SIO 210 Problem Set 4
December 1, 2014
Due Dec. 12, 2014

1. ENSO is a coupled climate phenomenon in the tropical Pacific that has both regional and global impacts.
a) What two parts of the climate systems are coupled in ENSO?_______________

b) One of the indicators of an impending El Nino event is a weakening of the trade winds.
What is the *normal* ocean circulation in response to the trade winds along the equator?

What is the *normal* ocean circulation in response to the trade winds off the equator, but still within about 5° latitude of the equator?

c) What happens to the ocean circulation and temperature distribution when the trade winds weaken?

d) How does this change in the ocean affect the atmosphere in turn?

e) During an El Nino event, the surface waters along the Peruvian coast become warmer. Why are the Peruvian surface waters usually cold? Why do they warm during an El Nino event?

f) What is the time scale of variability of ENSO? What is a possible explanation for why it has this time scale (as opposed to say the shorter time scale for a similar variation in the tropical Atlantic)?

2. Southern Ocean.
(a) South of the Polar Front, the Southern Ocean is characterized by a shallow temperature minimum layer in summer. Explain how this temperature minimum arises.

(b) If there is a temperature minimum, there must be a temperature maximum below it. What is the source of water in the temperature maximum layer in the Southern Ocean? Use the vertical sections and horizontal maps presented in class to assist with your answer.

(c) If the transport of the Antarctic Circumpolar Current is 100 Sv through Drake Passage, and if the flow is all eastward through Drake Passage, estimate its average eastward speed. Compare this with the normal maximum ACC speed listed in the class lecture. (You will need to estimate the width of Drake Passage from a map. Assume that the average depth is 4000 m.)

3. Global circulation.
(a) The formation of AABW is approximately 30 Sv. If 12 Sv enters the Indian Ocean across 30°S, estimate the average upwelling velocity within the Indian Ocean assuming

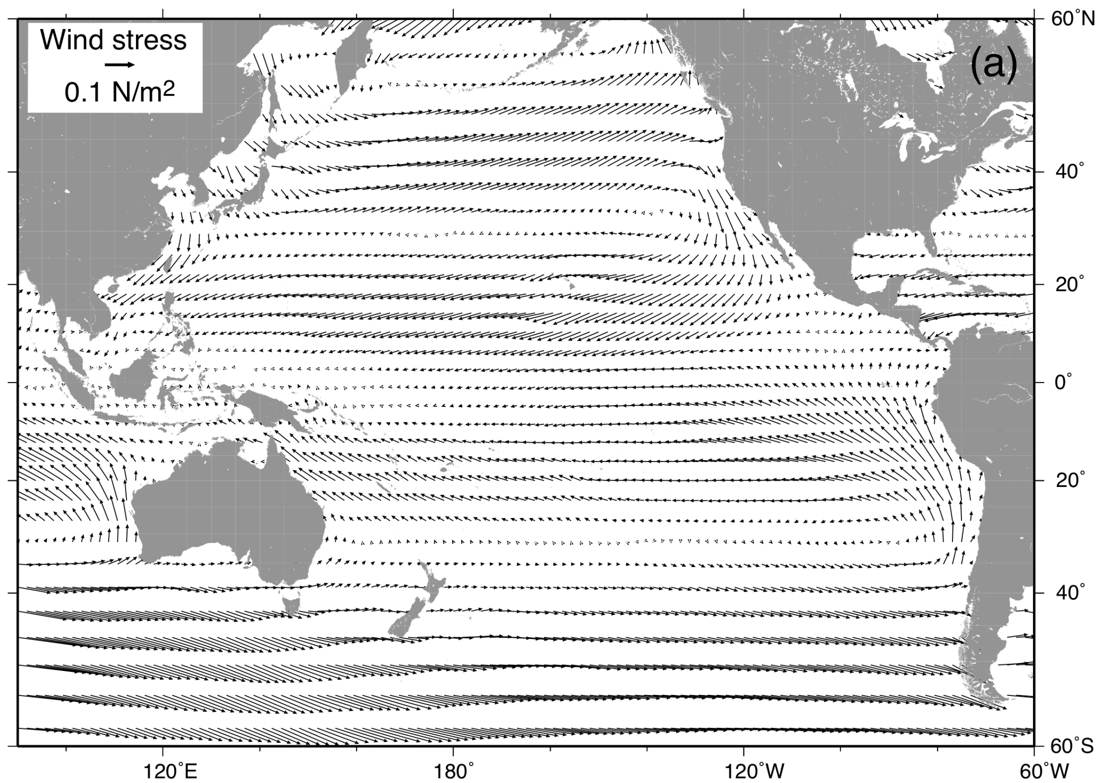
that it exits the Indian Ocean at a lower density. You will need to estimate the area of the Indian Ocean; you many simplify this as much as you wish, but please state your approach.

(b) If the potential temperature of the upwelled AABW in the Indian Ocean changes from 1°C to 5°C, what is the heating rate for this upwelled water?

(c) Find a vertical section of potential temperature at 30S in the Indian Ocean (textbook or online atlases). What is the approximate depth of water at 1°C and at 5°C in the Indian Ocean?

(c) What is the mechanism for this heating that allows AABW to warm to 5°C, assuming that the 1°C water flows northward into the Indian and 5°C water flows back to the south? (Look at a map of surface temperature for the Indian Ocean to assist with this answer.)

4. Eastern boundary currents.



Subtropical eastern boundary currents are driven by wind.

(a) On the wind stress map, circle three regions with the eastern boundary currents described in lecture, and label them with their names. (The Atlantic boundaries are missing of course.)
(b) In the North Pacific California Current region, indicate where there is upwelling.
(c) Describe one mechanism for EBC upwelling.

(d) Describe the second mechanism for EBC upwelling.
(e) On a separate piece of paper, sketch the sea surface height that you would expect from west to east across the California Current. Assume the simplest profile, without eddies – that is, the climatological mean. Make sure to indicate where it is high and low, and indicate the coast (land).
(f) On your sketch for (e), indicate the direction of the California Current, using either arrows or the circle-dot or circle-x symbols for current direction.
(g) On your sketch for (e, f), sketch the near surface isopycnals, making sure to indicate how they are related to the upwelling.

5. Climate feedbacks can be simply illustrated with examples from "Daisyworld", which is a very simple model developed by J. Lovelock to help teach about feedbacks.

In a very simple Daisyworld (simpler than Lovelock's), there are just BLACK ground and WHITE daisies.

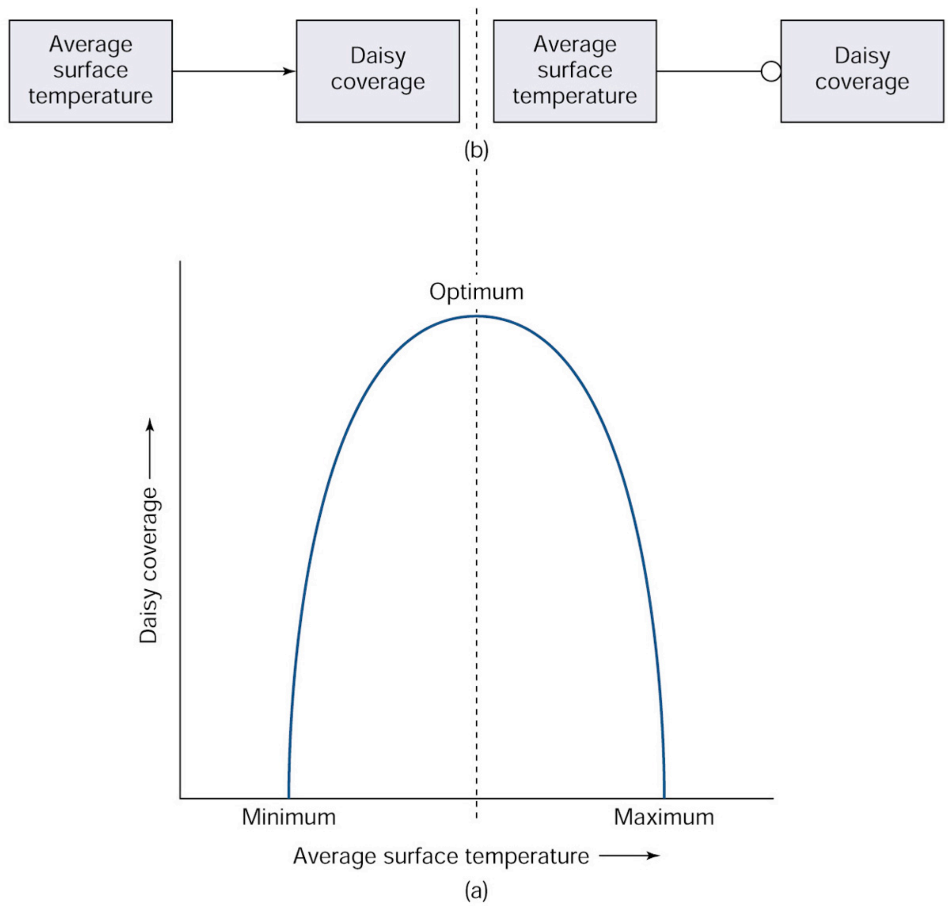
The sun will shine on Daisyworld and there will always be enough water for the daisies.

Daisies have an optimum temperature range for growth. When it is too cold, they die; when it is too hot, they die.

The temperature of the planet depends entirely on how much sunlight is absorbed and how much is reflected.

a. What is a feedback? (short answer)

b. The figure shows the dependence of white daisy growth on temperature. At the top of the figure there are two diagrams with boxes connecting temperature and daisies. The left diagram is appropriate for the left side of the graph and the right diagram for the right side of the graph. Explain what the two box diagrams mean, including the symbolism of the line-arrowhead and line-circle.



c. What is *albedo*? (give a short, general definition)

d. What is the qualitative difference between the albedo of the black ground and of the white daisies?

e. As daisy coverage increases, what happens to surface temperature (given your answer to b)? Illustrate this coupling with a box diagram like those at the top of the figure. (A line-arrow connecting boxes means that an increase in one quantity causes an increase in the other. A line-circle connecting boxes means that an increase in one quantity causes a decrease in the other.)

f. Suppose Daisyworld starts out with an average surface temperature that falls on the **left** side ("Minimum") side of the graph above. Use the coupling diagrams to look at the feedback between daisy coverage and temperature.

Is the feedback positive or negative?______________________

g. There is a feedback between large-scale ice coverage and air temperature that is somewhat similar to Daisyworld. Explain the feedback. Is it positive or negative?