SIO 210 Final examination
Wednesday, December 12, 2018
11:30-2:30 Eckart 227 Name:_____

Please put your initials or name on each page, especially if you pull pages apart.

Turn off all phones, iPods, etc. and put them away.
This is a **closed book exam**.
You may use **two pages** of notes, both sides, written or printed.
You may use a non-communicating calculator.

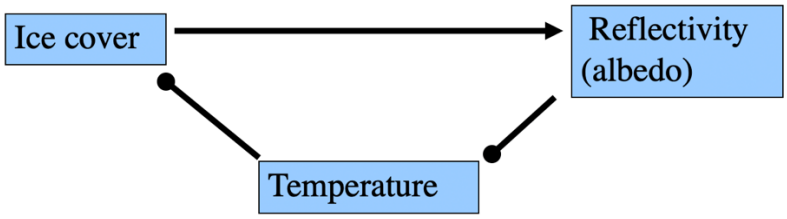
Check which you prefer regarding the return of this exam and other graded materials
_____I will pick up the exam (after Jan. 2)
_____Return the exam etc to me via campus mail (or full address)
Mailcode_____

Possibly useful expressions and values; you will not need all of these.
ρ: use 1025 kg/m^3 for generic calculations
c_p = 4000 J/kg°C
$\rho\ c_p\ T$
1 PW = 10^{15} W = 10^{15} J/sec
Earth's radius: 6371 km
$V_{Ek} = -\tau^{(x)}/(\rho f)$
$f = 2\Omega \sin(\text{latitude})$
$\Omega = 0.73 \times 10^{-4}$/sec
sin (30°) = 0.5
sin(50°) = 0.77
1° latitude = 111 km
1 Sv = 1x10^6 m^3/sec
g = 9.8 m/sec^2

Multiple choice (**2 points each; 20 points total**)
For each multiple choice problem, **circle ONE CORRECT answer**.

1) In the tropical Pacific, the Walker circulation
   (a) weakens during El Nino events
   (b) strengthens during El Nino events
   (c) causes the surface water along the equator to flow eastward
   (d) is associated with excess rainfall near Ecuador and Peru

2) The climate interaction between sea surface temperature, sea ice extent, and solar radiation (reflectivity) shown in the figure is an example of
   a) stable equilibrium
   b) negative feedback
   c) neutral stability
   d) positive feedback



3) North Atlantic Deep Water is formed mostly by
   a) Downward diffusion of heat accompanied by deep upwelling
   b) Brine rejection due to sea ice formation in the Greenland Sea
   c) Open ocean convection in limited locations
   d) Inflow of Arctic waters through the Canadian archipelago between Canada and Greenland

4) Geostrophic balance
   (a) Results from tilting (sloping) of isopycnals
   (b) In the Brazil Current is associated with high surface height in the center of the gyre (mid-Atlantic ridge region) and low surface height along the Brazilian coastline
   (c) Results from Ekman convergence in the mixed layer
   (d) In the Gulf Stream is associated with low surface height in the center of the gyre (near Bermuda) and high surface height along the U.S. coastline

5) Which of the following water mass/strait circulations is NOT associated with dense water formation in a semi-enclosed sea?
   a) Indonesian Throughflow Water
   b) Mediterranean Overflow Water
   c) Nordic Seas Overflow Water
   d) Red Sea Water

6) The Nyquist frequency
   a) Is calculated from the total length of time of a time series
   b) Is the typical frequency of surface waves
   c) Is calculated from the time separation between samples in a time series
   d) Is the typical frequency of internal waves

7) Upwelling in the California Current system
   a) Occurs only within a very narrow zone along the coast
   b) Is due to northward alongshore winds

c) Is often associated with large eddies/filaments of upwelled water that spread westward offshore
d) Brings water from the abyssal ocean (>1000 m) to the sea surface

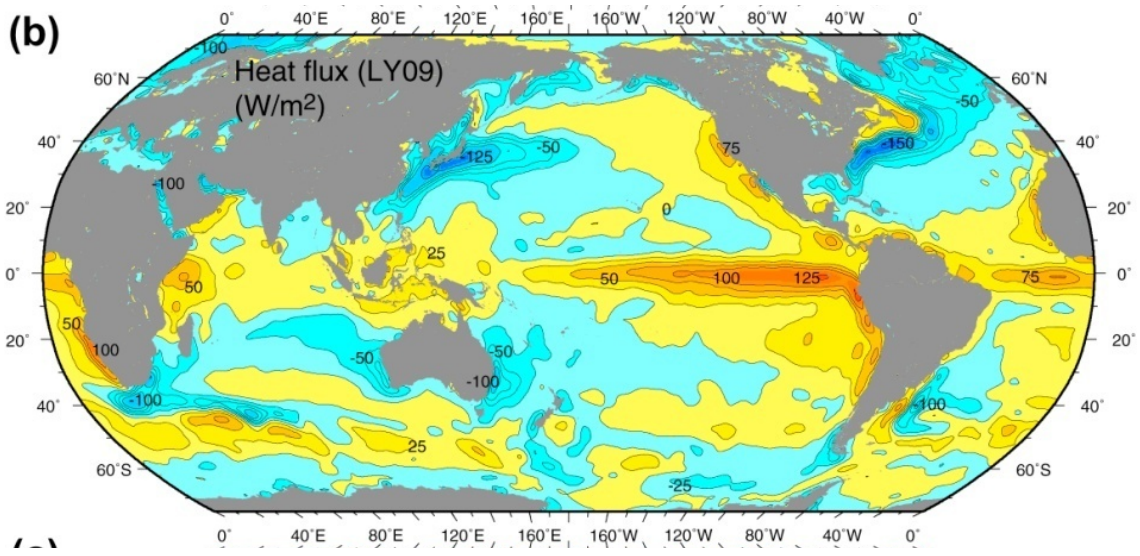
8) Subtropical gyres such as the Gulf Stream gyre
(a) Extend down to the bottom of the ocean without change of horizontal extent
(b) Are driven by Ekman convergence and downwelling (pumping)
(c) Usually have very fresh water in the center at the sea surface
(d) Are driven by cooling of the separated western boundary current (Gulf Stream)

9) Potential temperature
a) Does not change as a parcel of water is moved adiabatically from the sea surface to the deep ocean
b) Changes as a parcel of water is moved adiabatically from the surface to the deep ocean
c) Cannot have a vertical inversion (cold above warm)
d) Is measured directly with a thermistor or thermometer

10) The Leeuwin Current is
a) The western boundary current of the Indian Ocean
b) The eastern boundary current of the South Atlantic Ocean
c) An equatorward flowing eastern boundary current
d) A poleward flowing eastern boundary current

Problems

11) 14 (2, 3, 2, 3, 2, 2)
At the surface of the ocean, the tropical ocean is heated and the high latitude ocean is cooled, in the annual mean (average over many years). The **map** shows the annual mean surface heat flux. Positive: ocean is heated. Negative: ocean is cooled.



a) Circle the two regions of maximum ocean heat loss in the *mid-latitude* Northern Hemisphere. Name the major surface currents associated with these heat loss areas.

_____ (North Pacific)

_____ (North Atlantic).

Circle the one area of major heat loss in the *high-latitude* Northern Hemisphere.

b) Circle the three regions of maximum ocean heat loss in the mid-latitude Southern Hemisphere. Name the major surface currents associated with these heat loss areas.

_____(South Pacific)

_____(South Atlantic)

_____(Indian)

c) Explain in general terms how these currents in (a) and (b) contribute to large heat loss in these regions.

d) In the equatorial Pacific Ocean, there is heat gain. Where is the heat gain largest? (circle it)

Explain why the equatorial heat gain is larger in this region than at other locations along the equator. Describe the ocean circulation that results in this large heat gain.

e) In the mid-latitude North Pacific (around 30°N), the ocean's meridional heat transport is poleward (and large). Describe the circulation and heat loss/gain that creates this poleward heat transport. (Assume that the deep North Pacific does not contribute much to ocean heat transport.)

12) (6 points)
The horizontal momentum equations in a fluid in a rotating reference frame include acceleration, advection, Coriolis, pressure gradient, and viscous terms.

$$x: \partial u/\partial t + u\,\partial u/\partial x + v\,\partial u/\partial y + w\,\partial u/\partial z - fv = -(1/\rho)\partial p/\partial x + \partial/\partial x(A_H \partial u/\partial x) + \partial/\partial y(A_H \partial u/\partial y) + \partial/\partial z(A_V \partial u/\partial z)$$

$$y: \partial v/\partial t + u\,\partial v/\partial x + v\,\partial v/\partial y + w\,\partial v/\partial z + fu = -(1/\rho)\partial p/\partial y + \partial/\partial x(A_H \partial v/\partial x) + \partial/\partial y(A_H \partial v/\partial y) + \partial/\partial z(A_V \partial v/\partial z$$

(a) Which pairs of terms yield geostrophic balance? (circle and name the terms)

(b) Which pairs of terms yield Ekman balance? (circle and name the terms)

(c) Which pairs of terms yield inertial balance? (circle and name the terms)

13) 22 (2, 2, 4, 4, 4, 2, 4)
The map shows the annual mean wind vectors for the Pacific Ocean.

(a) Mark the location of the westerly winds in the North Pacific and South Pacific.

(b) Mark the trade winds in the North and South Pacific.

(c) In the eastern North and South Pacific, circle the regions where there is upwelling along the boundary. What is the name of the current system in each of these upwelling regions?

_____(North Pacific)

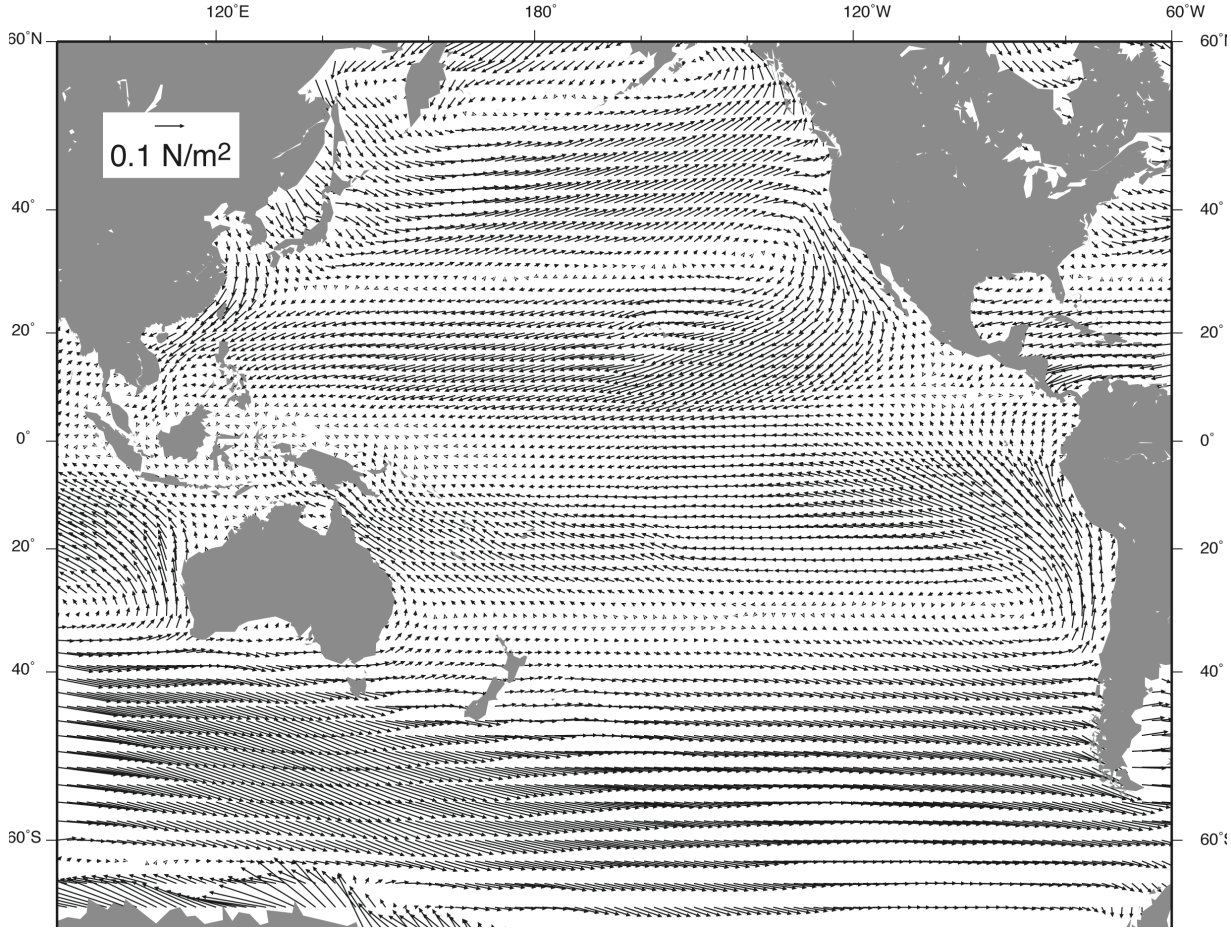
_____(South Pacific)

(d) Explain the upwelling in these two regions in terms of Ekman transport. You may draw relevant arrows on the map, and describe here in words.

(e) Describe the horizontal velocities within an Ekman layer, starting at the sea surface. Use your answer to Problem 12b as part of your explanation.

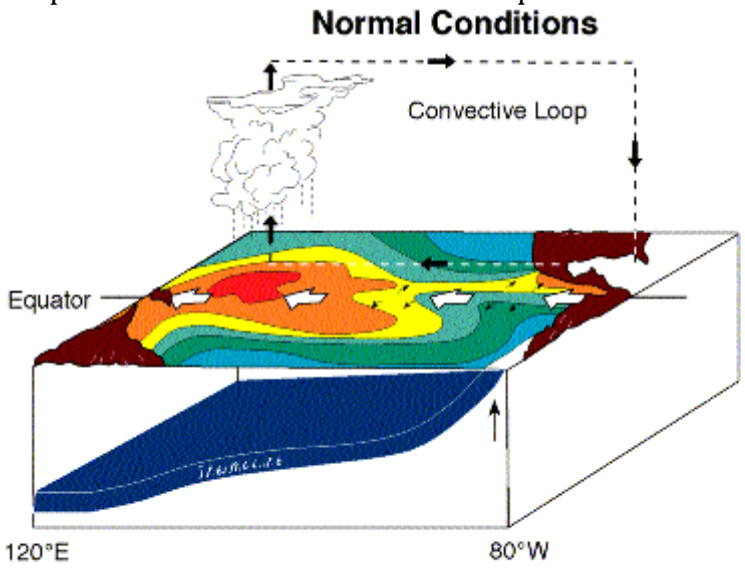
(f) How deep is a typical Ekman layer in meters?_____

(g) In the central North Pacific (180° to 160°W, and 10°N to 40°N), indicate the general direction of Ekman transport relative to the westerly and trade winds. Use arrows on the map. Is this a region of Ekman convergence (pumping) or divergence (suction)?



14) 12 (2, 2, 2, 2, 4)

The figure shows the cartoon of the normal winds, precipitation, currents, surface temperature and thermocline in the equatorial Pacific.



(a) On the figure, circle the part that is the trade winds and the Walker circulation. Explain how this circulation is driven by the ocean.

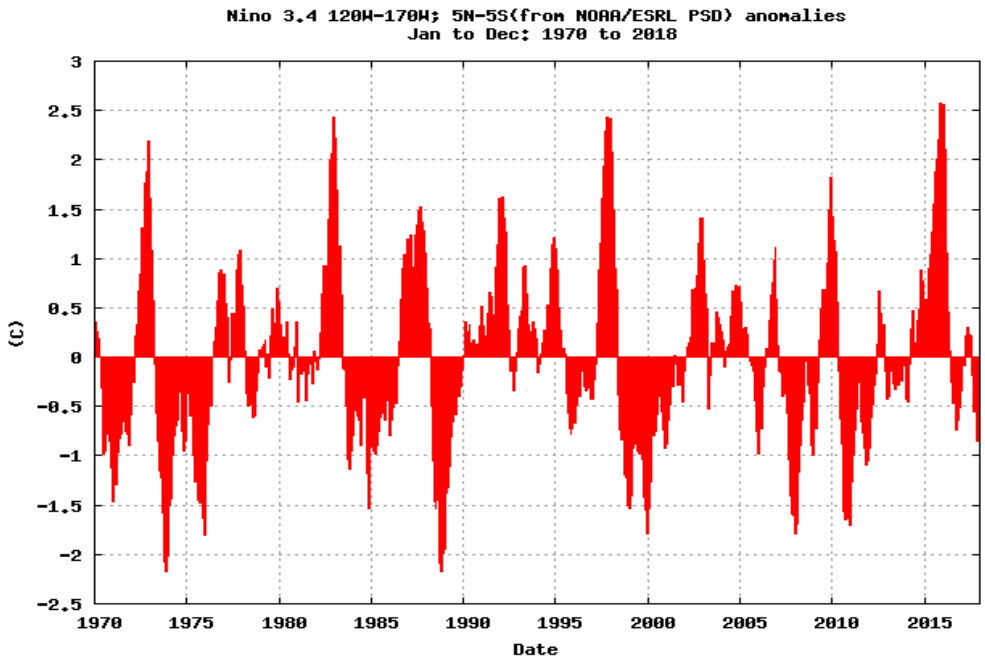
(b) Suppose the trade winds in the equatorial Pacific *weaken*. Explain how the surface ocean circulation changes in response to the wind change. Is this an El Nino or a La Nina state?

(c) Explain how these ocean circulation and wind changes affect the ocean surface temperature distribution.

(d) The figure is the time series of temperature anomaly for the tropical Pacific (also called the Nino 3.4 index). Positive means warm temperature anomaly.

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

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



(e) 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?

15) 10 (3,2, 3, 2)

SEE COLOR FIGURE ON LAST PAGE (SEPARATE PAGE)

NADW (green pathways) forms in the North Atlantic and its marginal seas.

(a) On the map, mark the location of the three deep convection sites that create the new (northern) components of NADW.

(b) What is the approximate net formation rate of NADW (overturning rate in units of Sverdrups) as a whole? (You can give a range of values or an order of magnitude.)

(c) If the temperature of the surface water feeding the Atlantic overturn averages 17 °C and the deep water formed in the overturn averages 2°C, use the overturning volume transport from your answer (a), and expressions given at the top of the exam, and calculate the net meridional heat transport associated with the overturn.

(d) In order for there to be upwelling from the deep ocean to the upper ocean, there must be a process that converts deep water to upper ocean water. List at least one process and circle it on the schematic circulation map_____

16) 16 (10,2, 2, 2)
The color figure with 4 panels shows Pacific Ocean properties along a meridional section at 150°W.

(a) Label the following water masses, and describe briefly how you identify them (salinity minimum, etc):

Subantarctic Mode Water (SAMW)_____

Antarctic Intermediate Water (AAIW)_____

Pacific Deep Water (PDW) _____

Lower Circumpolar Deep Water (North Atlantic Deep Water) (LCDW) _____

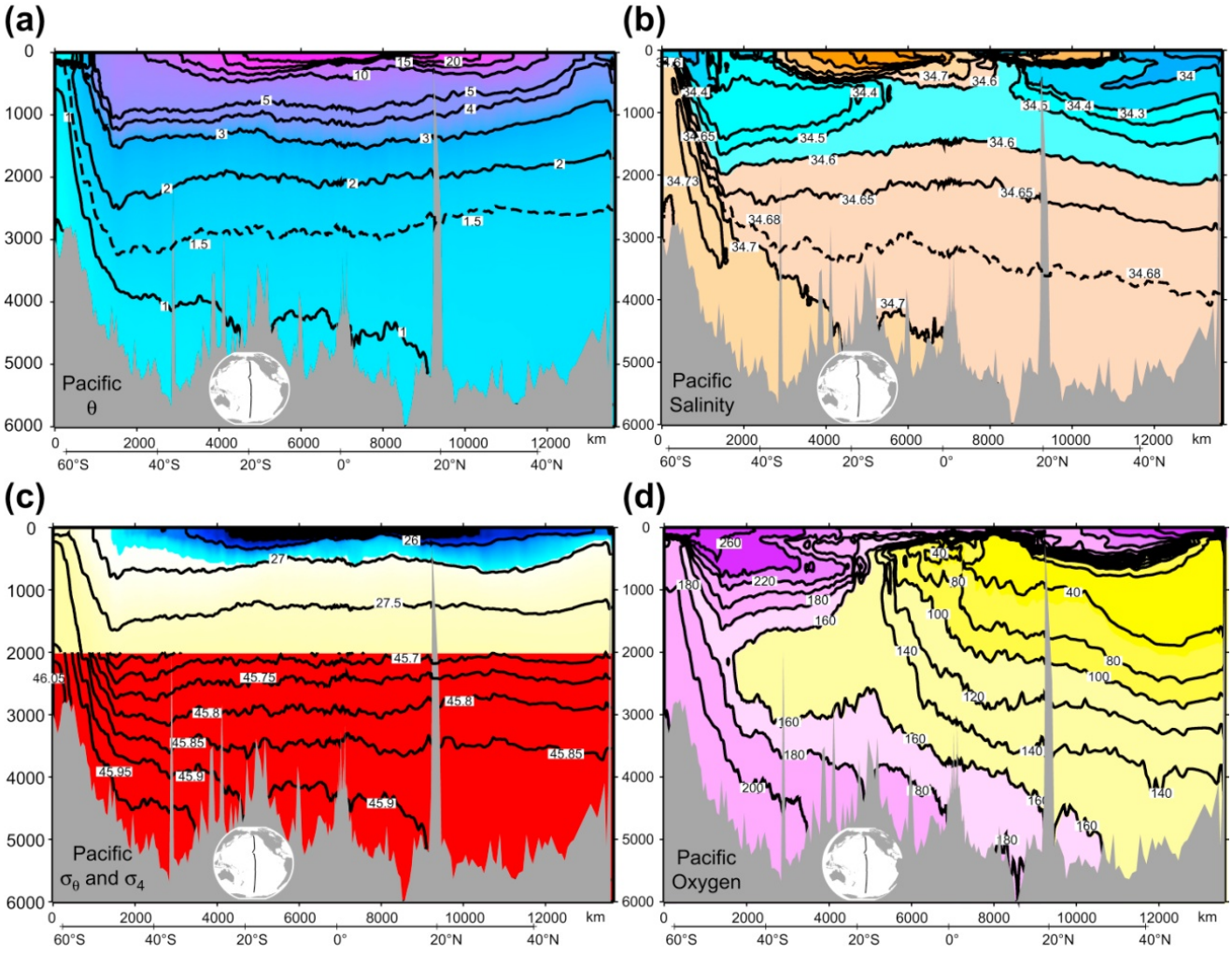
Antarctic Bottom Water (AABW) _____

(b) On the potential temperature section (top left), indicate the location of the Antarctic Circumpolar Current (ACC). Use our notation for currents (circle within a circle or x-within-a-circle, or arrow), to show the direction of the ACC.

(c) Across the top of the potential temperature section, sketch (draw) the sea surface height (SSH) that you infer from your answer to (b), and then continue the sea surface height for the whole section. Make sure that your low SSH and high SSH are in approximately the right locations.

(d) What dynamical balance (from problem 12) did you use in answering (c)?

Name:_____



----FOR PROBLEM 15---