USESO 2021

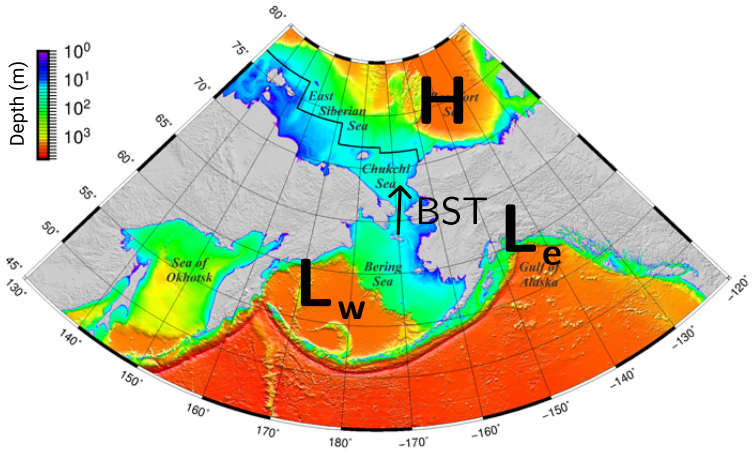
Hydrosphere

Instructions:

- Section I consists of 10 multiple choice questions, with each question worth 2 points. There is only one correct option on multiple choice questions
- Section II consists of 2 multipart free response questions
- A non-graphing, non-programmable calculator is allowed; show all work for calculations
- Recommended time management: 30 minutes on each section

Section I

1. (2 points) The Bering Strait Throughflow (BST) is an important quasi-geostrophic current transporting water from the Pacific to the Arctic Ocean. Its variability is mostly forced by wind, which affects the sea surface height.



The Beaufort High and Aleutian Low, shown above, are two semipermanent atmospheric pressure systems. Wind forcing in the Bering Strait is driven primarily by variability in the *strength* of the Beaufort High (shown as H) and variability in the *position* of the Aleutian Low (westernmost is L_w, easternmost is L_e).

Which of the following combinations generates the strongest BST?

A. Strong Beaufort High, western Aleutian Low

B. Strong Beaufort High, eastern Aleutian Low

C. Weak Beaufort High, western Aleutian Low

D. Weak Beaufort High, western Aleutian Low

2. (2 points) A geologist investigates a marine terrace, shown below.

Which of the following could have been responsible for the formation of the marine terrace?

I) A decrease in eustatic sea level

II) Regional tectonic subsidence

III) Relatively high resistance to erosion of the exposed rock

A. I, only

B. II, only

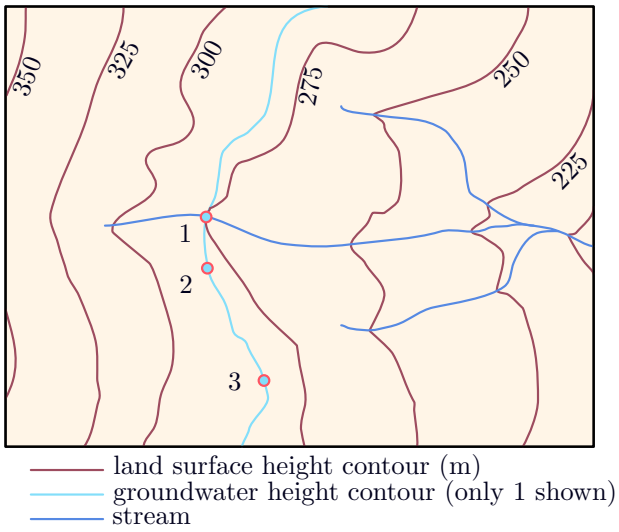
C. I and II

D. I and III

E. II and III

F. I, II, and III

3. (2 points) The figure below shows a topographical map with streams fed by groundwater. As seen with the light blue line, contours of groundwater usually follow surface topography.



If the overall permeability of the ground is increased, what are the most plausible resulting groundwater heights at the points 1, 2, and 3, respectively? Assume existing streams remain fed by groundwater.

A. 275 m; 270 m; 270 m

B. 275 m; 270 m; 260 m

C. 270 m; 270 m; 270 m

D. 255 m; 270 m; 270 m

E. 280 m; 275 m; 285 m

4. (2 points) Which of the following contributes the most to the abundance of nutrients in deep water?

   A. Downwelling of agricultural runoff

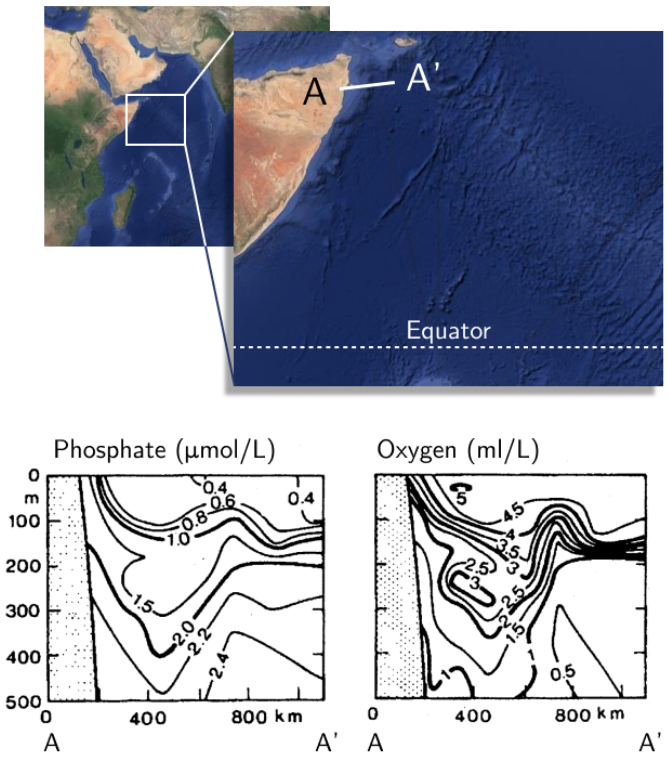
   B. Dissolution of seafloor sediments

   C. Greater solubility in cold water

   D. Largely anoxic conditions

   E. Minimal primary production

5. (2 points) The figure below shows phosphate and dissolved oxygen profiles off of the coast of Somalia. The transect is denoted on the map with endpoints at A and A'.



   (a) During which month were these profiles taken?

      A. December

      B. April

      C. August

   (b) During this month, towards which direction does the depth-averaged transport passing through the transect flow?

      A. North

      B. South

      C. East

      D. West

6. (2 points) Tropical cyclones (hereafter referred to as cyclones) are transient, powerful phenomena that have profound effects on large scale ocean circulation. The Kuroshio Current is the western boundary current of the subtropical Pacific Gyre.

   Which of the following best describes how cyclones interact with the Kuroshio?

   I) Cyclones enhance the strength of cold core eddies in the Kuroshio

   II) The dissipation time of cyclones is several orders of magnitude faster than that of ocean eddies

   III) Cyclones generate warm SST anomalies in their wake

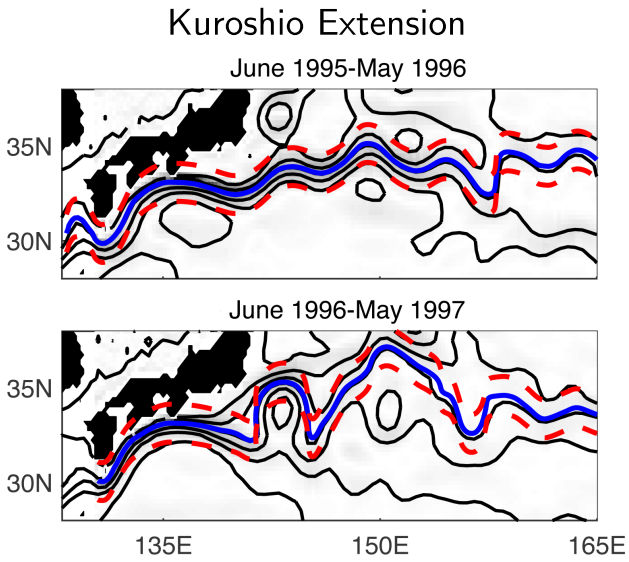


Figure 1: Schematic of Kuroshio paths.

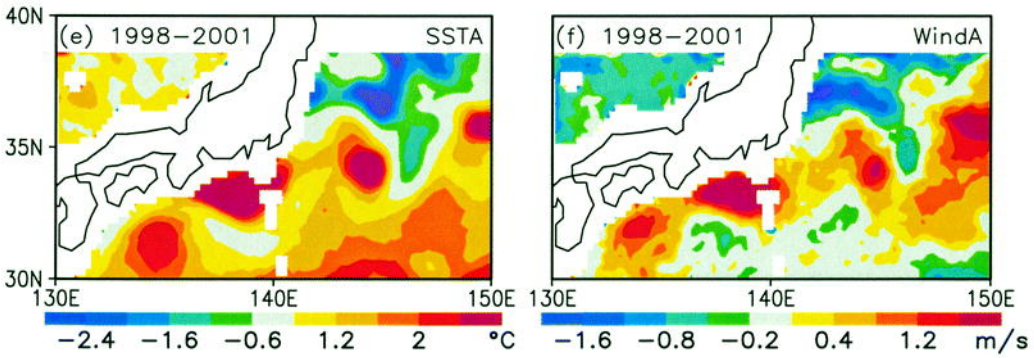


Figure 2 (Nonaka and Xie, 2003): the 1998 minus 2001 anomalies of annually-averaged sea surface temperature (SST) and surface wind velocity, both of which are taken as annual means. Note that the dates do not correspond with Figure 1.

A. I only

B. III only

C. II and III

D. I and II

E. I and III

F. I, II, and III

7. (2 points) Oceanographers collect samples of marine sediment, described in the table below.

Sample	Description
A	Black shale and pyrite with trace hydrogen sulfide (H_2S)
B	Red and brown clays interbedded with manganese nodules
C	Crystalline chert and opal

Which of the following is most likely true about the marine sediment samples?

A. Samples A and B represent sediment commonly found near hydrothermal vents, whereas Sample C represents terrigenous sediment widely found in abyssal plains

B. Samples A and B indicate regions of significant downwelling, whereas Sample C indicates a region of significant upwelling

C. Samples A and B are likely found in deep marine environments, whereas Sample C is likely found in warm, shallow waters

D. Samples A and B formed in regions with relatively low productivity, whereas Sample C formed in a region with relatively high productivity

E. Samples A and B are sourced from continental shelf deposits, whereas Sample C is sourced near a mid-ocean ridge

8. (2 points) The abundance of oxygen-18 (δ^{18}O, defined as a normalized ratio of $^{18}O/^{16}O$) in seawater is affected by various physical and chemical processes. Which seawater parameter best correlates with δ^{18}O of surface ocean water?

A. Temperature

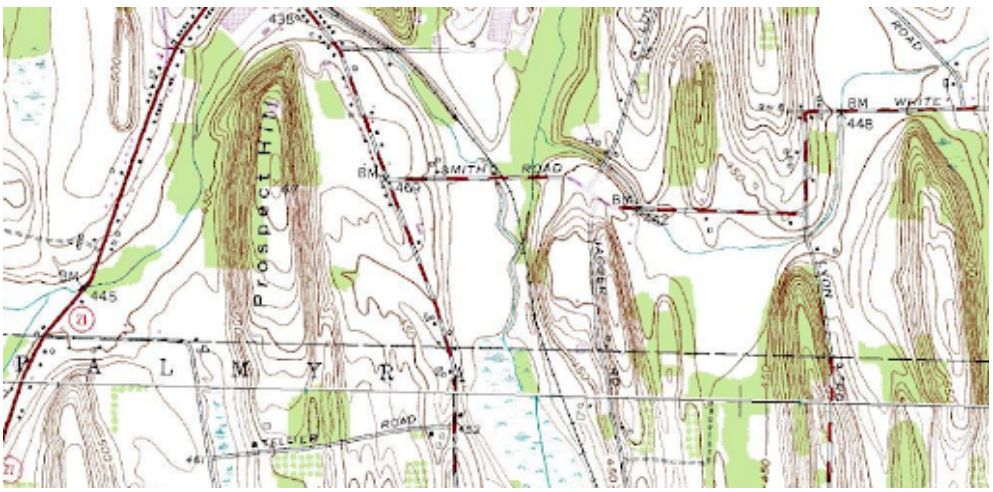
B. Salinity

C. Sea surface height

D. Density

E. Dissolved oxygen

9. (2 points) The figure below is a topographic map of an area previously covered by an ice sheet.



(a) Prospect hill is an example of which of the following landforms?

A. End moraine

B. Lateral shear moraine

C. Roche moutonnée

D. Drumlin

E. Crag and tail

(b) In which direction did the ice sheet flow? (Assume north is up)

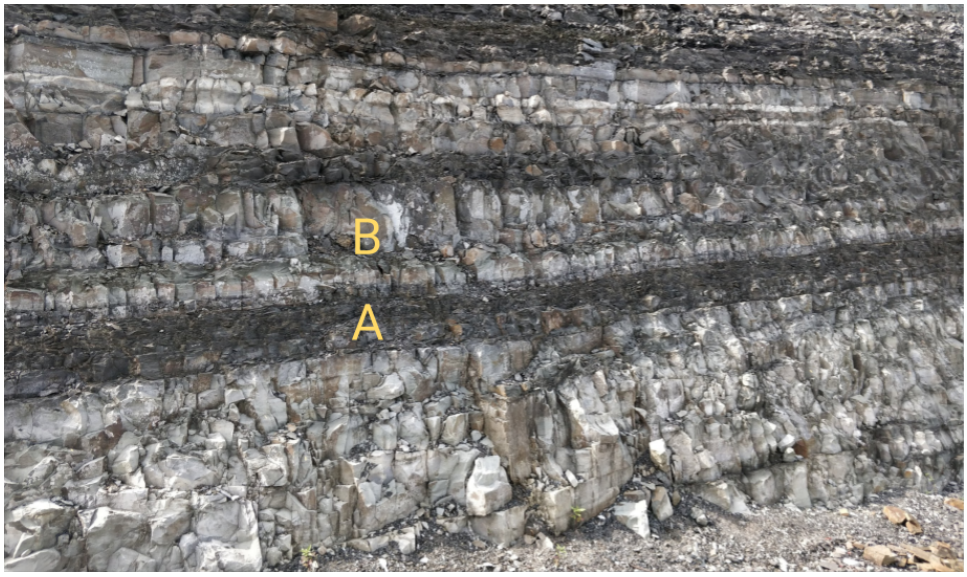
A. North to south

B. South to north

C. East to west

D. West to east

10. (2 points) In the image below, Rock A is layered and does not effervesce with hydrochloric acid while Rock B effervesces strongly with hydrochloric acid.



Which of the following processes most likely occurred between the formation of A and B? (Assume no overturning)

A. Local downwelling of asthenosphere

B. Eruption of a basaltic volcano

C. Formation of a supercontinent

D. Onset of widespread glaciation

E. Intrusion of metasomatic fluids into the rock body

Section II: Problem 1

Question	1	2	3	4	5	Total
Points	3	3	4	2	3	15 (30%)

The ocean plays a major role in regulating climate change and climate variability. The Atlantic Meridional Overturning Circulation (AMOC) is an important arm of thermohaline circulation.

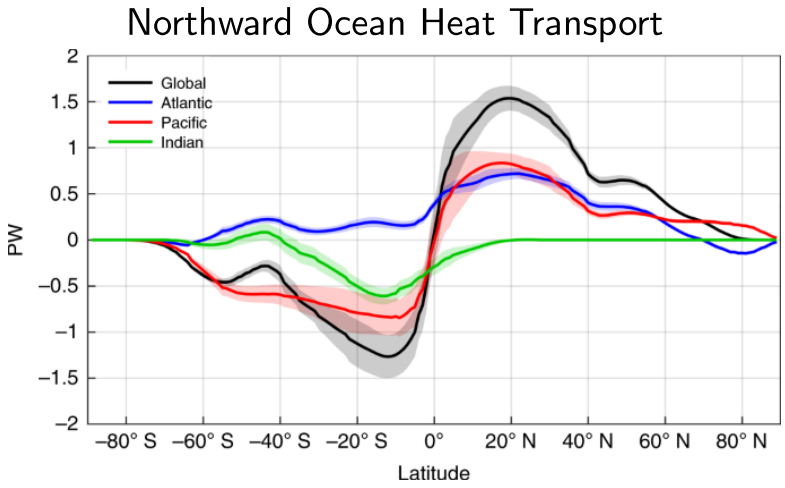


Figure 1: Northward ocean heat transport (measured in petawatts, 10^{15} W). Note the blue curve for the Atlantic Ocean.

1. (3 points) Estimates show that the northward ocean heat transport (OHT) at the equator is slightly positive. Use this fact to justify that the average position of the ITCZ is not at the equator. Is it north or south of the equator?

2. (3 points) AMOC is projected to weaken as a result of anthropogenic forcing. Briefly explain how this will affect the position of the intertropical convergence zone (ITCZ). Justify your answer.

A dominant mode of atmospheric variability in the Atlantic is the North Atlantic Oscillation (NAO), which has been shown to force variability onto AMOC.

The effects of NAO on AMOC were studied in a coupled climate model by applying surface heat fluxes associated with positive phase NAO on the ocean (see figure 2). In one model experiment, the heat fluxes were applied with full amplitude and at once, a "switch on."

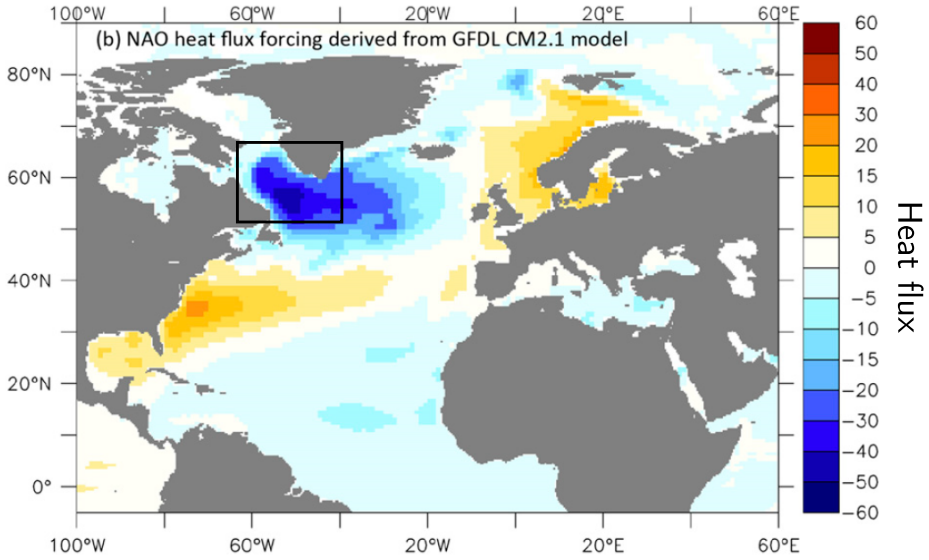


Figure 2 (modified after Delworth and Zeng, 2016): ocean heat fluxes ($\mathrm{W\,m^{-2}}$) corresponding to an increase of NAO index by one standard deviation. The box shows the Labrador Sea.

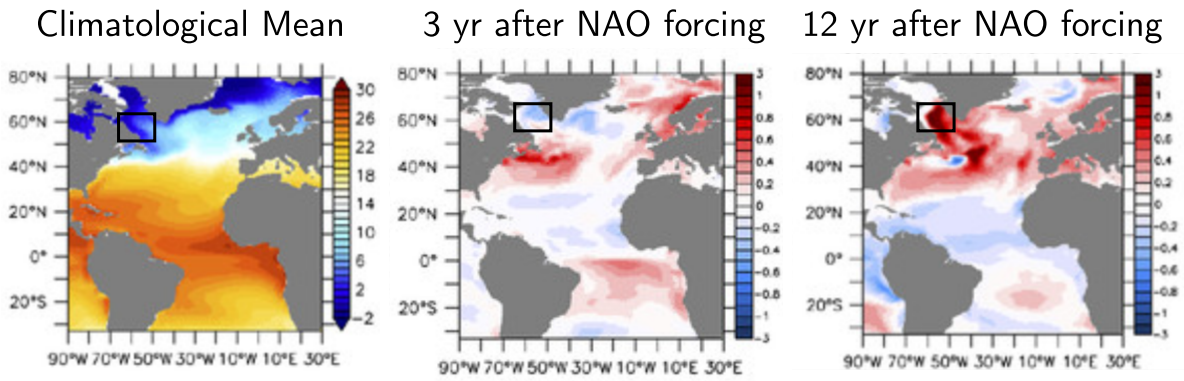


Figure 3 (modified after Delworth and Zeng, 2016): sea surface temperature (SST) during three stages: leftmost is the climatological mean, while the other panels show anomalies from the mean after positive NAO heat flux forcing has been applied. Red is warmer, blue is colder.

3. While a positive phase NAO imposes significant negative heat flux in the Labrador Sea (boxed), the SST actually warms by 1 - 2 deg C 12 years after the heat flux forcing is applied.

   (a) (2 points) Briefly explain how AMOC strength changes as a result of NAO forcing.

   (b) (2 points) Considering your answer in (a), briefly account for the warming of SSTs despite the negative heat flux forcing in the Labrador Sea.

Tectonic movements can affect the climate by changing pathways of the overturning circulation. The Drake Passage is an important body of water that connects the Pacific and Atlantic Oceans south of the tip of South America. The Drake Passage used to be closed such that there was no ocean throughflow.

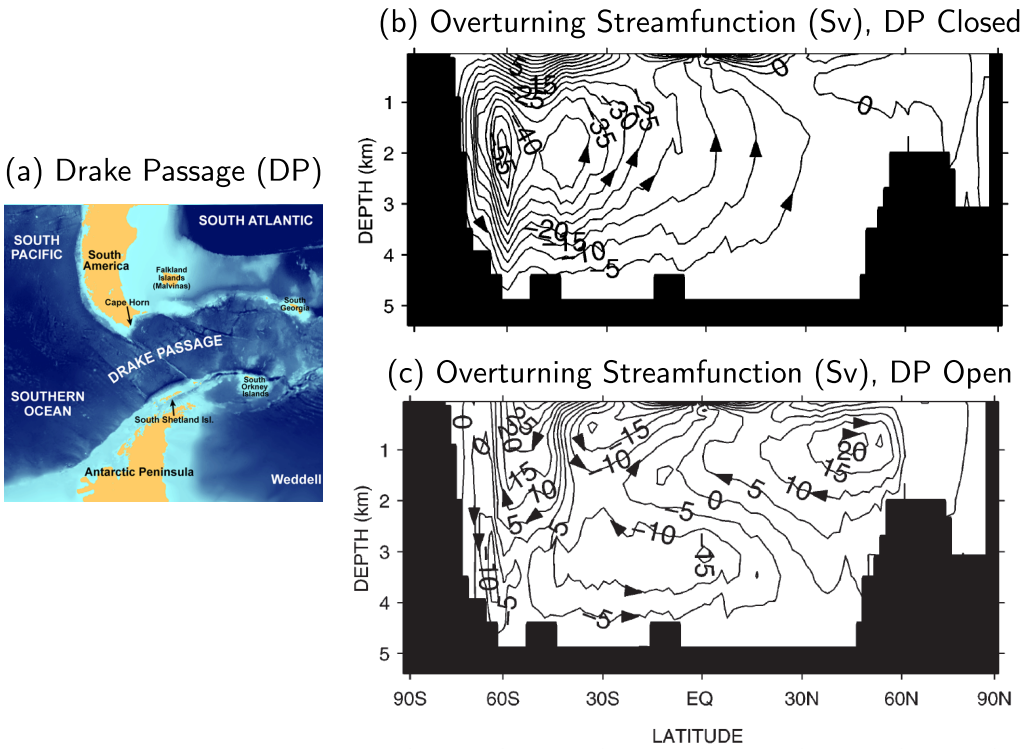


Figure 4 (modified after Sijp and England, 2004): (a) the Drake Passage (DP). (b) the global meridional overturning streamfunction, measured in Sverdrups (1 Sv = $1*10^6$ m^3/s), when the DP is closed. The magnitude of the overturning streamfunction is a measure of how strong the overturning circulation is, while the sign indicates the direction of overturning. Zonally-averaged currents go parallel to the isolines, as denoted by the arrows. (c) same as in (b), but when the DP is open.

The effect of the Drake Passage (DP) on the overturning circulation was studied in an idealized GCM, as shown in figure 4(b) and 4(c).

4. (2 points) Which of the following is true?

   I) There is no meridional overturning in the North Atlantic when the DP is closed.

   II) Deep water formation occurs in both the Northern and Southern Hemisphere when the DP is closed.

   A. I only

   B. II only

   C. I and II

   D. Neither I nor II

5. (3 points) It has been hypothesized that the opening of the DP had significant climatic effects on Antarctica. Justify how the opening of DP led to significant cooling of Antarctica. (Hint: how did ocean circulation change?)

Section II: Problem 2

Question	1	2	3	4	5	6	7	8	9	Total
Points	1	2	1	1	2	1	1	3	3	15 (30%)

Salinity is one of several key properties of seawater.

1. (1 point) Besides continental erosion of rocks and runoff from rivers and streams, identify one other source of oceanic salt.

2. (2 points) Which of these is/are reasonable mechanisms describing the effect of temperature changes on ocean salinity? Assume factors that are not mentioned remain constant. (*)

   A. A decrease in global tropospheric temperatures reduces the saturation vapor pressure, increasing precipitation and lowering ocean surface salinity.

   B. A decrease in global tropospheric temperatures causes sea ice formation, resulting in brine rejection and decreasing overall ocean salinity.

   C. Increased tropical sea surface temperatures (SSTs) results in added moisture to the air, increasing rainfall and lowering tropical ocean surface salinity.

   D. Increased tropospheric temperatures in a coastal region causes greater freshwater fluxes, lowering deep water salinity relative to surface salinity.

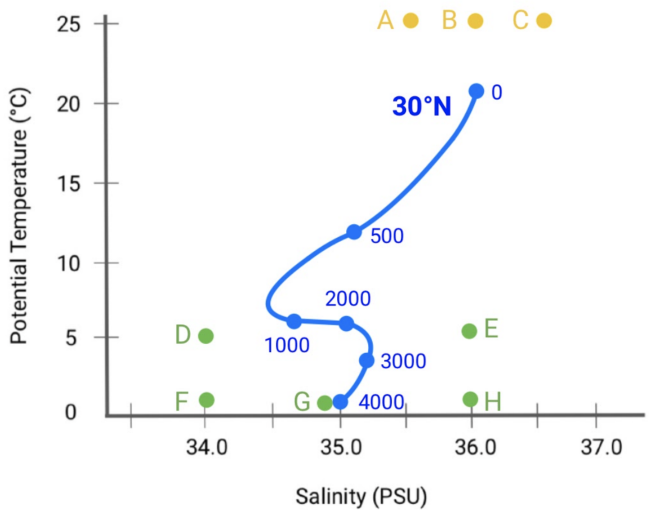
3. (1 point) What is the effect of a decrease in global average temperatures on the Cl^- (chloride ion) to Na^+ (sodium ion) ratio in seawater?

   A. Increases the Cl^- to Na^+ ratio

   B. Decreases the Cl^- to Na^+ ratio

   C. Does not affect the Cl^- to Na^+ ratio

   Consider the following T-S (temperature-salinity) diagram. The blue curve represents a column of seawater at 30°N. The numbers correspond to water depth in meters (e.g., "500" = 500 m below the surface). Points labeled A through H represent seawater at various potential temperatures and salinities at other latitudes.



4. (1 point) Identify the letter or letter(s) of the water mass(es) with the highest density.

5. (2 points) Which yellow point (A, B, or C) most closely corresponds to seawater located at the surface at the equator? Briefly explain the similarity or difference in surface salinity at the two latitudes.

6. (1 point) An oceanography student wants to plot a curve on the T-S diagram that represents a column of seawater at 55°N. Which points represent the surface water and the bottom water of the column, respectively?

   A. AH

   B. BH

   C. DF

   D. DG

   E. EF

   F. EG

7. (1 point) Assume that water masses E and G are isopycnal (at the same density) and equal volumes of E and G are mixed together. Will the combined water mass upwell, downwell, or do neither?

   A. Upwell, because the final water mass will have a lower density than the initial density

   B. Downwell, because the final water mass will have a higher density than the initial density

   C. Neither, because the final water mass will have the same density than the initial density

8. (a) (1 point) A climate model predicts both an increased SST and increased evaporation relative to precipitation at 55°N. These factors alone would cause the amount of CO_2 dissolved in seawater at 55°N to:

      A. Increase, resulting in greater ocean acidification

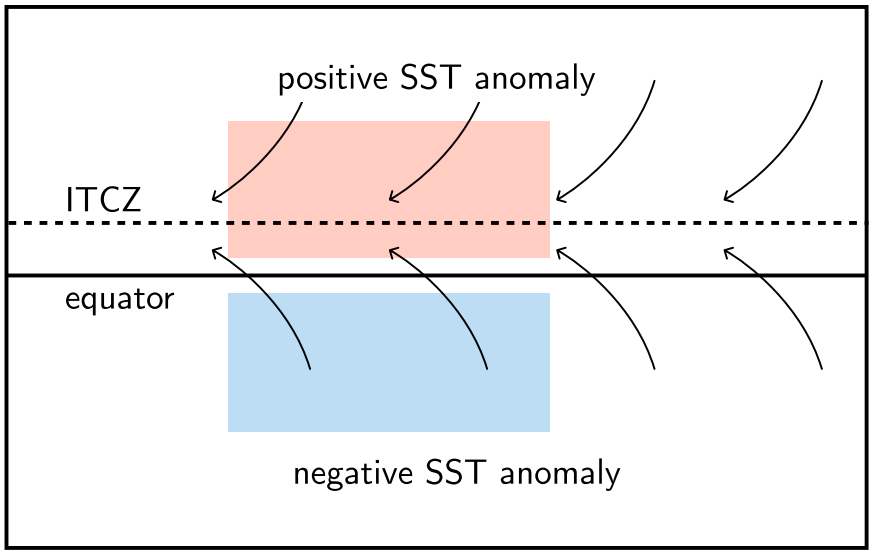
      B. Decrease, resulting in more CO_2 released to the atmosphere

      C. Remain unchanged, since temperature, evaporation, and precipitation have no effects on dissolved CO_2

      D. Inconclusive from the information given

   (b) (2 points) Justify your answer.

9. (3 points) The wind-evaporation-SST (WES) feedback is an interesting phenomenon found in tropical ocean-atmospheric coupling. Consider an initial meridional SST dipole like the one given in the figure (a top-down view). Describe the steps of the WES feedback and classify it as a positive or negative feedback. (Hint: how does the SST dipole affect winds?)



END OF EXAM