MATERIALS AND METHODS

Red coralline algae: Red coralline algae are long lived (<700 years (Frantz et al., 2005)) marine algae with slow growth rates (0.015 – 2.5 mm yr^{-1}) ((Adey and McKibbin, 1970; Blake and Maggs, 2003; Frantz et al., 2000; Kamenos et al., 2008) and encrusting (calcareous coralline algae) or free-living (maerl or rhodolith) growth forms. They occur from polar (Schwarz et al., 2005) to tropical (Littler et al., 1991) seas in the euphotic zone and form large beds such as those on the Brazilian shelf extending from 2°N to 25°S (Amado-Filho et al., 2012). Deposits are highly stratified (Kamenos, 2010), can attain 20 kys of growth (Bosence, 1983) and are common as far back as the Cambrian-Late Devonian (Cooper, 1994). While growing, individual red coralline algal thalli lay down annual or sub-annual high-Mg calcite growth bands (Fig. 1) (Foster, 2001). In some species, growth continues during periods of low winter temperature (*L.glaciale* (Henrich et al., 1996)) and darkness (*L. glaciale* (Freiwald and Henrich, 1994)), while in others there is reduced winter growth (*C. compactum* (Halfar et al., 2008)).

Algal collection: Red coralline algae (*Lithothamnion glaciale*) (Fig. 1) were collected using self contained underwater breathing apparatus (SCUBA) from Søndre Strømfjord, Greenland (Fig 1: 66°58'17''N, 53°29'43''W) in 2009. The Kangerlussuaq Drainage Basin (KDB) is a 66000 km^2 catchment draining a section of the GrIS that drains into Søndre Strømfjord.

Algae as environmental recorders: Palaeoenvironmental reconstructions using coralline algae have been achieved using geochemical and structural proxies. Mg concentrations within *L. glaciale* bands have been biogeochemically validated (Kamenos et al., 2009) and observed to represent *in situ* temperature at up to fortnightly resolution (Kamenos et al., 2008) over the last 650y at fortnightly resolution in the North Atlantic (Kamenos, 2010). $\delta^{18}O$ in *Clathromorphum compactum* also represents temperature change at sub-annual resolutions (Halfar et al., 2008). More recently, temperature (Kamenos and Law, 2010) and cloud cover (light) (Burdett et al., 2011) have been shown to influence the degree of calcification within cells of the red coralline alga *L. glaciale* and enabled a 96y cloud cover reconstruction in the North Atlantic. Similarly, annual growth in *Clathromorphum nereostratum* has been used to reconstruct a 225y record of temperature change in the in the North Pacific (Halfar et al., 2011). While light (cloud cover) affects cell calcification (Burdett et al., 2011), there is no evidence of light-dependent deposition of Mg/Ca and thus no light-effect on Mg-palaeothermometry (Kamenos et al., 2008). No organism stress-induced geochemical deviation is present in Mg/Ca-temperature relationships (Kamenos et al., 2008) and similarly there is no non-equilibrium-associated oxygen isotope fractionation in red coralline algae (Halfar et al., 2007). Red coralline algae do not suffer diagenetic effects due to the presence of the living membrane covering the carbonate skeleton (Alexandersson, 1974).

Chronology construction: All samples were collected live and band counting was used to calculate the absolute ages of each year. *Lithothamnion glaciale* is known to band annually (Kamenos et al., 2008) and band sizes were consistent with those found elsewhere in the North Atlantic (Kamenos, 2010).

Relative salinity – runoff relationship: Relative salinity followed a similar pattern to reconstructed summer *in situ* temperature (more/less negative $\delta^{18}O$ indicates more/less fresh water input) (Fig. 3). Directly measured runoff data from the KDB are available for <5 consecutive years, so modelled KDB and GrIS runoff data were used for comparisons. Our relative salinity reconstruction was compared to runoff for the KDB modelled by Mernild et al (2011). But also, as the KDB has a mass balance representative of the GrIS (Mernild et al., 2010), we compared relative salinity to GrIS runoff modelled by Hanna et al. (2008) as far back as 1958.

Rates of change in water temperature: Differences in rates of *in situ* water temperature change between summer and winter were assessed by regressing the difference between summer and winter temperatures on sums of summer and winter temperature between 1977-1989 and also 1989-2002 which were periods of pronounced increase and decrease in reconstructed water temperature, respectively.

Relative salinity comparisons: Modelled historical (1958-2002) melt water runoff volume for the KDB (Mernild et al., 2011) as well as the GrIS (Hanna et al., 2008) and instrumental atmospheric temperature in Kangerlussuaq (World Meteorological Organisation station 4231: 20 km from glacier influx, 100km from algal sampling location) were compared with reconstructed relative salinity. Correlations and regression were conducted on residuals of de-trended time series at 5y resolution (to match relative salinity reconstruction) with autocorrelation removed using successively higher order autoregressive integrated moving average (ARIMA) models on each input variable.

REFERENCES CITED

Adey, W. H., and McKibbin, D. L., 1970, Studies on maerl species *Phymatolithon calcareum* (Pallas) nov. comb. and *Lithothamnion coralloides* (Crouan) in the Rio Vigo: Botanica Marina, v. 13, p. 100-106.

Alexandersson, T., 1974, Carbonate cementation in coralline algal nodules in Skagerrak, North-Sea - biochemical precipitation in undersaturated waters: Journal of Sedimentary Petrology, v. 44, no. 1, p. 7-26.

Amado-Filho, G. M., Moura, R. L., Bastos, A. C., Salgado, L. T., Sumida, P. Y., Guth, A. Z., Francini-Filho, R. B., Pereira-Filho, G. H., Abrantes, D. P., Brasileiro, P. S., Bahia, R. G., Leal, R. N., Kaufman, L., Kleypas, J. A., Farina, M., and Thompson, F. L., 2012, Rhodolith Beds Are Major CaCO(3) Bio-Factories in the Tropical South West Atlantic: PloS one, v. 7, no. 4, p. e35171.

Blake, C., and Maggs, C., 2003, Comparative growth rates and internal banding periodicity of maerl species (Corallinales, Rhodophyta) from northern Europe: Phycologia, v. 42, p. 606-612.

Bosence, D. W. J., 1983, The occurence and ecology of recent rhodoliths-a review, *in* Peryt, T. M., ed., Coated Grains: Berlin, Springer-Verlang, p. 225-242.

Burdett, H. L., Kamenos, N. A., and Law, A., 2011, Using coralline algae to understand historic marine cloud cover: Palaeogeography Palaeoclimatology Palaeoecology, v. 302, p. 65-70.

Cooper, P., 1994, Ancient reef ecosystem expansion and collapse: Coral Reefs, v. 13, p. 3-11.

Foster, M. S., 2001, Rhodoliths: between rocks and soft places: Journal of Phycology, v. 37, p. 659-667.

Frantz, B. R., Foster, M. S., and Riosmena-Rodriguez, R., 2005, *Clathromorphum nereostratum* (Corallinales, Rhodophyta): The oldest alga?: Journal of Phycology, v. 41, no. 4, p. 770-773.

Frantz, B. R., Kashgarian, M., Coale, K. H., and Foster, M. S., 2000, Growth rate and potential climate record from a rhodolith using C-14 accelerator mass spectrometry: Limnology and Oceanography, v. 45, no. 8, p. 1773-1777.

Freiwald, A., and Henrich, R., 1994, Reefal coralline algal build-ups within the Arctic circle: morphology and sedimentary dynamics under extreme environmental seasonality: Sedimentology, v. 41, p. 963-984.

Halfar, J., Steneck, R., Schone, B., Moore, G. W. K., Joachimski, M., Kronz, A., Fietzke, J., and Estes, J., 2007, Coralline alga reveals first marine record of subarctic North Pacific climate change: Geophysical Research Letters, v. 34, p. L07702.

Halfar, J., Steneck, R. S., Joachimski, M., Kronz, A., and Wanamaker, A. D., 2008, Coralline red algae as high-resolution climate recorders: Geology, v. 36, no. 6, p. 463-466.

Halfar, J., Williams, B., Hetzinger, S., Steneck, R. S., Lebednik, P., Winsborough, C., Omar, A., Chan, P., and Wanamaker, A. D., 2011, 225 years of Bering Sea climate and ecosystem dynamics revealed by coralline algal growth-increment widths: Geology, v. 39, no. 6, p. 579-582.

Hanna, E., Huybrechts, P., Steffen, K., Cappelen, J., Huff, R., Shuman, C., Irvine-Fynn, T., Wise, S., and Griffiths, M., 2008, Increased runoff from melt from the Greenland Ice Sheet: A response to global warming: Journal of Climate, v. 21, no. 2, p. 331-341.

Henrich, R., Freiwald, A., Wehrmann, A., Schafer, P., Samtleben, C., and Zankl, H., 1996, Nordic-cold water carbonates: Occurrence and controls, *in* Reitner, J., Neuweiler, F., and Gunkel, F., eds., Global and regional controls on biogenic sedimentation: Gottingen, Gottinger Arbeiten Geol. Palaonton., p. 35-53.

Kamenos, N. A., 2010, North Atlantic summers have warmed more than winters since 1353, and the response of marine zooplankton: Proceedings of the National Academy of Sciences of the United States of America, v. 107, no. 52, p. 22442-22447.

Kamenos, N. A., Cusack, M., Huthwelker, T., Lagarde, P., and Scheibling, R. E., 2009, Mg-lattice associations in red coralline algae: Geochimica et Cosmochimica Acta, v. 73, p. 1901-1907.

Kamenos, N. A., Cusack, M., and Moore, P. G., 2008, Red coralline algae are global paleothermometers with bi-weekly resolution: Geochimica et Cosmochimica Acta, v. 72, p. 771-779.

Kamenos, N. A., and Law, A., 2010, Temperature controls on coralline algal skeletal growth: Journal of Phycology, v. 46, p. 331-335.

Littler, M. M., Littler, D. S., and Hanisak, M. D., 1991, Deep-water rhodolith distribution, productivity, and growth history at sites of formation and subsequent degradation: Journal of Experimental Marine Biology and Ecology, v. 150, no. 2, p. 163-182.

Mernild, S. H., Liston, G. E., Hiemstra, C. A., Christensen, J. H., Stendel, M., and Hasholt, B., 2011, Surface Mass Balance and Runoff Modeling Using HIRHAM4 RCM at Kangerlussuaq (Søndre Strømfjord), West Greenland, 1950–2080: Journal of Climate, v. 24, no. 3, p. 609-623.

Mernild, S. H., Liston, G. E., Steffen, K., Van den Broeke, M., and Hasholt, B., 2010, Runoff and mass-balance simulations from the Greenland Ice Sheet at Kangerlussuaq (Søndre Strømfjord) in a 30-year perspective, 1979–2008: The Cryosphere, v. 4, p. 231-242.

Schwarz, A. M., Hawes, I., Andrew, N., Mercer, S., Cummings, V., and Thrush, S., 2005, Primary production potential of non-geniculate coralline algae at Cape Evans, Ross Sea, Antarctica: Marine Ecology Progress Series, v. 294, p. 131-140.