Final Report: Collaborative Research: Abrupt Climate Change and the Atlantic Meridional Overturning Circulation – sensitivity and non-linear response to Arctic/sub-Arctic freshwater pulses"

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| Project Number: | DE-FG02-08ER64592 |
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**Abstract**

This project investigated possible mechanisms by which melt-water pulses can induce abrupt change in the Atlantic Meridional Overturning Circulation (AMOC) magnitude. AMOC magnitude is an important ingredient in present day climate. Previous studies have hypothesized abrupt reduction in AMOC magnitude in response to influxes of glacial melt water into the North Atlantic. Notable fresh-water influxes are associated with the terminus of the last ice age. During this period large volumes of melt water accumulated behind retreating ice sheets and subsequently drained rapidly when the ice weakened sufficiently. Rapid draining of glacial lakes into the North Atlantic is a possible origin of a number of paleo-record abrupt climate shifts. These include the Younger-Dryas cooling event and the 8,200 year cooling event.

The studies undertaken focused on whether the mechanistic sequence by which glacial melt-water impacts AMOC, which then impacts Northern Hemisphere global mean surface temperature, is dynamically plausible. The work has implications for better understanding past climate stability. The work also has relevance for today's environment, in which high-latitude ice melting in Greenland appears to be driving fresh water outflows at an accelerating pace.

## **Project Activities**

Key goals of the project were to

1. examine whether the AMOC impact interpretation of Younger-Dryas and 8,200 year events is a well understood result.
2. consider factors driving changes in the present-day Arctic fresh water budget and their connection to increased melt-rates and fresh-water exports

A major activity was examining the dynamics and mechanisms by which fresh-water pulses propagate in the North Atlantic. This entailed deploying, enhancing and calibrating a model that included relevant ocean (Menemenlis 2008) and sea-ice dynamics (Nguyen 2009, Losch 2010, Heimbach 2010, Nguyen 2011). The resulting global model reproduced modern the Pacific, Arctic, North Atlantic ocean and sea-ice dynamics well at resolutions high enough (roughly 16km horizontal resolution) to crudely resolve boundary currents that arise from a large buoyant fresh-water pulse. Figure 1 (reproduced from Losch 2010) shows Arctic seasonal ice-cover against satellite ice-edge measurements.

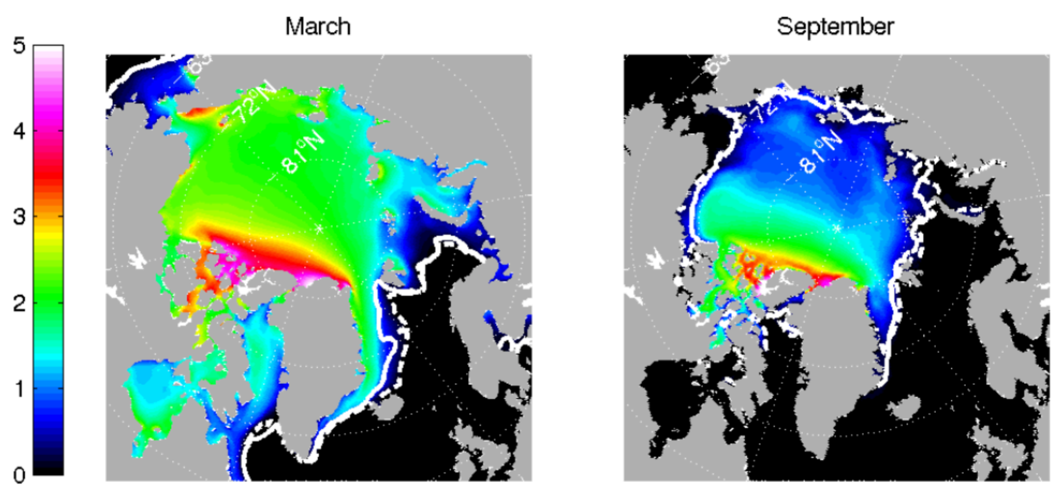


**Figure 1 Effective sea-ice thickness for 1992-2002. White solid line marks ice edge from passive microwave satellite data.**

The modeling tools developed provided a basis for examining the mechanistic pathways by which buoyant plumes enter the North Atlantic.

Previous generation modeling studies were restricted, by technology limitations, to relatively coarse spatial resolution (i.e. model spatial resolution of 100km or more). In this project we were able to use model resolutions that allowed the important effects of Coriolis and continental shelf bathymetry to be captured. In these studies horizontal resolutions of about 16km were employed. This resolution change was significant, because without the combined effects of Coriolis and bathymetry a buoyant plume can enter the open-ocean directly. With these effects more accurately accounted for, however, a buoyant plume is constrained by laws of fluid dynamics to follow a very different path. The results are illustrated in figure 2 (reproduced from Condron, 2011). The figure shows that increased resolution reveals a significant modulation of buoyant plumes by rotational and bathymetric effects, this alters the pathways to impact on regions important to AMOC.

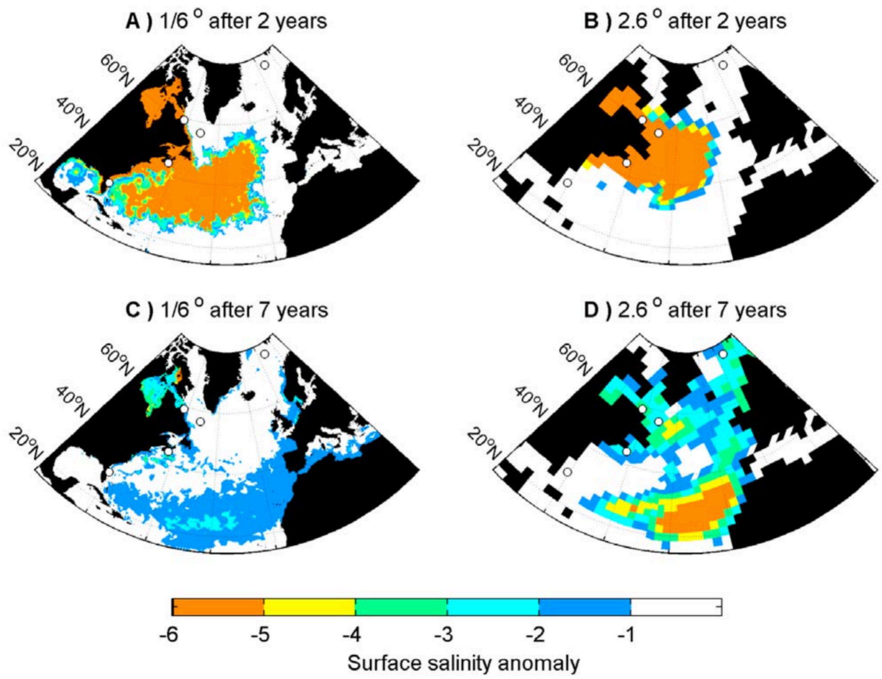


**Figure 2 Comparison of pathways followed by buoyant plume over 7 years at two different resolutions.**

The results in Figure 2 are consistent with contemporary float observations that track buoyant fluid parcels in the Labrador Current. These fluid parcels predominantly flow southward along coastal margins. They are entrained into the open ocean gradually at mid-latitudes, with little direct flow to open-ocean convection regions in the Labrador and Greenland Seas.

Overall these studies improve understanding of pathways for fresh water plumes from the Canadian shield via Hudson Bay (the case for some historic glacial lake events) and from Greenland (arising from contemporary melting). They show that the previously accepted abrupt climate impact mechanism may have been modulated or modified somewhat by fluid dynamics.

The impact of Arctic fresh water plumes was also examined, in a study that explored the role of atmospheric circulation in regulating fresh water surface layers in the Arctic. This study drew on recent records of Arctic state during alternating periods of the North Atlantic Oscillation (NAO) index. The NAO index is a simple measure of the surface atmospheric pressure difference between Iceland and the Azores. It shows variability on a broad range of time scales and captures shifts in the strength of the Arctic mean atmospheric circulation. Stronger mean atmospheric circulation can act to increase Ekman convergence in the Arctic ocean, leading to an accumulation of fresh-water. Conversely, weakening mean atmospheric circulation can result in accumulated fresh-water abruptly exiting the Arctic. Figure 3 (from Condron, 2009) compares Arctic fresh-water storage for different NAO “phases”.

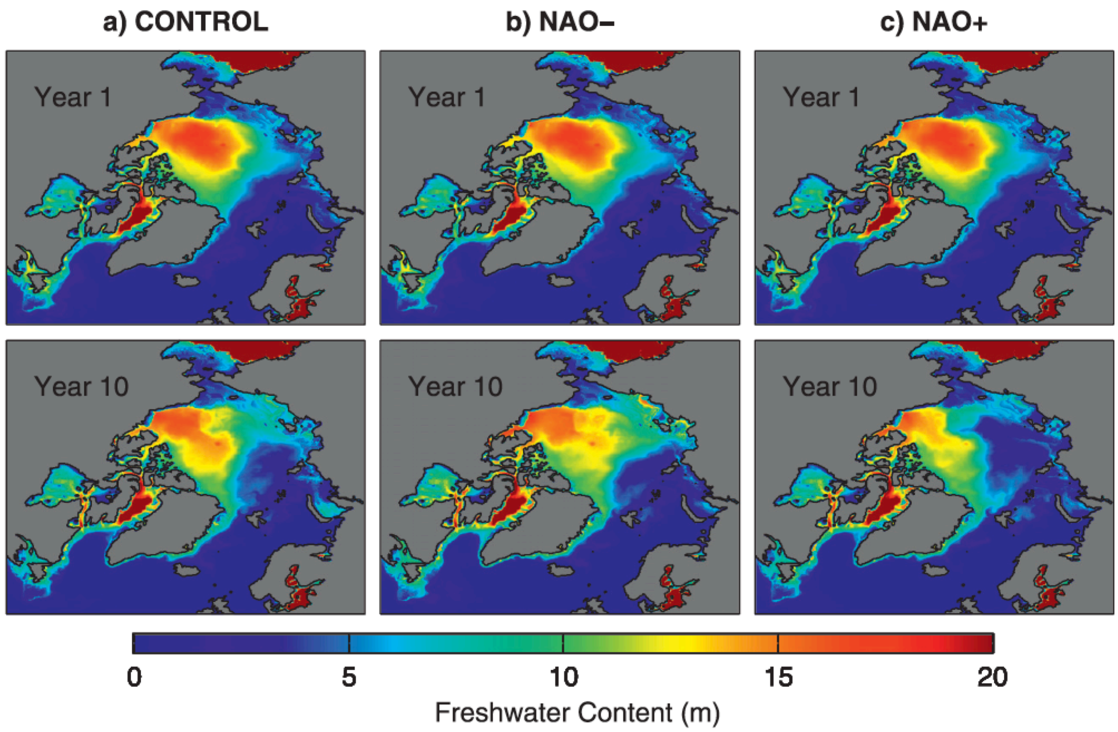


**Figure 3 Results from numerical experiments examining the role of atmospheric mean state on regulating Arctic fresh-water export.**

The study illustrated in Figure 3 showed that Arctic fresh-water pulses may be generated somewhat stochastically by atmospheric variations on decadal time-scales. These results are broadly consistent with contemporary observations of events such as the 1968-1982 salinity anomaly.

## Publications and References


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