SIO 210
Final Exam
Dec 7, 2004
11:30 - 2:30

Name:

Campus mailing address:
(for returning graded exam)

INSTRUCTIONS

This is a closed book exam - no notes, no books.
You may use a calculator but that is all. Please turn off all cell phones, pagers and PDAs.

Point Distribution: 163 points total
12 multiple choice (4 points each)

4 short answer questions (10 points each)
Do four of the five questions (Q13-Q17)

3 long answer questions (25 points each)
Do three of the four questions (Q18-Q21)

If you work on more then 4 short answer or 3 long answer questions, clearly indicate which questions you would like to be graded.

Overall grade in course: 10% book review, 40% midterm, 50% final.
The midterm grade will not be used if your final exam grade is higher.

Formulae

$fv = 10\frac{\partial \Phi}{\partial x}$ $fu = -10\frac{\partial \Phi}{\partial y}$

$fv = \frac{1}{\rho}\frac{\partial P}{\partial x}$ $fu = \frac{-1}{\rho}\frac{\partial P}{\partial y}$

$g = \frac{-1}{\rho}\frac{\partial P}{\partial z}$ $f = 2\Omega \sin\theta$

Constants

$\Omega = 0.7291 \times 10^{-4} s^{-1}$ g = 9.81 m/s^2

radius of earth = 6371 km 1 Sverdrup = 1x10^6 m^3/s

Multiple Choice (circle correct answer)

Q1. Which of the following is NOT TRUE of ocean ventilation?

A) Both the NAO and PDO represent examples of climate variability created by coupling between the atmosphere and subtropical ocean ventilation.

B) Water in the thermocline has a residence time of decades to a few hundred years.

C) Ekman pumping is one factor which contributes to thermocline ventilation

D) Property characteristics (T,S, tracers) show that the thermocline ventilates predominantly by diapycnal diffusion rather then subduction along isopycnals.

Q2. Which is NOT TRUE of the fundamental dynamical model of flow in the deep ocean?

A) Is named for 1960 paper by Henry Stommel and Arnold Arons.

B) Predicts that water in the deep North Pacific will flow northward,.

C) Requires Deep Eastern Boundary Currents to satisfy mass conservation

D) Is based on geostrophy and the linear vortiticy balance - the same assumptions used in the Sverdrup model of the wind-driven gyres.

Q3. Which is NOT TRUE of Kuroshio Extension Region?

A) Is the site of North Pacific Intermediate Water formation.

B) Large meanders of the current can spin off rings.

C) Advects warm water eastward

D) Characterized by large transfer of heat from ocean to atmosphere

Q4. Which is NOT TRUE of eastern boundary currents?

A) Generally flow equator ward

B) Act to compensate for mass transport of interior Sverdrup Circulation.

C) They are in geostrophic balance.

D) Reverse direction seasonally if overlying winds reverse.

Q5. Which of the following always acts on average to cool the ocean?

A) Evaporation

B) Sensible heat exchange

C) Solar Radiation

D) Sea Ice Formation

Q6. Which is false?

A) A weakening of the trade winds often marks the start of the El Nino phase.

B) ENSO is the largest mode of interannual variability of the coupled ocean-atmosphere

C) Interannual changes in sea surface height of the tropical Pacific are one of the strongest signals observed by satellite altimetry.

D) ENSO evolves via westward propagation of an equatorial Kelvin wave.

Q7. Which of the following water masses are NOT characterized by high salinity?

A) Mediterranean Sea Water

B) North Pacific Intermediate Water

C) Red Sea Water

D) Central Waters

Q8. During deep water formation, parcels of water sink from the surface into the deep ocean. Which DOES NOT occur during this process?

A) The temperature of water parcels increases due to adiabatic compression

B) Entrainment of ambient waters increases the net water mass formation rate

C) Resulting depression of sea surface spins up a surface cyclonic flow.

D) in situ density increases by a few percent.

Q9. Temperature in the atmosphere decreases with height from the surface up to the tropopause. What is the primary reason for this structure?

A) Wind shear

B) Moisture content

C) Solar radiation

D) Adiabatic expansion

Q10. Which is true of Ekman circulation?

A) Discovered by Karl Ekman after pondering the water draining from his bathtub.

B) Has a net transport to the left of the wind in the North Pacific

C) Interaction with coastlines can lead to strong upwelling or downwelling.

D) Is convergent at the Equator.

Q11. In terms of spatial pattern, the Pacific Decadal Oscillation (PDO) most closely resembles which one of the following climate patterns?

A) ENSO

B) Aleutian Low

C) Arctic Oscillation

D) North Atlantic Oscillation

Q12. Which of the following is NOT TRUE of mode waters?

A) Mode waters are one component of thermocline ocean ventilation

B) Mode water characteristics closely match the surface summertime water conditions in the region of formation.

C) Observationally mode waters are often identified by the characteristic signature of low vertical stratification of the temperature field.

D) Mode waters are the examples of buoyancy forced water mass formation advected predominantly by the wind driven circulation.

Short Answer (do four of the five questions 13-17)

Q13. Discuss the key distinctions between wind-driven ocean circulation and buoyancy driven ocean circulation. Include in your discussion rough estimates of scales (length,time,transport) of each. What is an example of a major ocean current driven predominantly by the wind and one driven predominantly by buoyancy forcing?

Q14. Atmospheric circulation. The Hadley circulation and the Walker circulation both include rising air in the tropics. Briefly describe:
(a) where the sinking occurs in both cells.
(b) the resulting surface winds associated with both cells.

Q15. Contrast surface gravity and Rossby waves in terms of the direction of particle velocities and in terms of time scales (wave frequency). Why does the Coriolis force have little effect on surface gravity waves and a major role for Rossby waves?

Q16. For two brief periods each year in the Indian Ocean, the surface current along the equator flows towards the east. ("Wyrtki jets") The surface flow is forced by the wind. Briefly describe the annual cycle of the winds in the tropical Indian Ocean that results in this reversal in circulation.

Q17. This figure shows the surface dynamic height (geopotential anomaly) in the Indian Ocean (Reid, 2003).

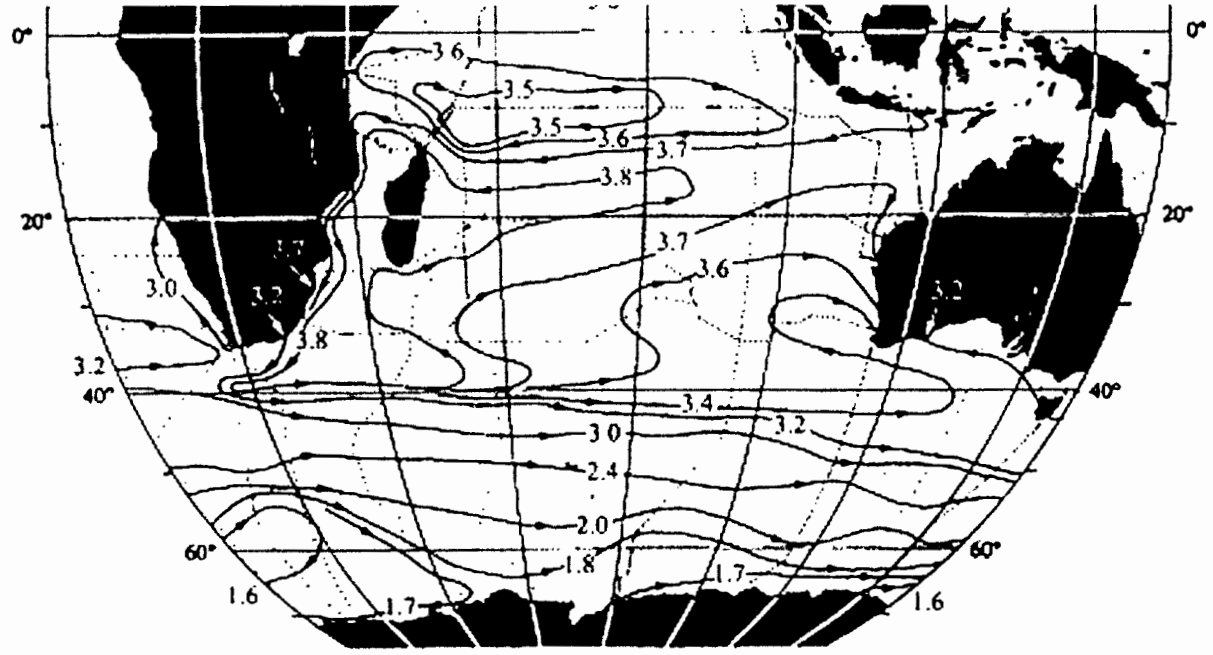
(a) Mark the highest pressure region on the map.

(b) Mark the lowest pressure region on the map.

(c) Mark the main anticyclone on the map.

(d) Is there a cyclone on the map? If so, mark it. (There might be more than one.)

(e) Mark the fastest currents *based on this plot.* Explain *why* you would find the fastest currents there.



Long Answer (do four of the five questions 18-21)

Q18. A) In *Salt: A World History*, Mark Kurlansky includes details on the current production of industrial rock salt on Great Inagua Island in the British Bahamas. Annually, the 38,000 acres (154 km^2) of evaporation ponds annually produce one million tons ($1x10^9$ kg) of salt. Calculate the net evaporation rate (meters per year) at this location.

B) How would the estimate of evaporation based on this methodology compare (higher/same/lower) with a measure of total evaporation of this ocean region based on scientific instruments.

C) Suppose this rate of evaporation is representative of the entire Caribbean Sea (2,754,000 km^2). The magnitude of the net flow into the Caribbean is 30 Sv
The net outflow of this sea feeds into the Florida Current. Neglecting the effects of river runoff, Calculate the mean change in salinity of the seawater in its passage through the Caribbean.

D) Based on this calculation, does the Caribbean Sea appear to be an important region for the net salinification which occurs in the North Atlantic? Justify your answer.

Q19. The wind drives a circulation in the subtropical North Atlantic. The figure on the next page shows the dynamic height (in units that are similar to meters) at the sea surface, from Reid (1997).

(a) Mark the Florida Current and the Gulf Stream on the map.

(b) Mark the Labrador Current on the map.

(c) Mark the Canary Current on the map.

(d) Mark the general region where you would expect to find subducted subtropical waters. What water mass or vertical structure do we associate with this subtropical subduction?

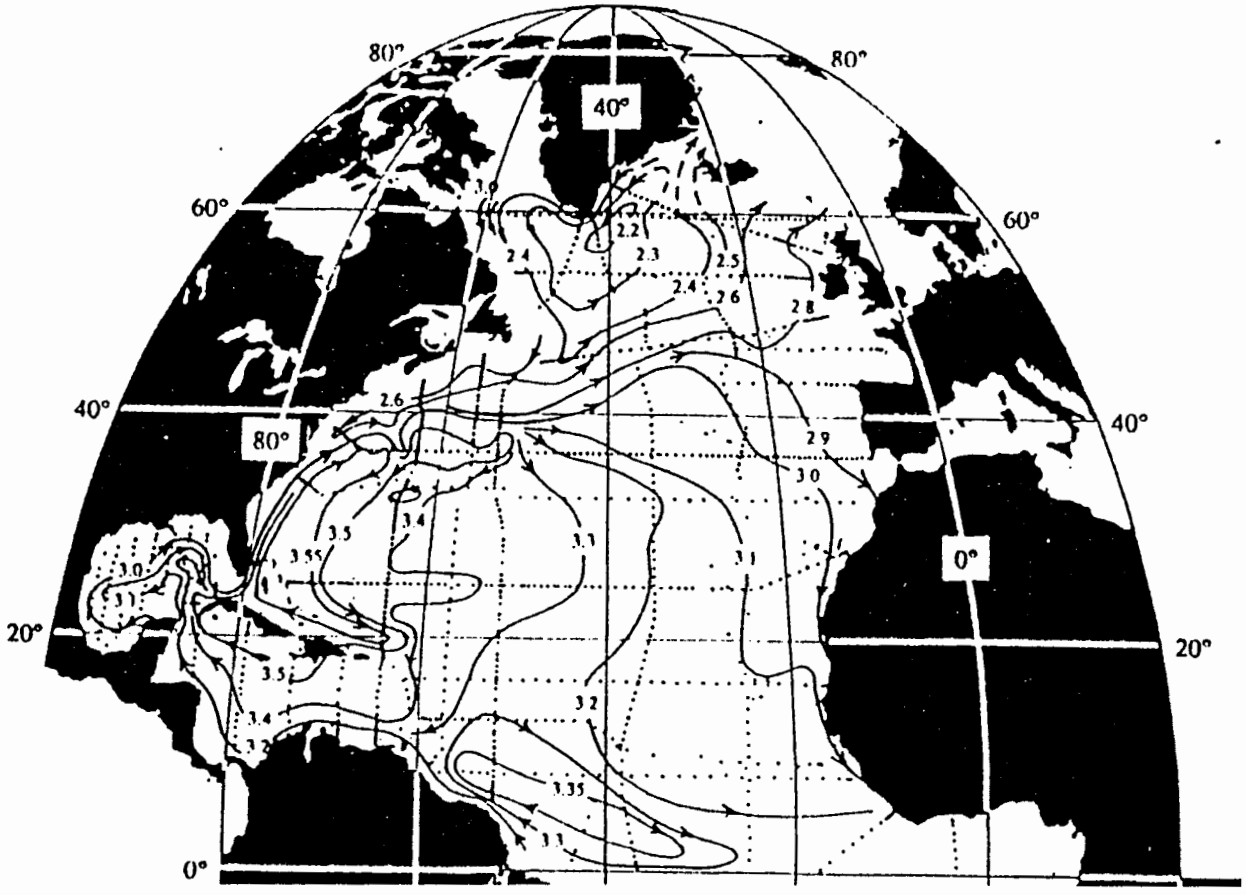
(e) Sketch (draw) on the map the direction of the prevailing winds that create the subtropical circulation.

(f) The Ekman layer is the **direct** response of the ocean to the wind stress. Approximately how thick is the Ekman layer?

(g) What direction does the Ekman layer transport go in response to the winds that you drew in (e)?

h) Mark the region on the map where the subtropical circulation is dominated by Sverdrup transport.

i) If the net Sverdrup transport at 25°N is 50 Sv and if it is distributed over the top 1000 m of the water column, compute the average velocity of the Sverdrup transport. Assume that 1° longitude = 100 km.



Q19 (continued)

(j) Mark the places where you would expect to find deep convection (> 1000 meters deep). What separate water masses are formed in these deep convection regions?

(k) What general water mass do these separate water masses in (j) contribute to?

Q20. Equatorial ocean response to changing forcing

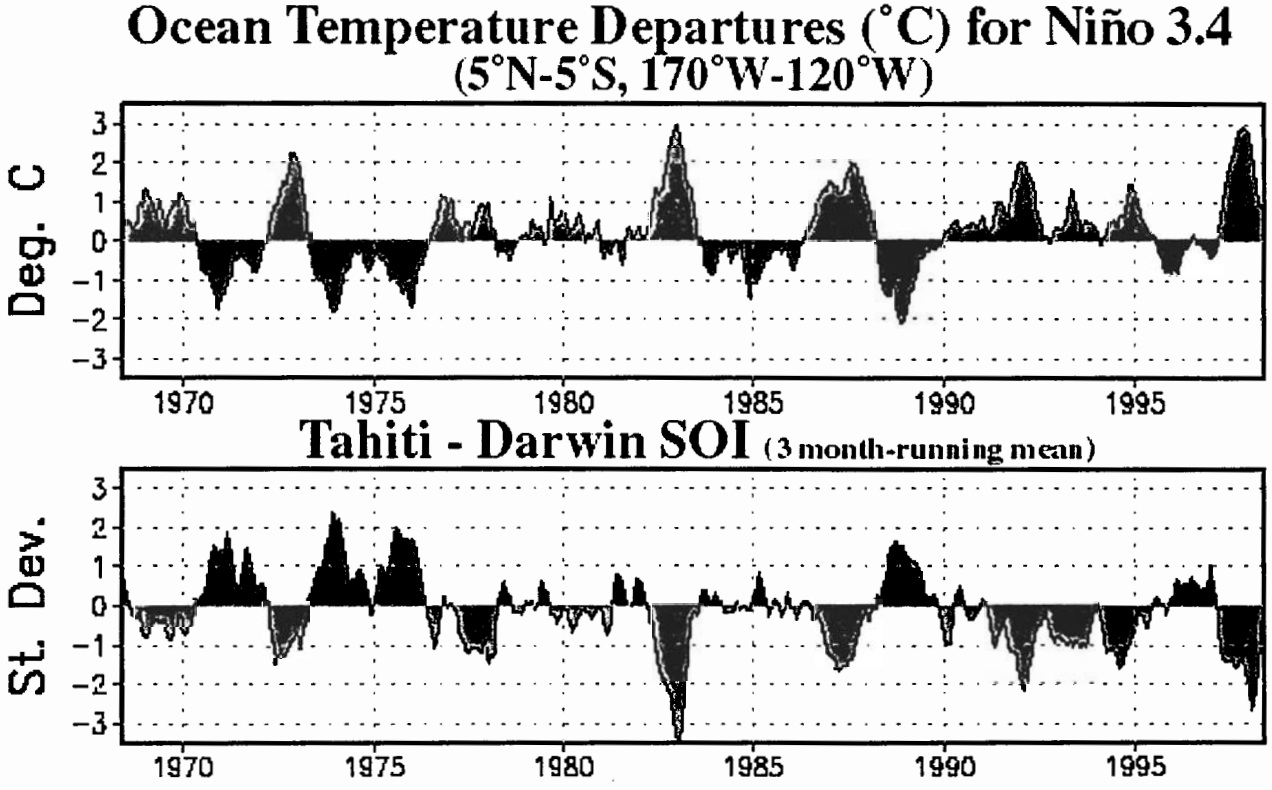
(a) Suppose the trade winds in the equatorial Pacific weaken. Explain how the surface ocean circulation changes in response to the wind change.

(b) Explain how the ocean circulation change affects the ocean temperature distribution.

(c) The figure is the time series of temperature anomaly for the tropical Pacific (upper panel) and the Southern Oscillation Index (SOI – lower panel).

Mark at least one major El Nino episode on the figure.

Mark at least one major La Nina episode on the figure.



(d) The Southern Oscillation Index is the difference in sea level pressure between Tahiti and Darwin (northern Australia). Explain the El Nino episode(s) you marked in (c) in terms of this index.

(e) Assume that an equatorial Kelvin wave can propagate the full width of the Pacific in 2 months. The Pacific Ocean is approximately 15,000 km wide at the equator. Calculate the wave's speed, and compare its speed with the flow speed of the Equatorial Undercurrent.

(f) The equatorial thermocline in the eastern Pacific, as marked by the 20°C isotherm, is centered at 70 meters depth. The vertical temperature gradient through the thermocline is 0.1°C/meter. How *far up* or *down* must the 20°C isotherm move in order to produce a positive (warm) 5°C temperature anomaly at 70 meters depth?

Q21. Calculation of flow through a mid-latitude flat-bottom channel.

i) Width **L** = 1500 km and depth **H** = 4000 m, latitude = 30 N.

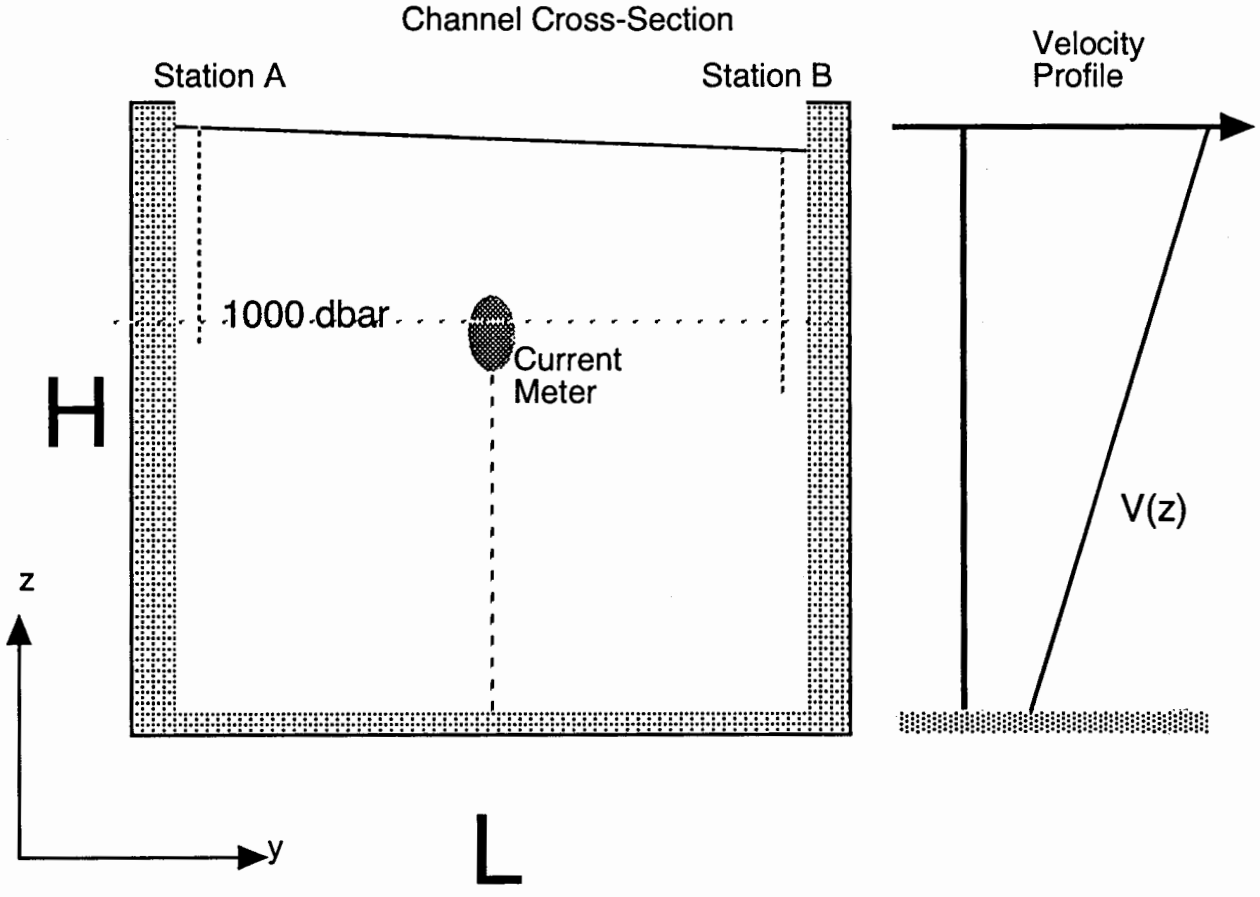
ii) A long term current meter moored at 1000 dbar in the middle of the channel records a mean velocity **u** = 2 cm/s.

iii) Hydrographic observations of the density profile on both sides of the channel have been used to calculated the dynamic height (geopotential) anomaly of the sea surface relative to 1000 dbar.

Station A (1 km from the southern coast) $\Delta\Phi = 0.5\ m^2/s^2$ (dynamic meters)

Station B (1 km from the northern coast) $\Delta\Phi = 0.2\ m^2/s^2$ (dynamic meters)

iv) Assume the along channel velocity field is independent of y and the vertical sheer is constant.



A) What is the cross channel pressure gradient at the bottom of the ocean?
B) What is the net transport through the channel?