IFM-GEOMAR

Leibniz-Institut für Meereswissenschaften
an der Universität Kiel

IFM-GEOMAR Report 2002-2004

From the Seafloor to the Atmosphere

- Marine Sciences at IFM-GEOMAR Kiel -

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Preface

For the first time, the Leibniz Institute of Marine Sciences (IFM-GEOMAR) presents a joint report of its research activities and developments in the years 2002-2004. In January 2004 the institute was founded through a merger of the former Institute for Marine Research (IfM) and the GEOMAR Research Center for Marine Geosciences. This report addresses friends and partners in science, politics and private enterprises. It gives an insight into the scientific achievements of IFM-GEOMAR and its predecessor institutes during the last three years.

3.3 Millennial-scale Variability of the Global Ocean Circulation

Our recent view of Earth's climate system is influenced by the traditional perspective of long-term stable and favourable conditions. Some ten thousand years ago during the Late Pleistocene, however, rapid and profound changes in the operational mode of the combined climate - ocean system took place over the course of a few decades or centuries. The most spectacular perturbations are the Heinrich meltwater events and the Dansgaard-Oeschger (D/O) oscillations in the North Atlantic region. Transient warm climatic conditions prevailed during D/O stadials and an armada of icebergs was released into the North Atlantic during Heinrich events. The variability of these climatic events is mutually linked with changes in North Atlantic Deep Water (NADW) formation. The amplitudes of these changes are largest at high northern latitudes. In view of recent human-induced environmental changes it is important to assess the response of climates at mid latitudes where the majority of industrial centres and food-production areas are located. This appears urgent as recent oceanographic surveys have revealed that changes in oceanographic conditions can happen quickly and can spread throughout the North Atlantic basin within a few years. Studies on the late Pleistocene thermohaline circulation history in the northern North Atlantic and Nordic Seas have likewise demonstrated that rapid climatic changes affected the deep-water production „instantaneously".

We used high-resolution paleoceanographic records from two IMAGES cores from the west-

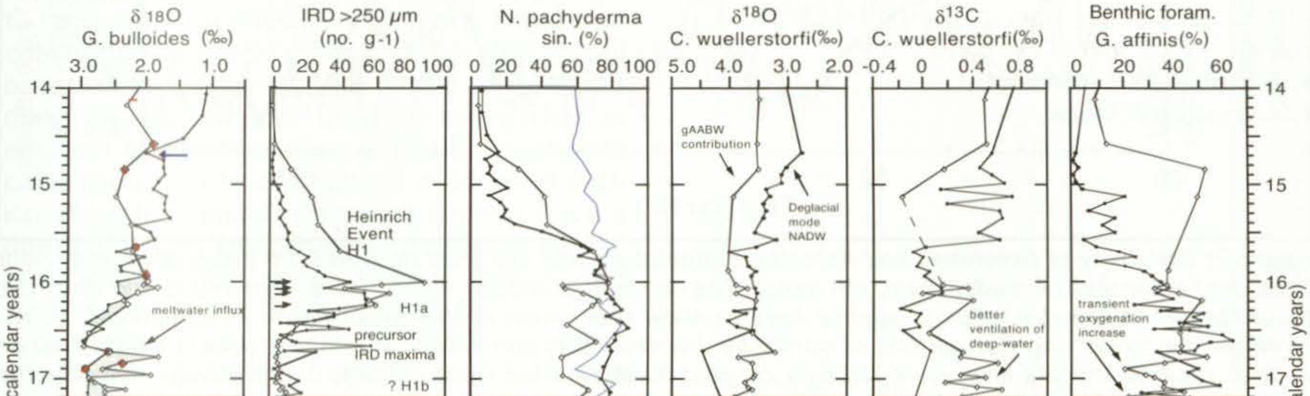

Figure 1. Oxygen isotopes of planktonic foraminifera, abundance of ice-rafted detritus (IRD), proportion of Neogloboquadrina pachyderma (sin.), oxygen and carbon isotopes of benthic foraminifera, and abundances of Uvigerina pygmea und Globobulimina affinis during the early Termination I in cores MD952039 and MD952040 off northern Portugal. The chronostratigraphy is based on ^{14}C AMS datings (red symbols), correlation with GISP2 ice core from Central Greenland (blue arrows), and correlation between the records (black arrows). The data indicate a sudden and profound environmental change (highlighted by a pink bar) that commenced 200 years before the last maximum in planktonic oxygen isotopes of Globigerina bulloides and took 670 years to affect all environments. The strongest effect is a drawdown in bottom oxygenation as indicated by a shift towards lighter benthic $\delta^{13}C$ values and increasing abundances of the suboxic benthic foraminiferal species Globobulimina affinis. The benthic environmental change is preceeded by a successively increasing influx of cold subpolar surface waters as depicted by massive abundances of Neogloboquadrina pachyderma (sin.). The planktonic $\delta^{18}O$ record from core PS2644-5 depicting the meltwater influx into the Islandic Sea (Voelker et al., 2000) is given for comparison.

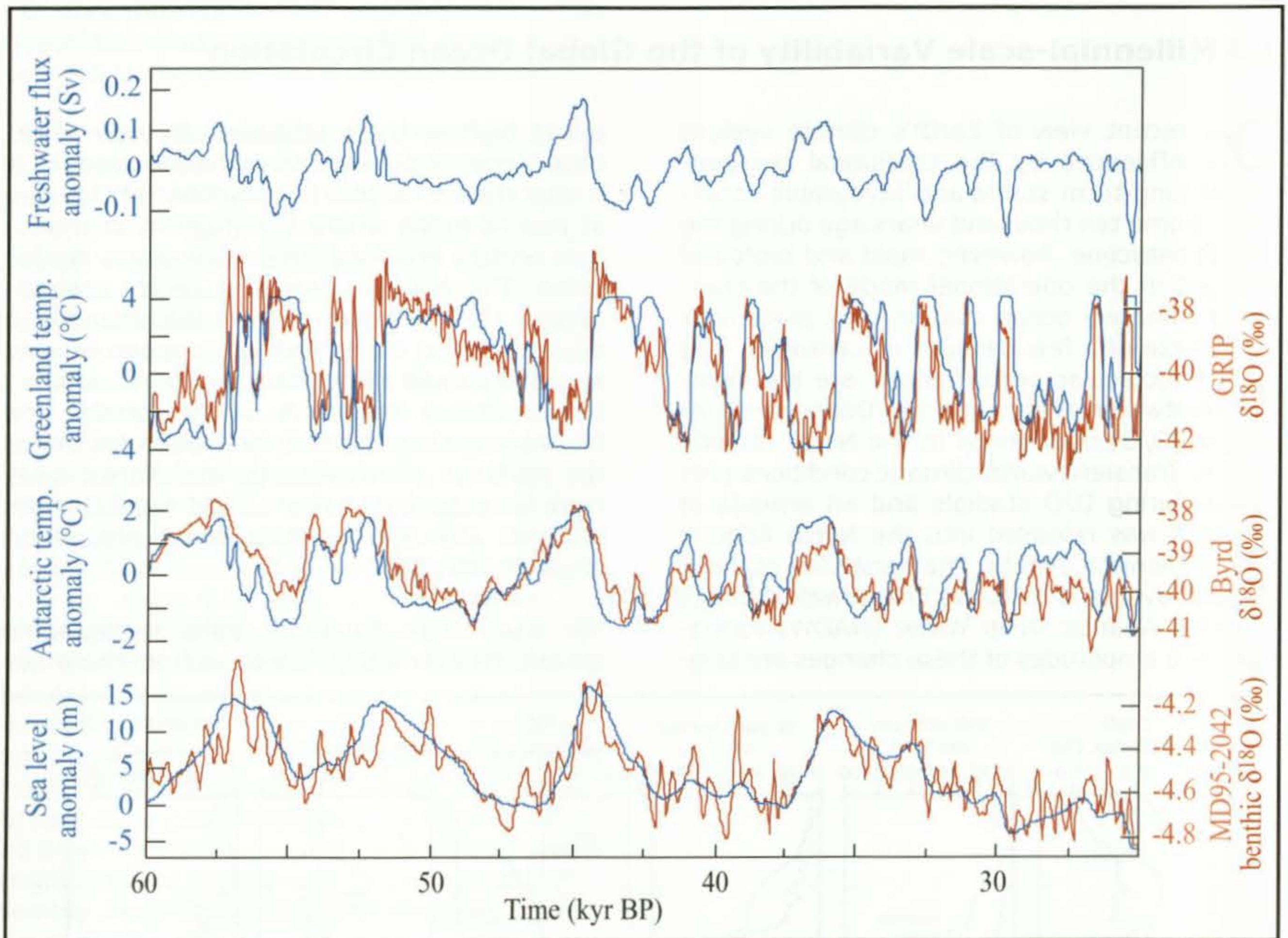

Figure 2: Variability of Greenland and Antarctic temperature and sea level derived from proxy data (red, right axes) and a conceptual model (blue, left axes). The conceptual model, which relates Greenland and Antarctic temperature, freshwater influx is applied here to show that much of the paleoclimatic evolution can be reproduced by co-varying fluctuations of nordic freshwater input and Antarctic temperatures. Climate change in polar regions and sea level were strongly coupled during Marine Isotope Stage 3. Iteratively changing the freshwater flux into the North Atlantic to maximize correlation with the proxy records yields a model solution (blue), which explains 60% (r^2) of the variability seen in the water isotopic composition of the GRIP and Byrd ice cores, and in the benthic oxygen isotope record off Portugal, which may be used as a measure for short-term sea level changes. Sv: water mass flow in Sverdrup (10^6 m^3 s^{-1}).

ern Iberian margin to assess how sea surface temperatures, deep-water production and ventilation, and benthic communities responded to rapid climatic changes during the Late Pleistocene. We linked the response patterns to marine environmental changes in high-latitude areas. A detailed chronostratigraphy allows to assess the speed of the signal transmission from high to mid latitudes.

At the onset of the last Deglaciation, a major reorganisation of surface water hydrography, benthic foraminiferal community structure, and deep water isotopic composition commenced 17,970 calendar years ago (Figure 1). Changes were initiated by glacier-derived meltwater shedding in the Nordic Seas and northern North Atlantic that commenced 100 years before concomitant changes were felt off western Iberia. The overturn affected all environments within 670 years. The intensity reduction of the thermohaline circulation, glacial NADW production, and oxygen availability in deep waters during meltwater spill and Heinrich-Events H1 and H4 is mirrored by benthic foraminiferal associations with a bloom of species which can withstand a low oxygen supply. Benthic oxygen isotopes depict the influence of brines from sea ice formation during ice-rafting pulses and meltwater spill. The brines conceivably were a source of ventilation and provided oxygen to the deeper water masses. This process has been invoked for the northern North Atlantic and Nordic Seas, and it has been discussed controversely, but our new data confirm the environmental significance of North Atlantic brine formation. For Heinrich Events H1 and H4, response times of surface water properties off western Iberia to meltwater injection to the Nordic Seas were extremely short, in the range of a few decades only. The ensuing reduction in thermohaline circulation and deep-water ventilation commenced within 500 to 600 years after the first onset of meltwater spill. These pertubations in thermohaline circulation affected the meridional heat transport and were suggested to have triggered the millennial-scale asynchrony of Greenland and Antarctic temperatures, a concept known as the 'thermal bipolar seesaw'.

Although in general agreement with the paleoceanographic record and modelling results, important issues remain unclear. The large temperature shifts of up to 16°C in Greenland, the changes of about 3°C over Antarctica, and the temporal relationships between the abrupt shifts in Greenland and the relatively slow changes over Antarcica (Figure 2) are difficult to reconcile in a physically consistant way and challenge numerical models. A coupled global ocean-atmosphere-sea ice model of intermediate complexity was used to prove that in addition to the reduction of the thermohaline circulation, sea-level changes associated with ice-sheet instabilities (Heinrich events) have a direct effect on the temperature of the Southern Ocean. Then, much heat is transported southwards in the deep Atlantic Ocean which is caused by a stronger zonal density gradient in the subtropical North Atlantic and by a fast wave adjustment process. An extended and quantitative bipolar seesaw concept is suggested to explain the timing and amplitude of Greenland and Antarctic temperature changes, the slow changes in Antarctic temperature and its similarity to sea level, as well as the time lag of sea level with respect to Antarctic temperature seen during Marine Isotope Stage 3. Figure 2 shows a comparison between our revised seesaw concept (blue) and the paleo-reconstructions (red). In addition, our analysis provides a reconstruction of meltwater discharge into the North Atlantic during Marine Isotope Stage 3. The results from our analytical work agree in their evidence that timing of the optimized freshwater discharge peaks match with the input of ice-rafted debris during Heinrich events and low values of benthic $\delta^{13}C$, indicating a reduced ventilation of the North Atlantic Deep Water. Future work will explore whether multidecadal and expected future changes of the deep-water formation in the North Atlantic have an impact on southern-hemispheric temperatures affecting living conditions in Australia, New Zealand, South Africa and South America and on sea-ice extent in the North Atlantic affecting fisheries and marine transport off northwestern Europe.

IFM-GEOMAR Contributions

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