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MODELING OF SEDIMENT AND WATER VOLUMES TRANSPORT IN LARGE BASINS: THE LATE QUATERNARY IN THE NORTH ATLANTIC

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SUMMARY

Oceanic general circulation models and sedimentation models are used to simulate the climatically induced complex interactions of the ocean–sediment system in the late Quaternary North Atlantic (NA).

The prognostic sedimentation model SEDLOB (SEDimentation in Large Ocean Basins) and PATLOB (Particle Tracing in Large Ocean Basins) are driven by the output (temperature, salinity, velocity, and convection) of an ocean general circulation model.

Modeling the last glacial maximum on the 21600 calendar years time slice, the most probable scenario for the glacial summer resembles closely the modern winter with ice–free Greenland–Iceland–Norwegian (GIN) Seas in contrast to the CLIMAP scenario with ice–covered GIN Seas. During the meltwater event the deep convection breaks down completely and reestablishes itself at the beginning of the Holocene/Modern state leading to the known modern circulation regime. The simulated sedimentation patterns and particle drifts fit very well the observed sediment distribution in the NA. Particle path and accumulation of fine grained sediments depend strongly on deep convection and vertical mixing–depth.

INTRODUCTION

Sedimentation processes including erosion, transport and deposition in large ocean basins depend strongly on sediment input from various sources and on ocean circulation patterns. Sedimentation and ocean thermohaline circulation are controlled to a large extent by the morphology of a basin and climate, and are subject to long term tectonic and short term climatic changes. Given a specific steady state oceanic circulation pattern with its temperature–, salinity–, velocity fields and convection depths, it is possible to add sediment defined by its physical properties from various sources to the circulating water volumes.

An ocean general circulation model (OGCM) and two three–dimensional (3–D) large–scale models, i.e. an ocean sediment transport and a semi–lagrangian trajectory–tracing model, are used for a better understanding of the ocean circulation and complex interactions in the ocean–sediment system since the last glacial maximum (LGM). The 3–D sedimentation model SEDLOB (SEDimentation in Large Ocean Basins) and the trajectory–tracing model PATLOB (Particle Tracing in Large Ocean Basins) are initialized and driven by the thermohaline circulation (temperature, salinity, velocity and convection depths) which is generated from the OGCM.

MODELS

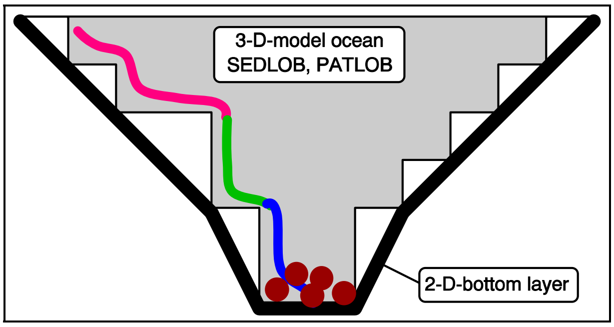

Figure1: Coupling of the 2 submodels of SEDLOB and PATLOB.

SEDLOB is a 3–D large-scale dynamic sedimentation model fully described in [1]. We emphasize that SEDLOB can be coupled to any 3–D OGCM that provides adequate input fields of temperature, salinity, velocity, and convection depth. The importance of convection depth input has been shown by [2]. The model itself basically consists of two linked components: (1) a 3–D sediment transport model in the ocean interior, and (2) a 2–D sediment transport model in a thin near–bottom layer following smoothed bottom topography (Figure 1). The lower 2–D sub–model is initialized and forced at every time step by the data generated within the 3–D sub–model: The OGCMs temperature, salinity, and velocity fields are projected on the smoothed bottom. In addition, the near–bottom velocities are reduced to take bottom friction into account. The sediment is continuously exchanged between both parts of SEDLOB depending on sediment concentration, vertical velocity, and settling velocity. SEDLOB simulates the sedimentation rates depending on the corresponding circulation patterns and pelagic sediment dynamics.

PATLOB exercises a hybrid Eulerian–Lagrangian (or semi–Lagrangian) approach; the velocity components are interpolated to the current positions of the Lagrangian particles from the nearby grid points of an Eulerian numerical grid. As in the sediment transport model described above, the Eulerian velocity field is provided by the OGCM, whereas the coordinates of Lagrangian particles are calculated straightforwardly, using the Lagrangian velocity along the trajectory. More details about the design are given by [1].

PATLOB traces transport pathways of material particles, e.g., water parcels, sediment components, pollutants, and natural or artificial organic material.

Convection mixes water vertically in water columns or ‘‘chimneys’’. As we have emphasized above, ventilating convection induced by hydrostatic instability is included in all three components of our simulations. The semi–Lagrangian trajectory–tracing model calls, however, for a different convective procedure to exercise vertical ventilation. Here the velocity field is supplemented by the convection depths showing where and to what depth the vertically mixing volume should be propelled in the turbulent chimney.

RESULTS

Our objective is to quantify the sedimentation rates and pelagic sediment dynamics at three time slices of different climatic forcing: the Holocene/Modern (HM), the meltwater event at 13,500 ^{14}C yrs BP (MWE), and the LGM. The HM state is displayed in Figure 2–5 as reference time slice. Modern velocity patterns for the upper and deep ocean are shown in Figure 2a, b. The paleocirculation patterns differed from the HM significantly, though the locations of the sedimentation drifts did practically not change in the North Atlantic. However, the sedimentation rates in these drifts were different during both the LGM and MWE, as compared to each other and to the HM as reference in Figure 3.

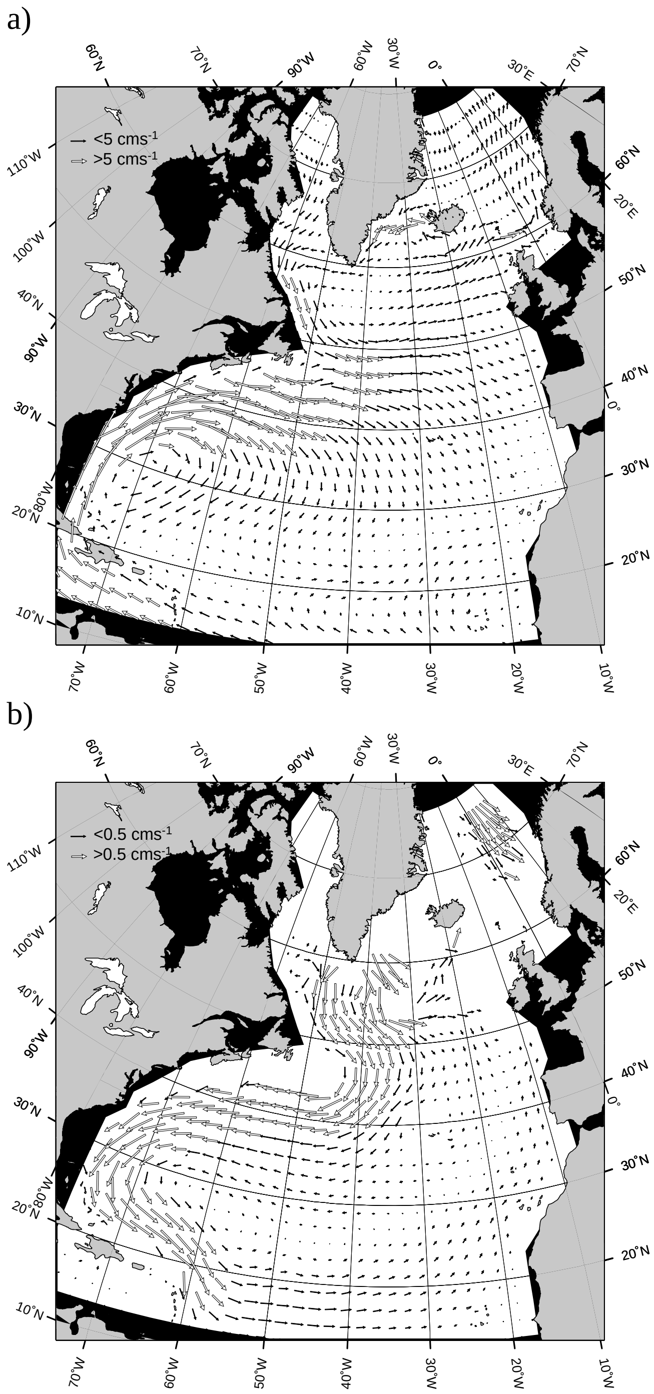

Figure 2: Modern velocity (a) at z=50 m and (b) at z=2000 m.

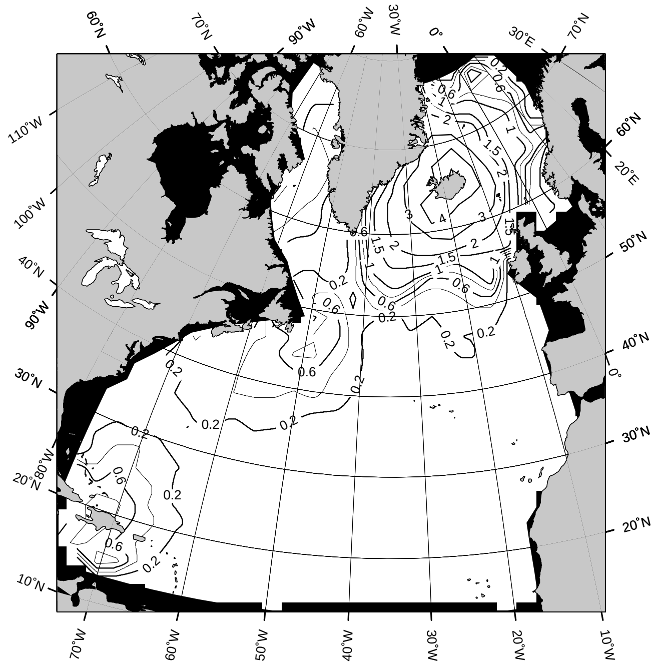

Figure 3: Sedimentation rate (cm/ka) facilitated by the modern ocean circulation pattern.

PATLOB is used to interpret the ventilation of the deep ocean and to analyze changes of the routes of the major ocean currents and/or transports of settling particles. The modern deep ventilation is shown in Figure 4. Particle transport paths depend on starting location (Figure 5a, b). A computer animation program has been developed to utilize this advantage of the semi–Lagrangian technique, providing us with a very useful tool to address both sedimentation and deep ocean ventilation problems.

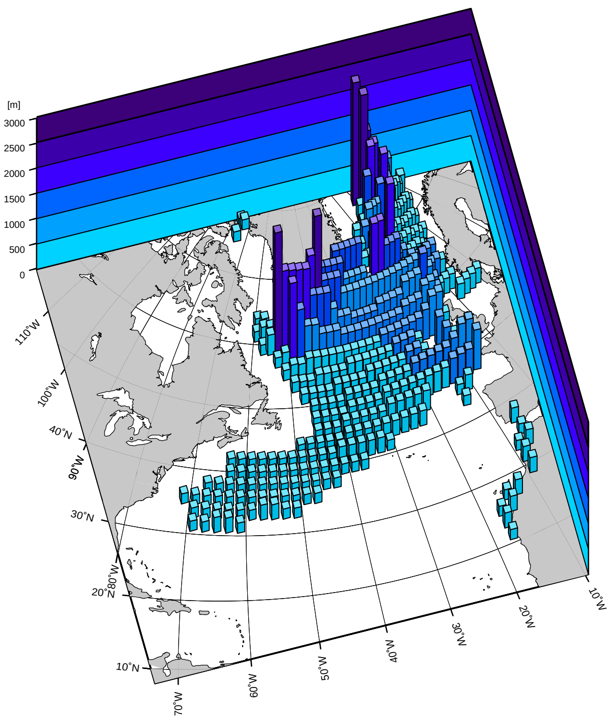

Figure 4: Diagram of modern convection. The height of the bars are equal to the depth of convection.

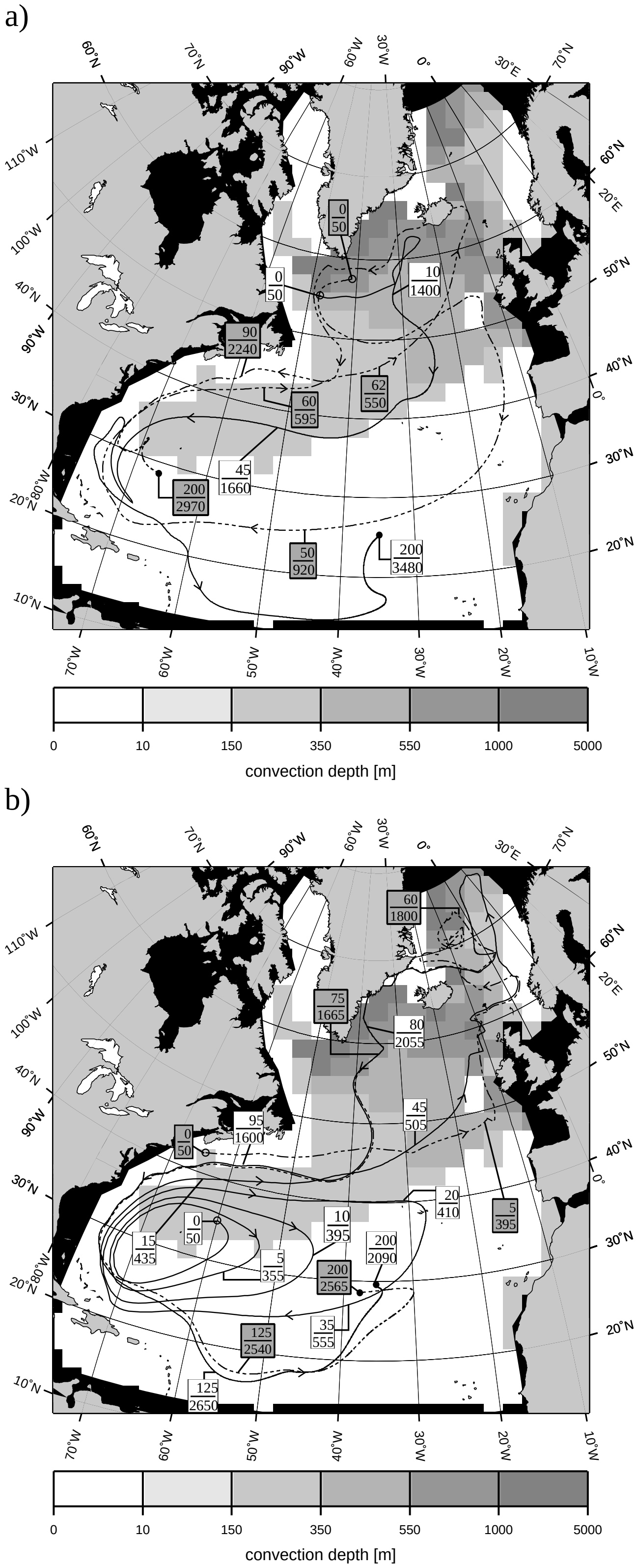

Figure 5: A 200–year history of pairs of the Lagrangian particles calculated from the HM circulation. Small rectangles show elapsed time and depth, and small circles indicate starting points; the arrows show the direction of motion, and the bullets indicate the end points of the trajectories. One of the trajectories of each pair is presented by a dashed line

The different 3–D pathways of settling particles, their deposition, and the growing of sediment bodies can be demonstrated by several video presentations.

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