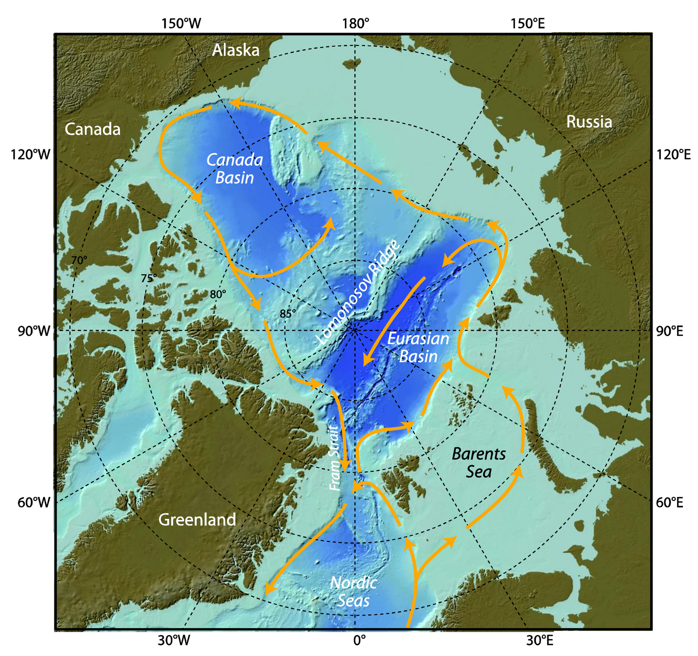
B19: A Simple Model for the Halocline and Circulation of Atlantic Water in the Arctic

Michael Spall WHOI

Motivation



What drives Atlantic Water into the Arctic Ocean ?

Wind forcing, heat flux, precipitation, and ice are all potentially important

Approach

Develop an idealized eddy-resolving model of the Arctic Ocean that allows for explicit control over parameters

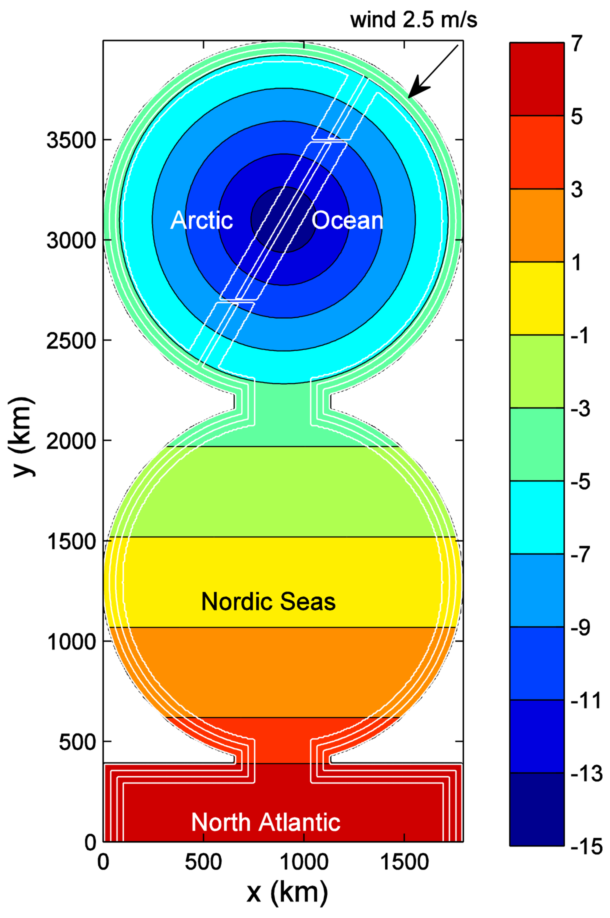
Develop analytic three layer model that represents the halocline, Atlantic layer, and low salinity shelf water

Compare basic characteristics of the GCM Arctic with those predicted by the theory:
- halocline thickness
- halocline salinity
- transport of Atlantic Water
- freshwater content of the halocline

Summary

1. Idealized GCM reproduces many basic aspects of the Arctic:
   - halocline
   - exchange through Fram Strait
   - circulation of Atlantic Water
   - ice thickness and transport
2. Predictions from the analytic model compare well with that found in the GCM over a wide range of parameters.
3. Eddy fluxes and vertical diffusion close the salt budget and determine the properties of the halocline.
4. The pressure gradient associated with the halocline drives Atlantic Water in the cyclonic boundary current.
5. The contrast between fresh shelf waters and salty AW drives the circulation and maintains the halocline. Different dynamics on open and closed geostrophic contours is key.

Numerical Model



FORCING:

Uniform wind stress (northeast to southwest, see vector)

Restoring of SST to "Atmospheric" temperature (colors)

Restoring of salinity towards S_1 near the Arctic boundary (runoff, Pacific Water)

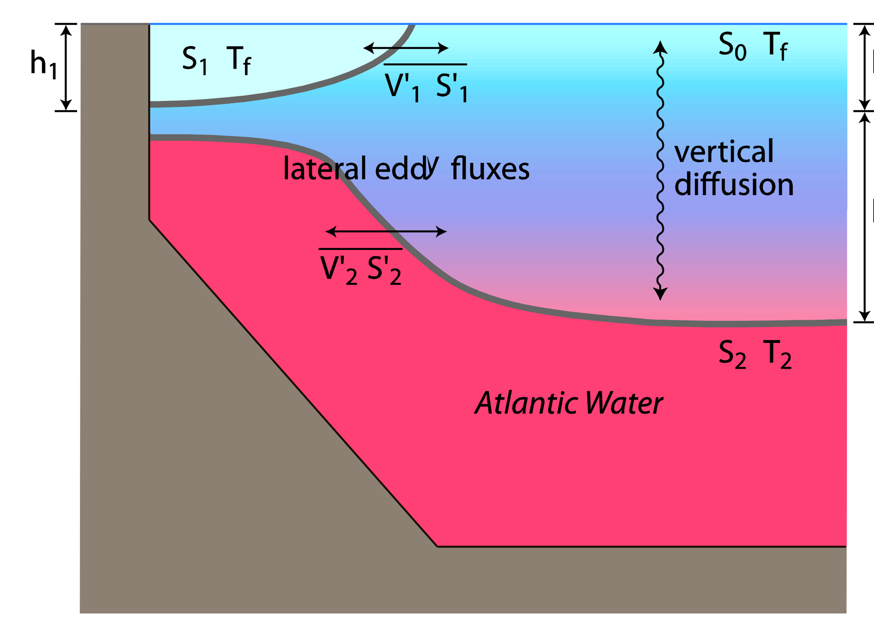
T, S are restored towards 6 °C and 35 for y < 350 km (source of Atlantic Water)

MITgcm with seaice package, 6.7 km grid spacing, f-plane. 1000 m deep with continental slope and mid-Arctic ridge (white contours)

Model is initialized at rest and run for 100 years

Theory

Consider a 3 layer system
1. Halocline
2. AW layer
3. thin, fresh layer near boundary (representing runoff, Pacific, etc)



The boundary current is the region over the sloping bottom (open geostrophic contours)

Mean advection is along the topography

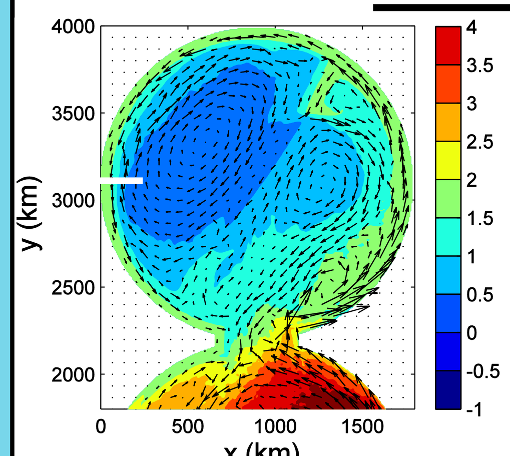
Lateral density gradients will drive eddy fluxes through baroclinic instability

Since surface forcing and mean flow are weak in the interior, the eddy flux integrated around the basin interior must be zero

Vertical diffusion is required to close salt balance in the interior

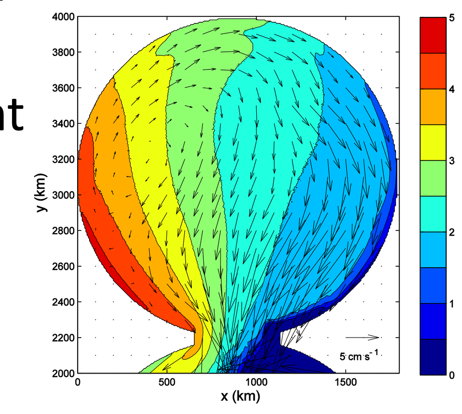
This gives two equations and two unknowns : surface salinity and halocline thickness

Mean Circulation



Branches of AW circulation:
1. cyclonic boundary current
2. recirc @ Fram Strait
3. return in Eurasian basin

Mean flow is along topog, (see section below)



T at 162 m, V (every 10th point)

Ice thickness and velocity

Analytic solution

Parameterize eddy fluxes between the boundary and the interior as $v'S' = cV(S - S_i)$ where c is a constant and S_i is salinity in the interior

Requiring that the net salt flux into the basin is zero and that vertical diffusion balances the horizontal salt flux results in the governing equation

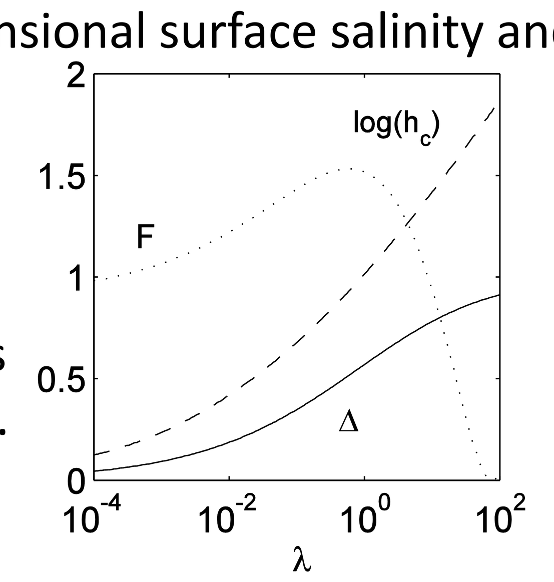
$$\Delta^3 - \lambda(1-\Delta)^2 = 0$$

where $\Delta = (S_0 - S_1)/(S_2 - S_1)$ is a nondimensional surface salinity and

$$\lambda = \frac{\rho_0 f_0 L \kappa A c_2^{0.5}}{2 g \beta_S P c_1^{1.5} h_1^3 (S_2 - S_1)}$$

Surface salinity and halocline thickness increase with λ.

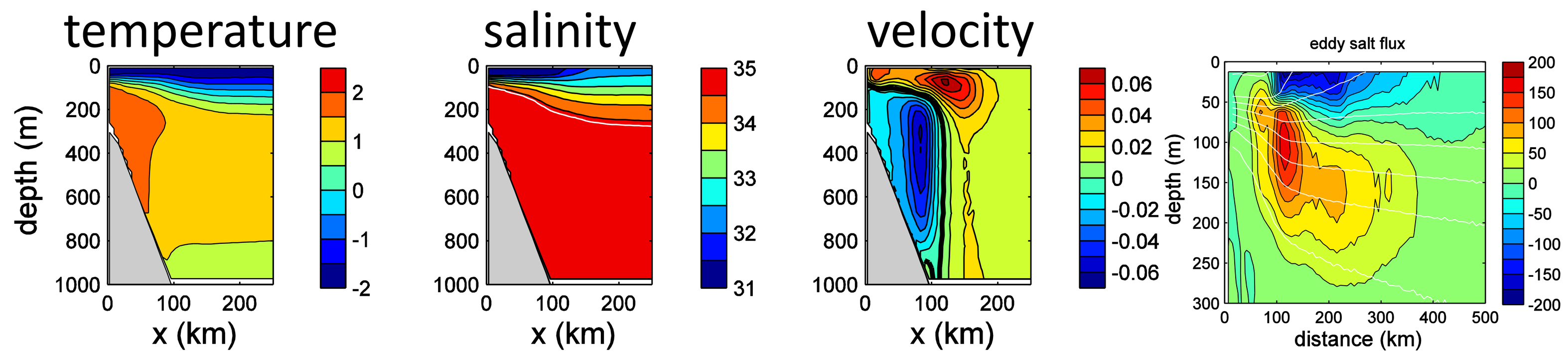
Freshwater content F initially increases then decreases as halocline gets salty.



Arctic λ=.01 to 0.1

model λ=0.08

Boundary Current and Fluxes



MEAN SECTIONS NEAR WESTERN BOUNDARY (white line on mean map)

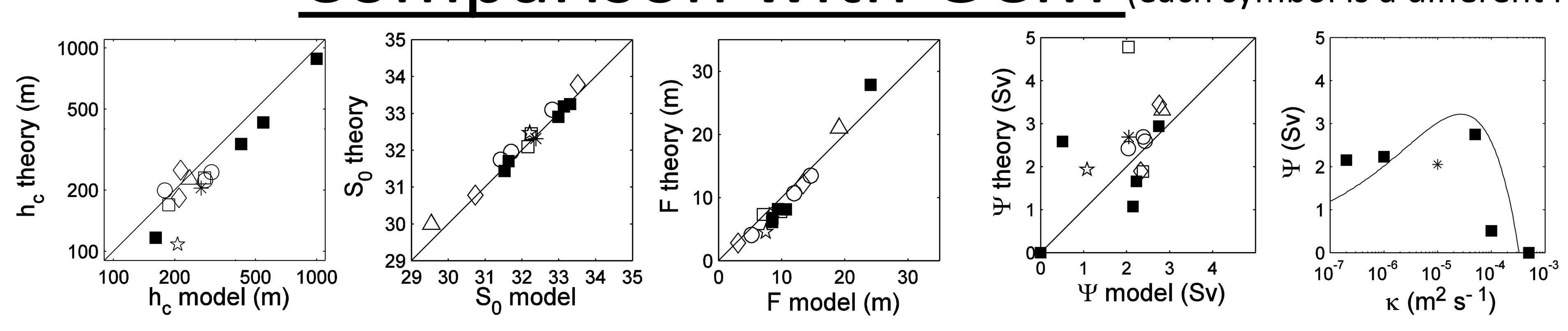
Cold, fresh halocline ~ 200 m thick

Warm, salty Atlantic Water in cyclonic boundary current (~ 2 Sv)

Eddy fluxes of salt from boundary into the interior
- negative in upper halocline (decrease salinity)
- positive in lower halocline (increase salinity)

must be closed by vertical diffusion because mean advection and surface forcing are weak – This forms the basis for the theory

Comparison with GCM (each symbol is a different run)



halocline thickness, surface salinity, and freshwater content all compare well with GCM over a wide range of diffusivity, Coriolis parameter, salinity and thickness of shelf water

transport of AW is also well predicted by the theory relatively insensitive to params until it collapses (large κ or λ)

Values of $\kappa = 10^{-6}$ to 10^{-5} m^2/s produce a realistic halocline