Effects of different grid resolutions when simulating passive ocean tracers using NEMO and AGRIF

Clark Pennelly[1] and Paul G. Myers[1]

[1]Department of Earth and Atmospheric Sciences, University of Alberta, Canada

Research Objectives:

Determine the effects of higher resolution ocean model simulations in the Gulf of Mexico, particularly when simulating a Deepwater Horizon oil spill event. We will use a grid-refinement tool to produce a high-resolution numerical grid, over a small spatial area.

Hypothesis:

The inclusion of a high resolution grid nested inside a standard ocean model simulation will produce more realistic features than without the high-resolution nest, with only a moderate increase of computational costs.

Methods:

•Ran two NEMO [1] simulations
•Control simulation with 1/4° resolution
•AGRIF[2] simulation with 1/12° resolution in Gulf of Mexico, 1/12° outside the Gulf of Mexico
•Simulations were spun-up from 2005 through 2010
•We simulated a Deepwater Horizon oil spill event[3] in both simulations, which started on April 20th 2010 and terminated on July 15th 2010.
•Oil tracers were released throughout the event.
•Oil decay was subject to a temperature dependent removal rate[4].

AGRIF:

AGRIF (Adaptive Grid Refinement in Fortran) is a mesh refinement tool which can be used inside numerical models to include high resolution at user selected locations. AGRIF interpolates from a coarse grid, to a finer grid, to perform the same numerical calculations on. We used a grid refinement of 1:3, meaning a grid 10 X 10 was interpolated to 30 X 30.

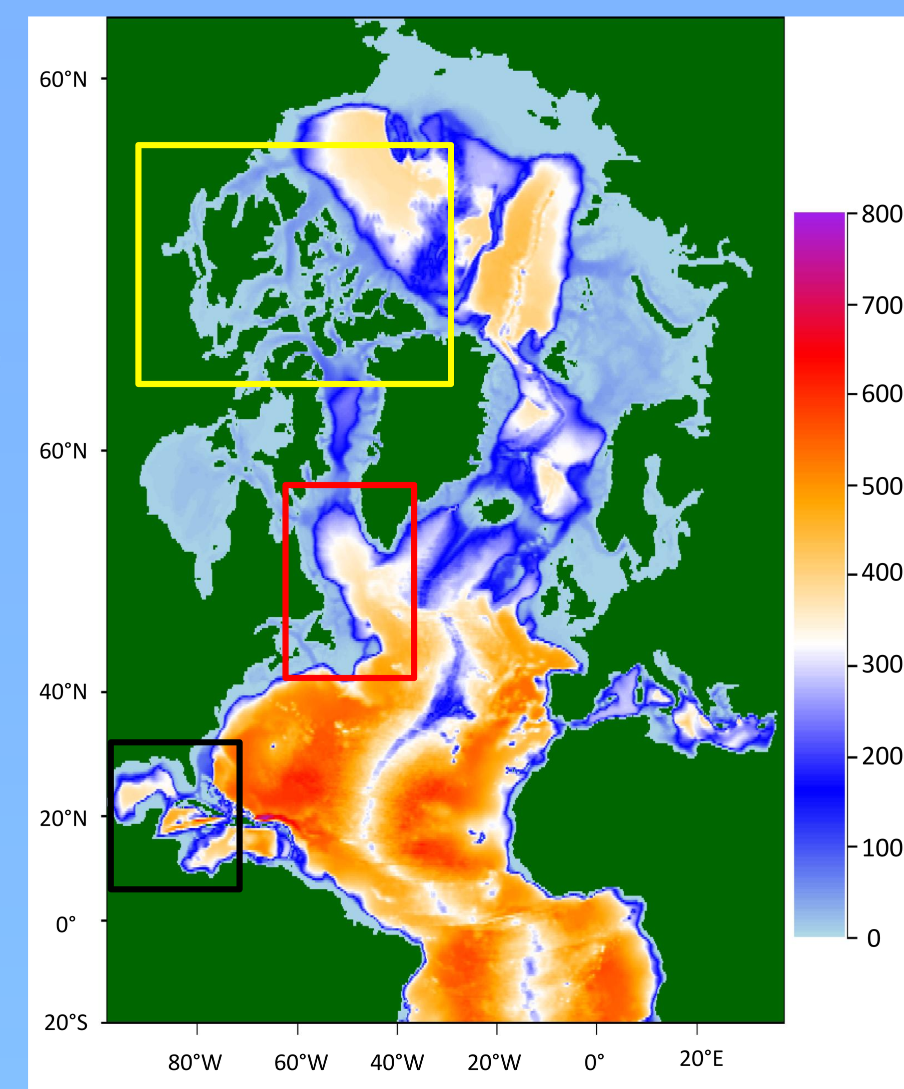

Figure 1: Bathymetry, in meters, of the control simulation. The color boxes indicate specific AGRIF high-resolution nests: **BLACK** is the Gulf of Mexico, **RED** is the Labrador Sea, and **YELLOW** is the Canadian archipelago. The Labrador Sea and Canadian archipelago nests were not included alongside the Gulf of Mexico nest, and will be discussed below in our "work in progress" section.

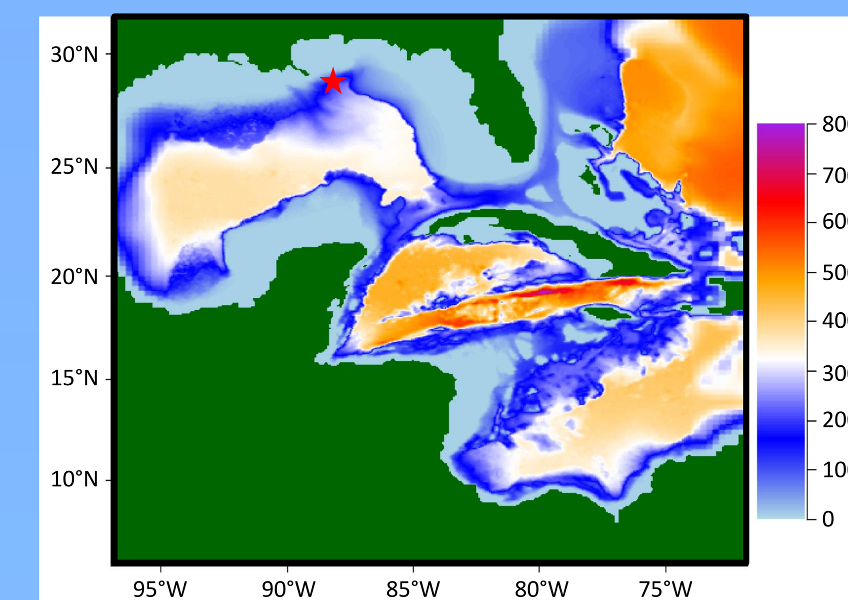

Figure 2: Bathymetry, in meters, of the AGRIF nest inside the Gulf of Mexico. The location of the Deepwater Horizon oil leak is indicated with a red star. We used a 1/12° bathymetry dataset for the AGRIF domain, rather than interpolate from 1/4° bathymetry data. Sponge layers are maintained near the borders, to maintain stability. The AGRIF simulation also includes the domain depicted in Fig. 1, at the same resolution as our control.

Table 1: Model differences between the control and AGRIF simulation

Parameter	Control	AGRIF
Time-step	1200 s	400 s
Grid points (dx:dy:dz)	544:800:50	300:330:50
Model Resolution	1/4°	1/12°
Time to simulate 1 yr	10 hr	24 hr

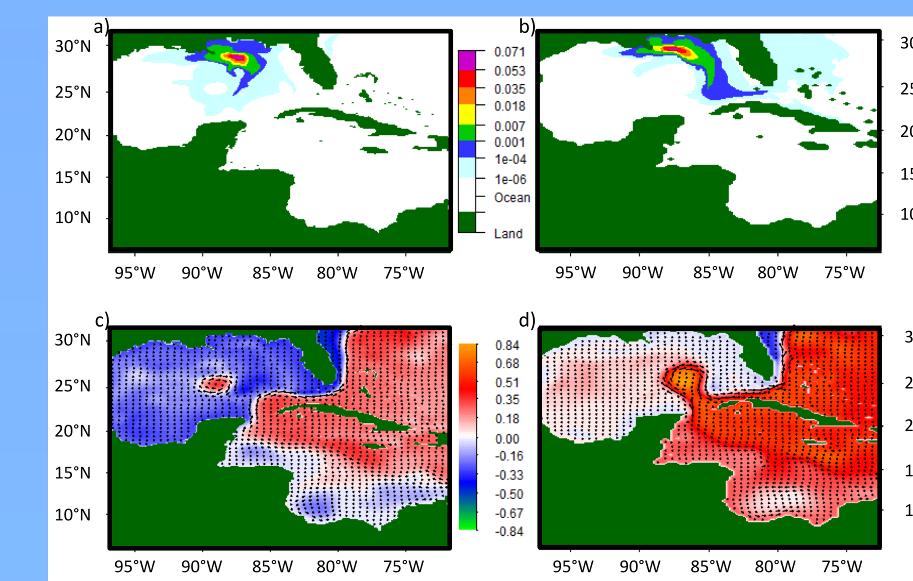

Figure 3: Contour plot of the concentration of oil on the surface of the water (cm^3/m^2), on July 30th, 15 days after the oil leak was contained, when simulated with AGRIF (a) and with our control (b). On this date, only a small amount oil was observed on the ocean's surface (figure omitted), all of which was south of Louisiana. Sea surface height (m) and velocity are shown, for the same date, when simulated with AGRIF (c) and our control (d). The Loop Current was clearly simulated differently between the AGRIF simulation and our control. The Loop Current was a critical feature to simulate for this event, as any oil which entered the Loop Current was likely to quickly move away from the source region and impact a larger area as well. Thus explaining more oil exiting the Gulf of Mexico in our control simulation.

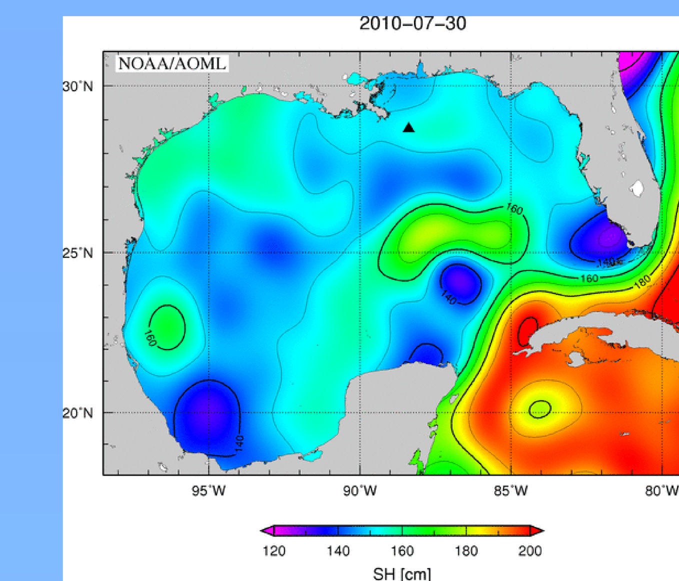

Figure 4: Contour plot of the observed sea surface height, on July 30. The Loop Current flows north-east from the Yucatan peninsula until it is halfway to Florida, where it then flow eastward out of the Gulf of Mexico. The AGRIF simulation (Fig. 3c) depicts this important feature far more accurately than our control simulation (Fig. 3d). In reality, no oil was believed to have entered the Loop Current and exit the Gulf of Mexico in this manner, which was more consistent with the AGRIF simulation than the control simulation.

Work in Progress:

Canadian Archipelago: Sea-Ice Processes

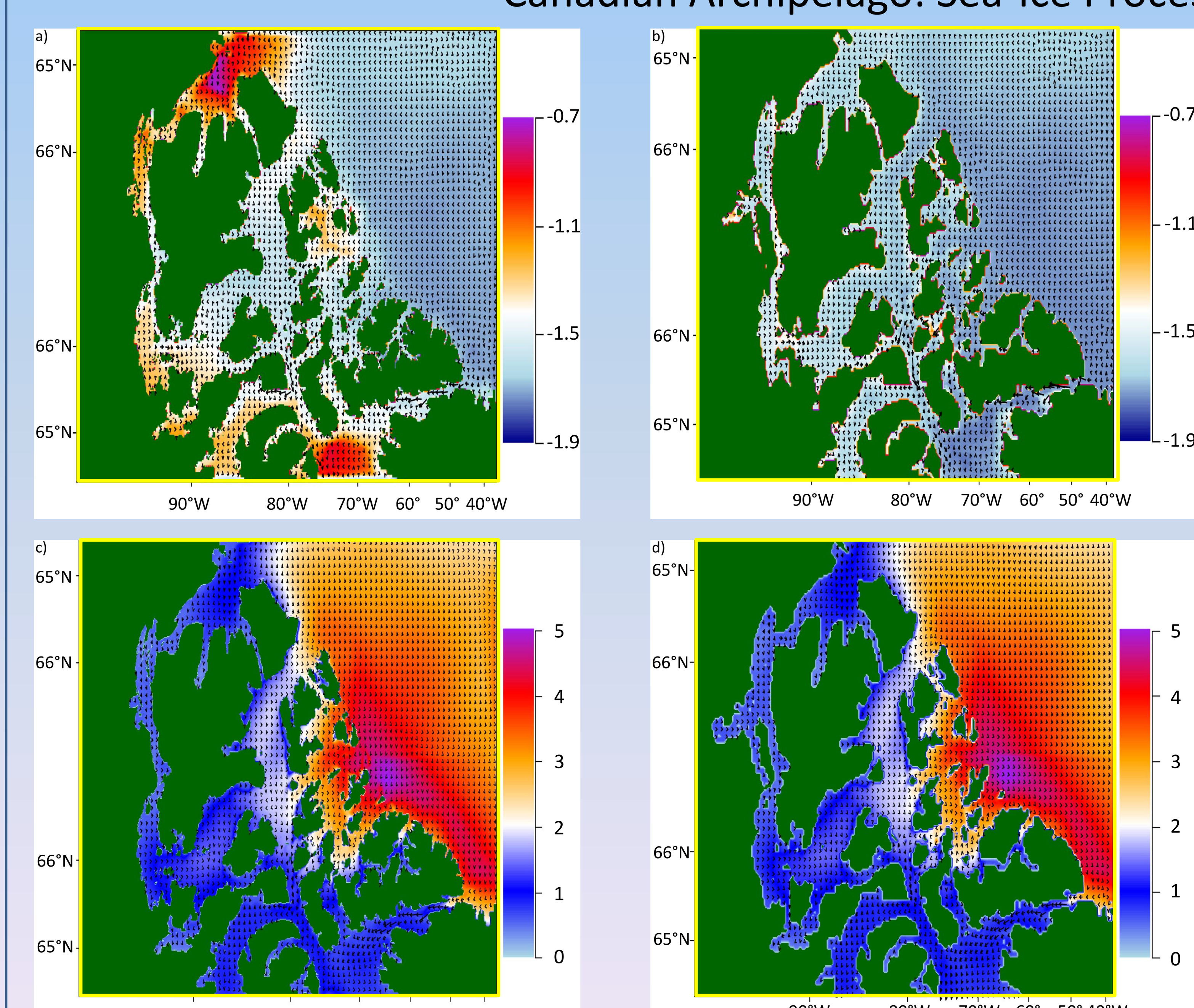

Figure 5: Ocean temperature (°C) at the 10th vertical level (roughly 15m) for an AGRIF simulation (a) and a simulation without AGRIF (b), as well as ocean velocity vectors. Ice thickness (m) is shown for an AGRIF simulation (c) and a simulation without AGRIF (d). Ice velocity vectors are superimposed. We note AGRIF simulations had differences compared to simulations without AGRIF, such as areas with warmer ocean waters, though minimal differences when simulating ice processes.

Future steps: We plan to implement AGRIF inside the Canadian archipelago to research ice processes including ocean circulation, pathways, hydrology, and fluxes through the archipelago. Using AGRIF allows for higher resolution simulations over a region which has complex and narrow ocean pathways, and could produce more accurate simulations by resolving finer scale features.

Labrador Sea: Boundary Currents and Deep Convection

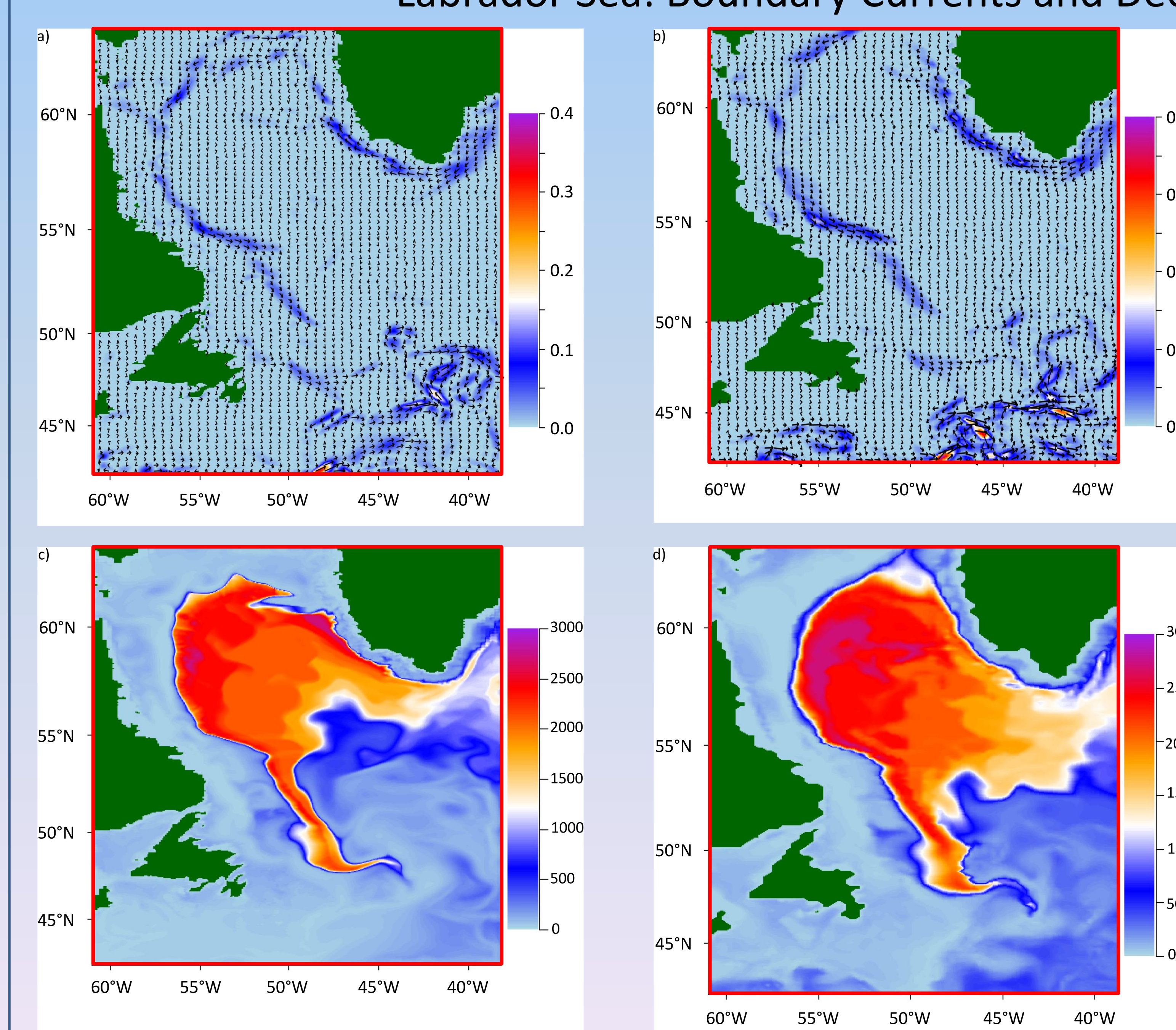

Figure 6: Sea surface velocity values (m/s) for a simulation using AGRIF (a) as well as a simulation without AGRIF (b). Mixed layer depths (m) are shown for a simulation with AGRIF (c) as well as a simulation without AGRIF (d). We note some differences between the two simulations: AGRIF simulations had similar boundary currents, though with more resolved eddies, and our non-AGRIF simulation. AGRIF simulations also generally had a shallower mixed layer depth that covered less area than a simulation without AGRIF.

Future steps: We plan to implement AGRIF inside the Labrador sea to research boundary currents, deep convection, and glacial melt pathways.

References:

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[2] Debreu, Laurent, Christophe Vouland, and Eric Blayo. "AGRIF: Adaptive grid refinement in Fortran." *Computers & Geosciences* 34.1 (2008): 8-13
[3] McNutt, Marcia K., et al. "Review of flow rate estimates of the Deepwater Horizon oil spill." *Proceedings of the National Academy of Sciences* 109.50 (2012): 20260-20267
[4] Adcroft, Alistair, et al. "Simulations of underwater plumes of dissolved oil in the Gulf of Mexico." *Geophysical Research Letters* 37.18 (2010).

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Email: Pmyers@ualberta.ca