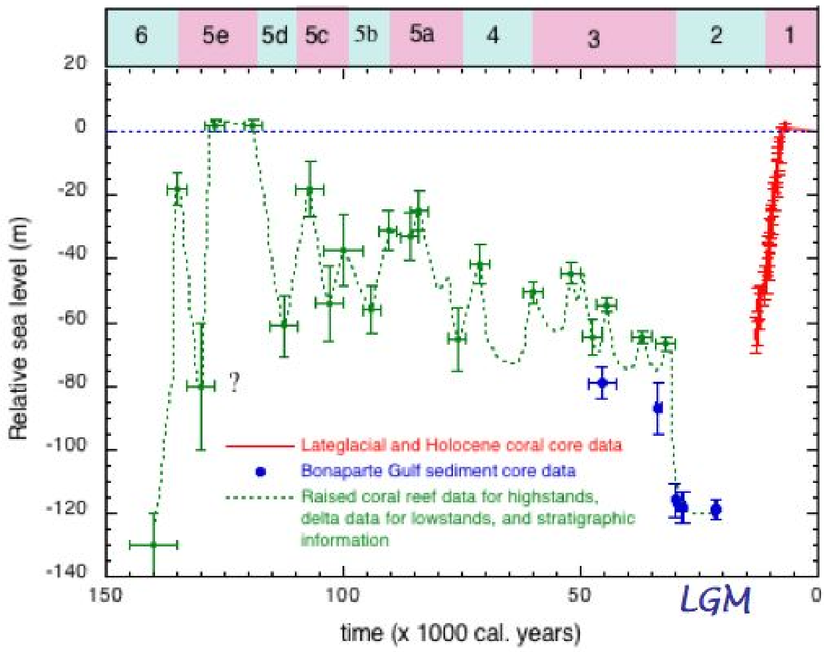

Figure: Global ice volume reconstruction over the last 150,000 years. Numbers at the top of the graph refer to varuous marine isotope stages (MIS) where the odd numbers represent relatively warmer periods. During the last glacial maximum (LGM), large ice sheets existed over North America and Northern Europe represented by an excess of $55x10^6$ km^3 of land based ice. Present interglacial is labelled MIS-1 and the last interglacial MIS-5e. Detailed studies of both interglacial and glacial sea-levels potentially provide better constrains on future sea-level changes.