

# Deep dive: What do polar oceans conceal?

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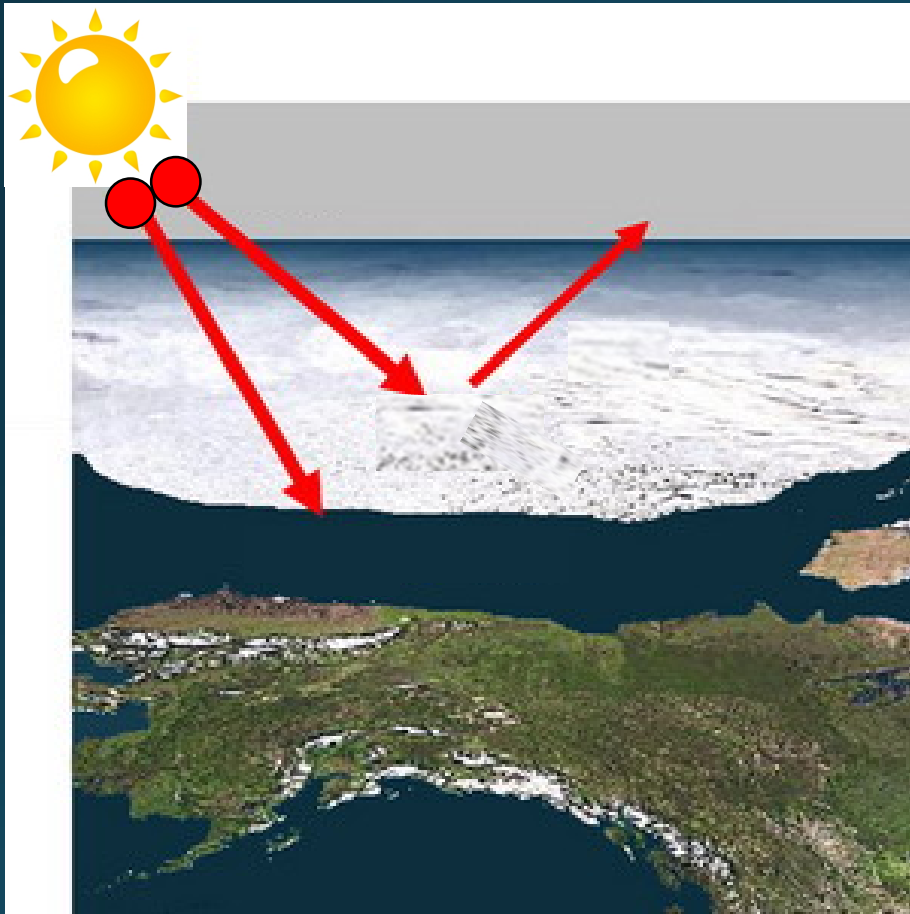


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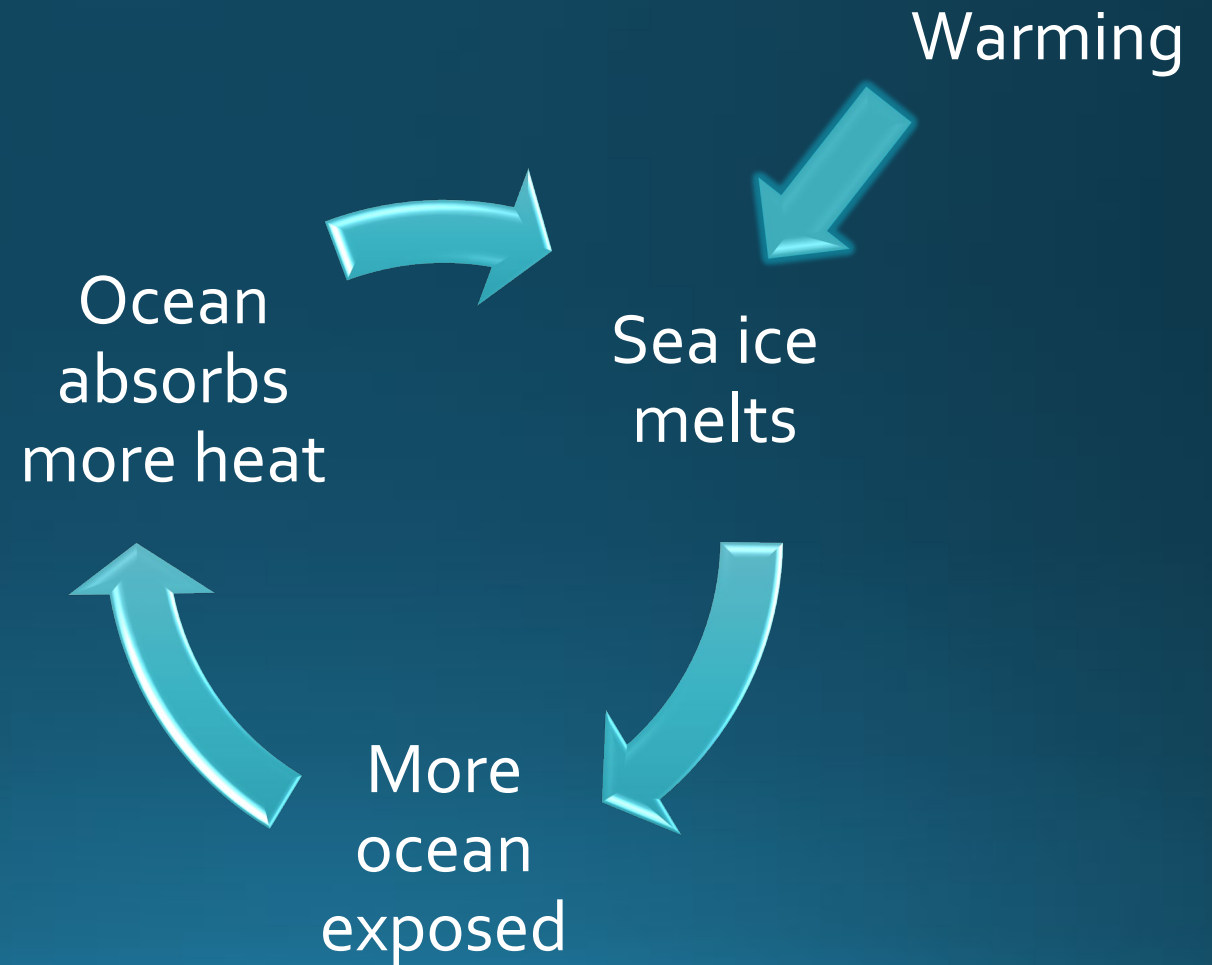
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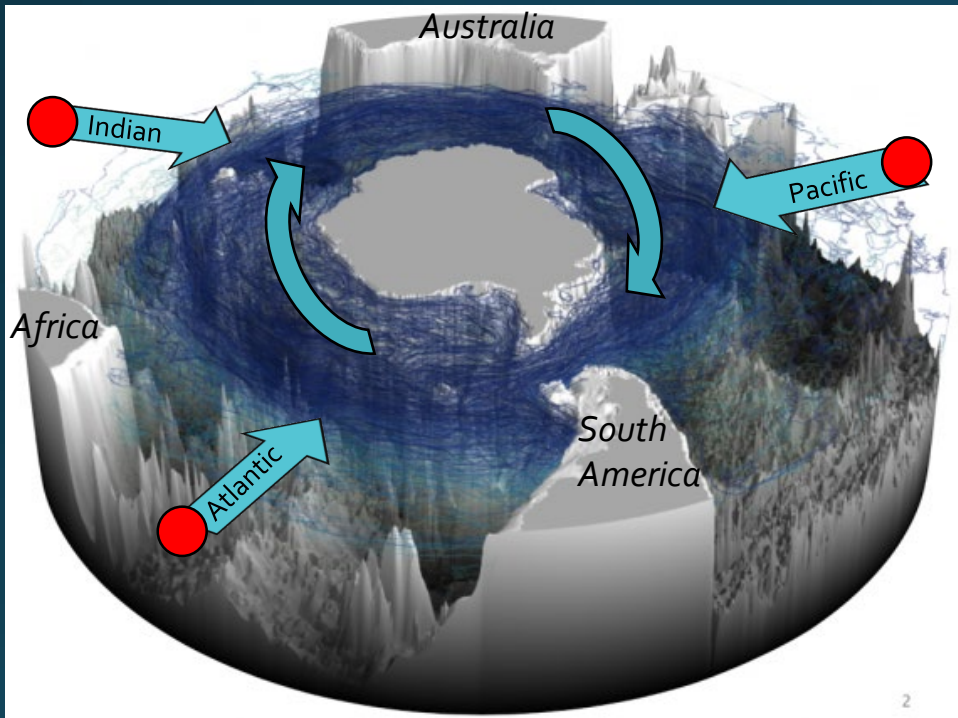


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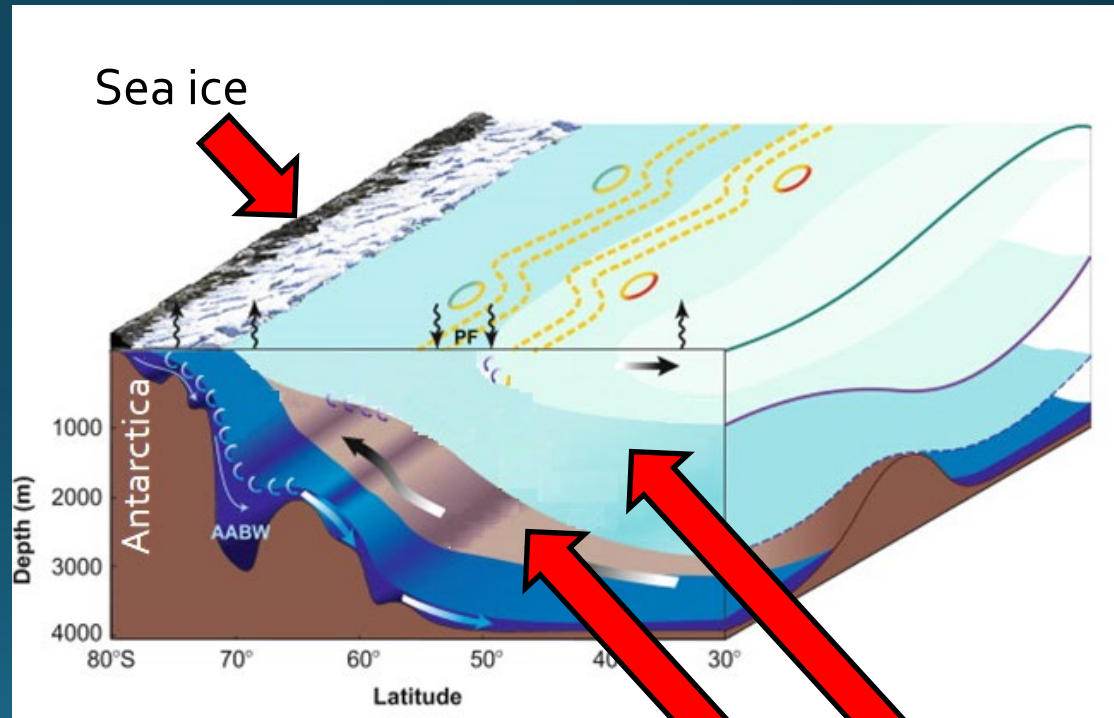
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Schematic of the Southern Ocean circulation



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Vertical slice through the Southern Ocean



*Speer et al. (2000)*

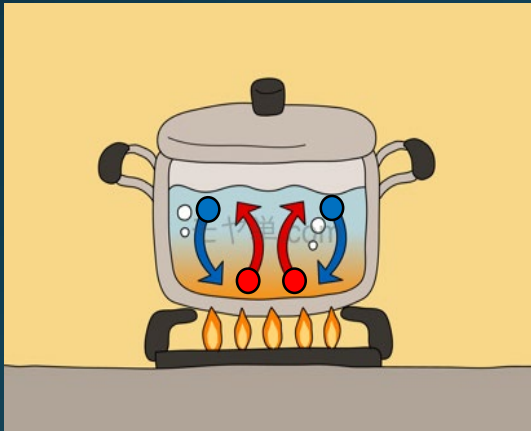
Cold & Fresh Water  
Warm & Salty Water

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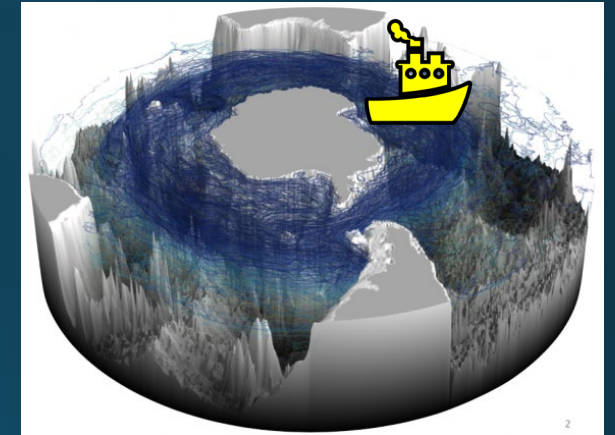
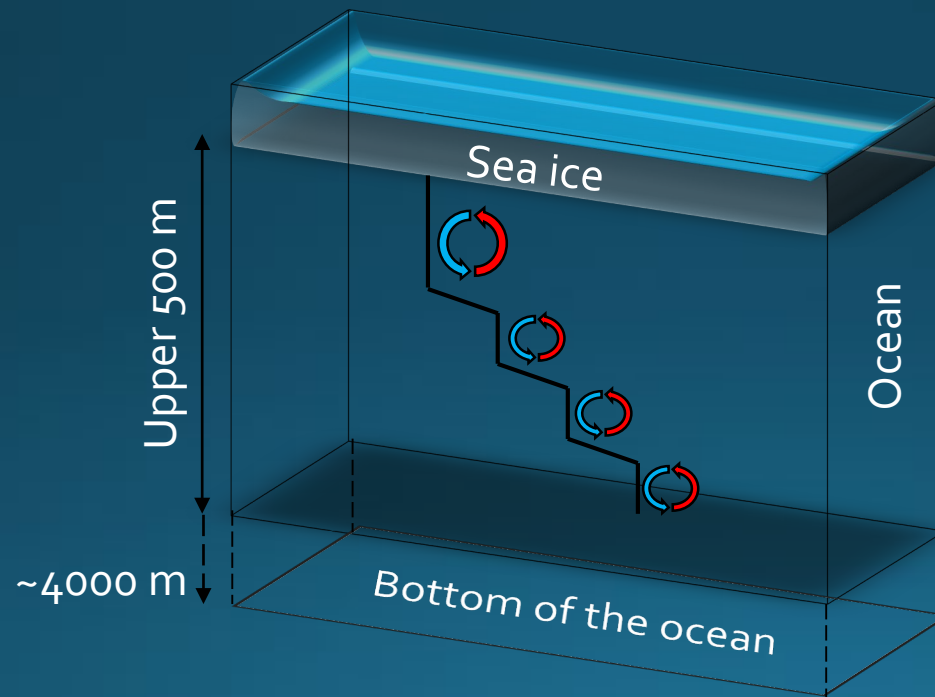
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Convection



Typical vertical structure



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Boundary conditions:  $\rho \frac{\partial u}{\partial t} = f - \text{grad} p + (\lambda_1 + \mu_1) \text{grad}(\text{div} u) + \mu_1 \Delta u$

**Solid walls**  
 $u=0$   
 $\mu \frac{\partial u}{\partial n} = 0$   
 viscous layers

**Order 2 space derivatives**  
 $\frac{\partial F}{\partial t} = 0$   
 $\frac{\partial F}{\partial n} = N$   
 $\sigma \cdot N = \sigma_a \cdot N$   
 $\mu \frac{\partial u}{\partial n} = 0$   
 viscous

**Free surface**  
 $\frac{\partial F}{\partial t} = 0$   
 $\frac{\partial F}{\partial n} = N$   
 $\sigma \cdot N = \sigma_a \cdot N$   
 $\mu \frac{\partial u}{\partial n} = 0$   
 viscous

Kinematic boundary condition:  $\frac{\partial F}{\partial t} + u \cdot \text{grad} F = 0$  on  $F(x, t) = 0$   
 from  $W = \frac{1}{\|\text{grad} F\|} \frac{\partial F}{\partial t}$ ,  $N = \frac{\text{grad} F}{\|\text{grad} F\|}$  and  $u \cdot N = W \cdot N$

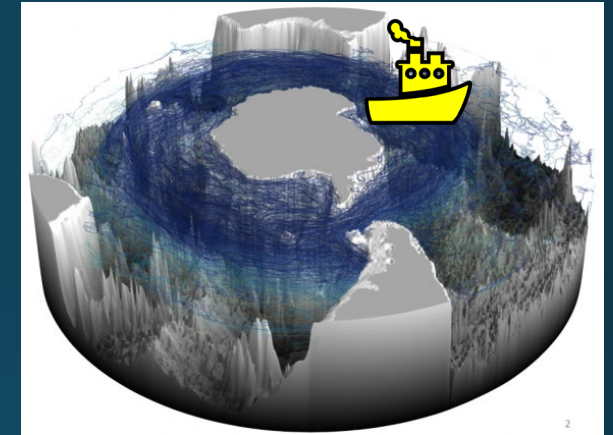
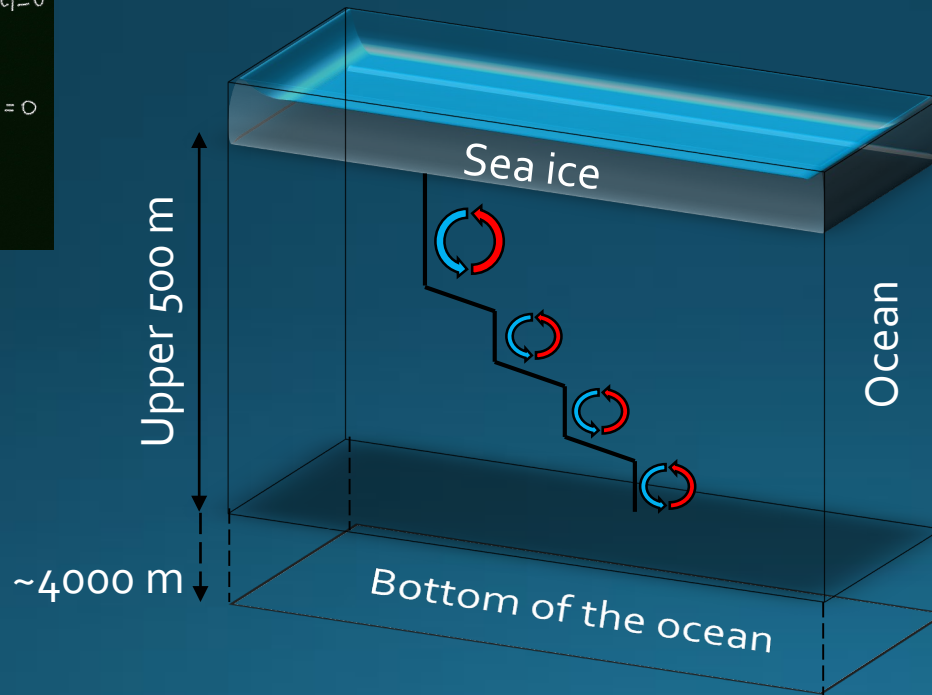
Dynamic boundary condition: on  $F(x, t) = 0$   
 a) viscous:  $\sigma \cdot N = \sigma_a \cdot N$  b) inviscid ( $\sigma = -pI$ ):  $-p = N \cdot \sigma_a \cdot N$

<http://thual.perso.enseeiht.fr/>



<http://clipart-library.com/>

Typical vertical structure



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Boundary conditions:  $\rho \frac{\partial u}{\partial t} = f - \text{grad} p + (\lambda_1 + \mu_1) \text{grad}(\text{div} u) + \mu_1 \Delta u$

Solid walls:  $u=0$

Order 2 space derivatives:  $\frac{\partial F}{\partial t} = 0$ ,  $\frac{\partial F}{\partial x} = 0$

Free surface:  $\frac{\partial F}{\partial t} = 0$ ,  $\frac{\partial F}{\partial x} = 0$

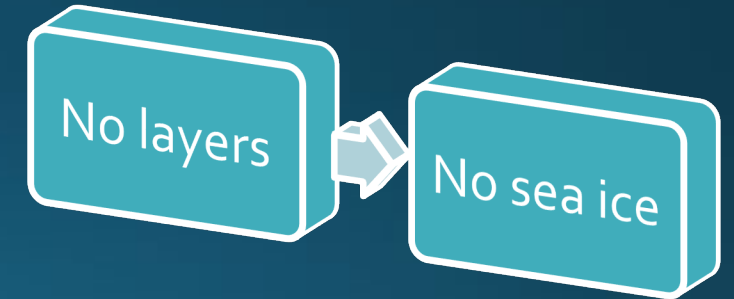
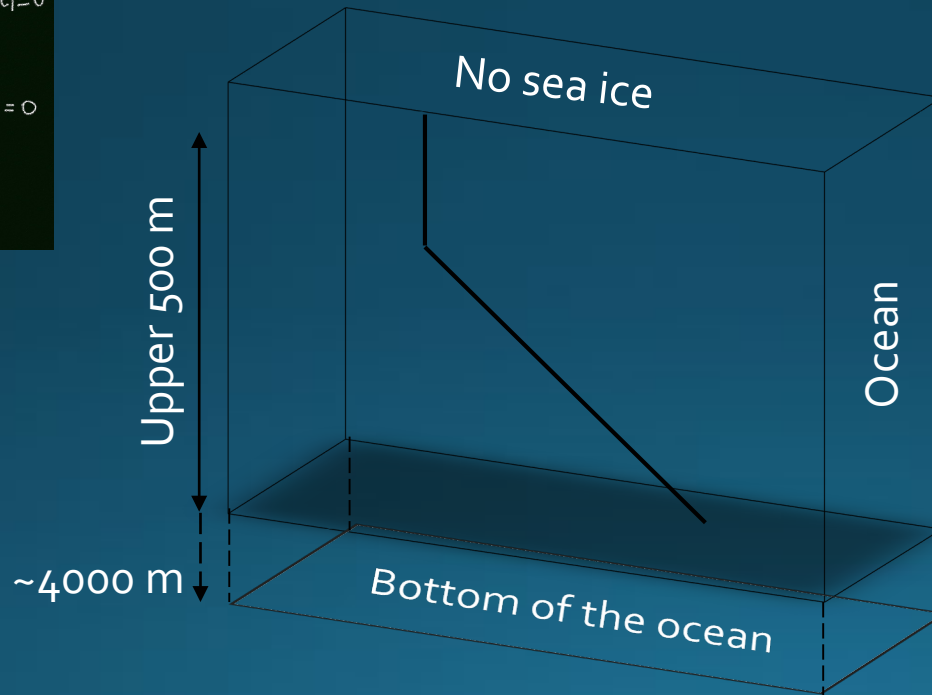
Kinematic boundary condition:  $\frac{\partial F}{\partial t} + u \cdot \text{grad} F = 0$  on  $F(x,t) = 0$

Dynamic boundary condition: on  $F(x,t) = 0$

<http://thual.perso.enseeiht.fr/>



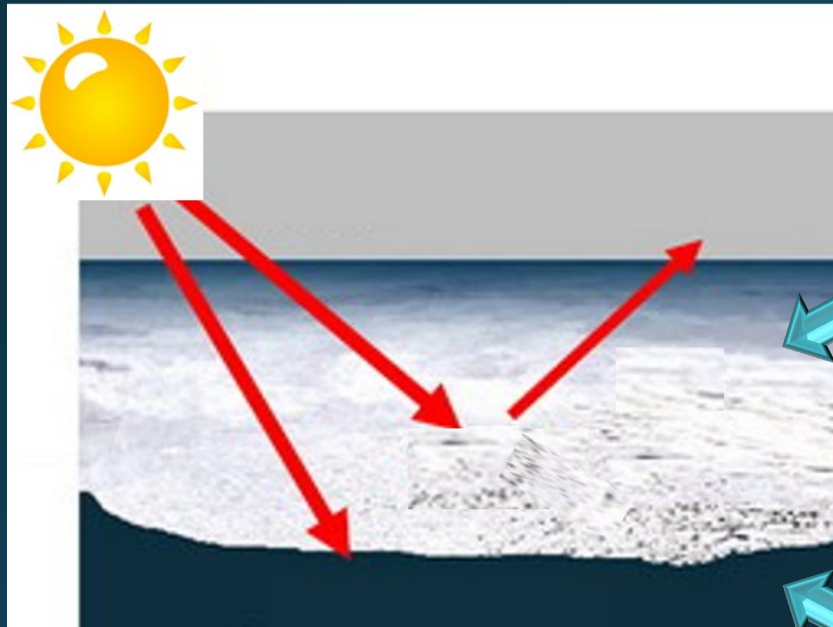
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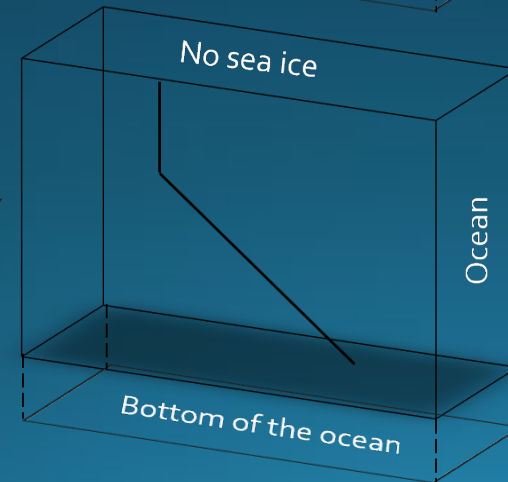
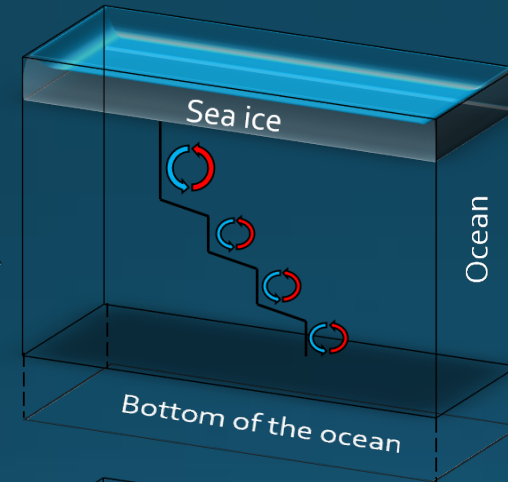
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Take home messages:

1. In the Southern Ocean, sea ice forms if there are layers in the upper ocean.
2. Layers slow down the overall ocean warming.

Implication:

Our results improve climate modeling.