

## 1. Introduction & Motivation

- It is important to study the Greenland Ice Sheet (GRIS) in past warm climates as there is a large uncertainty in its response to warming climate conditions. Approximately 7.36m of sea level equivalent could melt over the next 1000 years.
- The late Pliocene has similarities to the projected 21<sup>st</sup> century climate and data are available to constrain ice sheet and iceberg models.
- Marine Isotope Stage M2 (3.3Ma) is a cold period in the late Pliocene. Localized evidence of ice exists, but not of a larger Northern Hemisphere glaciation. A drop in sea level up to 60m and CO<sub>2</sub> at 220ppmv.
- In the mid Piacenzian Warm Period (mPWP), temperatures were 2–3°C warmer than present and CO<sub>2</sub> was about 405ppmv.

- The exact extent of GRIS during both warm and cold periods in the late Pliocene remains unclear.

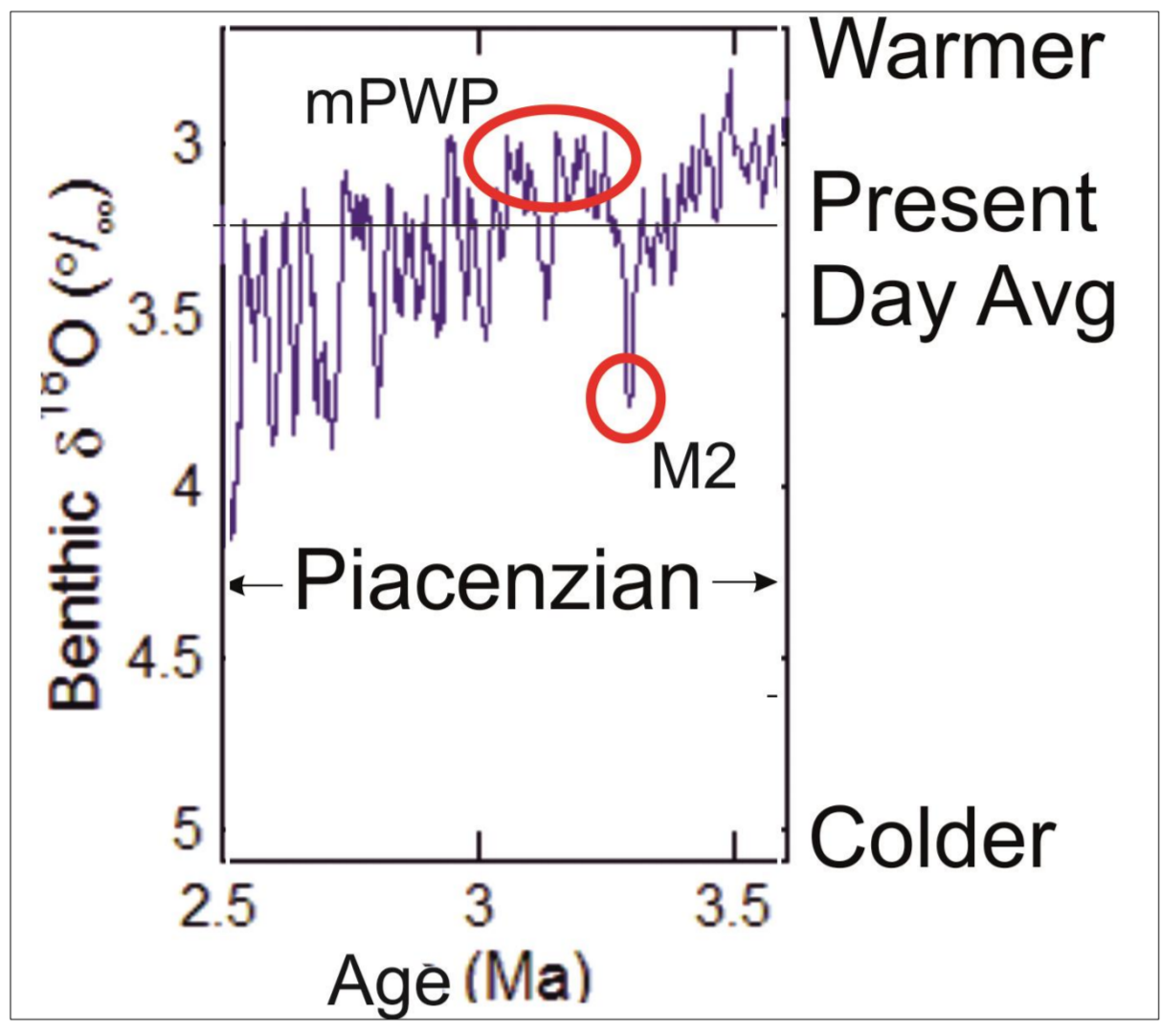


Figure 1. Benthic δ<sup>18</sup>O image shows the mPWP and the MIS M2 (modified from Lisiecki and Raymo, 2005).

## 2. Modelling

- Climate model simulations run by Hill (2015) and Dolan et al (2015) were used. USGS PRISM (Pliocene Research, Interpretation & Synoptic Mapping) data were used to construct boundary conditions of the mPWP scenario (Figure 2).
- Present day - using a pre-industrial climate scenario.
- MIS M2 climate scenarios used in Dolan et al (2015).
- mPWP climate scenario used in Hill (2015).
- The thermodynamic iceberg model of Bigg et al (1997) was seeded with 100 icebergs each month from several marine terminating glaciers based on locations given by Matsumoto (1997) and Bigg et al (1997) (Figure 3).

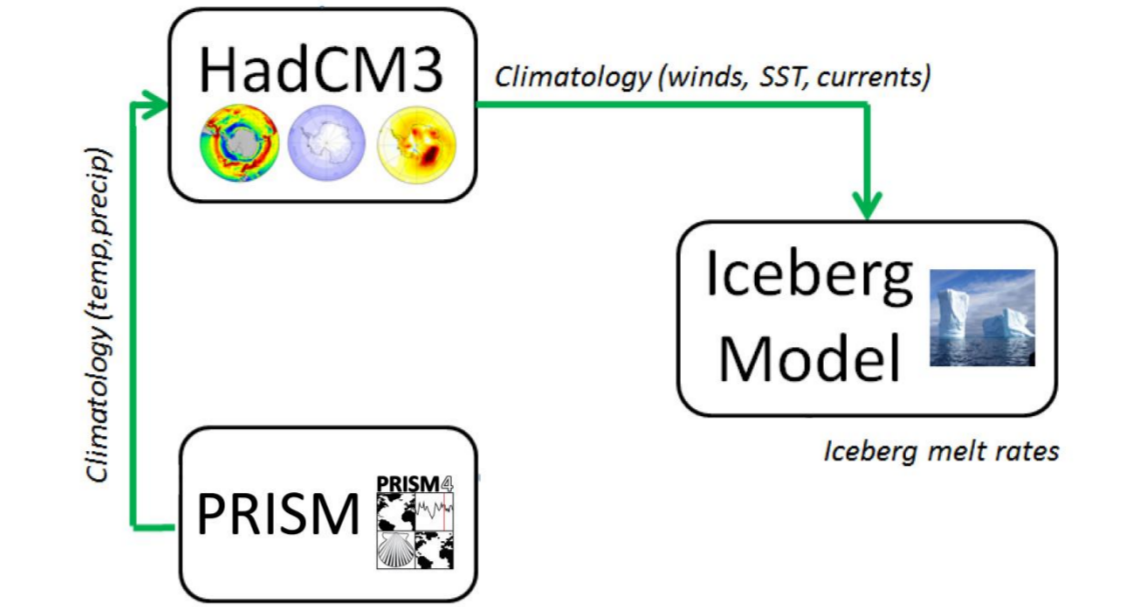


Figure 2. HadCM3 climate forcing fields feed into the iceberg model to produce melt rates.



Figure 3. Iceberg seeding locations

## 3. Evidence of Ice Rafted Debris

- Ice rafted debris (IRD) is evidence found in marine sediment cores which help decipher the state of the ice sheet.
- The distribution of North Atlantic IRD in space and time tells us about the location of iceberg-producing glaciers of the northern hemisphere.
- Iceberg trajectories were modelled using the cold M2 and warm mPWP Pliocene climate scenarios to see where IRD would be found in the North Atlantic under these conditions.
- The trajectories are compared with the location of IRD found in the North Atlantic using marine sediment samples at the USGS, Reston, Virginia (Figure 4).



Figure 4. Pre-washed and dried samples of sediment are kept in glass vials at the USGS lab. The sediment is tipped onto a sorting tray and a microscope is then used to visually search for IRD

## 4. Climate Model Scenarios

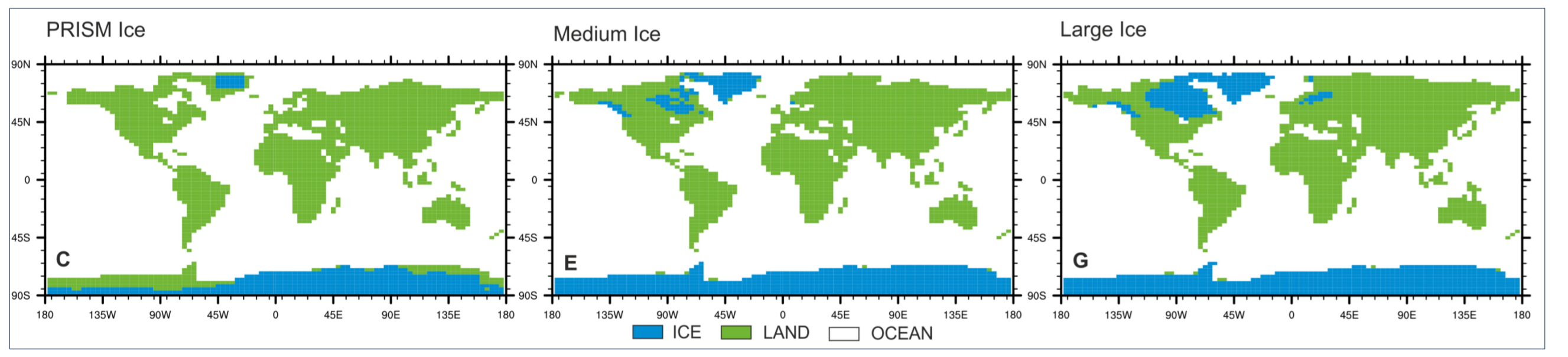


Figure 5. Visual representation of the ice sheet extent used within the climate models.

## 6. Sensitivity Results: North America

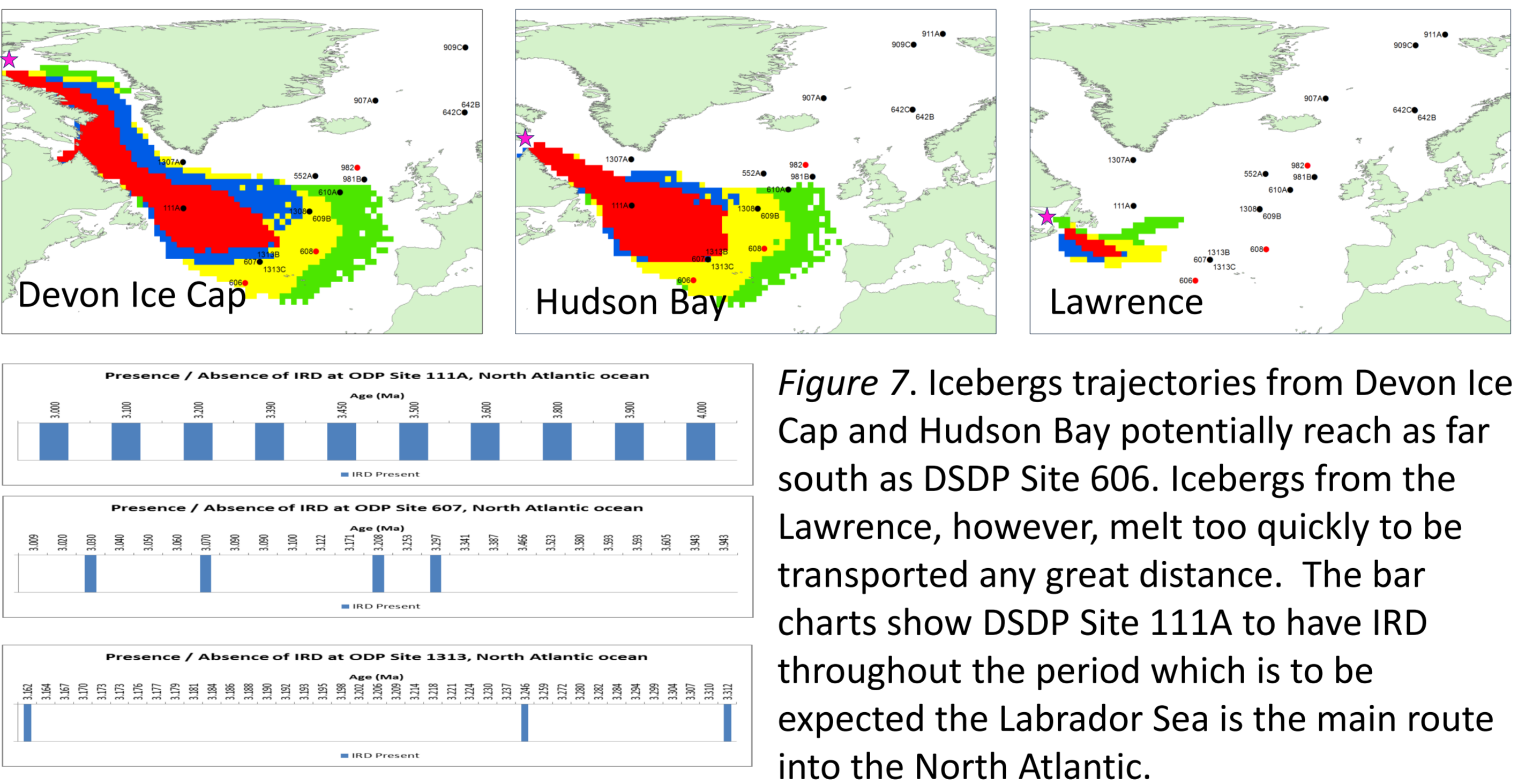


Figure 7. Icebergs trajectories from Devon Ice Cap and Hudson Bay potentially reach as far south as DSDP Site 606. Icebergs from the Lawrence, however, melt too quickly to be transported any great distance. The bar charts show DSDP Site 111A to have IRD throughout the period which is to be expected the Labrador Sea is the main route into the North Atlantic.

## 8. Sensitivity Results: Climate Scenarios

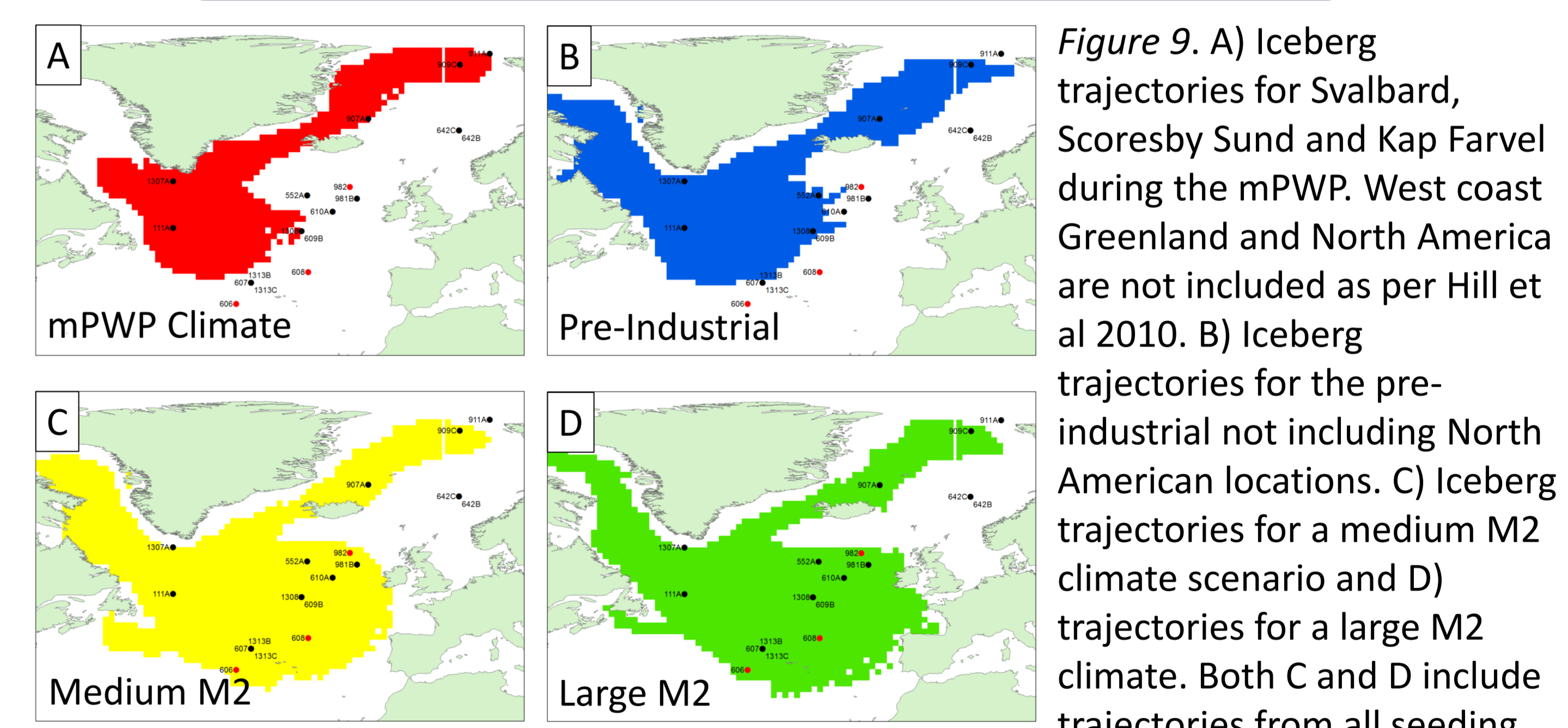


Figure 9. A) Iceberg trajectories for Svalbard, Scoresby Sund and Kap Farvel during the mPWP. West coast Greenland and North America are not included as per Hill et al 2010. B) Iceberg trajectories for the pre-industrial not including North American locations. C) Iceberg trajectories for a medium M2 climate scenario and D) trajectories for a large M2 climate. Both C and D include trajectories from all seeding locations.

## 5. Sensitivity Results: Greenland

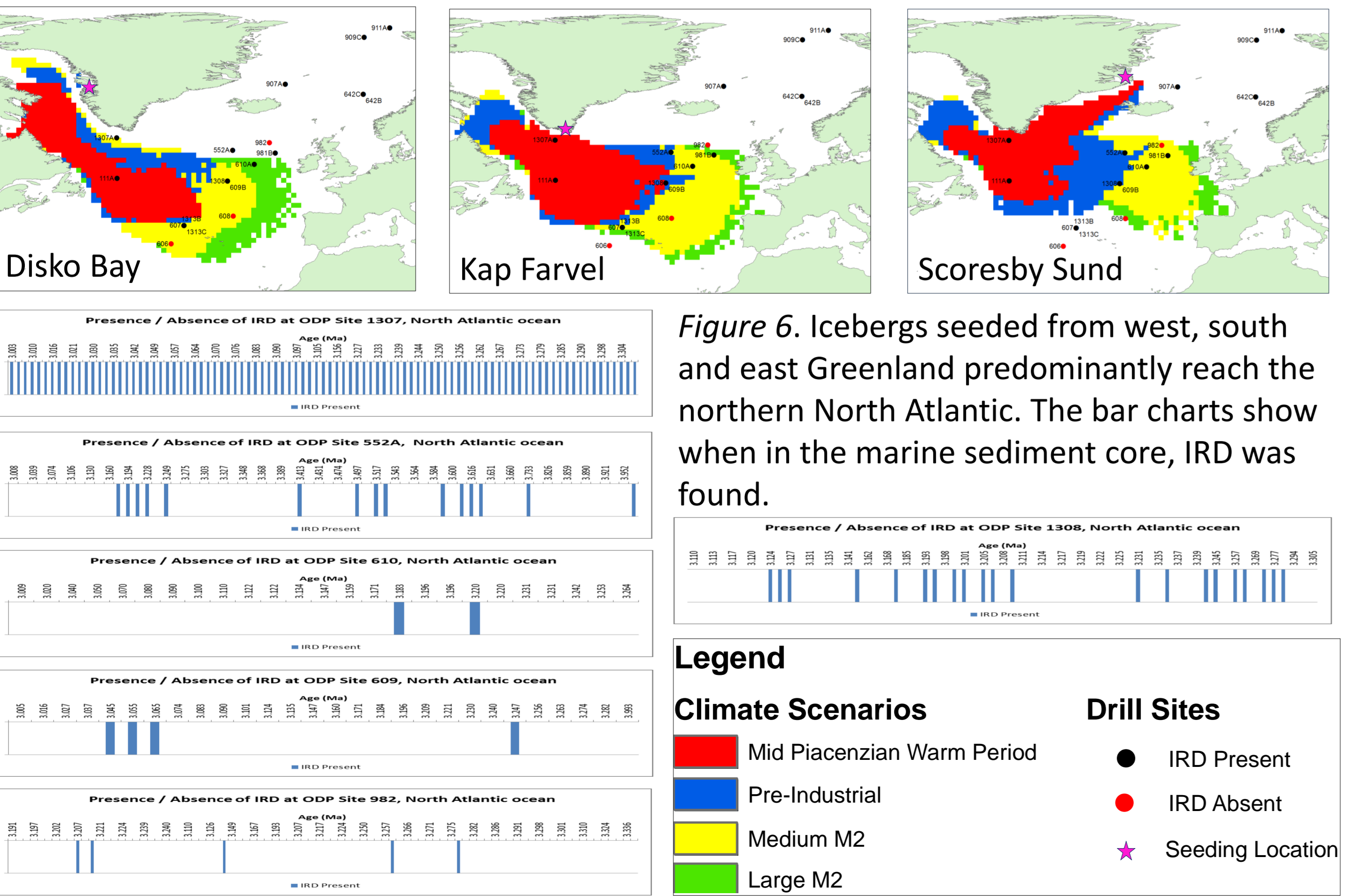


Figure 6. Icebergs seeded from west, south and east Greenland predominantly reach the northern North Atlantic. The bar charts show when in the marine sediment core, IRD was found.

**Legend**

Climate Scenarios	Drill Sites
Mid Piacenzian Warm Period	● IRD Present
Pre-Industrial	● IRD Absent
Medium M2	★ Seeding Location
Large M2	

## 7. Sensitivity Results: Svalbard

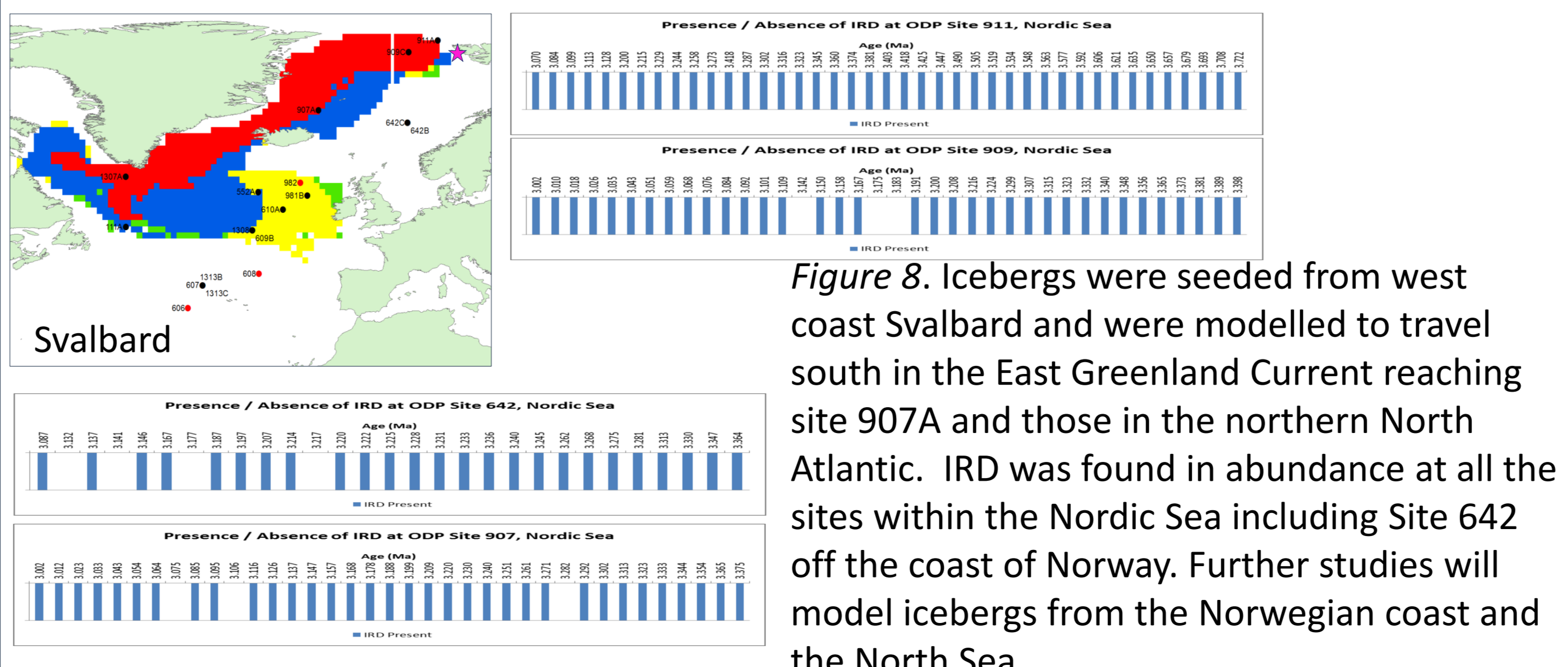


Figure 8. Icebergs were seeded from west coast Svalbard and were modelled to travel south in the East Greenland Current reaching site 907A and those in the northern North Atlantic. IRD was found in abundance at all the sites within the Nordic Sea including Site 642 off the coast of Norway. Further studies will model icebergs from the Norwegian coast and the North Sea.

## 9. Conclusions

- Modelling iceberg trajectories can give an indication of where IRD from a potential ice mass could be found.
- IRD found in these three areas give a clue to the extent of ice sheets in the Northern Hemisphere during the M2 and the mPWP.
- It is hypothesised that icebergs from North America reach as far south as Area 3. Icebergs from Greenland reach predominantly Area 2. Icebergs from Svalbard reach Area 1 and 2 (Figure 10).

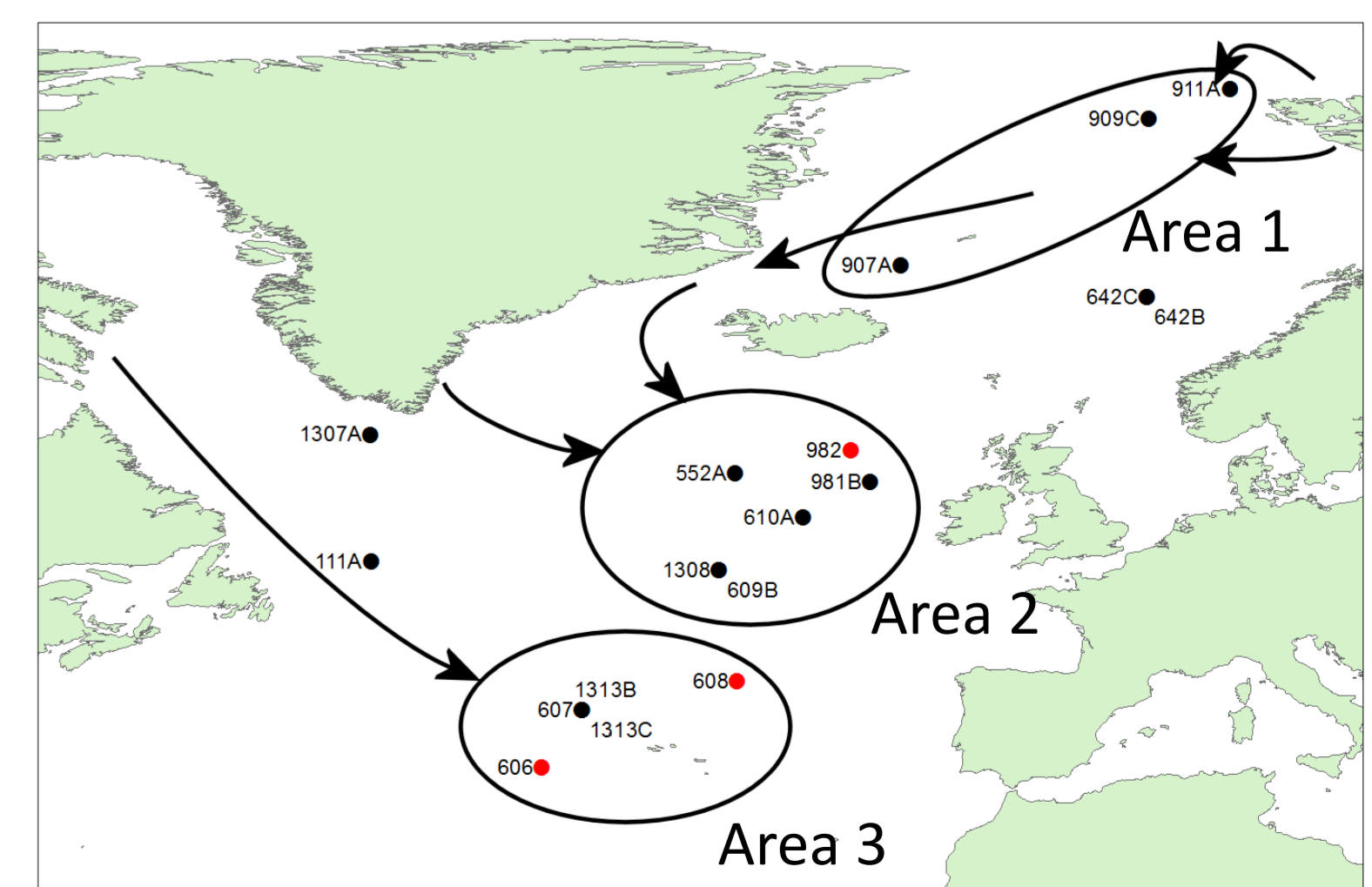


Figure 10. Location of sites with a presence of IRD with arrows showing potential sources