Miniproject for EOSC 511: Arctic Ocean Near Surface Temperature Maximum

Consider summer in the Arctic Ocean (Canada Basin). The surface of the ocean is partially covered by ice (say ice fraction β). The sun is bright (assume no clouds) and shines most of the day (assume all day). Take an incoming radiative flux of 100 W m^{-2}, a water albedo of 0.1 and assume that no light penetrates through the ice-covered portion (i.e. it has lots of snow on top). Ice is melting, and so the surface temperature is the freezing temperature of salty water, say -1^{o}C. Deep in the water column, at 200 m depth, the temperature is -2^{o}C. The light energy I decays exponentially with depth with an e-folding scale of α.

In the polar ocean, density is determined by salinity.[1] The surface layer of the ocean of depth (h) is well-mixed and relatively fresh. Below that is a strongly stratified layer and then less stratified water. Assume an eddy-viscosity or mixing coefficient (A_h) of the form

$$A_{max}, \quad d < h \tag{1}$$

$$A_{depth} + \left[A_{max} - A_{depth} - A_{dip}(d-h)\right] \exp\left[-0.5(d-h)\right], \quad d > h. \tag{2}$$

where d is the depth, positive in the ocean, measured down from the surface.

An equation for the temperature T as a function of depth, d is

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial d}\left(A_h \frac{\partial T}{\partial d}\right) - \frac{1}{c_p}\frac{\partial I}{\partial d} \tag{3}$$

where $c_p = 4000\text{J kg}^{-1}\ {}^o\text{C}^{-1} = 4 \times 10^6\text{J m}^{-3}\ {}^o\text{C}^{-1}$ is specific heat.

1. Assuming steady state, calculate the solution and explore temperature profiles for various ice concentrations β, mixing profiles (make sure your A_h does not go negative), and light attenuation rates (α). Starting parameter suggestions: $\beta = 0.5$, $\alpha = 10$ m, $h = 10$ m, $A_{max} = 1 \times 10^{-2}\text{m}^2\text{s}^{-1}$, $A_{depth} = 1 \times 10^{-4}\text{m}^2\text{s}^{-1}$, and $A_{dip} = 1.5 \times 10^{-3}\text{m}^2\text{s}^{-1}$. These should give you a Near Surface Temperature Maximum (NSTM) — see Figure 2 of Jackson et al. https://circle.ubc.ca/handle/2429/34555 but note that the vertical axis is a logscale.

2. Once you understand your steady state solutions, we will add in time dependence of the system, so we can no longer set $\partial T/\partial t$ to 0. You can assume that the ice coverage is fixed, so is not changing with time. You have already calculated a matrix for the right hand side of the equation above ($= \frac{\partial T}{\partial t}$), so use this as your derivative in a time stepping scheme (I recommend the forward Euler for simplicity - we'll get into more complex ways of solving partial differential equations in Lab 7). Choose some boundary conditions for the surface and deep ocean and justify these; describe your equations and how you chose to code your solution. Explore the evolution for each of the initial condition scenarios below - for each initial condition scenario, describe, using both words and plots:

- a. what happens during the initial timesteps
- b. what happens as the system approaches a new equilibrium.
- c. whether these simulations conserve energy, and how you can tell. If not, why not - where is energy being lost or gained, and why?

[1] Which means its perfectly possible to have colder water above warmer water

Initial Condition Scenarios

I. One of your steady state solutions from the previous section (hint! This shouldn't change with time if your code is correct!)
II. Starting from the steady state solution you used in part 1, suppose there was an input of heat energy into the surface (say, an Arctic heatwave), such that the top 5 layers warmed by 0.2C, taking the system out of equilibrium. The input of heat is then removed. Decide on a reasonable surface boundary condition, and solve for how this system evolves with time (once there is no longer a heat source, but the water near the surface has been warmed).
III. Starting from the steady state solution you used in part 1, impose a temperature increase of 0.2C at depths of 150-160m. Discuss how the speed of the temporal evolution of this heat energy differs from that in scenario II, and describe what physical properties of this system determine this.

Hand-In, as a notebook

1. Derivation of the equations you put into your computer model.
2. A paragraph discussing the method of solution.
3. Your code
4. Results of the base case and your variations (graphs, summary tables)
5. A discussion of your results and conclusions