SIO 210 Introduction to Physical Oceanography
Final Examination, Fall, 1999

December 14, 1999
2 PM - 5 PM
This is a 3-hour closed book exam - no notes, no books. You may use a calculator. I will have a calculator at the exam if you need to borrow one.

The final grade will be an average from the Hendershott mid-term and this final.

Please do not discuss the exam with fellow students who are taking it at a later time.
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1. The attached figure shows a zonal (east-west) vertical section of potential temperature from the western Indian Ocean, at around 32°S.

(a) The large slope in isotherms close to the left side of the figure is the (circle one):

Leeuwin Current Benguela Current Agulhas Current Durban Current None of these

(b) Indicate on the figure the direction of the current.

(c) From what you know about western boundary currents, the surface flow is approximately (circle one):
1 cm/sec 10 m/sec 1 mm/sec 100 cm/sec

(d) Above the figure, sketch the shape of the sea surface, assuming that the current is strongest at the sea surface.

(e) Indicate the direction of the pressure gradient force for this current.

(f) Offshore of the current and in the upper part of the water column, the isotherms are somewhat spread apart. What is the approximate temperature of this spread?
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(g) What is the water mass name associated with this isotherm spread?
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(h) Briefly explain what happens when this current reaches the southern tip of Africa.

2. The attached figure is the nutrient nitrate close to the sea surface (at 10 meters depth) in the Pacific.

(a) Why are there regions of nitrate that are nearly zero? (explain briefly) (hint: nitrate increases strongly with increasing depth)

(b) What process is occurring where nitrate is not zero in this near-surface map?________________________

(c) Along the coast of North America between 30° and 40°N, there is non-zero nitrate in a narrow strip. What current is associated with this feature?
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(d) What is the wind direction in the narrow strip of non-zero nitrate along the North American Coast? _____________________

3. Refer again to the map of nitrate used in problem 2. Along the equator (0°), nitrate varies from west to east. The eastern region of non-zero nitrate closely corresponds to a feature in the surface temperature distribution.

(a) Is the temperature in this eastern, non-zero nitrate region relatively HIGH or LOW? (circle one)

(b) What is the name often given to this temperature feature? (circle one)

Warm pool   North Equatorial Countercurrent   Cold tongue   Davidson Current

(c) What is the overall direction of the winds in the region of this equatorial feature?

(d) Assume that the winds in the western tropics and eastern tropics are about the same strength. Why are the non-zero nitrate feature and the associated temperature feature found in the eastern equatorial region and not in the western? (explain briefly)

4. The attached figure is a well-known cartoon of an aspect of the global circulation. The northward arrows in the Atlantic correspond to near-surface waters and the southward arrows in the Atlantic correspond to sub-surface waters.

(a) The sub-surface arrows represent a water mass. What is the name of this water mass in the Atlantic Ocean? ______________________________

(b) What is the approximate depth range of this sub-surface water mass in the Atlantic Ocean?____________________

(c) List TWO of the North Atlantic sources(or source locations) of this water mass.

____________________________________ and _______________________________

(d) In the Pacific Ocean, the subsurface water is indicated as flowing northward, and is associated with a water mass. What is a name for this water mass? ___________________

(e) What is the approximate depth range of this northward sub-surface flow in the Pacific Ocean?__________________________

(f) What is the approximate age difference between the newly-formed subsurface water in the North Atlantic and the deep water in the North Pacific? (circle one)

10 years 1000 years 100 years

(g) What is the approximate volume transport associated with the global circulation depicted in the figure? (1 Sv = $1 \times 10^{6} m^{3} sec^{-1}$) (circle one)

2 Sv 1000 Sv 150 Sv 20 Sv

5. The attached figure shows "adjusted steric height" at the sea surface in the Pacific Ocean, from Reid (1998). This quantity is very similar to dynamic height. It is meant to depict the absolute height of the sea surface.

(a) Label the Kuroshio and Kuroshio Extension on the figure.

(b) Label the Antarctic Circumpolar Current.

(c) Label the North Equatorial Countercurrent.

(d) Label the East Australia Current.

(e) Label at least TWO high pressure regions, one in the northern hemisphere and one in the southern hemisphere.

(f) Label at least TWO low pressure regions, one in the northern hemisphere and one in the southern hemisphere.

(g) Calculation. Across the Kuroshio Extension, steric height changes by about 0.8 (contours 3.2 to 4.0). Assume that this corresponds to a current of 50 cm/sec over a width of 200 km.

The interior flow of the subtropical gyre has the same change in steric height across its full width. What is the approximate speed of the current in the interior? (111 km/1° latitude or per 1°longitude at the equator.)

6. The classical theory of what drives the deep circulation (due to Stommel and Arons) includes sources and sinks of water.

(a) What are the global sources of deep water (name 2)? ________________ and __________________________.

(b) If 20 Sverdrups (see problem 4 for definition of a Sverdrup) is formed at one source, and if it rises uniformly everywhere, what is the average vertical velocity of the rising? Assume that the earth's radius is 6300 km, and assume that deep ocean basins cover abou 60% of the earth

(c) This rising is assumed to drive a deep horizontal circulation through stretching the water column. In what meridional direction does the interior flow of this theoretical deep circulation go? _______________________________________

(d) The deep interior circulation and rising water have to be connected by narrow currents to balance mass. Where do these narrow currents occur? ___________________

What are the narrow currents called? ___________________________

7. The attached figures are potential temperature, salinity and oxygen along the zonal section at 24°N in the North Atlantic. The section is between Florida and Africa (the westernmost portion, crossing the Gulf Stream is omitted). Several water masses are apparent in this section.

(a) Label two water masses on the section. Please select at least one to be at least 1000 m deep or deeper.

(b) Discuss the origin of one of the water masses you labeled in (a). In particular, explain where it comes from, and why it has the relative salinity (or oxygen or potential temperature) signature that identifies it.

(c) The actual measurements in the water masses that you identified were of temperature, salinity and pressure. Is the actual measured temperature of the water parcels HIGHER or LOWER than the potential temperature (circle one)?

(d) A blank potential temperature/salinity diagram is also attached. Contoured on it is potential density relative to the sea surface, . From the salinity and temperature sections, and your identification of two water masses on the section, mark where the water masses occur on the potential temperature/salinity diagram.

(e) Choose one of the two water masses you marked. (If one was quite shallow, please select the deeper one.) What is its approximate pressure on the vertical sections?___________________ What would be the most appropriate potential density parameter to use to describe its local flow and evolution? ________________. Explain in words what this potential density parameter is.

(f) On the potential temperature/salinity diagram, sketch (draw roughly) the contours of this potential density parameter (selected in (e)). Explain briefly the relative orientation of these contours to the potential density contours.

8. Consider an idealized ocean, with three regions that represent the tropics, the North Atlantic and the North Pacific. Assume for the argument that Central America doesn't exist and so the Atlantic and Pacific are connected in the tropics.

Assume a net heat flux from the ocean to the atmosphere in both the North Atlantic and North Pacific of 100 W/m2, over an area that is 20° x 20° in the N. Pacific and over a larger area of 20° x 60° in the N. Atlantic (see diagram). Assume that the tropical box size is 240° x 20°. Assume that 1° = 100 km (To make this simple, ignore the change in length with latitude.)

(a) What features of the actual surface heat flux patterns do these idealized heat losses represent? (in particular, why have I assumed that the heat loss area is larger in the N. Atlantic?)

(b) If this ocean is in a steady state (no box warming or cooling on average), what is the heat transport from the tropical box to the North Pacific box?

(c) What is the heat transport from the tropical box to the North Atlantic box?

(d) What is net air-sea surface heat flux in the tropical box that is required to balance these heat transports, in W/m2?

(e) Assume that there is an exchange of 10 Sverdrups between the tropical box and each of the two northern boxes (see diagram). Assume for simplicity that this starts at one warm temperature and is converted into another temperature (don't consider continuous changes in temperature). If the temperature of the water in the tropical box that flows into the two Northern boxes is 30°C, what temperature is the return flow from each of the two northern boxes into the tropics? (Use for simplicity a single density of sea water

=1025 kg m-3, and a specific heat of seawater of = 4000 Jkg-1K-1.)

North Pacific return flow temperature = ___________________

North Atlantic return flow temperature = ___________________