MASTER SYLLABUS
MAR 110: NATURAL HAZARDS AND THE OCEAN
CLUSTER REQUIREMENT: 2A

Course Overview:

This course addresses an understanding of geological and physical oceanic processes as related to natural hazards, such as earthquakes, volcanoes, tsunamis, hurricanes, ocean storms, erosion, rogue waves, and climate change.   Within this context, a number of classical oceanographic topics are addressed including plate tectonics, the creation and destruction of ocean crust, the earth's heat budget, ocean circulation, ocean currents, wind wave generation, tidal generation, and basic meteorological principles. The course is taught in a lecture format where complex concepts are taught in a conceptual, as opposed to analytical manner. The lectures are accompanied by a series of homework assignments that, while related to the lectures, are self-contained, and teach basic techniques such as unit conversion, contouring, storm tracking, etc. Three exams are given during the semester, including a cumulative final exam. An opportunity to write a report on a topic related to the course is sometimes provided for extra credit.

Course-specific learning outcomes:

- Students will have an understanding of basic oceanographic principles.
- Students will gain an appreciation for the science underpinning real life events that they frequently encounter in the media, and in some cases, in person.
- Students will gain an understanding of how science works, how scientific theories are advanced, and how science is an evolving understanding of the world around us.

University Studies learning outcomes:

Cluster 2 –The Natural World: Scientific Inquiry and Understanding
   A. Science of the Natural World

After completing this course, students will be able to:
  1. Recount the fundamental concepts and methods in one or more specific fields of science.
  2. Explain how the scientific method is used to produce knowledge.
  3. Successfully use quantitative information to communicate their understanding of scientific knowledge.
  4. Use appropriate scientific knowledge to solve problems.

Examples of texts and/or assigned readings:

<u>Required Course Text</u>
      Pinet, P.R. **"Invitation to Oceanography"**, 5th Edition, Jones & Bartlett
           Publishers, Sudbury, MA, 2009. (ItO)

General Oceanography References
      Chauffe, K.M., & M.G. Jefferies. "Laboratory Exercises to accompany Invitation
           to Oceanography", 2007. (CJ)
      Ericson, D.B., and G. Wollin, "The Ever-Changing Sea", Alfred A. Knopf, Inc.,
           1967. (ECS)
      Pipkin, B.W., D.S. Gorsline, R.E. Casey, D.A. Dunn & S.A. Schellenberg,
      "Laboratory Exercises in Oceanography", W.H. Freeman & Co., 2001. (LEiO)

General Meteorology Reference
      Aguado, E. & Burt, J.E., "Understanding Weather and Climate", Prentice-Hall,
           Inc., Upper Saddle River, NJ, 1999. (UWaC)

General Geology Reference
      Hamblin, W.K., "The Earth's Dynamic Systems", Burgess Publishing,
           Minneapolis, MN, 1985. (tEDS)

Gulf Stream References
      MacLeish, W.H. 1989. The Blue God, Tracking the Mighty Gulf Stream,
           Smithsonian 19 (11): 44-59.(BG1)
      MacLeish, W.H. 1989. Painting A Portrait of the Stream from Miles Above and
           Below. Smithsonian 19 (12): 42-55. (BG2)

Climate Change References
      Burroughs, W.J., "Climate Change: A Multidisciplinary Approach", Cambridge
           University Press, Cambridge, UK, 2001. (CCaMA)
      Bigg, G., "The Oceans and Climate", Cambridge University Press, Cambridge,
           UK, 2005. (tOaC)
      Pugh, D., "Changing Sea Levels", Cambridge University Press, Cambridge, UK,
           2005. (CSL)

Earthquakes Reference
      Winchester, S., "A Crack at the Edge of the World", Harper Collins Publishers,
           NY, 2005. (aCEW)

Natural Hazards Reference
      Bryant, E., "Natural Hazards", Cambridge University Press, Cambridge, UK,
           2005. (NH)

Volcano Reference
      Winchester, S., "Krakatoa", HarperCollins Publishers, NY, 2003. (K)

Example Assignments:

Homework Assignments

1. Unit Conversions
2. Bathymetric Charts
3. Ocean Bathymetry
4. Graphs
5. Ocean Water Properties
6. Ocean Currents
7. Ocean Waves
8. Hurricane Damage
9. Hurricane Forecasting
10. El Nino / ENSO

Collectively, these homework assignments build a collective understanding of the University Studies Learning Outcomes discussed above. Although all assignments contain elements that address multiple learning outcomes, some are more intently focused on certain outcomes than others. For example, HW 6 requires students to use fundamental concepts of the Earth's rotation around the sun, the heat budget of the Earth, and the daily rotation of the Earth to determine the changing position of ocean current systems. This clearly addresses the fundamental concepts of Outcome 1. Others, such as HWs 2 and 5 focus on the scientific tools, and thus address Outcome 2. HWs 8 and 9 require the use of quantitative information, and its interpretation, and are directly related to Outcome 3. HW 7 requires problem solving based on material presented in class, and directly addresses Outcome 4.

Regular recitation/office-hour sessions are held by the Professor and/or Teaching Assistant in order to provide guided instruction for the hands-on homework assignments, as well as general help on concepts presented in lecture.

In addition, three exams are given through the semester, including a cumulative final exam. The exams contain a combination of closed-ended and open-ended components designed to evaluate the students' understanding of basic concepts covered in class, as well as their ability to combine those basic concepts effectively to explain their understanding of larger scientific issues. Occasional quizzes are also given. The exams, and the approach taken during course lectures, are heavily geared towards the understanding of complicated scientific concepts, and how these concepts can be brought together to tell a "scientific story". In relation to the University Studies Learning Outcomes, the lectures and exams primarily emphasize Outcome 1, although all Outcomes are addressed.

Overall, the assignments, lectures, and exams are designed to work in concert to address the cluster outcomes described above. Rather than a specific assignment focused exclusively on one learning outcome, the intent of the course structure is to have the homework assignments, lectures, and exams collectively establish a learning environment

where all the outcomes are addressed. A recent final exam is attached to this document, as well as three of the above homework assignments that evaluate the students' problem solving, scientific communication, and fundamental knowledge. Note that each homework is a self-contained unit, with extensive background material in addition to the assignment itself. The homework topics also link to material covered during class lectures. Examples of other homework assignments are available on request, and can also be found online at:

http://naturaloceanhazardsmar110.umassd.wikispaces.net/

This website includes all homework assignments, lecture notes, homework tutorials, glossary lists, supplementary readings, and useful internet links.

Examples of student work (both homework assignments and exams) will be kept on file for periodic evaluation of outcomes.

Generalized Grading Rubric:

Questions on the homework assignments generally fall into one of two categories, being either (1) quantitative in nature, or (2) interpretations/analysis of data. Each question is assigned an appropriate number of points on the assignment key, with each homework assignment graded on a scale of 0 to 10.

(1) Quantitative questions: These include numerical and/or graphical problems, and are graded as correct or incorrect, with points given to correct answers. When appropriate, the students are required to show their work, and partial credit will be given when the right approach is used, even if the answer given is incorrect.

(2) Interpretation/Analysis questions: These include questions where the student is expected to draw conclusions from the data, typically drawing on concepts discussed in class lectures, and also reviewed in the background material accompanying each homework. Full credit is given for answers that provide an interpretation consistent with the concepts discussed in class, and that is clearly and logically communicated. Partial credit is given if the student invoked the right concept, but did not provide an entirely consistent response.

Sample Course Outline:

MAR 110: Natural Hazards and the Oceans

	Lecture Title	Readings		Homework Due Date
LEC		Pinet	Web	
1	Course Introduction	Chp 1		
2	Energy Sources & Earth Interior (T1; HW 1-Units)	Chp 2	HW 1	
3	Bathymetry & Plate Tectonics	Pgs 59-75		
4	Plate Tectonics & Earthquakes (T2; HW 2-Bathy Charts)	Pgs 75-86	HW 2	HW 1 – Units
5	Tsunamis	Pgs 254-257	Article 1	
6	Volcanoes (T3; HW 3-Plate Tectonics)		HW 3	HW 2 – Bathy Charts
7	Earthquakes/Volcanoes		Articles 2, 3	
8	Review #1			HW 3 – Plate Tectonics
	EXAMINATION #1			
9	Atmos./Ocean Intro & Atmos. Dynamics	Pgs 188-194 Pgs 141-152		
10	Ocean Conveyor Belt (T4; HW 4-Graphs)	Pgs 153-160 Pgs 210-218	HW 4	
11	Ocean Dynamics	Pgs 194-207, 210		
12	Case Study: Gulf Stream (T5; HW 5-Ocean Props)		HW 5	HW 4 - Graphs
13	Ocean Storms			
14	Ocean Waves (T6; HW 6-Ocean Currents)	Pgs 231-247	HW 6	HW 5 – Ocean Properties
15	Waves as Hazards (Rogue, Erosion)	Pgs 248-251 Pgs 263-271	Article 5	
16	Tides & Standing Waves (T7; HW 7-Ocean Waves)	Pgs 262-288	HW 7	HW 6 - Ocean Currents
17	Hurricanes	Pgs 208-209		
18	Hurricane Dynamics (T8/9; HW 8/9–Hurricanes)		HW 8/9 Article 6	HW 7- Ocean Waves
19	Hurricane of '38 & Katrina	Pgs 414-415		
20	Exam #2 Review (T10; HW 10-ENSO)		HW 10	HW 8/9-Hurricanes
	EXAMINATION #2			
21	Case Study: Deepwater Horizon Oil Spill	Pgs 490-495	TBA	
22	Global Climate Change	Pgs 549-580		HW 10 – ENSO
23	ENSO		Article 7	
24	Cooling and Warming		Article 8	
25	Anthropogenic Climate Change?		Article 9	

NAME _____

MAR 110 Natural Hazards & the Oceans

FINAL EXAMINATION

Wednesday, 21 December 2011

I. **<u>Term Definitions</u>** (**30%** or 1 point for each correct answer.)
Write the term from above that is <u>best defined</u> by the respective phrase below.

1. _____ The molten mantle rock material that forms ocean crust.

2. _____ The vertical zone in the ocean with a relatively rapidly changing density.

3. _____ The central region of a tropical cyclone that is surrounded by a wall structure of intense, inwardly-spiraling winds.

4. _____ The Gulf Stream is one of these due to its position in the North Atlantic Ocean.

5. _____ The degree to which short wave solar radiation is reflected from any surface or object.

6. _____ The longest geologic feature on the Earth's surface; where plates are formed.

7. _____ Islands that are formed when they pass over an isolated volcanic region in the middle of an ocean plate.

8. _____ An indicator of the strength of El Nino events in the equatorial Pacific, equal to the difference in atmospheric pressure between a station in Australia and in Tahiti.

9. _____ The process that changes the propagation direction of a shallow water wave due to its interaction with the ocean bottom.

10. _____ The trapping of long wave Earth radiation by atmospheric water vapor and carbon dioxide.

11. _____ The length of time it takes for a wave to pass a fixed point.

12. _____ The general name for a boundary between crustal plates that move horizontally in opposite directions.

13. _____ The name of easterly (east to west) winds in the tropical zone of the northern hemisphere.

14. _____ A tropical storm in the Atlantic Ocean, with cyclonic circulation and wind speeds greater than 74 miles/hour.

15. _____ A 500 year long period of increased temperatures prior to 1300 and the onset of the Little Ice Age.

16. _____ The process by which the deeper, nutrient-rich waters near the coast replace waters moved offshore by Ekman transport.

17. _____ The thickest interior layer in the Earth.

18. _____ The long narrow feature where ocean crust is being destroyed.

19. _____ The condition whereby upper Earth layers "float" on lower Earth layers; having adjusted vertically to thickness and/or density changes that come with tectonic activity

20. _____ The kind of water wave that is generated by a sudden change in the seabed due to an earthquake.

21. _____ The volcano that violently erupted in 79 AD that covered Pompeii.

22. _____ The plate against which the North American plate collides – producing the potential for a deadly west US coast tsunami in the future.

23. _____ The thermohaline circulation mode of the ocean in which there is (1) cooling-induced, deep sinking of water in the polar ocean, (2) transported in a deep western boundary current to the Southern Ocean, (3) from where it flows to the Indian and Pacific Oceans, (4) where it rises to the surface, (5) is warmed and (6) returned to the Atlantic.

24. _____ Components in the atmosphere that absorb long wave radiation from the Earth.

25. _____ An oceanographic event occurring every 3 to 7 years in the equatorial Pacific Ocean; marked by abnormally warm surface waters and reduced upwelling in the eastern Pacific.

26. _____ Significant changes in the climate regime that occur very rapidly compared to the time period of the old or new climate regime.

27. _____ The thinnest part of the Earth's crust.

28. _____ The point on the Earth's surface directly above the location of a deep earthquake.

29. _____ The mass per unit volume of a substance (with units of grams per cubic centimeter or gm/cm3).

30. _____ The upward transfer of heat through the movement of heated air or water parcels.

EXTRA CREDIT

31. _____ The normal westward movement of air across the surface tropical Pacific ocean; upward movement over the western Pacific; and eastward movement at elevation to close the loop.

32. _____ The turning of the direction and slowing down of water movement as you move further from the surface, induced by a steady wind that has blown for several days.

II. Multiple Choice (30% or 1 point per correct answer)   Place the letter corresponding to the best answer in the box to the left of each question.

1. **Scientists can reconstruct records of temperature, precipitation, and other climate related variables by studying the material trapped in what kind of cores?**

   a) ice cores from Greenland and Antarctica.

   b) sediment cores from the ocean floor.

   c) rock cores from the Hawaiian Islands.

   d) both a and b.

   e) all of the above.

2. **Global temperatures in the past 70 million years have been generally _____?, but with _____?.**

   a) increasing, but with abrupt climate changes.

   b) decreasing, but with multiple abrupt increases of a few degrees.

   c) staying constant, but with many glaciations.

   d) decreasing, but with many wet spells.

   e) none of the above

3. **Winter storms are most effective in eroding sand from**

a) an offshore bar and building the beach front (or berm).

b) a beach front (or berm) and building the offshore bar.

c) a coastal embayment beach and building an adjacent coastal point.

d) a coastal point and building an adjacent coastal embayment beach

e) None of the above

4. **A classic storm called an East Coast Low (for example, Blizzard of '78) is generated by a**

a) westward moving atmospheric disturbance arising off the coast of Africa.

b) mounding of water in the central Atlantic Ocean.

c) kink in the Jet Stream over the Southeastern US.

d) realignment of the Gulf Stream.

e) None of the above

5. **The oceanic conveyer belt consists of sinking <u>primarily</u> in the _____ region**.

a) North Pacific Ocean

b) Atlantic tropical

c) North Atlantic polar

d) Antarctic

e) none of the above

6. **The earthquakes in mid-ocean ridge regions are relatively**

a) shallow in association with transform faulting and magma intrusion.

b) deep in the mantle where the magma is produced.

c) deep in association with transform faulting.

d) shallow in association with plunging lithosphere.

e) none of the above

7. **The Vikings settled Greenland during the latter stages of the first millennia (~1000 years ago) and then abandoned it because the**

a) sheep became diseased.

b) native Inuits were better fishermen.

c) Little Ice Age caused unbearable climatic conditions.

d) excessive warning of the Medieval Warm Period killed the crops.

e) none of the above

8. The deep waters of the world's oceans are cold because

a) water at the poles sinks due to salinity, and spreads throughout the world's oceans.

b) the thermocline insulates the deep water from tropical warming.

c) water at the poles cools then sinks, and spreads throughout the world's oceans.

d) cooling by the interior Earth.

e) none of the above.

9. England and Ireland are warmer than the parts of eastern Canada at the same latitude because of

a) the greenhouse effect.

b) heat from the Earth's interior is concentrated there.

c) the Gulf Stream, which comes ashore in the UK.

d) winds from the west warmed by passing over the Gulf Stream in the N. Atlantic.

e) none of the above.

10. Most ocean hazards are the result of concentrated energy. This concentrated energy can come in the form of either potential energy (PE) or kinetic energy (KE). **Which of the following hazards best represents a <u>sudden</u> transformation of PE to KE?**

a) hurricane.

b) earthquake.

c) rogue wave.

d) abrupt climate change.

e) coastal erosion.

11. One important characteristic of a wave is its wavelength, which is defined as the:

a) elevation difference between its crest and trough.

b) horizontal distance between two successive crests.

c) horizontal distance between a crest and adjacent trough.

d) depth of its orbital currents.

e) none of the above.

12. Tsunami are shallow water waves, because the average ocean depth is

a) greater than 1/20 of its wavelength.

b) greater than 1/2 of its wavelength.

c) less than 1/20 of its wavelength.

d) less than 1/2 of its wavelength.

e) none of the above.

13. The speed of a tsunami in the open ocean is determined by

a) it's wavelength and travels about 50 miles/hour.

b) it's wavelength and travels about 500 miles/hour.

c) the water depth and travels about 500 miles/hour.

d) the water depth and travels about 50 miles/hour.

e) none of the above.

14. All of the following are processes that reduced the impact of the recent Gulf of Mexico oil spill, <u>except</u>:

a) biodegradation.

b) weathering.

c) the use of dispersants.

d) natural oil seeps.

e) controlled burning.

15. El Nino events in the Pacific Ocean typically have the following impacts on hurricanes formed in the southern North Atlantic?

a) increase in hurricane intensity.

b) increase in the number of hurricanes.

c) decrease in the number of hurricanes.

d) the same number of hurricanes overall, but a larger number likely to strike New England.

e) El Nino has no affect on Atlantic hurricanes.

16. The Saffir-Simpson scale is used to categorize the strength of

a) rip currents.

b) east-coast lows (or bombs).

c) hurricanes.

d) storm-related coastal erosion.

e) none of the above

17. ENSO is an acronym for

a) El Nino Sunspot Occurrence

b) El Nino Southern Ocean

c) El Nino Solar Oscillation

d) El Nino Southern Oscillation

e) none of the above

18. The amount of destructiveness of a particular hurricane (in human and economic terms) is related to:

a) the density of human population in the path of the hurricane.

b) the wind speed of the particular hurricane (i.e. Category 1-5).

c) the particular hurricane's width.

d) the effectiveness of weather forecasting and local emergency action plans.

e) all of the above.

19. The Earth's annual average temperature is relatively steady because

a) incoming radiation heat energy is <u>slightly greater</u> than outgoing radiation heat energy.

b) outgoing radiation heat energy is <u>equal to</u> the incoming radiation heat energy.

c) radioactive decay in the mantle <u>is heating</u> the atmosphere.

d) incoming radiation heat energy <u>is trapped</u> by greenhouse gases.

e) none of the above.

20. The Earth is warmer than "it should be" and hospitable to life because

a) incoming radiation heat energy is slightly greater than outgoing radiation heat energy.

b) outgoing radiation heat energy is equal to the incoming radiation heat energy.

c) radioactive decay in the mantle is heating the atmosphere.

d) greenhouse gases trap outgoing radiation heat energy.

e) none of the above.

21. The world's oceans fill the indentations in the Earth's crust formed by elevation differences between land and ocean crustal materials. **The continental crust rises above sea level (and the oceanic crust) because the**

a) continental crust has relatively more volcanoes that build it upward.

b) weight of the ocean water forces the oceanic crust downward into the mantle.

c) continental crust is thicker than oceanic crust and thus floats higher in the mantle.

d) plate collisions force continental crust higher.

e) none of the above.

22. **Typhoons and hurricanes in the northern hemisphere consist of**

a) clockwise-turning winds.

b) clockwise tropical winds.

c) counter-clockwise subtropical winds.

d) counter-clockwise tropical winds.

e) none of the above

23. **The main energy source for plate tectonics-related oceanic hazards is**

a) the Earth's internal heat energy

b) the sun's heat energy

c) kinetic energy

d) potential energy

e) none of the above.

24. **Global temperatures in the past 150 years have been generally _____,**

a) decreasing.

 b) decreasing, but with abrupt increases.

c) staying constant.

d) increasing, and accompanied by increases of atmospheric carbon dioxide.

e) none of the above

25. Which of the following is not considered to be a possible cause of the Little Ice Age?

a) increased volcanic activity

b) an abrupt reversal of the Gulf Stream

c) a decrease in energy radiating from the sun

d) melting of polar ice caps during the Medieval Warm Period and subsequent impacts to ocean circulation.

e) none of the above.

26. A swimmer trapped in a rip current should swim parallel to the beach because _____

a) it is more likely they will be seen and help will come if they swim along the beach

b) the rip current flows parallel to the beach

c) rip currents flow offshore and are narrow and fast – so the best way out is to swim to the side.

d) a fast moving current towards the beach exists right next to the rip current.

e) none of the above.

27. A sudden and dramatic offshore movement of water at the beach suggests what type of impending ocean hazard?

a) hurricane

b) climate change

c) tsunami

d) rogue wave

e) earthquake.

28. The features of continental margin along the eastern US are dominated by millions of years of sedimentation. Starting at the coast and moving seaward, the order of its principal features is

a) continental slope, continental shelf, continental rise, and abyssal plain.

b) continental rise, continental shelf, continental slope, and abyssal plain.

c) abyssal plain, continental shelf, continental slope, and continental rise.

d) continental shelf, continental slope, continental rise, and abyssal plain.

e) none of the above.

29. Which of the following is not a geostrophic current?

a) Agulhas Current

b) Jet Stream

c) Canary Current

d) Rip Current

e) Gulf Stream

30. Which of the following is <u>not</u> a short-term climate change hazard?

a) some sea level rise

b) melting of polar ice

c) displaced regions of raininess and drought

d) initiation of a major glaciation

e) none of the above.

31. (EXTRA CREDIT) Scientists believe that a reversal of the snowball earth glaciation was caused by _____

a) man-made CO_2 increases

b) sunspot activity

c) ENSO

d) volcanic activity and cold-loving microorganisms increasing atmospheric CO_2

e) none of the above.

32. (EXTRA CREDIT) The Gulf Stream was first discovered by Ponce de Leon, a Spanish explorer in 1513. Who is recognized as the first to create a useful map of the Gulf Stream?

a) Ponce de Leon

b) Benjamin Franklin

c) Winslow Homer

d) Christopher Columbus

e) John Cabot

III. Short Answers (40%)

Do any 4 of 5 (A, B, C, D, or E) for full credit.

A. Pacific Ocean Climate   (10 points)
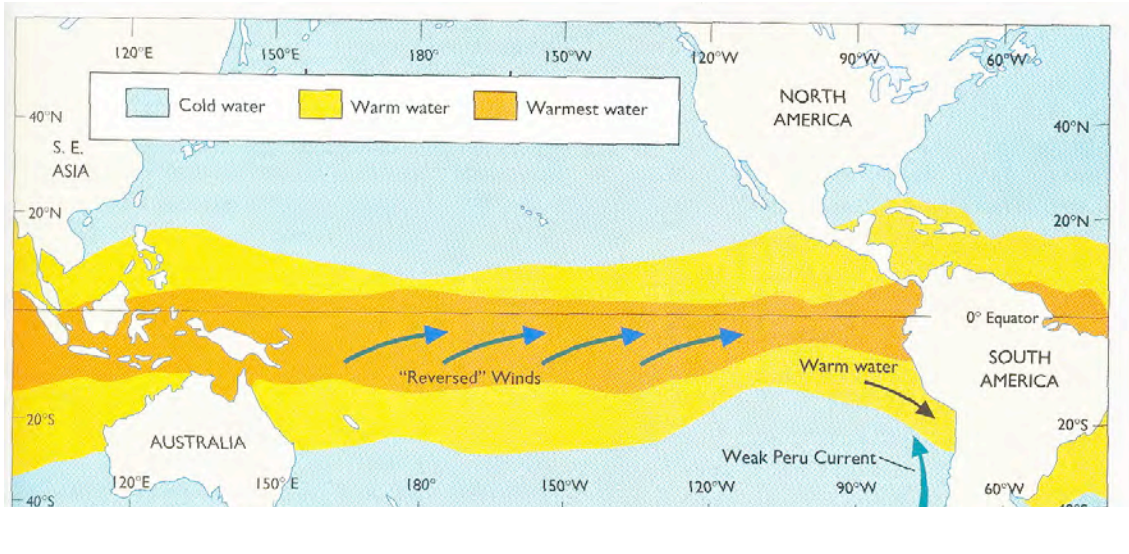
1. (1 pt) The picture above is associated with a phenomenon called _____.

    (1 pt) The opposite condition to that shown here also has a name. It is called _____.

2. (2 pts) Describe in words or with a figure what the "normal" pattern of sea surface temperature in this region would look like
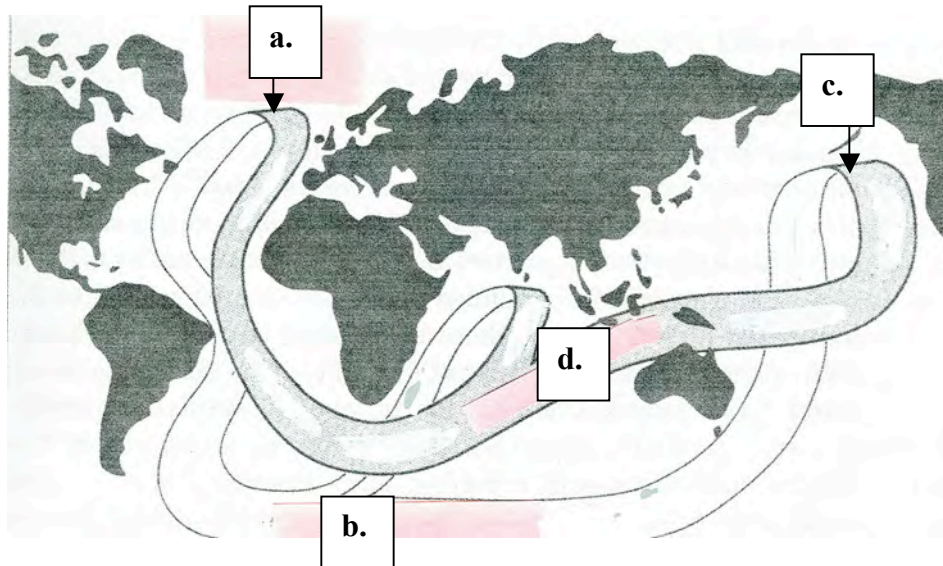
CONTINUE ON NEXT PAGE

3. (3 pts) This phenomenon can have devastating economic impacts to countries on the west coast of South America, such as Peru. Explain why. Your answer must have two parts: (1) how are the local economies impacted (what industries) and (2) why they are affected (i.e., what's the science behind it).

4. (2 pts) Can this phenomenon have impacts beyond the immediate region of the equatorial Pacific? _____ If you answered yes, briefly explain why.

5. (1 pt) This phenomenon occurs on a somewhat regular cycle. Approximately how long does it take for this cycle to repeat itself? _____

B. CONVEYOR BELT CIRCULATION and CLIMATE CHANGE   (10 points)

1. (1 pt) The basic function of the Conveyor Belt circulation is to

    _____.

2. (2 pts) What are *the directions of the flows* at the indicated locations in the
    thermohaline or conveyor belt circulation pattern depicted below (note that the gray
    portion represents surface flows, with the remainder representing deep ocean flows)?

    (Hint - Choose from such terms as: upward or rising, downward or sinking, eastward, westward,
    northeastward, southwestward, northward, southward, etc.)

    a. _____   **c.** _____

    b. _____   **d.** _____

3. (1 pt) The name of the high-speed flow in the western North Atlantic gyre that transports
    heat poleward is the .. _____.

4. (1 pts) What causes the conveyor belt water to sink?

    _____.

CONTINUED ON NEXT PAGE

5. (1 pt) The names of the ocean basin(s) where the conveyor belt waters rise to the surface are

    _____.

6. (2 pts) If the ocean conveyor belt stopped, then what might you expect to happen to the climate in Western Europe (after a few years)?

    _____

    _____

    _____

7. (2 pts) Why might the conveyor belt circulation slow or even stop?

    _____

    _____

    _____

C. GLOBAL WARMING & THE GREENHOUSE EFFECT   (10 points)
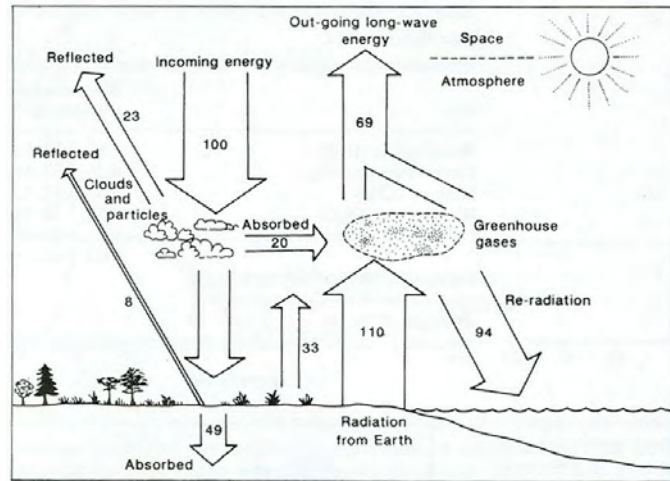
The above picture shows how the incoming radiation energy (100%) is redistributed in the Earth environment on a global and annual average.

1. (2 pts) What percentage of the incoming energy is:
    (a)   *reflected* back to space?   _____

    (b)   *radiated* back to space as long wave energy?   _____

2. (2 pts) What do your answers to (1) say about the overall heat budget of the Earth?

    _____

    _____

3. (2 pts) What percentage of the incoming energy is *absorbed by the* :
    (a)   atmosphere?   _____

    (b)   Earth?   _____

    (c)   The combined Earth-atmosphere system?   _____

CONTINUED ON NEXT PAGE

4. (2 pts) As the previous answer shows, less than 100% of the incoming energy is absorbed by the Earth system. Yet the picture shows correctly that *"Radiation from Earth"* is 110 % incoming energy.
    How can that be?

    _____

    _____

    _____

5.   (2 pts) What is trapping the large percentage of the "Radiation from Earth"?

    (a) _____

    where are these located?

    (b) _____

    what is the most significant of these?

    (c) _____

D. HOT SPOT ISLANDS (10 points)

A

Kauai

Oahu

Molokai

Maui

Hawaii

B
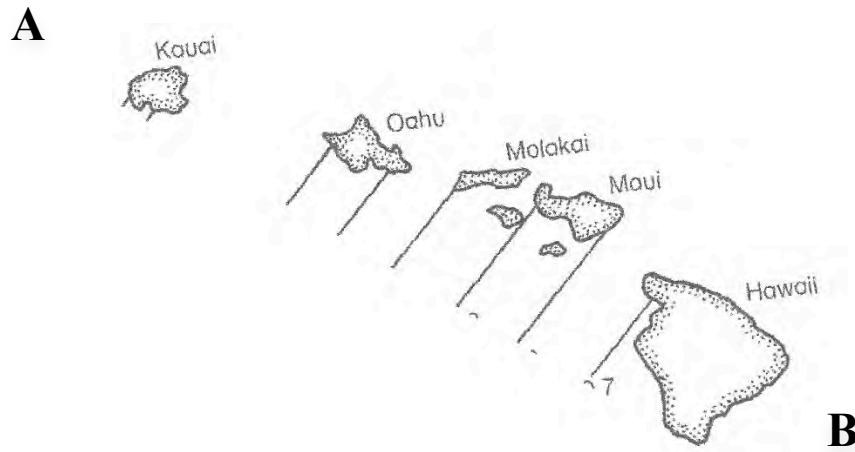
The approximate ages of the islands in the Hawaiian Island chain are:

ISLAND	AGE in millions (or 10^6) of years
Hawaii	0. 0
Molakai	1. 5
Kauai	5. 0

The distance between the islands of Kauai and Hawaii is about 500km.

1) Which of the islands above is an active volcano (1 pt)? _____.

    Why (2 pts)? _____

    _____.

2) Does this information suggest that the Pacific plate is moving (3 pts)?_____

    If your answer is YES to the above question, draw an arrow on the diagram above to
    indicate the direction of plate movement.

3) Describe what might exist in the vicinity of point A (2 pts) : _____

    _____.

4) Describe what might exist in the vicinity of point B (2 pts): _____

    _____.

E. Hurricane Formation (10 points)
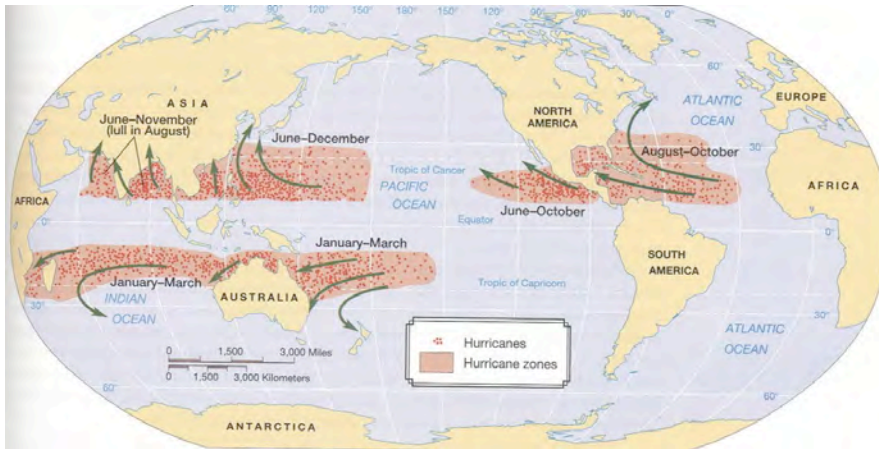
The figure above shows the regions of hurricane formation over the last fifty years around the globe. Based on this figure answer the following questions (2 pts. each).

1. No hurricanes are formed along the equator because _____

    _____.

2. No hurricanes are formed north or south of 30° latitude because _____

    _____ .

3. The hurricane tracks shown tend to move from east to west because _____

    _____.

4. More hurricanes tend to reach hurricane strength on the western side of ocean basins (particularly in the Atlantic and Pacific). This is partly because hurricanes always move from east to west and strengthen over time, but there is also another reason. What is is? _____

    _____.

5. In which sense does a hurricane rotate in the (circle the correct answers):

    Northern Hemisphere: Clockwise   Counterclockwise

    Southern Hemisphere: Clockwise   Counterclockwise

IV.   Extra Credit

1.   Explain how some scientists believe that climate change may be important to evolution, particularly human evolution (3 pts).

2.   What is the Northwest Passage, and how is it related to climate change (4 pts)?

3.   In the assigned reading by Carl Wunsch, it is proposed that it might be possible for truly random fluctuations to account for much of the climate change the earth has experienced over the last 4 billion years. What simple example is used in the reading to demonstrate this, and how (3 pts)?

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WORD BANK

1. Abrupt Climate Change
2. African Plate
3. Albedo
4. Asthenosphere
5. Continental Crust
6. Conveyor Belt
7. Convection
8. Coriolis Force
9. Density
10. Deep Ocean Trench
11. Downwelling
12. Ekman Spiral
13. Ekman Transport
14. El Nino
15. Epicenter
16. Eye
17. Greenhouse Effect
18. Greenhouse Gasses
19. Hot Spot Islands
20. Hurricane
21. Island Arc
22. Isostatic Equilibrium
23. Isopycnals
24. Juan de Fuca Plate
25. Krakatoa
26. Landslide
27. Lithosphere
28. Little Ice Age
29. Magma
30. Mantle
31. Medieval Warm Period
32. Mid-Ocean Ridge
33. NE Trade Winds
34. North Atlantic Oscillation
35. Oceanic Crust
36. Plate Tectonics
37. Pycnocline
38. Rift Valley
39. Southern Oscillation Index
40. Transform Fault
41. Tsunami
42. Typhoon
43. Upwelling
44. Vesuvius
45. Walker Circulation
46. Wave Height
47. Wave Length
48. Wave Period
49. Wave Refraction
50. Western Boundary Current

Homework 2
Bathymetric Charts
[based on the Chauffe & Jefferies (2007)]

2-1. BATHYMETRIC CHARTS

Bathymetric charts are maps of a region of the ocean used primarily for navigation and piloting. They display the **bathymetry** or depths of the sea floor below sea level. Historically, the sea floor depths were obtained by lowering a weighted cable to the sea floor. Today, sea floor depths are obtained with a ship-mounted **sonic depth recorder** which bounces sound waves off the sea floor (Figure 2-1a). A **sound generator** on the ship emits sound waves that strike the sea floor and are reflected upward to a listening device called a **hydrophone**. The method is faster, more accurate and allows continuous depth determination as a ship travels. Each measurement of depth to the sea floor is called a **sounding**.
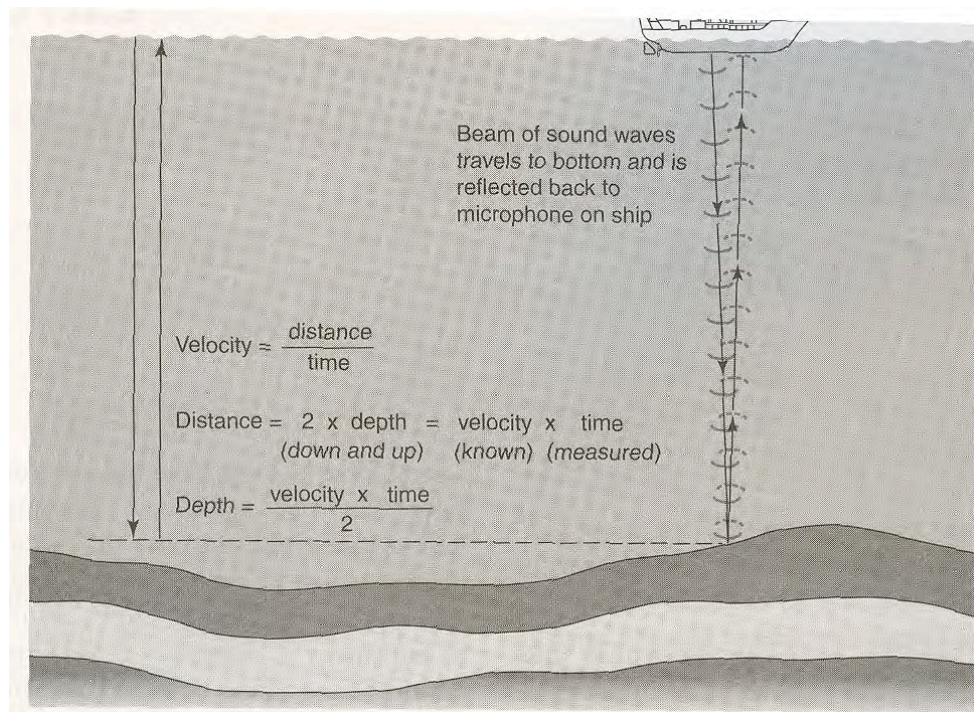
Figure 2-1a.**Acoustic Depth-Sounding.** A ship's hull-mounted "acoustic pinger" emits a sound pulse that travels to the seafloor, reflects, and then travels back to the ship's listening devise called a hydrophone. The roundtrip travel time of the sound pulse is recorded and the depth is computed (see formula). The depth recorder operates continuously making a dense set of depth measurements along the ship's track.

Shipboard computers record the round-trip *travel time* of the sound waves and calculate depth by multiplying the known speed of sound in water ($S_w = 1460$ meters/second) by half of the travel time:

$$D = S_w \, x \; \tfrac{1}{2} \; travel \; time \, ,$$

where the depth of the water D in meters is the product of the sound speed in water and one half of the total travel time to the bottom and back. For example, if the total travel time is 4 sec, then the time for sound to reach bottom is 2 sec and the water depth is 1460 m/sec x 2 sec = 2920 m.

Figure 2.1b A bathymetric chart showing an array of depth soundings (given in fathoms, where 1 fathom = 6 ft). On many charts the soundings are "contoured" to give a more useful visual representation of the regional bathymetry. Here we have drawn the 100 and 200 fathom isobaths, each which connects only those depths with the same depths. Note in this case, the depths on upper side of either of the isobaths are shallower, while the ones on the lower side are deeper. Thus we can see how the sea floor slopes away from the coast, which run diagonally across the upper right corner. What would the 50 fathom, 150 fathom, and 250 fathom isobaths look like? (LEiO)

Bathymetric charts are constructed from arrays of depth soundings by drawing a set of **contour lines** (or **isobaths**); each of which connects points of equal depth. The example in Figure 2-2 shows an idealized region in which the sea floor slopes smoothly away from the coast and how that is represented on a nautical chart. The "20" contour line connects all 20 ft sea floor depths relative to the mean sea level (i.e., the 0 ft **datum** or reference depth, which is determined from a

long-term time-average of sea level). Likewise the "40" contour connects depths of 40 ft below sea level and so on. The difference between two adjacent contours is called the **contour interval**, which is 10 ft for the Figure 2-2 example.
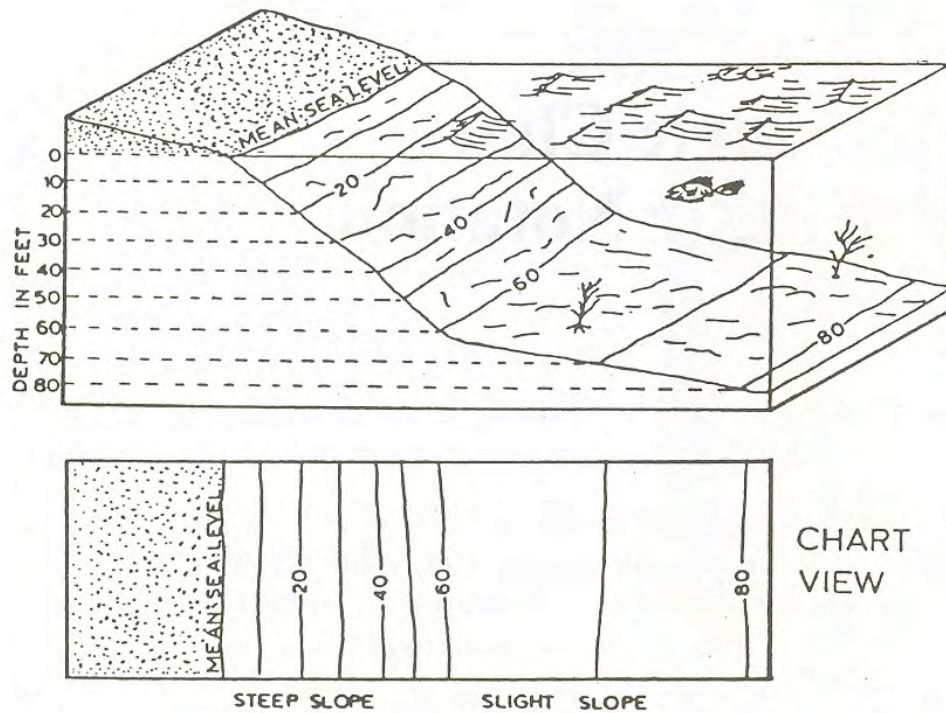
Figure 2-2. The bathymetry or depth distribution of the ocean in the upper panel is depicted by the set of depth contour lines (in units of feet) on chart below. Note that the closer together the contours, the steeper the slope of the sea floor.

Contoured bathymetric charts provide a more useful "picture" of the seascape not easily seen from soundings alone. In a more realistic example of a bathymetric chart, I have drawn the 100 and 200 fathom isobaths approximating the array of depth soundings from a survey of an offshore region southwest of Long Beach, California (Figure 2.1b). Note that depths on charts can be given in a variety of units; e.g., feet –as in Figure 2-2, or fathoms – as in Figure 2-1b, or meters. **A convenient "rule-of-thumb" relating these different units is that 1 fm = 6 ft or approximately ~ 2 m because 1 meter = 3.28 ft exactly**.

➢ **Try and produce the 50 fathom (fm), 150 fm, and 250 fm contours on the Figure 2-1b chart.**

➢ **Do any of these contours show submarine hills, valleys, ridges, or undersea mountains?**

2-2. CONTOURING A BATHYMETRIC CHART

When constructing a contoured bathymetric chart from soundings, the following guidelines should be considered.

1. Contour lines connect points of equal depths; usually with smoothly curving lines.

2. Contour lines can terminate abruptly at the edge of the chart (e.g., Figures 2-2 & 2-3).

3. **The steepness of a sea floor slope** (or **gradient)** is indicated by the relative distance between adjacent contour lines; the closer the steeper (e.g., Figure 2-2).

4. Contour lines can **never** split or intersect (see Figure 2-4), because the point of intersection would have two different depths simultaneously - an impossibility. However, contour lines can merge at a truly vertical feature and/or overhanging cliff (also see Figure 2-4).

5. Contours in the region of undersea valleys have a distinct V shape that points up-valley as shown in Figure 2-3.
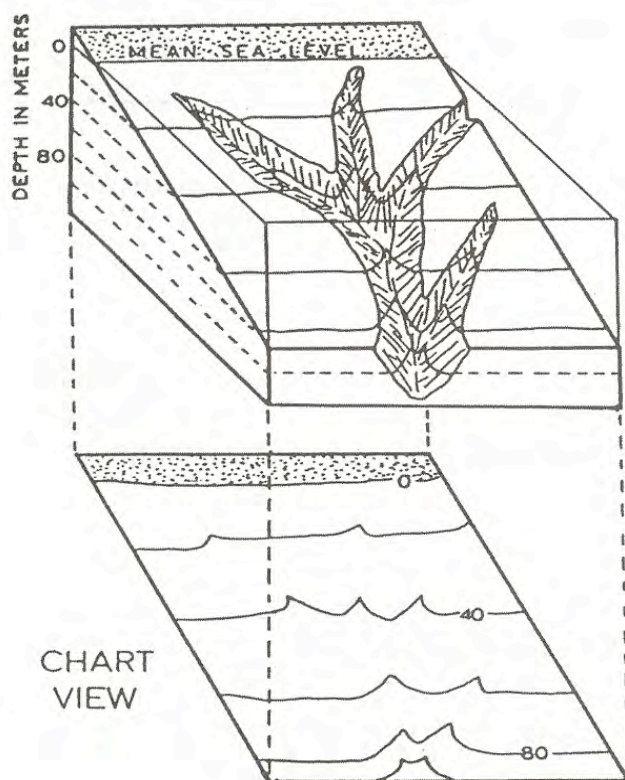
Figure 2-3. Along-coast isobaths that intersect an undersea valley (above) have distinct V shapes on the bathymetric chart (below) that point upslope.
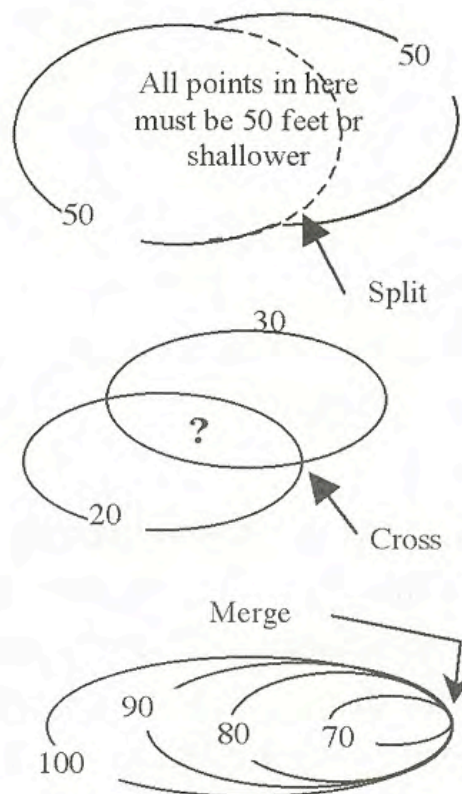
Figure 2-4. Contour lines never split or cross, but may merge.

6. Contour lines **always** close around bathymetric mounds or depressions that are located

locally within the chart domain (Figure 2-5). The contours around a depression are distinguished by small tick marks (hachured marks) that point into the depression.
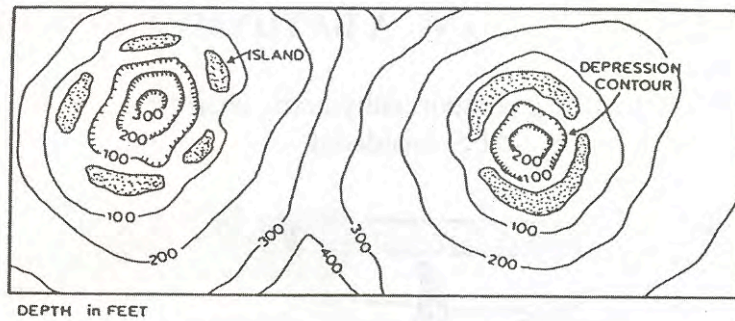
Figure 2-5. Depression contours are indicated by hachured marks (tick marks pointing downslope) on the contour lines.

2-3. CHART SCALE AND HORIZONTAL DISTANCE

Charts represent the Earth's surface, but at a reduced size. To interpret the chart properly, it is important to know the **chart scale,** that is the fixed relationship between a distance on the chart and the corresponding distance on the Earth. For example, when one centimeter (cm) on the chart equals 125,000 cm (which equals 1250 meters (m) or 1.25 kilometers (km)) on the Earth. The chart scale can be given as a fraction 1/125,000 or the ratio 1:125,000. Effectively the size of the Earth's surface has been reduced or scaled down by 125,000 times so that it can fit on the chart. All useful charts contain a **bar scale** (Figure 2-6) which is used to interpret chart distances in terms of real Earth distances. The total length of the bar scale in Figure 2-6 represents a total Earth distance of four km which is subdivided into both 1 km and 0.25 km segments.
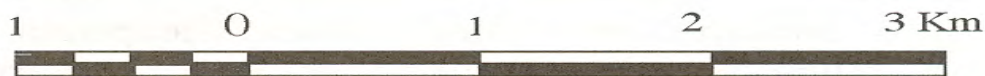
Figure 2-6. Graphic bar scale. Always note the "0" position.

2-4. DETERMINING SLOPE OR GRADIENT

The slope of the sea floor (or gradient) may be numerically expressed as a ratio, percentage, or angle. **Slope is the ratio of the relief (or change in depth of a sea floor feature) to the horizontal distance over which the slope is measured,** according to

Slope = relief/horizontal distance of slope

EXERCISE 2   OCEAN BATHYMETRY   Name _____

A.   The Sandy Harbor Chart

Your task is to convert the sounding chart of Sandy Harbor (Figure 2-8) into a contoured
bathymetric chart using a *contour interval* of 1 fathom (fm).

- You will notice that part of the *1 fathom depth contour line* has already been drawn by
  comparing pairs of soundings – the **depth-comparison method**. Beginning on the upper
  left side edge of the chart, we started the *1 fm depth contour* so that it would go between
  the 0.1 fm and 1.9 fm soundings as shown. Continuing to the to the right, <u>it is very likely</u>
  that *1 fm depth contour* lies between the (a) 0.5 fm and 1.9 fm soundings (midway is a
  good guess); (b) 0.5 fm and 2.7 fm soundings, and (c) 0.5 fm and 1.8 fm, respectively as
  shown. The *1 fm depth contour* was continued to the right between the appropriate
  soundings, including the 0 fm depth contour of the coast.

- Now that you have "gotten the hang of it", complete drawing the *1 fathom depth contour*
  as a smoothly curving line along the coast, keeping the larger depth soundings seaward of
  the contour.

- Now draw the *2 fm depth contour* on the deeper side of the *1 fathom depth contour*
  starting in the upper left. You will note that *2 fathom depth contour* will generally "track"
  the *1 fathom depth contour* similar to the way that the *1 fathom depth contour* tracked the
  0 fathom coastline.

- Continue drawing contours every *1 fathom* of depth down to the *8 fathom depth contour*.

.
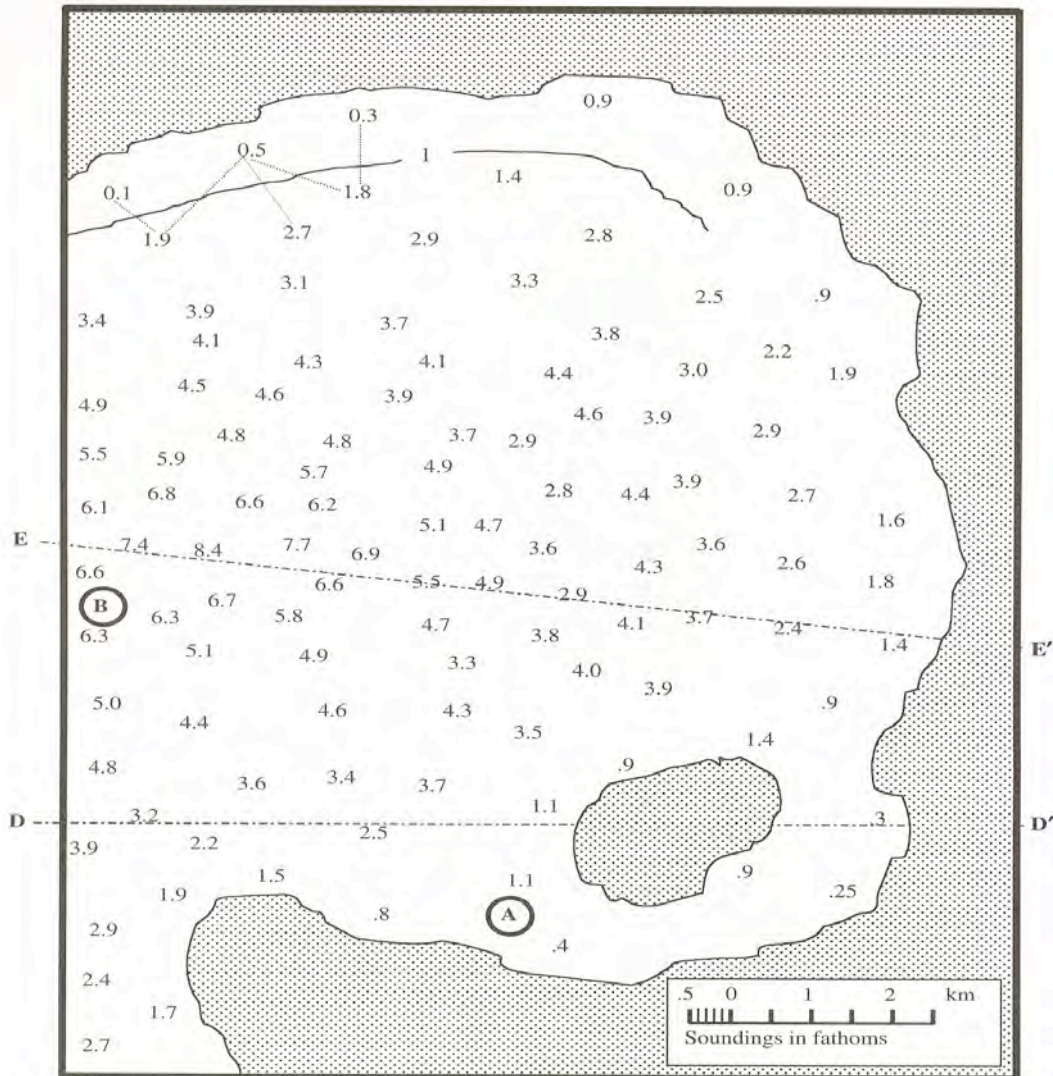
Figure 2-8 Sandy Harbor Sounding Chart

Questions Concerning Your Sandy Harbor Chart

1. What is the depth at point A in fathoms? _____ meters? _____

2. Where is the deepest part of the bay? _____

3. What is the relief (or depth difference) between points A and B? _____

4. What is the distance in kilometers between points A and B? _____

5. Convert km to miles, using the conversion factor chart in HW 1 _____

6. Determine the slope of the bay from points A to B using the formula on page 5 and the appropriate conversion factors.

_____ fathom/mi = _____ ft/mi = _____ m/km

7. If the chart had been contoured using meters (instead of fathoms) as the contour interval, how would the map appear different?

B. Pacific Ocean Chart

Convert the sounding chart of a portion of the southern Pacific Ocean (Figure 2-9) into a contoured bathymetric chart. Draw contours for 200 m, 400 m, 600 m, 800 m, etc. up to 2000m
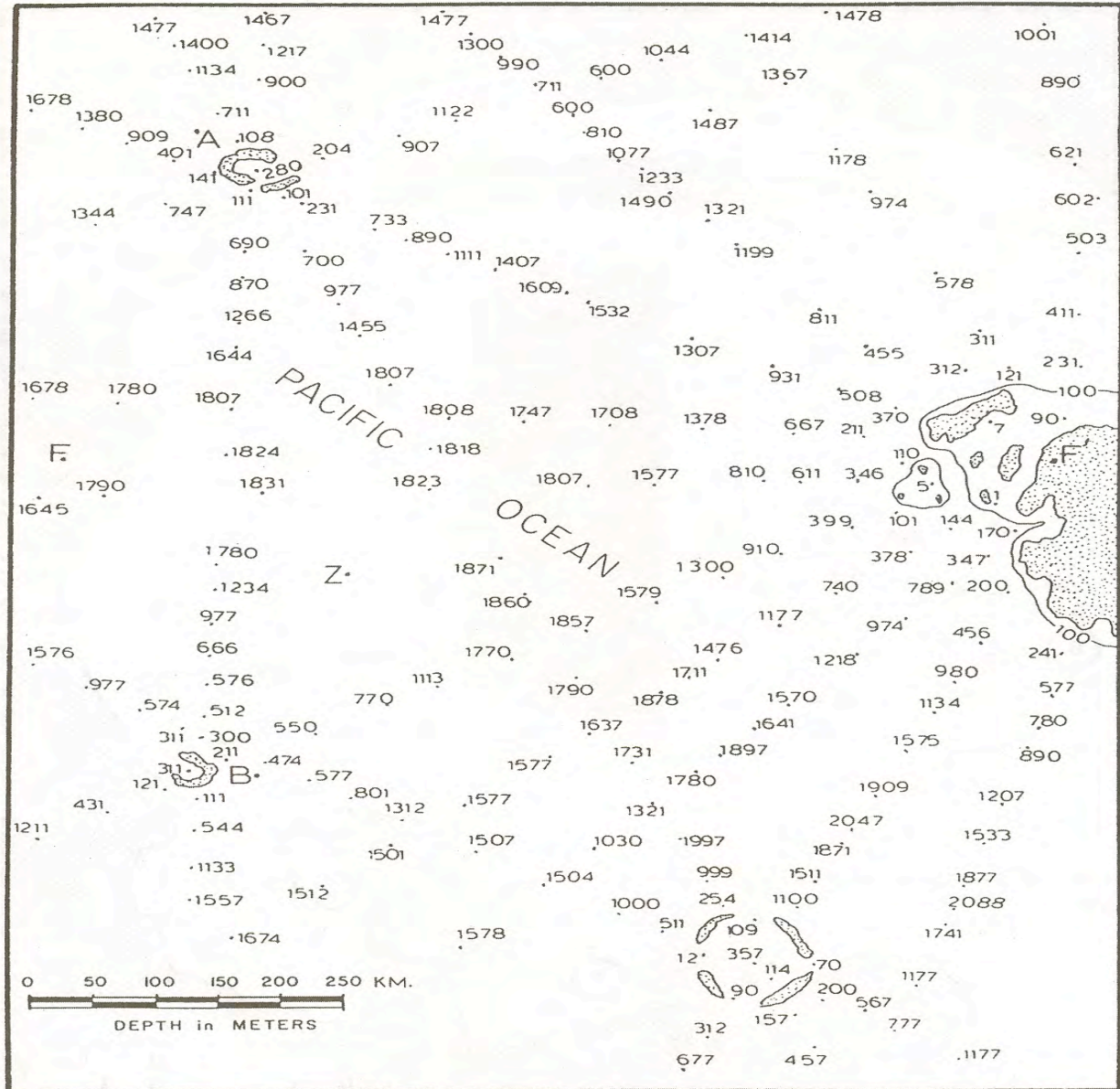
Figure 2-9. Sounding chart of a portion of the southern Pacific Ocean.

Questions Concerning Your Pacific Ocean Chart

1. What is the depth of the sea floor at point A? _____B? _____

2. What is the relief between points A and B? _____

3. What is the depth at point Z? _____

4. Compare the contour interval used in this map to the one used in Exercise 1.

Homework 6: Ocean Currents

6-1. OCEAN CURRENTS

Ocean currents are water motions induced by winds, tidal forces, and/or density differences with adjacent water masses. **Thermohaline currents** are generated by under-surface temperature- and salinity-related water mass density differences.. The major oceanic thermohaline circulation system – the so-called conveyer belt- originates with temperature-induced density increases and sinking in the North Atlantic polar regions. The deep current system distributes these cold, dense waters from the polar and subpolar regions toward the Southern Ocean polar region form where they are directed to the other ocean basins and eventual upwelling. Other smaller-scale forms of thermohaline circulation occur in marginal semi-isolated seas, where winter surface cooling and highly saline water inflows cause sinking and water mass formation; and in estuaries, where fresh river water inflows mix with saltier coastal sea water. **Wind-driven currents** are horizontal motions in the upper layer of the ocean that are primarily driven by the winds and tidal forces. The global winds drive surface current gyres in the major ocean basins. Both thermohaline and wind-driven currents are affected by Earth rotation in ways considered next.

6-2. CORIOLIS EFFECT

The Coriolis Effect as it relates to the Earth refers to the *deflection of an object* from a straight path as observed by an observer on the Earth (or Earth observer). The Earth rotates counterclockwise (**CCW**) **(**see **Figure 6-1)** as viewed by an observer on a point above the North Pole – say the North Star. Now consider the difference between what a North Star observer and an Earth observer see as a jet airplane that takes off from the pole and flies directly southward towards a point in space above the Earth observer at the equator **(Figure 6-1a).** To the North Star observer, the plane continues flying in *a straight course* towards its original destination **(Figure 6-1b).** Meanwhile our Earth observer has been moving CCW (eastward -**Figure 6-1c)** Thus our Earth observer will observe a plane that is curving (or deflecting) to the right of its original direction toward the observer **(Figure 6-1d)**.
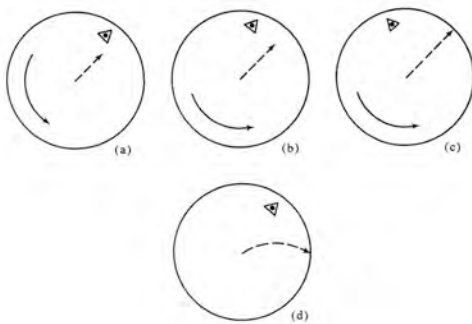
Figure 6-1. Consider the deflection of an airplane path as seen by an Earth observer. **(a)** The dashed line is the actual straight line path of the plane as observed by our North Star observer. **(b)** As the flight proceeds in its straight path as seen by our North Star observer. **(c)** However, the Earth and the Earth observer (triangle) move in a counterclockwise circle with the rotating Earth. **(d)** Thus the Earth observer sees a trajectory of the plane that veers to the right (in the Northern Hemisphere) of its initial direction of travel.

To summarize, the plane has flown in a straight line in space, <u>but</u> the Earth has rotated out from beneath it thus has a rightward deflection according to our Earth observer. To physically explain this rightward deflection in the Northern Hemisphere, Earth observers construct a "pseudo-force" called the Coriolis force that *acts to the right of the direction of a moving object*. The Coriolis force acts is the opposite Because Earth observers in the Southern Hemisphere "see" clockwise-rotating Earth, the Coriolis force *acts to the right of the direction of a moving object* – explaining the observed leftward deflection..

6-3. THERMOHALINE CIRCULATION

Thermohaline circulation is generated by density differences between water masses. Water density increases as water becomes cooler and/or more saline. If the density of surface increases, the water sinks to a level, where all water below is denser and above is less dense.

The global-scale thermohaline circulation has its origins in the North Atlantic and Antarctic and sub-polar and polar regions **(Figure 6-2)**. In those regions particularly dense water masses form due to (1) the cooling effect of cold polar region winds and/or (b) ice formation extracts freshwater and thus increases the ocean water salinity. The cold, dense water descends, find a level appropriate for their density, and slowly flows towards the equator. As these currents slowly flow, they mix with adjacent water masses **(Figure 6-3)**.
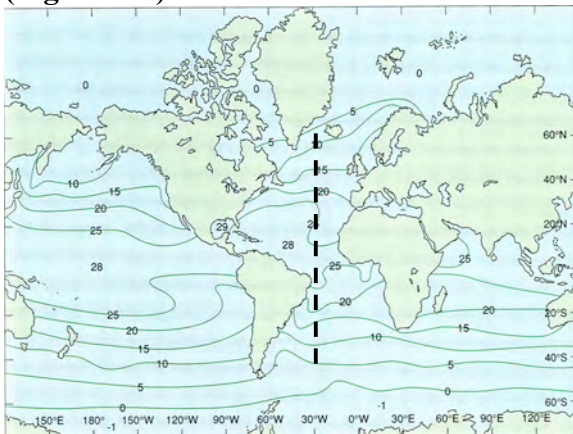
Figure 6-2 The ocean climatic temperature zones defined by the surface **isotherms** (lines of constant temperature), which are approximately parallel to lines of latitude - reflecting the equator-to-pole solar heating contrasts.

- A North/South Meridional Section -
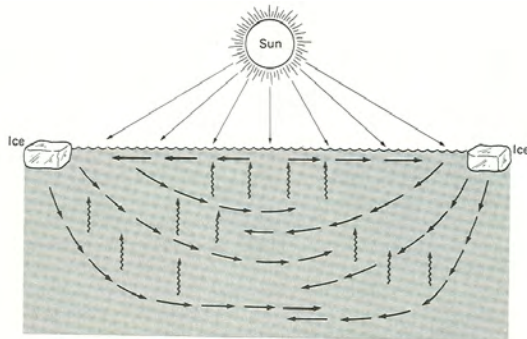
FIGURE 6.3   Schematic view of the thermohaline circulation. The sun pro-

Figure 6.3 A schematic cross-section (located in Figure 6-2) of thermohaline circulation between the poles in the Atlantic Ocean. Cold water at the poles becomes dense as it cools, becomes more saline through ice-formation, and sinks to depths that depend on their. The coldest, densest water forms in the Antarctic (right). The largest volume of deep water is formed in the North Atlantic (left). As the water warms through mixing, it becomes less dense and rises (wiggly vertical lines).

6-4. WIND-DRIVEN GLOBAL OCEAN CIRCULATION

Global winds have profound effects on the large-scale ocean current systems. The Coriolis Effect deflects the NH surface winds to the right (and SH winds to the left) creating a three convection-cell system with zonal (west-east) winds in **Figure 6-4**.
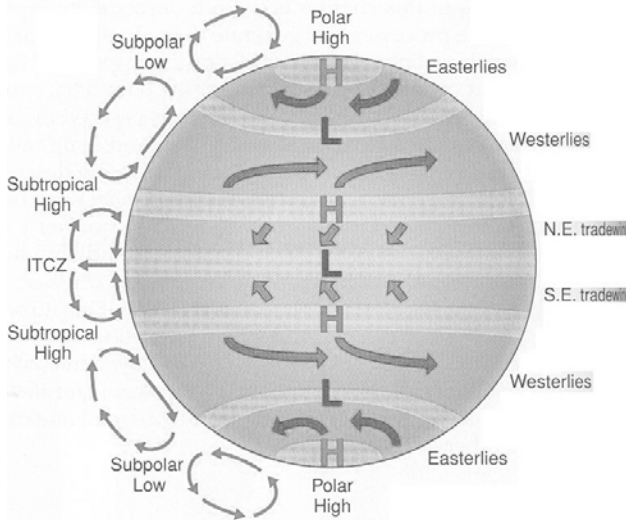

Figure 6-4 Earth Rotation Makes Single Cell System Unstable. The wind fields are dominated by a trio of atmospheric cell convection cells marked by pairs of high and low pressure regions and related zonal wind fields in each hemisphere. (UWaC)

The major surface winds (Figure 6-4) are the **Trade Winds** (0° to 30°N and S, respectively), **Westerlies** (30° to 60°N/S) and **Polar Easterlies** (60° to 90°N/S). The meteorological convention is to name winds for the direction from which they originate. For example, the Westerlies blow from the west to the east. Between these primary wind zones lie zones of reduced surface winds, but stronger rising or sinking convective air flow. For example, in zones of high air pressure zones at 30°N and S respectively, cold, dry air sinks to Earth's surface in regions known as the **Horse Latitudes**. Conversely warm, moist air rises from Earth's surface in the **Doldrums -** a low pressure zone near the equator at ~ 0°**.** In the **Subpolar Low** pressure regions (60°N/S), somewhat colder, dryer air rises, while in **Polar High** pressure regions (90°N/S) very cold air sinks.

As **surface winds** blow across the open ocean surface waters, the air friction drags the surface water in the general direction of the winds – at least initially. Within a few hours, water propelled by the wind is affected by Coriolis in that surface currents are deflected 45° to the right (NH) direction of the winds. This is called Ekman flow, which spirals to the right and decreases in strength going downward through the upper ocean to a layer depth of about 30m. The vertical average of the Ekman flow in that layer is called the **Ekman transport** and is 90° to the right (NH) of the direction of the wind (**Figure 6-5**).

The winds produce gyre flows in the confined ocean basins. Consider the ocean flow in a NH ocean basin (**Figure 6-6).** The action of the Westerlies and Trade winds produces an Ekman transport which forms a mound of water in the center. The gravity force **g** (or pressure gradient force) causes the water to flow "downhill", but the Coriolis force **C** forces the water to curve to the right. This curving continues until the forces are in balance; **C** = **g** and in opposite directions. This balanced flow called **geostrophic current** follows the contours of the mound (or is perpendicular to the slope of the mound).
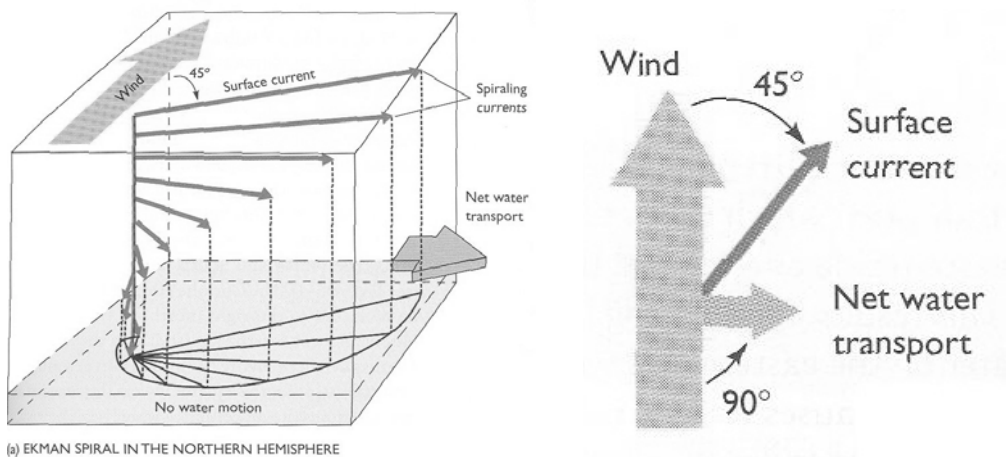
Figure 6-5b Ekman Flow Schematic. **(Left)** The Coriolis force deflects the wind-forced surface flow 45° to the right (NH). Friction drives the layers below at increasing right-twisting directions with decreasing strength in an Ekman spiral. **(Right)** The net effect of the wind is to drive overall transport in that layer –the Ekman transport - 90° to the right (NH) of the direction of the wind. In the southern hemisphere, the Ekman transport is to the left of the direction of the wind. (ItO)

NH
Subtropical
Ocean Basin

Zonal Winds
&
Ekman Transport
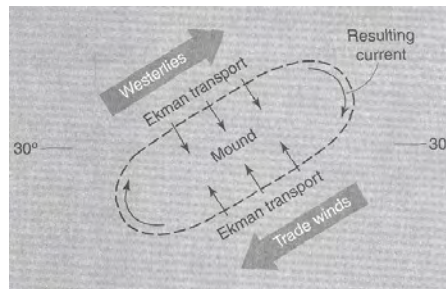
Geostrophic
Ocean
Flow
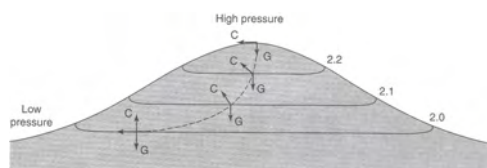
Same Physics as Geostrophic Winds

Figure 6-6 Geostrophic Flow. The action of the Westerlies and Trade winds in a NH ocean basin is to produce an Ekman transport which forms a mound of water in the center. The gravity force g (or pressure gradient force) causes the water to flow "downhill", but the Coriolis force (C) forces the water to curve until the forces are in balance (i.e. C = g). The resulting **geostrophic current** follows the elevation contours of the mound (or is perpendicular to the slope of the mound). (LEiO)

The Earth rotation also acts on the gyre itself. Through its west to east rotation the Earth slides out from under the gyre causing gyre flow to pile up against the western boundary of the ocean basin in a Western Boundary Current WBC (**Figure 6-7**). In the North Atlantic the WBC is called the Gulf Stream. The Gulf Stream connects to the eastward

North Atlantic Current (see **Figure 6-8**) that in turn connects to the southward flowing Canary current, which is much slower and broader than the Gulf Stream. The westward North Equatorial current connects the two to the south (also see **Figure 6-8**). The same type of wind-driven processes produce gyres in the South Atlantic as well as other ocean basins that are confined by continents (see **Figure 6-8**). In the Atlantic and Pacific oceans the northern gyres rotate clockwise, the northern equatorial countercurrents turn counterclockwise, the southern equatorial countercurrents spin clockwise and the southern gyres rotate counterclockwise.

GEOSTROPHIC FLOW AROUND THE NORTH ATLANTIC OCEAN
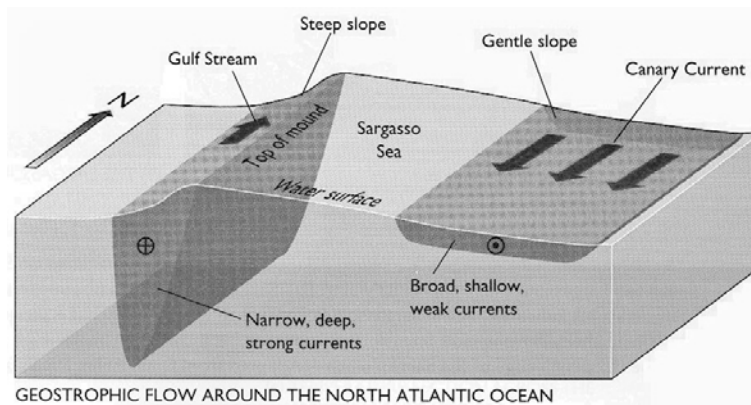
Figure 6-7 North Atlantic Gyre Flow. The gyre in the North Atlantic Ocean basin is formed on the west by the northward flowing Gulf Stream., and on the east by the southward flowing Canary Current. The Sargasso Sea resides in the center of the gyre. The Gulf Stream flow is concentrated and rapid due to Earth rotation effects. (LEiO)
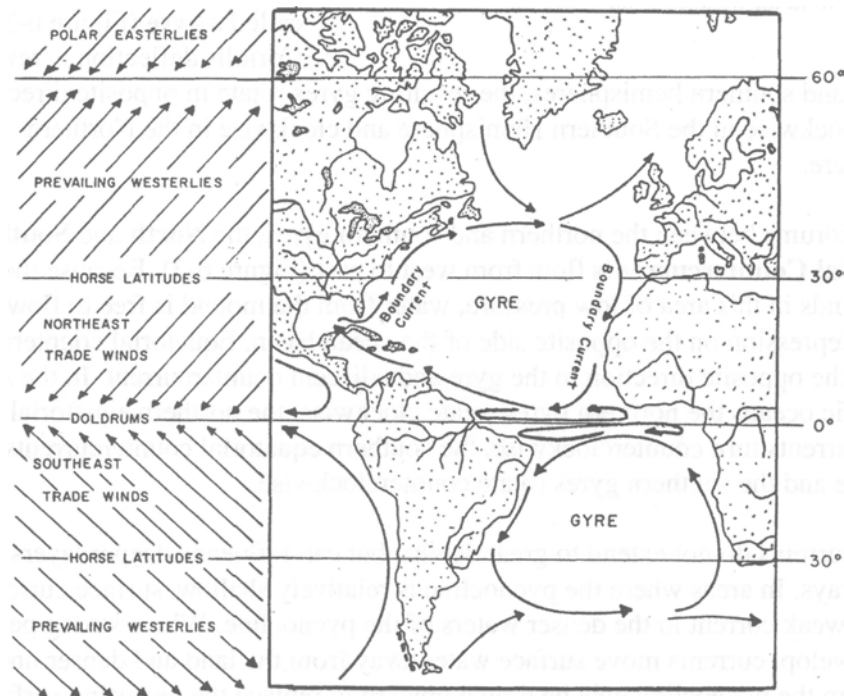
Figure 6-8. Major winds zones and the Atlantic Ocean gyres and countercurrents

Between these gyres in the tropics, wind-driven ocean currents flow east and west, perpendicular to the lines of longitude and parallel to the lines of latitude. In the North Pacific (& Atlantic), the Northeast Trade Winds produce the **North Equatorial Current** (NEC – in **Figure 6-9**) that flows westward from South America to Indonesia. In the South Pacific (& Atlantic), the Southeast Trade Winds produce the **South Equatorial Current** (SEC) that also flows westward. In the doldrums between these branches of the northern and southern gyres, the **North** and **South Equatorial Countercurrents** (ECC) flow from west to east along with the **Equatorial Undercurrent** (EUC).
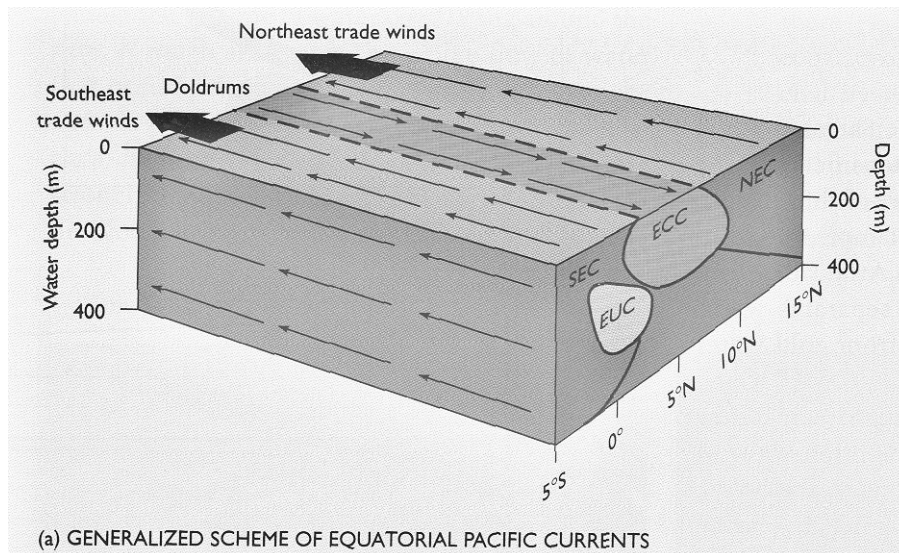
Figure 6-9. Tropical ocean currents and countercurrents

6-7. SEASONAL MIGRATION OF CURRENTS

Over the course of a year, the overhead position of the Sun changes relative to Earth's surface (**Figure 6-10**) because of the 23.5^o tilt in the Earth's rotation axis relative to the plane of the Earth and the Sun. The position of the Sun is important because it determines the location of high and low atmospheric pressure zones, and thus the location of the wind zones **(Figure 6-4).** As the wind zones change, so do the locations of the ocean gyres and countercurrents change **(**see **Figure 6-8)**.

At noon on March 20 (or 21), the Sun is directly above the equator – a situation called the **equinox** (**Figure 6-11**)**.** Between March 21 and June 21 (or 22), the Sun's overhead position moves steadily northward to its furthest northward position at the Tropic of Cancer (23.5^{o}N) at **summer solstice** in the Northern Hemisphere and **winter solstice** in the Southern Hemisphere. Between June 21 and September 22 (or 23), the Sun's overhead position moves steadily southward to the equator at **equinox**. Between June 21 and September 22 and December 21 (or 22), the Sun's overhead position moves steadily southward to its furthest southward position at the Tropic of Capricorn (23.5^{o}S) at **winter solstice** in the Northern Hemisphere and **summer solstice** in the Southern Hemisphere. Between December 21 and March 21 (or 22), the Sun's overhead position moves steadily northward to the equator at **equinox** –completing the annual cycle.
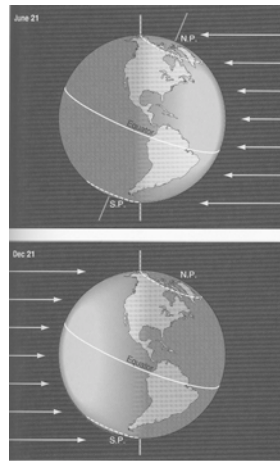
Figure 6-10. The latitude of the direct overhead rays of the Sun change from 23.5°N (Tropic of Cancer) to 23.5°S (Tropic of Capricorn) between 21 June (Northern hemisphere summer solstice) and 21 December (Northern hemisphere winter solstice). At the equinoxes, the sun's position is directly over the Equator.

June 21/22   Summer solstice (N)
                   Winter solstice (S)

March 20/21   Equinoxes
or Sept 22/23

Dec 21/22   Winter solstice (N)
                   Summer solstice (S)
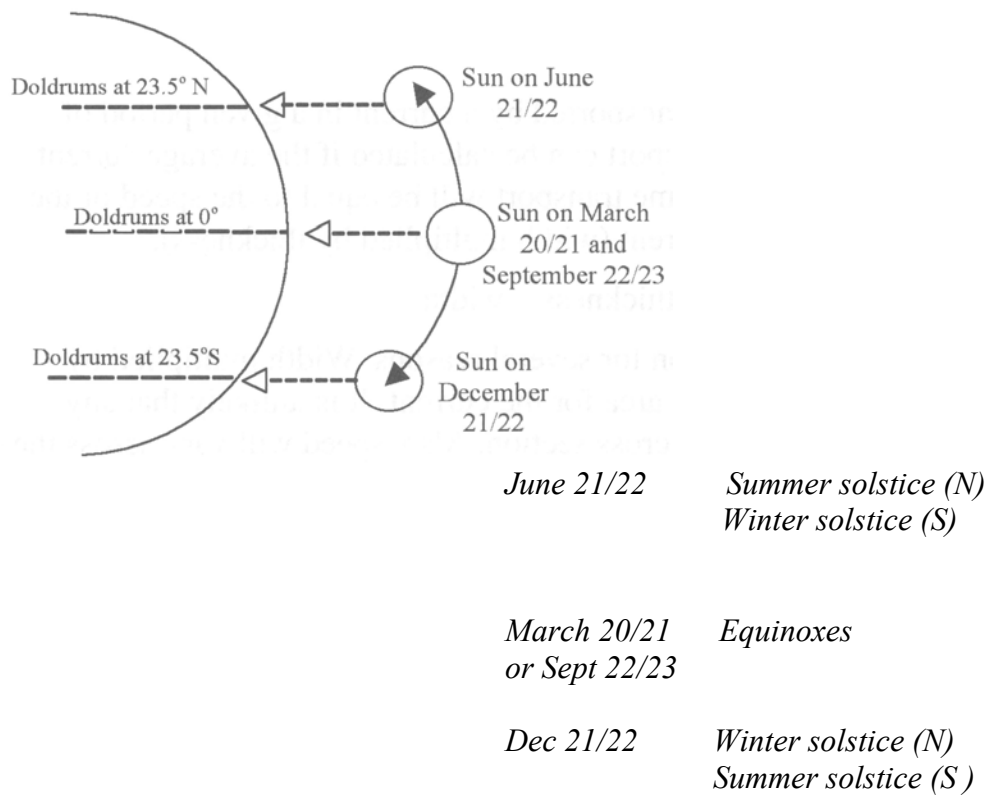
Figure 6-11. Movement of the Sun's overhead position relative to Earth's surface over the course of a year, and corresponding dates of solstices and equinoxes (see also Fig. 6-10).

EX. 6 SEASONAL CURRENTS   Name _____

On the next page are maps of a theoretical ocean (white) surrounded by land (gray) for **March 21, June 21, September 22 and December 21**. On the maps to the **left**, indicate the locations and latitudes where each of the following would be found for the dates indicated: **doldrums, subtropical highs, and subpolar lows**.
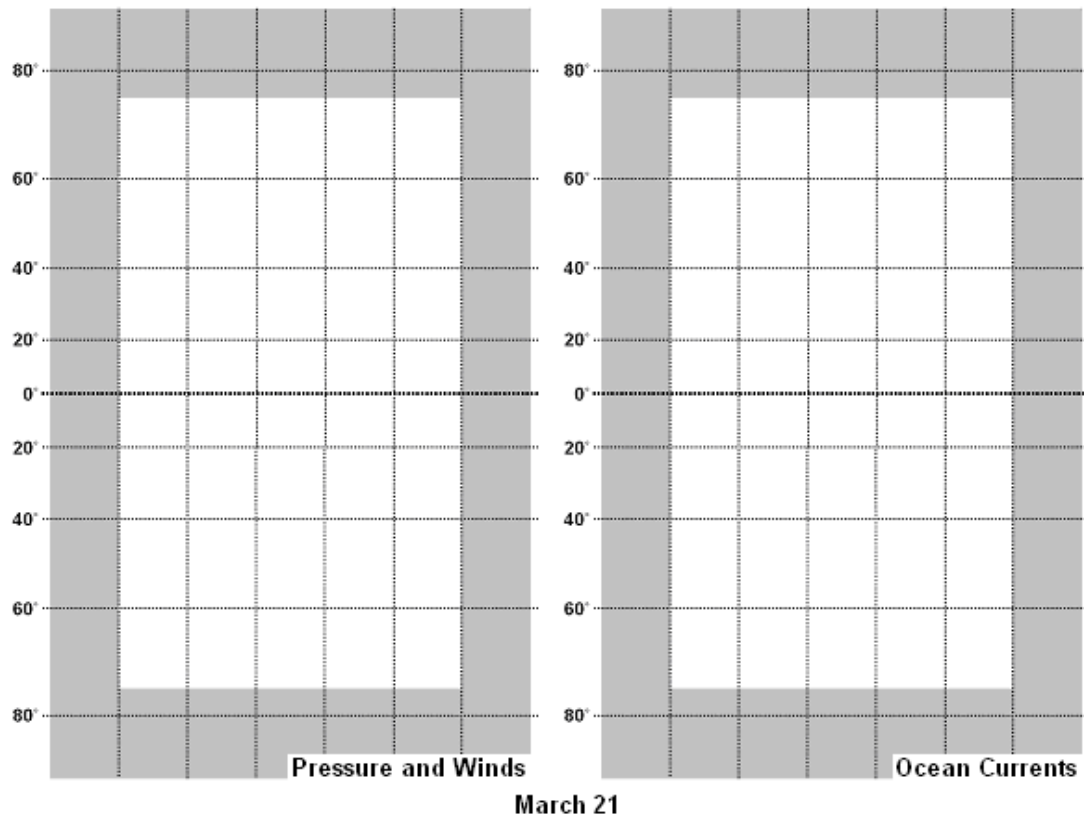
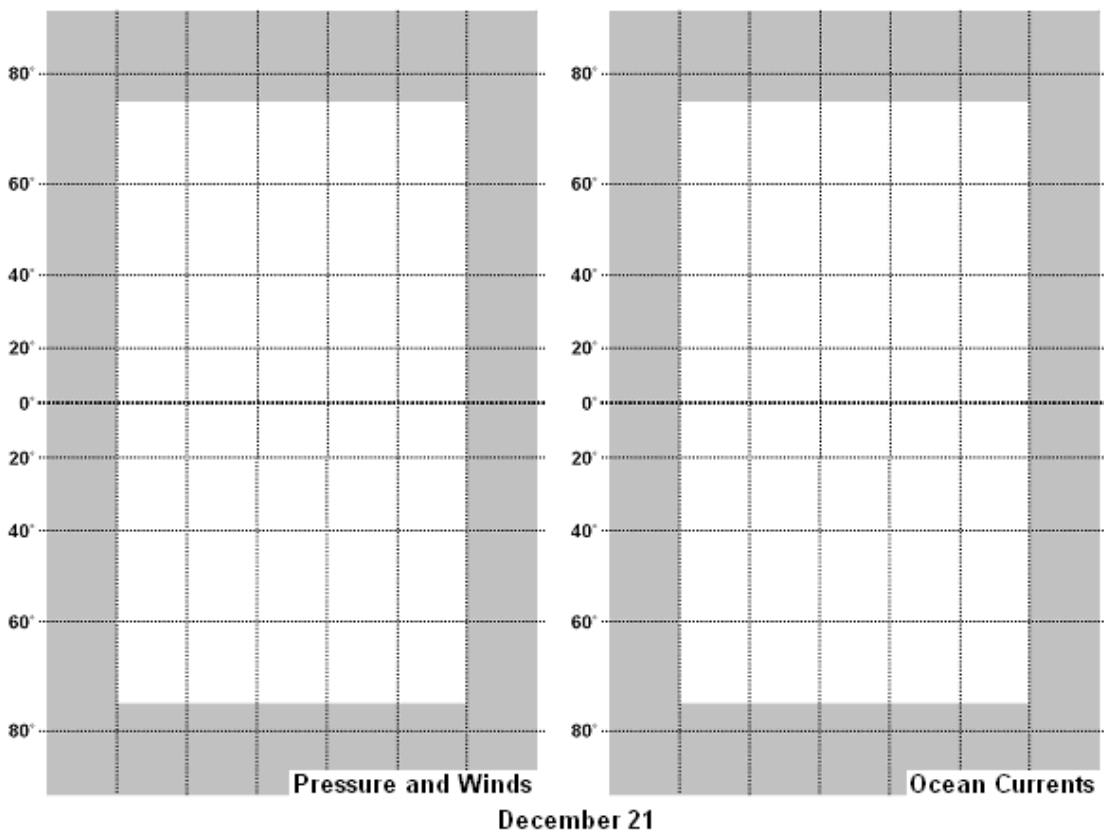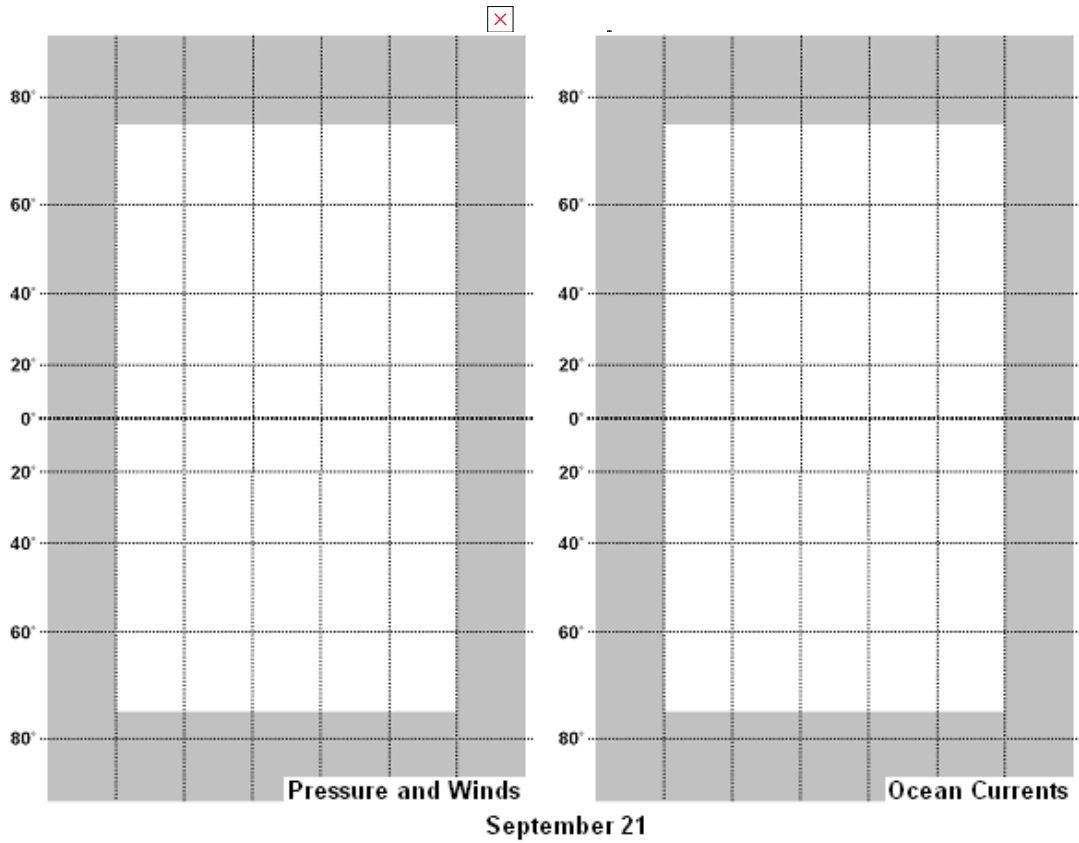On the **same** map, draw the **Trade Winds, Westerlies and Polar Easterlies**.

On the maps to the **right**, draw the **north and south gyres and their counter currents** for the indicated dates.

After filling in the map, answer these questions:

Questions

1. Are the counter currents always on opposite sides of the equator? Why?

2. On the equinox, the counter currents flow more swiftly than they do on the solstice. How can Coriolis explain this?

3. If the Earth rotated in the opposite direction, how would this alter the flow of the gyres and the counter currents?

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Pressure and Winds   Ocean Currents

March 21

Pressure and Winds   Ocean Currents

June 21

Pressure and Winds   Ocean Currents

September 21

Pressure and Winds   Ocean Currents

December 21
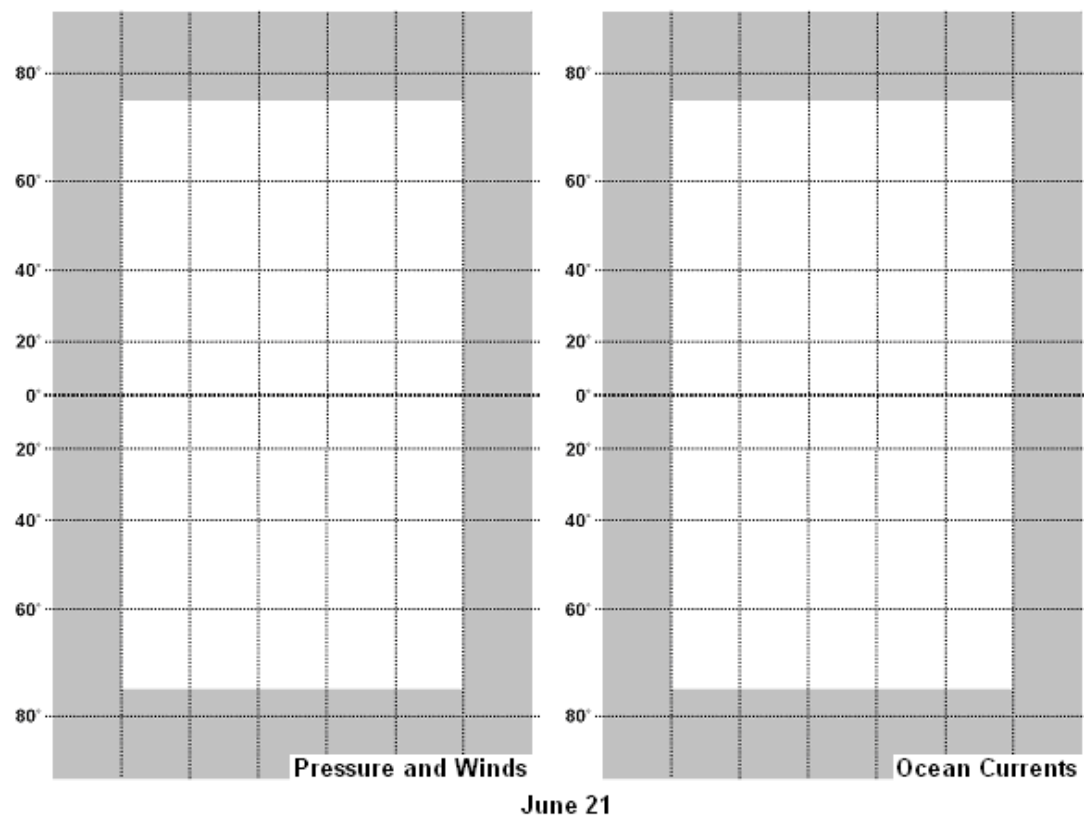
Homework10 ENSO - Background
(Pipkin et al)

Objectives:

- To know the atmospheric and oceanographic factors leading to El Nino/Southern Oscillation (ENSO) "events."

- To understand the impact of El Nino on humans and on marine life.

Although it may be hard to believe from the common references in broadcast and print media, before the winter of 1997-98, only oceanographers and Pacific fishermen were familiar with El Nino. This oceanographic phenomenon in the Pacific Ocean was originally noticed by fishermen along the Pacific coast of Peru and Ecuador, when periodic appearances of warm, nutrient-poor ocean waters led to decreases in the local fishing industry. In 1892, fishermen in the Peruvian port of Paita called an invasion of warm water off the coast around Christmas time "Corriente del Nino" (current of the Christ Child). In 1958, the term *E1 Nino* was proposed for the oceanographic and meteorological events that occurred across the Pacific Ocean during December of that year, and persisted for several months before the restoration of "normal" ocean currents and surface-water temperatures. In 1972, oceanographers and meteorologists used the term **El Nino-Southern Oscillation** (ENSO), broadening the definition of these events to include periodic climate-related shifts in weather patterns in the equatorial Pacific and Indian oceans. To complicate matters, during the 1990s, the news media began to refer to times when anomalously *cold* surface-water masses appeared in the eastern equatorial Pacific Ocean as *La Nina* events.

The Generation of E1 Nino Events

Occurrences of unusually warm surface water in the Pacific Ocean are episodic, and eight severe El Nino events have occurred since the late 1950s. Although the 1997-98 El Nino was widely reported in news broadcasts, it remains to be proved whether its effects exceeded those of the 1982-83 El Nino, which was the strongest event of the twentieth century, affecting the entire Pacific Rim and the Indian Ocean.

To understand the El Nino-Southern Oscillation, it is first necessary to understand the "normal" circulation of the equatorial Pacific Ocean (Figure 10-1). During normal times, the coastal current along the Pacific margin of South America is the Peru Current (also previously known as the Humboldt Current), which moves cold waters northward from Antarctic regions. Southeast trade winds in the equatorial Pacific Ocean, combined with Coriolis deflection to the left in the Southern Hemisphere, push the water in the northward-flowing Peru Current offshore, causing surface waters to be replaced by upwelling of cool, nutrient-rich water from below the thermocline (Figure 10-2). This cold upwelled inshore water is so distinct that it is called the *Peru Coastal Current* to distinguish it from the offshore Peru Current. The Peru Coastal Current supports one of the richest fisheries in the world, and commercial fishermen from southern California travel thousands of miles to the coastal waters off Peru.
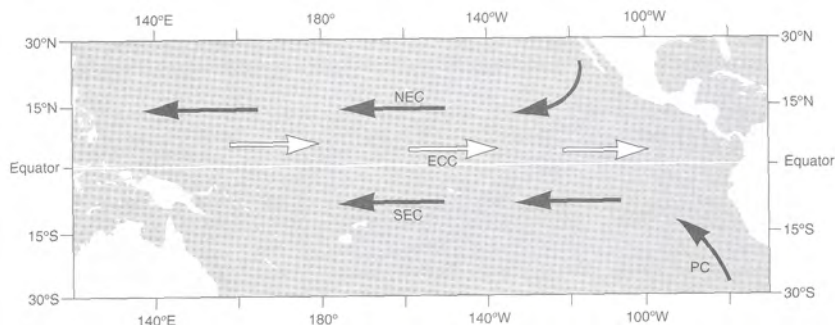
Figure **10-1** Surface currents in the equatorial Pacific Ocean. N EC = North Equatorial Current; SEC = South Equatorial Current; ECC = Equatorial Countercurrent; PC = Peru Current.

Under normal conditions, the North Equatorial Current and the South Equatorial Current force surface waters westward across the Pacific. These surface waters are warmed in their transit across the ocean, forming a distinct "bulge" of warmer water in the western equatorial Pacific, which may be seen on satellite images showing relative sea level. During EI Nino years, the usual low atmospheric pressure in the western equatorial Pacific is replaced by high-pressure cells. This shift in pressure is known as the Southern Oscillation. Since this change lessens the pressure differential that drives the trade winds from east to west, those winds decrease or even reverse direction, allowing the huge mass of warm surface water in the western Pacific to surge back toward South America in an intensified Equatorial Countercurrent (ECC) (see Figure 10-1).
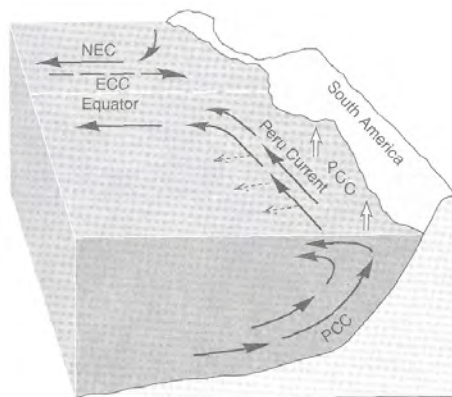
Figure 10-2 Three-dimensional view of upwelling off the western coast of South America. The cool, nutrien-trich upwelled waters of the Peru Coastal Current (PCC) create a rich fishing ground off Peru and Ecuador. Cessation of upwelling during EI Nino events leads to the collapse of the fishery in this area. NEC = North Equatorial Current; SEC = South Equatorial Current; ECC = Equatorial Countercurrent.

When this warm, dilute, nutrient-poor water strikes the coast of South America, it moves southward over the cooler coastal waters, forming a "lid" that stops the upwelling of the Peru Coastal Current. Lower nutrient concentrations in surface waters result in the disappearance of fish species that depend on the upwelling of cool, nutrient-rich water, and thus the collapse of the local fishing industry. The disappearance of these fish also leads to the deaths of millions of seabirds that normally feed on them. In turn, the local guano fertilizer industry vanishes because of the decrease in seabird abundances.

Eventually, coastal communities in Peru and Ecuador experience economic hardship and sometimes even famine.

Monitoring El Nino

The onset of EI Nino events can be predicted by oceanographic changes in the central equatorial Pacific Ocean before they affect the west coasts of North and South America. NOAA has attempted to track and predict the onset and relative impact of EI Nino events. The NOAA Pacific Marine Environmental Laboratory maintains the **Tropical Atmospheric Ocean Array** (TAO), an array of 70 buoys moored in the central Pacific, between 160^0E and 150^0W and from 5^0S to 5^0N, in an area termed the Nino-4 Region (Figure 10-3). NOAATAO buoys measure temperature, winds, and currents in the Nino-4 region, and transmit these data back to the Pacific Marine Environmental Laboratory.
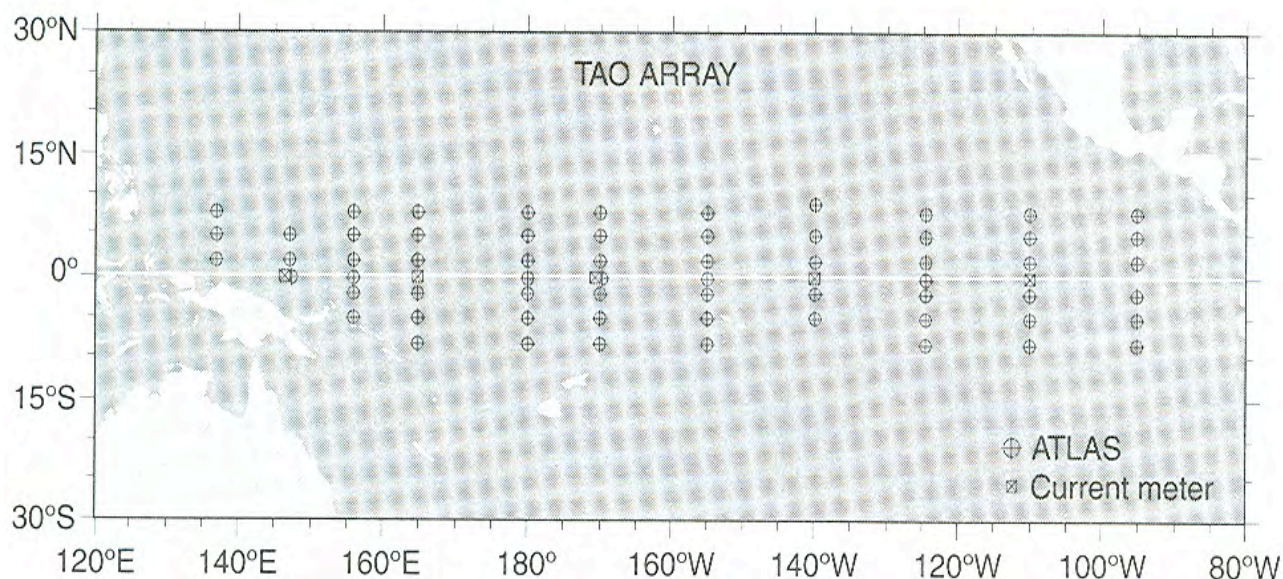
Figure 10-3 The Tropical Atmospheric Ocean Array (TAO) of oceanographic sensor buoys and moored current meters in the Nino-4 region of central Pacific Ocean (between 160^0E and 150^0W, and from 5^0S to 5°N). Data obtained from these sensors is used by NOAA to monitor oceanic conditions that might mark the onset of EI Nino events.

One means of tracking EI Nino is by monitoring sea-surface temperatures. Under normal conditions, surface waters in the eastern Pacific are cooler (around 22°C) than those in the western Pacific (around 30°C). If temperatures in the eastern Pacific are *warmer* **than usual, this is a positive SST anomaly**. Conversely, **negative SST anomalies mark times when surface waters there are *cooler* than usual**. EI Nino events may be seen in SST data collected by the TAO array (Color Plate 6). During EI Nino, higher than usual temperatures displace the typical "cold tongue" of water that normally extends westward across the equatorial Pacific Ocean. The atmospheric pressure shifts that trigger El Nino are also periodic and can be detected by orbiting weather satellites.
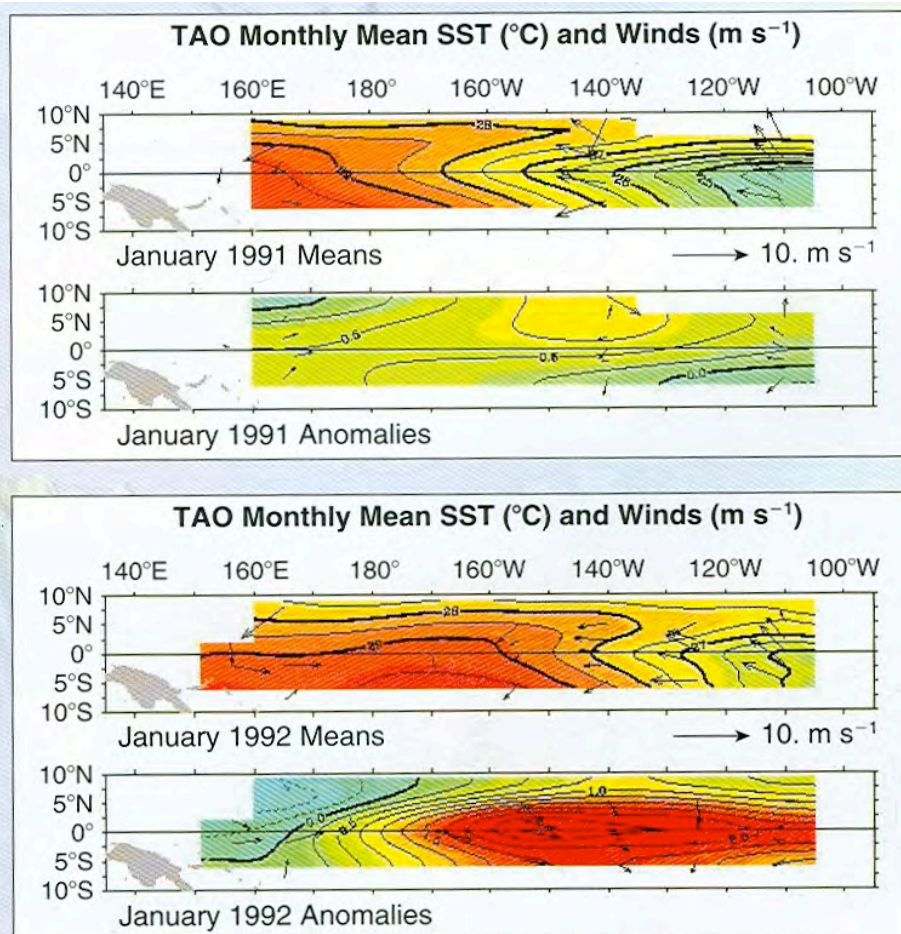
Color plate 6 Monthly mean sea-surface temperature data for the Niño-4 region, compiled by the Tropical Atmospheric Ocean Array (TAO) of the NOAA Pacific Marine Environmental Laboratory. January, 1991 is a normal (non-El Niño) year, while January, 1992 shows data for an El Niño event. [Courtesy of NOAA.]

Effects of El Nino

The El Nino-Southern Oscillation can cause global shifts in weather patterns, as well as latitudinal changes in the position of the jet streams (stratospheric winds that affect weather patterns by "steering" high- and low-pressure cells, and thus weather fronts). In particular, deflection of the subtropical jet stream (often called the "Pineapple Express" because it flows near Hawaii) to the north may allow tropical storms to flow northward, causing flooding as far north as Washington and Oregon (Figure 17-4). The 1982-83 ENSO was responsible for flooding and droughts in 12 countries, thousands of deaths, and billions of dollars in property damage. In southern California, the rainfall nearly tripled, and the coast was battered by destructive winds and high waves.
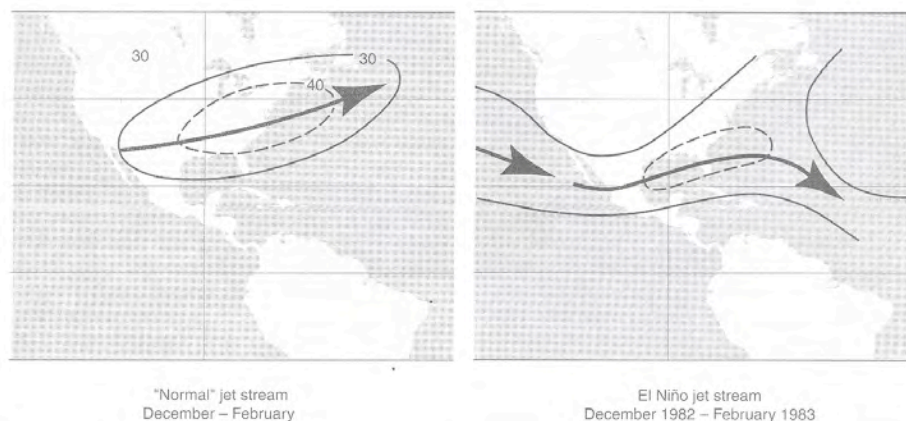
Figure **17-4** Typical December-February location of the subtropical jet stream (left) and northward deflection of the subtropical jet stream during the EI Nino of 1982-83 *(right)*. [After Eugene M. Rasmusson, "EI Nino: The Ocean/Atmosphere Connection." *Oceanus,* Vol. 27, no. 2, 1984, pp. 5-13].

During El Nino years, the presence of high pressure cells in the western equatorial Pacific disrupts the rainfall regime of the tropical Pacific. Normally, heavy rainfall occurs over the North Australian-Indonesian region and along the South Pacific convergence zone from New Guinea eastward to the International Date Line. The 1982-83 El Nino was marked by severe droughts in Australia, Indonesia, and the western equatorial Pacific. It was also associated with dust storms and brush fires in Australia. Drought during the 1997 -98 El Nino caused forest fires of such severity that aircraft were unable to land at Indonesian airports because of impenetrable smoke.

El Nino events may also affect the Atlantic Ocean, as the northward shift of the subtropical jet stream allows warmer, moister air to flow eastward into the Gulf of Mexico and the Caribbean Sea. The invasion of this air from the Pacific tends to slow down the development of tropical storms and hurricanes in the Atlantic basin. This is because Atlantic tropical storms increase in strength and can evolve into hurricanes as they move northward into regions of cooler, drier air at higher latitudes. Only seven named storms formed during the Atlantic hurricane season of 1997, and only three of these developed into hurricanes.

ENSO events are periodic, with a return interval of 3-7 years (Figure 10-5). Because of this short return period, predicting these events is important to government preparedness agencies and the general public. Pacific equatorial sea-surface temperatures determined by the TAO buoy network are shown in Figure 10-5. Averaging temperatures over this region allows oceanographers to identify positive (warmer) temperature anomalies that may signal the onset of an ENSO event. Pronounced events may last for an entire year before conditions return to normal, but most events persist for only 3–4 months. La Nina events are seen as negative temperature anomalies; that is, cooler than usual surface waters move eastward across the equatorial Pacific Ocean.
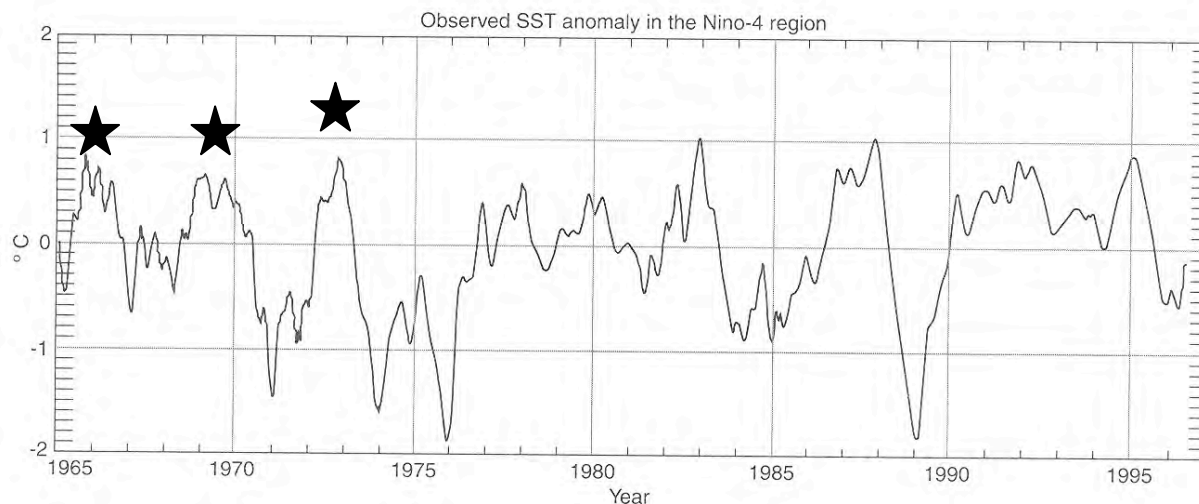
Figure **10-5** The periodicity of EI Nino is demonstrated by the sea-surface temperature anomalies observed over time in the Pacific Ocean near 180^0 latitude at the equator. **Positive anomalies are temperatures higher than average, and mark the warm surface waters of EI Nino event** (see stars on graph for the first 3 El Nino events).

How do El Nino events end? The accumulation of warm surface waters in the eastern Pacific causes a weakening of the westward-flowing trade winds, leading to the further strengthening of ENSO events by positive feedback. However, sea-surface height in the western Pacific eventually decreases as surface waters "slosh" across the equatorial Pacific in eastward-flowing *Kelvin waves.* Kelvin waves are similar to seiches, having an up-down motion similar to that of the wave that develops in a bathtub as the bather moves, causing water to slosh back and forth in the tub. These slow-moving waves eventually slosh back to the eastern Pacific, leading to the reestablishment of the normal east-to-west motion of surface currents. As the surface currents are restored, the eastern equatorial Pacific cools, and the pole-to-equator motion of the Peru Current restores the normal upwelling regime of the Peru Coastal Current.
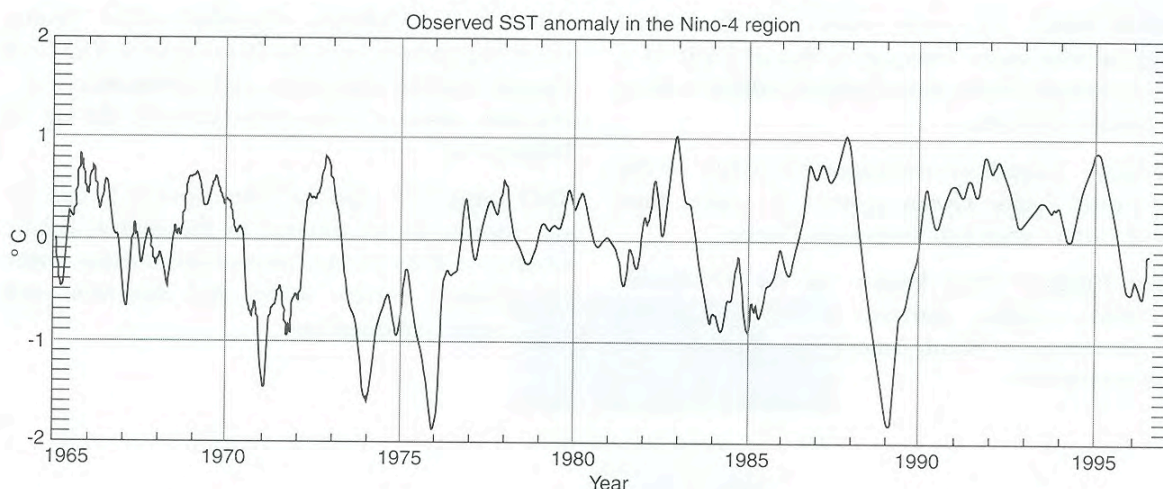
Web Sites
Current information on sea-surface temperatures, El Nino, and La Nina, with animations and interactive questions and answers, may be found at the following sites:

http://www.elnino.noaa.gov/lanina.html   NOAA site

http://www.ogp.noaa.gov/enso/   More NOAA

http://www.pmel.noaa.gov/toga-tao/ la-nina-story-nas.html   NOAA and TAO Buoy array

http://www.pmel.noaa.gov/toga-tao/ el-nino/home.html with animations of SST in the he Pacific

http://www.pbs.orglnova/elnino   Public Broadcasting System *Nova*

http://www.nws.noaa.gov   National Weather Service

http://observe.ivy.nasa.gov/nasa/ earth/el nino/elninol.html   NASA's site

MAR110 HW 10: ENSO   Name _____

Observed SST anomaly in the Nino-4 region

Figure 17-5 The periodicity of El Niño is demonstrated by the sea-surface temperature anomalies observed over time in the Pacific Ocean near 180° latitude at the equator. Positive anomalies are temperatures higher than average, and mark the warm surface waters of El Niño events.
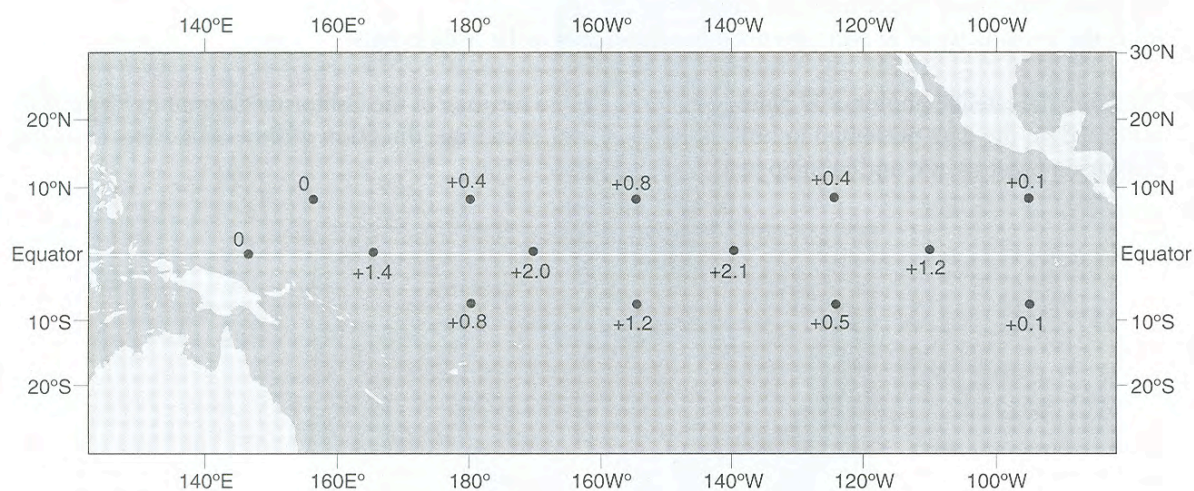
QUESTION 1.

Use the information in Figure 17.5 to determine the periodicity of El Nino.

a) How many El Nino events can be recognized in this figure (keep in mind that a single event can last more than one year). Mark them on the figure too _____

b) How many years elapse between El Nino events? (this should be a range of years). _____

c) How many La Nina events (cooler than usual) conditions are there? (mark them on the figure too) _____

d) How many years elapse between La Nina events? _____ (this should also be a range of years).

e) Is the periodicity (range of years) of El Nino events the same as that of La Nina events? _____ . Explain your answer.

QUESTION 2

The figure below shows the locations of selected oceanographic buoys from the NOAA-TAO array in the central equatorial Pacific, with mean sea-surface temperature (SST) anomaly data indicated for each buoy. Contour these data, using 0.5° intervals.
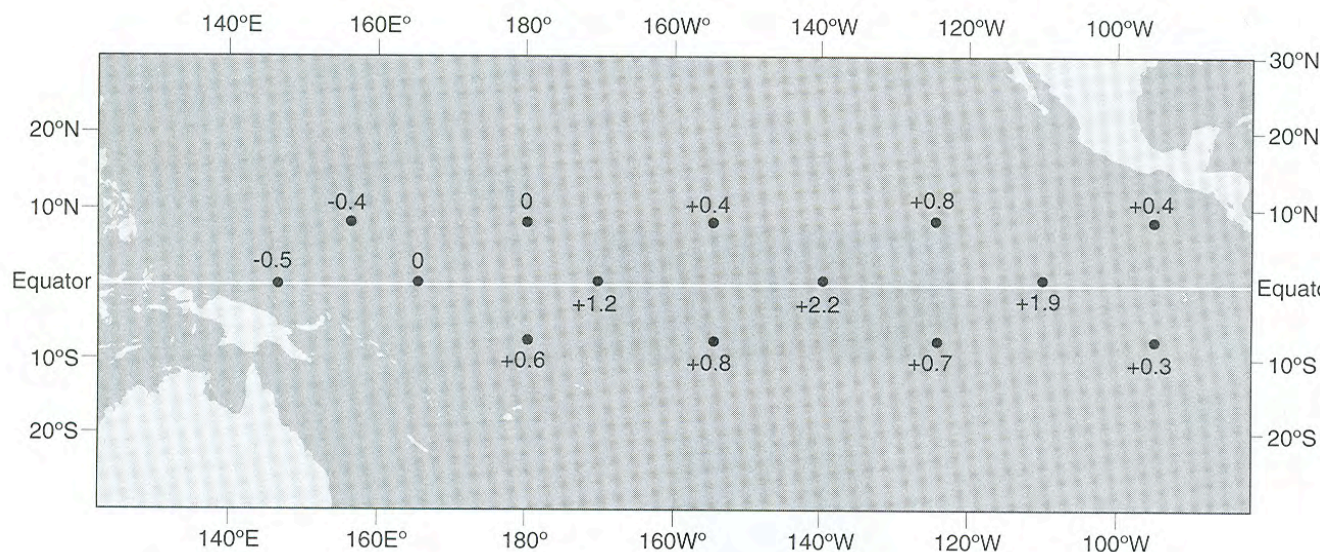

(a) Do these data indicate normal conditions, an El Niño event, or La Niña? Justify your answer by comparing to the SST anomaly data plotted in Figure 17-5. _____

_____

QUESTION 3

The figure below shows SST anomaly data for the same buoys as in Question 4, but from a different time period. Once again, contour these data, using 0.5° intervals.

(a) Compare these data to those in Question 2. Assuming a time difference of one month between these two "snapshots" of equatorial Pacific surface temperatures, what do you think might happen soon along the west coast of South America? Be specific with regards to both physical changes in the environment, and their effects on biology, economics, etc.

(b) What do we call this type of event?

(c) **Extra Credit:** Assuming a time difference of one month between these data and those in Question 2, when would you expect the changes described in (a) to occur at Guayaquil, Ecuador (3°S, 82°W – note that this location is just off the right hand side of the above chart)?