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Scottish sea lochs (fjords): testing the evidence for Holocene rapid climate change events

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Rapid climate change (RCC; Mayewski *et al*., 2004. *Quaternary Research*) during the present Holocene interglacial period, particularly post-dating the demise of large Northern Hemisphere ice sheets after 8000 cal. yr BP, is a global phenomenon and is almost certainly driven by long-term changes in insolation, upon which solar variability, although a weak direct forcing mechanism, is superimposed (e.g. Denton & Karlén, 1973. *Quaternary Research*; Bond *et al*., 2001. *Science*). At least five significant intervals are identified in numerous palaeoclimate records since the major 9000-8000 cal. yr RCC, within which the intensively studied 8200 cal. yr 'event' is embedded (Alley *et al*., 1997. *Geology*); these are: 6000-5000, 4200-3800, 3500-2500, 1200-1000 and 600-150 cal. yr BP. Most of the Holocene RCCs are associated with bipolar cooling, an expansion-intensification of high latitude circulation systems and drying-aridity at low latitudes. These intervals of RCC have large ecosystem and societal impacts; for example, the collapse of the Mayan civilization of Central America is associated with a drought that can be related to RCC 1200-1000 cal. yr BP (Hodell *et al*., 2001. *Science*).

During the summer 2004, an opportunity arose to collect a giant piston core (MD04-2832) from the main basin of Loch Sunart, Argyll, NW Scotland aboard the French research vessel *Marion Dufresne*. The core, 22m long, has preliminary range-finder AMS ^{14}C dates available, suggesting that it contains a record of continuous sedimentation back to nearly 8000 cal. yr BP. To date, the record obtained, based on an initial 10 cm sampling interval, reveals a remarkable stable isotope record from the benthic

foraminifera *Ammonia beccarii* and also in sediment grain size parameters.

Numerical models of fjordic circulation were developed for Loch Sunart during the *HOLSMEER* project and sensitivity analyses, based on recent extremes in the North Atlantic Oscillation (NAO) indices (Jones *et al*., 1997. *Int. J. Climat.*), reveal that its circulation is extremely sensitive to the strength of the prevailing Westerlies (Gillibrand *et al*., 2005. *Cont. Shelf Res*.). Data from the Greenland Summit Ice Core (GISP2) reveal patterns of changing high latitude atmospheric circulation during the Holocene which influenced the location and strength of the Westerlies and should therefore be recorded in circulation proxies from Loch Sunart.

Despite the uncertainties associated with the preliminary age-depth model for core MD04-2832, some of the isotopic shifts recorded in *A.beccarii* coincide with both the rate and magnitude of the Holocene RCCs. For example, $\delta^{13}C_{foram}$ exhibits a shifting balance between the $\delta^{13}C_{DIC}$ of fjord (-ve) and coastal (+ve) waters, which can readily be explained by the renewal history of basin waters driven by circulation changes i.e. stronger Westerlies force more frequent deep water renewal events (DWRE), which change the balance of $\delta^{13}C_{DIC}$ in the main basin in favour of coastal waters, so that $\delta^{13}C_{foram}$ becomes more +ve. If $\delta^{13}C_{foram}$ reflects the timing and rate of DWRE, then it appears that $\delta^{18}O_{foram}$ provides a unique record of bottom water temperature and salinity. Our models suggest that Loch Sunart main basin salinity remains very stable between recent NAO extreme-years, which may imply changes in bottom water temperatures of between 2-4˚C throughout the Holocene. The $\delta^{18}O_{foram}$ is controlled by the temperature and *in situ* $\delta^{18}O_{water}$ at the time of calcification. In coastal waters, $\delta^{18}O_{water}$ is a function of salinity; however, because regional precipitation in the Scottish Highlands is not significantly depleted in ^{18}O relative to oceanic (shelf) water, the salinity:$\delta^{18}O$ relationship in Scottish fjord waters is rather weak, with a mixing line slope of 0.18 (Austin and Inall, 2002. *Polar Res*.).