SIO 40 Fall 2007 Homework 6 **Due Nov 26th**

This homework covers materials presented in lectures 17, 18, and 19 as well as the accompanying reading assignments for those lectures (see syllabus). These are primarily short answer questions. In most cases, a few sentences should suffice. Please try to answer all questions in the space provided, use the back of the page if you have to. Be careful to answer each part of multi-part questions. **Note:** Homeworks will be graded on the basis of a *random subset* of these questions – so your best strategy will be to answer all the questions to the best of your ability.

1) Suppose you have a record of oxygen isotope variations in foram shells in a marine sediment core. During one point in your record (say about 20 thousand years ago), you see that the foram shells have a significantly higher $\delta^{18}O$ than, say, 2 thousand years ago. What does that tell you about a) the relative size of the glacial ice sheets 20,000 vs 2,000 years ago; and b) the relative sea level 20,000 vs 2,000 years ago? (Explain the reasoning behind your answers).

Higher $\delta^{18}O$ in fossil marine forams at 20,000 years ago relative to 2,000 years ago indicates a) Bigger ice sheets 20,000 years ago; and b) lower sea level 20,000 years ago. This is because when seawater evaporates at low latitudes and moves to higher latitudes through the atmosphere, $H_2{}^{18}O$ preferentially stays in or partitions into the liquid phase relative to $H_2{}^{16}O$. This means that during times when the mass balance of the hydrologic cycle is shifted towards increased continental glaciers, the remaining seawater is enriched in $H_2{}^{18}O$ (the $H_2{}^{16}O$ having been preferentially evaporated, retained in the atmosphere, and eventually deposited on the glaciers as snow). The increased $\delta^{18}O$ of the seawater will be recorded in fossil marine carbonates like forams. Because of the increase in continental glaciers 20,000 years ago, sea level was lower (mass balance).

2) What do foram oxygen isotope records as discussed in question #1 show about the number and timescale of glacial-interglacial cycles over the past 700,000 years of Earth history?

Oxygen isotope records from ocean sediment cores show that over the past 700,000 years there have been a number of large amplitude glacial-interglacial cycles, occurring about every 100,000 years.

3) Which of the three major Milankovitch orbital parameters shows the closest match to the major periodic component of the marine oxygen isotope record, and why does this suggest the involvement of positive climate feedback loops in the Pleistocene glaciation cycles?

Eccentricity is the orbital parameter whose periodicity most closely matches that of the dominant cycle in the observed glacial-interglacial cycles in $\delta^{18}O$ (ie. 100,000 years), but the direct climate forcing associated with eccentricity is really pretty small, not enough to explain the apparent climate response every 100,000 years. This makes it seem like a positive climate feedback loop might be operating to magnify the climatic response to eccentricity forcing.

4) Explain why iron fertilization of the oceans could represent one positive feedback loop operative during Pleistocene glacial times. How would this feedback loop work, and what evidence is there to support this scenario?

During glacial times, the equator-to-pole temperature gradient is thought to have been greater than during interglacial times, creating stronger east-west winds. Also, the glacial climate is thought to have been relatively dry. This combination of factors is thought to have increased the supply of wind-blown dust to the ocean. The dust contains high concentrations of iron, which would “fertilize” high-nutrient low-chlorophyll areas of the ocean where iron is a limiting micronutrient, resulting in increased growth of phytoplankton and an enhancement of the biological pump. This enhanced biological pump would act to reduce CO_2 concentrations in the atmosphere, serving to cool the Earth further and foster the growth of the glacial ice sheets. Evidence which supports this scenario is the higher concentrations of dust found in ice cores during glacial intervals, suggesting that there was indeed an increased flux of windblown dust during glacial times.

5) What types of proxy data are used to reconstruct northern hemisphere climate and temperature variations over the Holocene period?

Over the Holocene, the following types of climate proxies are particularly useful: ice core data (oxygen and hydrogen isotope variations, data on ancient atmospheres from bubbles trapped in the ice, windblown materials in the ice, etc.), pollen grains, tree rings and terrestrial borehole data.

6) Describe the Younger Dryas event in terms of when it occurred and its effects on climate. Were the effects global or regional?

The Younger Dryas was a sudden climate reversal that occurred during the transition from the last glacial phase to the current interglacial, probably around 11,000 – 12,000 years ago. (Note that 10,500 years ago date in lecture summary a mis-print). Climate effects associated with the Younger Dryas included a sudden and significant cooling and re-advance of the glacial ice sheets in the Northern Hemisphere. Pollen data show a re-emergence of cold-tolerant vegetation, including the Dryas flower for which the event is named. Although there has been some evidence to suggest that climate cooling events synchronous with the Younger Dryas occurred in some (not all) locations in the southern hemisphere and in other parts of the globe, the event does appear to primarily have affected the North Atlantic region.

7) Explain why the formation of North Atlantic deep water might have played a role in causing the Younger Dryas event.

It is now thought that the Younger Dryas was triggered, at least in part, by a large influx of glacial meltwater into the North Atlantic (by an as yet unknown mechanism). The significant decrease in salinity due to this freshwater influx caused deep water formation in the North Atlantic to largely cease. This prevented the normal North Atlantic “conveyor belt” circulation which draws warm salty surface water northwards from lower latitudes to fill the void created by sinking deep water. Without the presence of warm surface waters in the high latitude North Atlantic, climate cooled dramatically in that region.

8) Give an example of how historical records have provided information about past climate.

Evidence for the “Medieval Warm Period” includes records of Vikings establishing a settlement on the southwest coast of Greenland, including farms. Other agricultural records indicate a mild climate in Norway, Iceland, and England during that period. The “Little Ice Age” which followed this relatively warm period in Europe is also well-documented in Medieval records, such as the paintings of Bruegel the Elder in the late 1500’s, the failure of the Greenland Viking colony established during the earlier warm period, records of canals freezing in Holland, and advance of glaciers into villages in the Swiss Alps.

9) How do volcanic eruptions affect climate?

On short timescales, volcanoes cause a cooling effect on climate by injecting ash and debris into the atmosphere, which can block sunlight and cause cooling. Somewhat longer term (multi-year) cooling effects are created by the injection of sulfur dioxide into the stratosphere. The sulfur dioxide forms sulfuric acid droplets which reflect solar radiation and absorb long waver radiation from the troposphere, causing net cooling of the troposphere. Volcanoes can also have a heating effect over longer timescales by adding greenhouse gases (CO_2, CH_4) to the atmosphere.

10) What are sunspots and why are they thought to have a possible effect on climate?

Sunspots are dark patches that appear on the surface of the sun. Although the dark part of the patch reflects a region of lower energy, surrounding the patch is a brighter, higher energy region, so when sun spots are more abundant, overall solar activity and output is higher. This will affect Earth's climate by influencing the amount of solar energy reaching the Earth. Sunspots currently appear to have an 11-year cycle of abundance. The Little Ice Age corresponds to a period of unusually low or negligible sunspot activity.

11) Explain what happens to atmospheric and ocean circulation in the tropical Pacific during an El Nino-Southern Oscillation event.

Characteristic features of El Nino include a slackening or reversal of the westward-blowing trade winds, which causes a pooling of warm water in the eastern tropical Pacific. This tends to depress the thermocline and reduce the intensity of coastal upwelling along the eastern ocean boundary region (eg. off the west coast of South America). Reduced upwelling decreases the productivity of the oceanic ecosystem, leading to a decline in traditional coastal fisheries. El Nino also changes the east-west balance of precipitation in the tropical Pacific, causing it to move eastward. Larger regional effects associated with El Nino changes include extensive droughts in Indonesia, Malaysia and Australia. In North America, effects on Jet Stream circulation lead to increased wintertime precipitation in the American southwest. La Nina conditions are the inverse of El Nino, leading to stronger trade winds, cooler water in the eastern tropical Pacific, and more upwelling. El Nino's tend to occur every 2-7 years, lasting 1-2 years on average.

12) Identify and briefly describe three major interactions and/or feedback processes between sea ice and climate.

Ice-albedo feedback – the more ice there is, the higher the albedo, the cooler the climate. This positive feedback loop will also exacerbate sea ice melting .

Ice ocean heat flux feedback – the ocean loses heat to the atmosphere much more rapidly in ice-free zones. This also creates a positive feedback loop when decreasing ice creates more zones of open water, which heats the atmosphere further, and contributes to reducing ice.

Sea ice also interacts with thermohaline circulation patterns in the ocean because exclusion of salt from the ice lattice during sea ice formation leads to brine formation, which increases the salinity and density of seawater (especially in the North Atlantic), contributing to more efficient deep water formation during winter.