// PAST OCEAN CIRCULATION

DOES ICE-RAFTED DEBRIS DISRUPT THE NEODYMIUM PALAEOCIRCULATION TRACER?

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1 BACKGROUND

The discovery of abrupt climate variability in high-resolution geological archives is one of the most exciting and alarming developments in modern climate science. Changes in ocean circulation may explain some of the dramatic climate oscillations estimated for the North Atlantic throughout the past glaciations and deglaciations, but reconstructing past ocean circulation is a major challenge.

One approach is through the use of '**palaeocirculation tracers**', chemical signals of known origin that are conserved by parcels of water as they move through the oceans and are then permanently recorded in sediments, allowing water motion to be reconstructed.

A serious problem facing the use of palaeocirculation tracers is the question of tracer conservation. For a tracer to be useful, a water mass must faithfully conserve its characteristic chemical signal as it moves around the ocean. There has been much interest in the use of **neodymium isotopes** as a conservative tracer, but recent research has shed doubt on this assumption[1,2].

In particular, measurements taken from sediment cores in the eastern North Atlantic appear to represent highly non-conservative behaviour (figure 1) during periods of time (the **last glacial maximum** [LGM] and **Heinrich Events** [HE]) in the Earth's history where icebergs were depositing vast quantities of sediment into the water column, known as **ice-rafted debris** (IRD). It has therefore been suggested that adsorption-desorption interactions between neodymium and settling IRD (known as **reversible scavenging**) could be the cause of this non-conservative behaviour[1]. But is this actually possible?

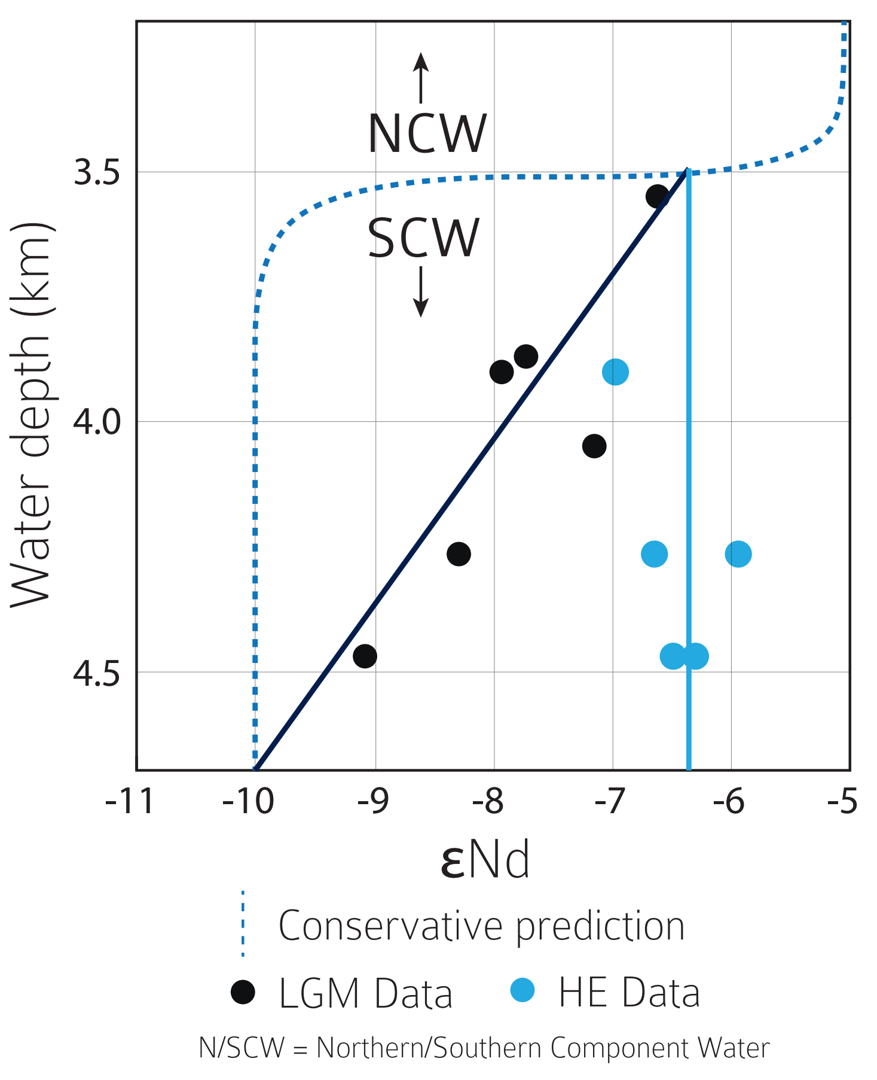

Figure 1 (Adapted from [1])

2 METHODS

To test the hypothesis that IRD could be redistributing neodymium throughout the water-column, I developed a 50-layer **water-column geochemical box model**, incorporating the main dynamics involved in neodymium cycling in the IRD belt, eastern North Atlantic, as summarised in figures 2a and 2b.

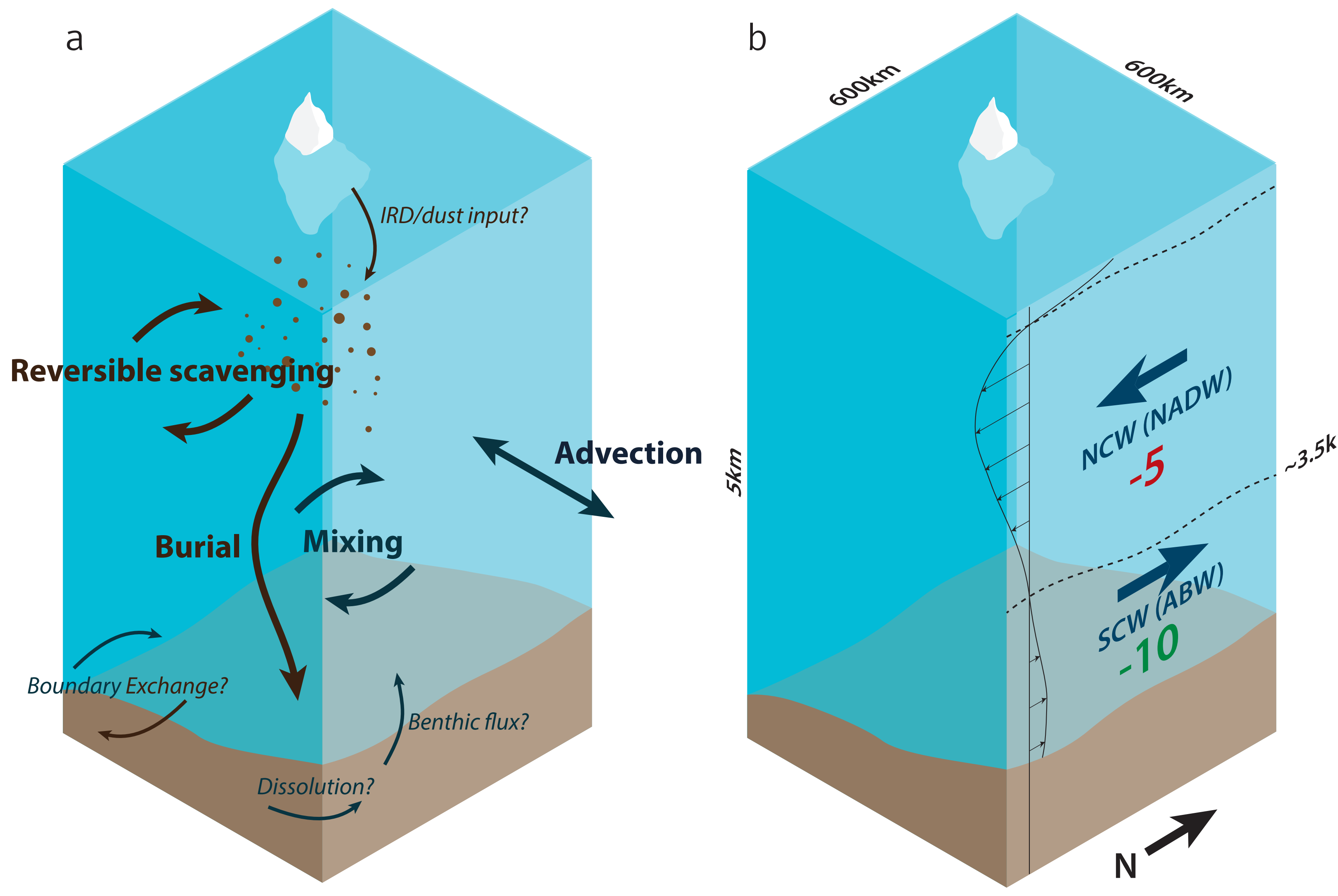

Figure 2: (a) The key dynamical processes involved in the cycling of neodymium in the open ocean, integrated into the model; (b) Boundary conditions relevant to the eastern North Atlantic during the last glaciation and deglaciation, including model domain dimensions and velocity profile. N/SCW = Northern/Southern Component Water. NADW = North Atlantic Deep Water. ABW = Atlantic Bottom Water.

Critically, since the model assumes that scavenging is the main sink term for dissolved neodymium, the scavenging rate is broadly equivalent to the residence time of neodymium in the water column. For context, the residence time of neodymium in the global ocean is **more than 500 years**[3]. Whilst scavenging rate is the key variable of interest, a list of variables is given below:

Parameters	Boundary conditions
• Adsorption/desorption rates	• Upstream [Nd] and **ε**Nd
• Water-column velocity profile	• Preloaded surface [Nd] and **ε**Nd
• Particle sinking rate	
• Vertical diffusivity (mixing)	
• Benthic flux piston velocity	

3 RESULTS

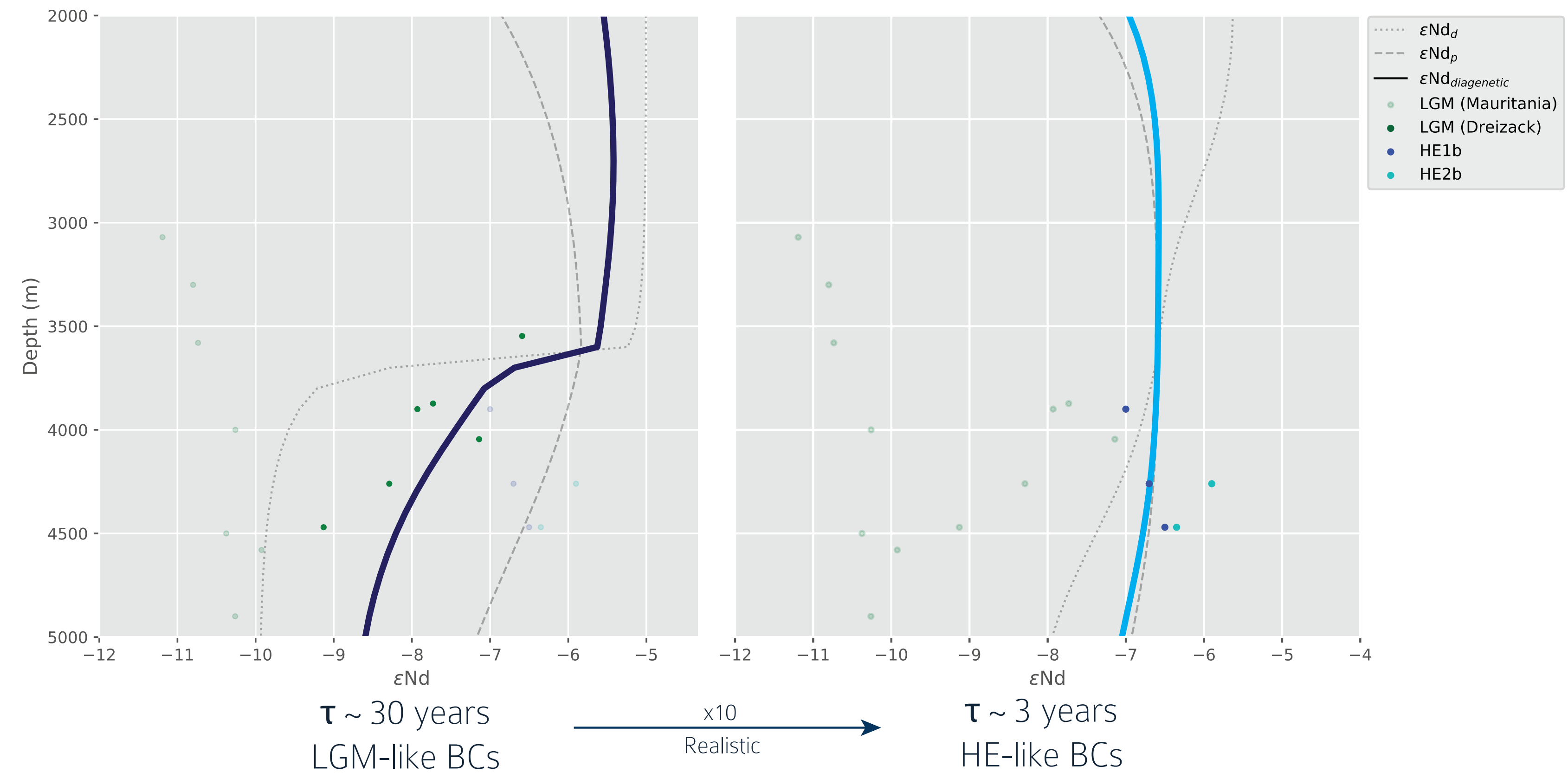

Figure 3: Model output for Neodymium profiles in the case of (1) LGM-like and (2) HE-like boundary conditions. In each case, scavenging rates have been chosen to maximise fit whilst minimising rate.

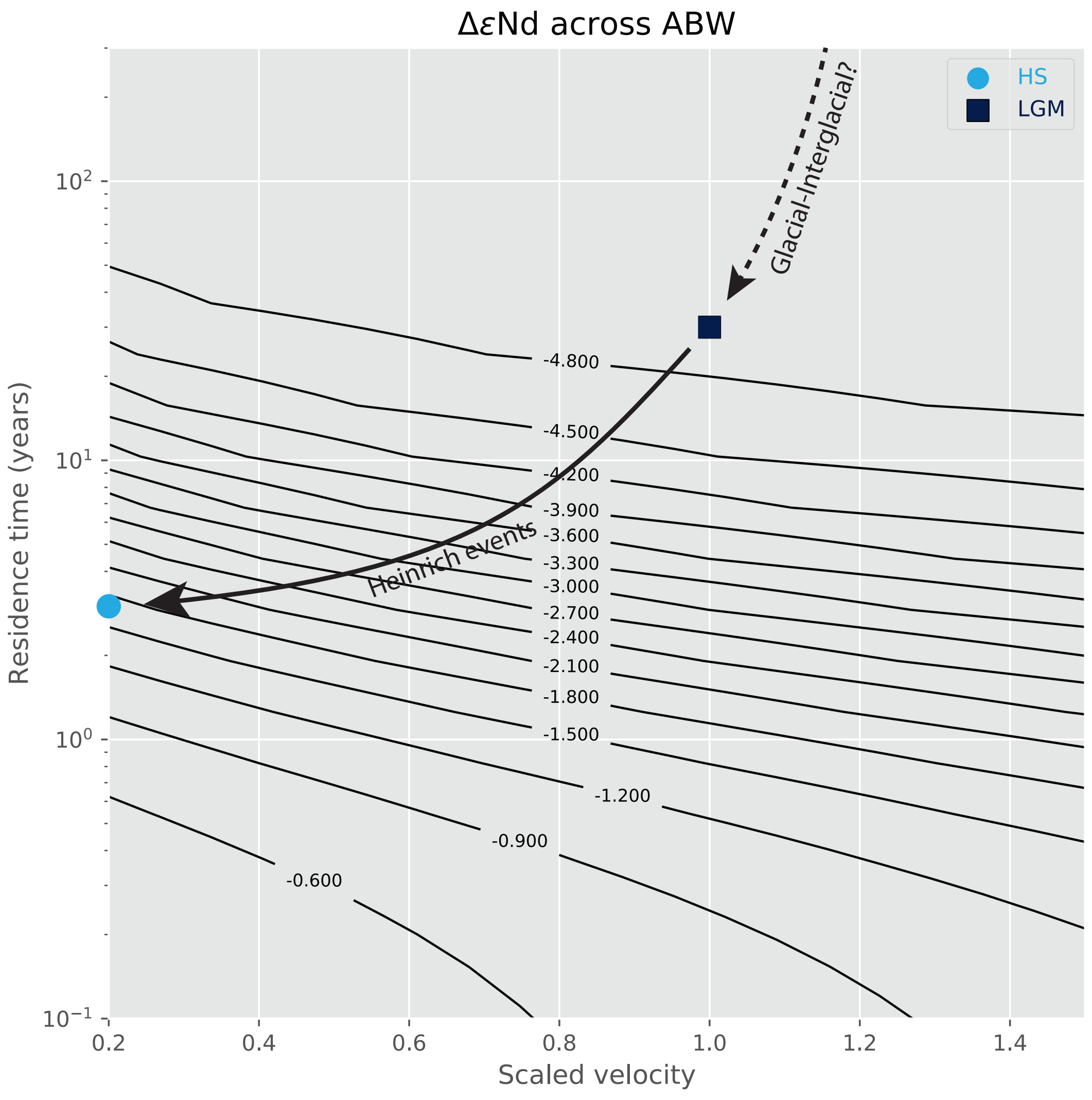

Figure 4: Model parameter space, plotting the change in **ε**Nd across SCW versus scavenging rate (as residence time) and velocity (normalised to the LGM scenario). Entirely conservative behaviour would be represented by the -5 contour; higher values represent non-conservative behaviour.

Crucially, significant deviations from conservative behaviour only occur with residence times of decades or less, independent of water column velocity.

The discrepancy with figure 3 is because **ε**Nd$_{d}$ is plotted instead of **ε**Nd$_{diagenetic}$.

Whilst this model has generated a number of interesting findings, the key discovery is that the model is able to **reproduce reconstructed εNd profiles for the LGM and HEs**. Furthermore, the increase in scavenging rate required to transition from an LGM-like profile to a HE-like profile is c. 10, which is approximately equal to the increase in IRD flux from the LGM to HEs.

The caveat is that non-conservative behaviour can only be triggered by IRD with scavenging rates equivalent to very short residence times of years and decades, significantly below the whole-ocean residence time. This suggests that, if this hypothesis is correct, neodymium cycling was **radically different** in the glacial and deglacial Atlantic versus the modern. This would also raise questions about the reliability of the **ε**Nd palaeocirculation tracer, especially since ocean circulation during times of high IRD flux is of particular interest.

However, despite intriguing recent findings from the Bay of Bengal[4] and Panama Basin[5], empirical estimates for **ε**Nd scavenging rates under varying IRD fluxes do not exist. This should therefore be a priority for future research.

1 Blaser et al., 2018. The resilience and sensitivity of Northeast Atlantic deep water εNd to overprinting by detrital fluxes over the past 30,000 years. *In review.*
2 Roberts and Piotrowski., 2015. Radiogenic Nd isotope labeling of the northern NE Atlantic during MIS 2. *Earth and Planetary Science Letters (423) 125-133*
3 Tachikawa et al., 2003. Neodymium budget in the modern ocean and paleo-oceanographic implications. *J. Geophys. Res. (108) 3254*
4 Yu et al., 2017. Seasonal variations in dissolved neodymium isotope composition in the Bay of Bengal. *Earth and Planetary Science Letters (479) 310-321*
5 Grasse et al., 2017. Short-term variability of dissolved rare earth elements and neodymium isotopes in the entire water column of the Panama Basin. *Earth and Planetary Science Letters (475) 242-253*

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