

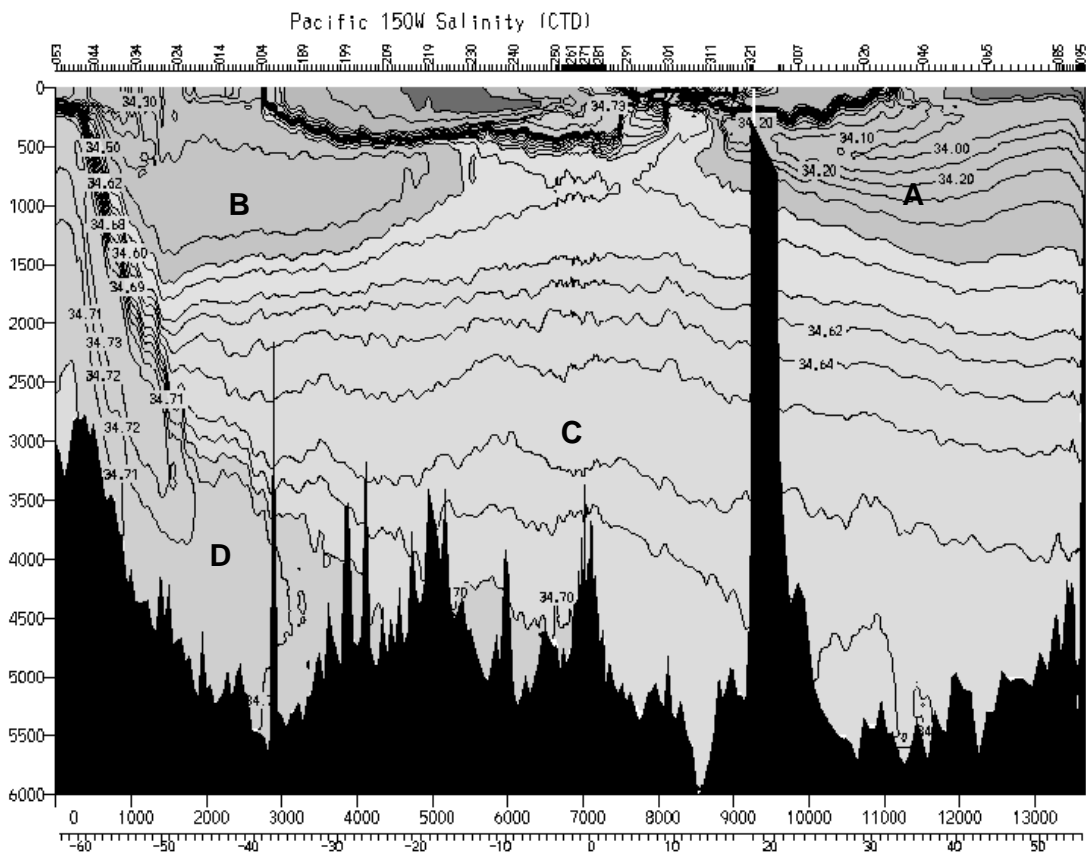
Please write your name in the upper right corner of each page
You have 90 minutes to complete this exam.
This is a closed book exam: no notes, no books.
You may use a calculator and a dictionary.
Constants and selected formulae are included on page 7.

I Multiple Choice

Clearly circle your answer (3 points each)

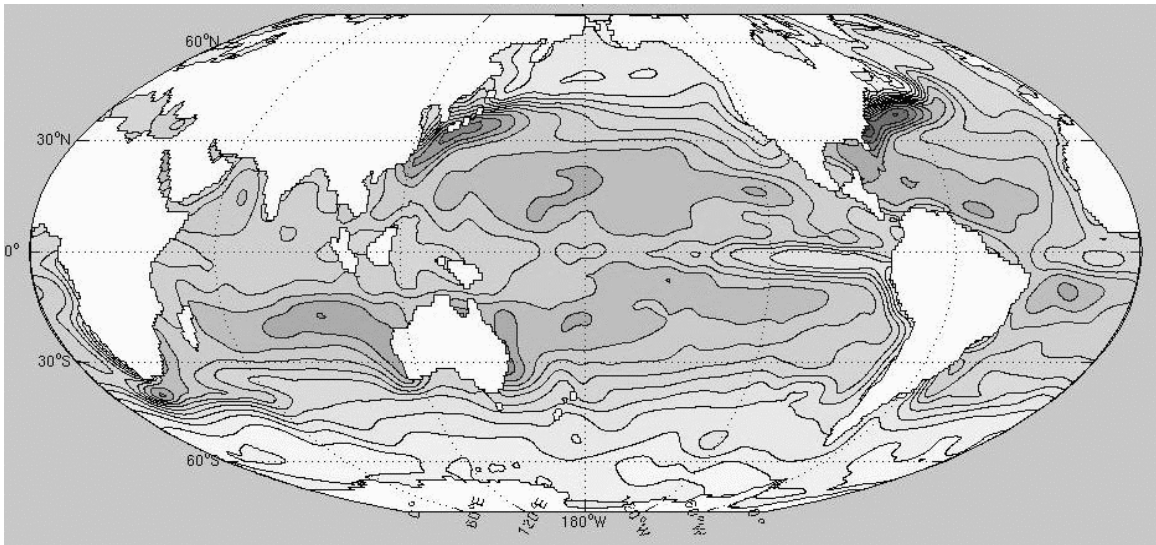
1. Which of the following would be the best method for determining the transport of the Equatorial Undercurrent?
 - (a) surface drifters
 - (b) geostrophic method
 - (c) moored current meters
 - (d) ALL of these would do equally well
2. 18° mode water is:
 - (a) formed north of the Gulf Stream
 - (b) characterized by rapidly changing temperature with depth
 - (c) the primary component of the North Atlantic deep western boundary current
 - (d) a dominant ventilated water of the North Atlantic thermocline
3. The *in situ* temperature of a parcel of water at 3000m is 2°C. If the parcel was raised adiabatically to the surface its temperature would:
 - (a) decrease
 - (b) stay the same
 - (c) increase
 - (d) Not enough information is given here to answer this question.
4. Which if the following is NOT associated with the onset of El Nino?
 - (a) Weakening of the trade winds
 - (b) Deepening of the western warm pool
 - (c) Eastward shift of primary site of convection in the atmosphere
 - (d) Increasing sea surface temperature in the eastern tropical Pacific
5. If the magnitude of Ekman pumping over the subtropical gyre were to double, which of the following would happen?
 - (a) Increased western boundary current transport
 - (b) Increased strength of the “Global Conveyor Belt”
 - (c) Increased eastern boundary current transport
 - (d) ALL of the above would happen

6. Which is NOT a property of North Atlantic Deep Water?
- Salinity maximum
 - Temperature minimum
 - Oxygen maximum
 - Silicate minimum
7. Below is a meridional section of salinity through the Pacific Ocean. Which best describes the location of the Antarctic Intermediate Water?
- -
 -
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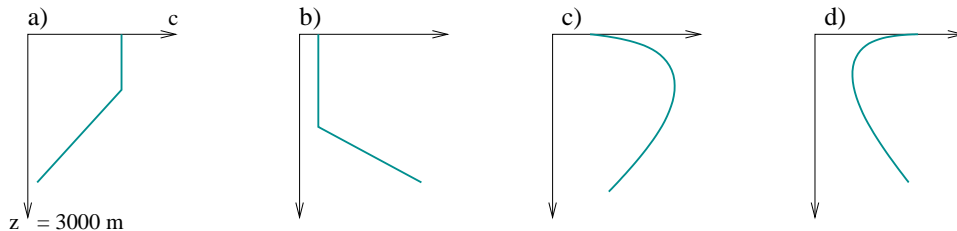


8. Which of the following is NOT related to wind-driven subduction in the thermocline?
- High salinity of Mediterranean outflow water
 - The Temperature-Salinity structure of thermocline waters
 - The subsurface CFC maximum at mid-latitudes
 - Renewal of oxygen consumed by biological respiration

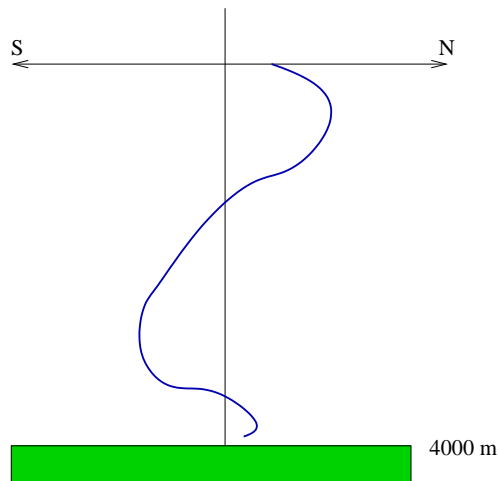
9. If the wind speed over the ocean doubles, the stress at the ocean surface....
- stays the same
 - also doubles
 - increases by a factor of 4
 - increases by a factor of 10
10. The following figure represents the global air/sea exchange pattern of some parameter. Dark colors are high values and light colors are low values. This is a map of
- net heat transfer
 - precipitation
 - evaporation
 - magnitude of wind stress



11. Two hydrographic stations (designated as Pair A) are 100 km apart and the observed difference in their sea surface steric height relative to the geoid is 17 cm. A second pair of stations (Pair B) at the same latitude also differ in observed sea surface steric height by 17 cm but are only 50 km apart. Which of the following is true?
- The surface velocity between both station pairs is the same
 - The surface velocity at station Pair B is exactly twice that at Pair A
 - The surface velocity at station Pair B is exactly half that at Pair A
 - This problem cannot be answered without knowing the exact latitude of the station pairs
12. Which of the following is a typical profile of sound speed in the mid-latitude ocean?



13. Which of the following is NOT a site which contributes to deep water formation?
- (a) Barents Sea
 - (b) Ross Sea
 - (c) Labrador Sea
 - (d) Weddell Sea
14. The western boundary current of the subtropical gyre of an ocean basin carries 30 Sv of water poleward with a mean temperature of 25°C. What is the poleward heat transport in this ocean basin?
- (a) 3.1×10^9 W
 - (b) 3.1×10^{14} W
 - (c) 1.2×10^{15} W
 - (d) Not enough information is given here to answer this question
15. The following figure shows the average meridional velocity as a function of depth. Which ocean basin is this?
- (a) South Atlantic
 - (b) South Pacific
 - (c) South Indian
 - (d) Flow through the Drake Passage

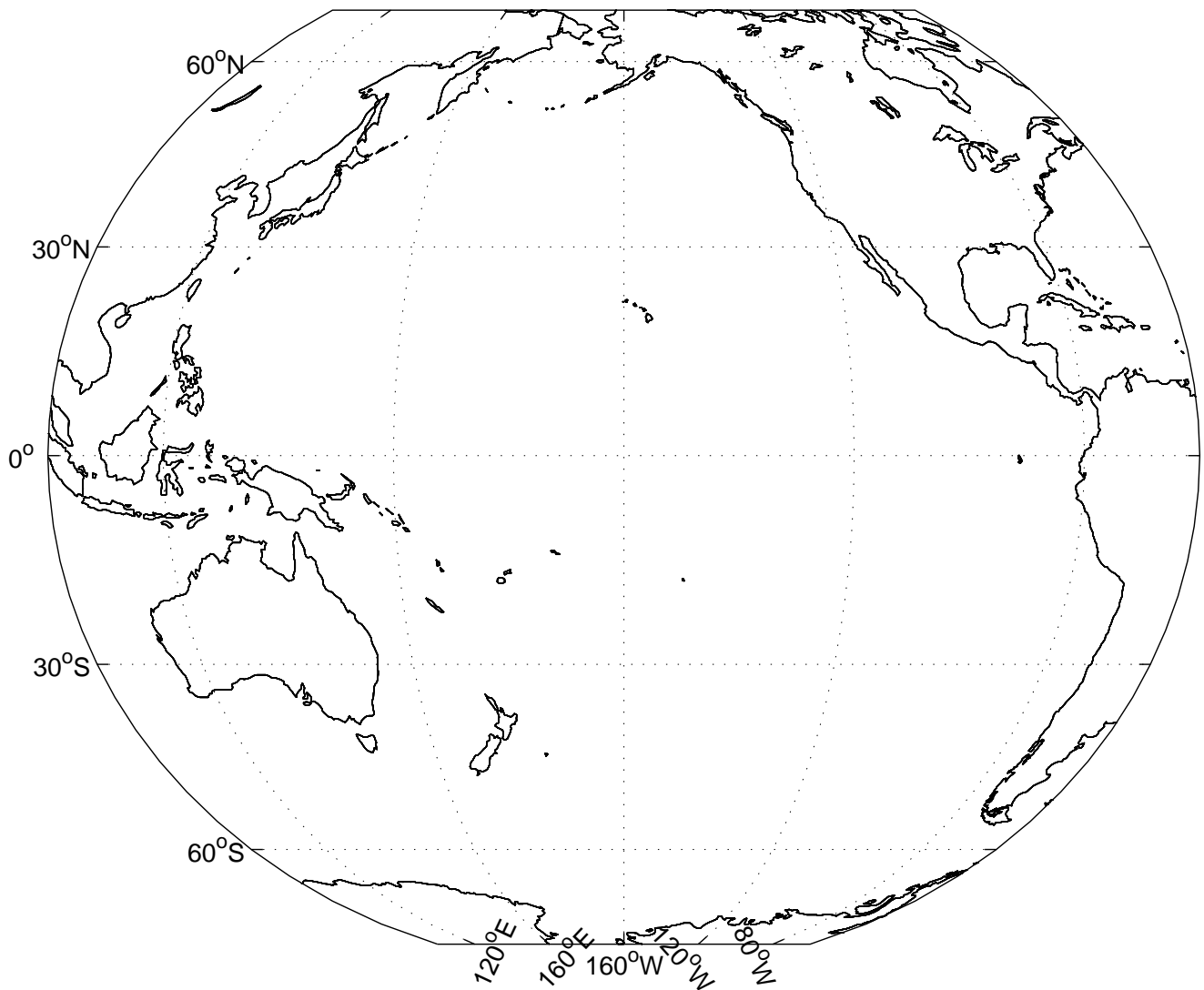


16. Captain Ahab is sailing his vessel from New York City to Lisbon, Portugal. Being an ever vigilant fellow, he notices a change in the height of the sea surface (with respect to the geoid) as he crosses the Gulf Stream. In his log book he records:
- (a) Shiver me timbers! The sea surface elevation increased 10 cm.
 - (b) The sea surface elevation increased 100 cm. Crew looking more mutinous.
 - (c) The sea surface elevation decreased 10 cm. Scurvy setting in.
 - (d) Rum supplies running low. The sea surface elevation decreased 100 cm.

II Short Answer

Answer two out of the four questions (17-20). Please organize your answer before you start to write so that it will be very clear and will fit into the space provided (13 Points each.)

17. Sketch the pattern of the surface circulation in the Pacific Basin. Label all major currents.



18. Compare and contrast the heat transport in the Atlantic and Pacific Oceans. Include discussion of directions, mechanisms, and approximate magnitudes.

19. Satellite sensors have revolutionized the way we can observe the ocean. Name two properties associated with ocean circulation which can be measured from satellites. For each, briefly discuss 1) how the satellite measurement relates to ocean circulation and 2) the advantages and disadvantages of satellite observations versus ship-based observations.

20. List the individual air/sea processes which contribute to the heat balance of the surface ocean. Briefly describe each of them and state the typical annual-average value.

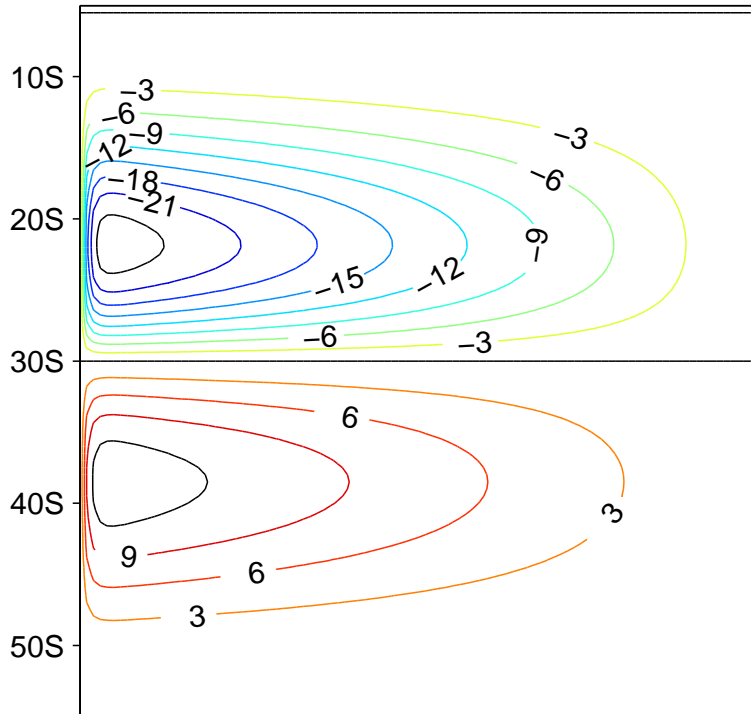
Useful Values and Equations

- Rotation rate of earth: $\Omega = 7.292 \times 10^{-5} \text{ s}^{-1}$
- Coriolis parameter: $f = 2\Omega \sin\theta$
- Radius of earth: 6375 km
- Surface area of ocean: $3.61 \times 10^{14} \text{ m}^2$
- Mass of the ocean: $1.4 \times 10^{21} \text{ kg}$
- Heat capacity of sea water: $c_p = 3985 \text{ J kg}^{-1} \text{ }^\circ\text{C}^{-1}$
- one degree of latitude = 111.12 km
- acceleration due to gravity: $g = 9.8 \text{ m s}^{-2}$
- 1 Sv = $1 \times 10^6 \text{ m}^3/\text{s}$
- $\Delta Q = m c_p \Delta T$
- $PV = \frac{f}{h}$
- $M_e = \left| \frac{\tau}{f} \right|$
- $w = \frac{1}{\rho} \frac{\Delta \tau / f}{\Delta y}$
- $v = \frac{g \Delta h}{f \Delta x}$

III Problems

Complete two out of the three problems (21-23). If you work on all three problems, indicate in a clear manner which two you want to be graded. Show your work. (13 Points each.)

21. The figure below shows contours of sea surface height (with respect to the geoid) in a southern hemisphere ocean basin. The contour spacing is 3 cm and the basin is 1000 m deep. Indicate on the figure the direction of flow for each gyre. Estimate the transport of the western boundary current at 20°S assuming the velocity at all depths is the same as at the surface. (Express your answer in Sv)



22. The mythical Frigidus Sea is the site of intense cooling. It is known from ocean observations that 6 Sv enters the sea with a mean temperature of 10°C but exits the basin with a mean temperature of only 2°C. The surface area of the sea is 1.5×10^6 km². Assuming the temperature of the sea is not changing, what is the mean value of heat lost to the atmosphere (in W/m²)?

23. A flat bottomed ocean basin is 700 m deep. The mean meridional velocity of the interior circulation at 30° is 0.5 cm/s towards the equator. Estimate the rate of Ekman pumping. (Express your answer in either m/s or m/yr)