

## BASIC CONCEPTS IN PHYSICAL OCEANOGRAPHY

After finishing the core course in physical oceanography the students should have an understanding of the basic principles of the field. The following list of topics and questions gives what is expected.

1. History of physical oceanography - Understand that the roots of physical oceanography are in dynamical meteorology, the observations of early expeditions such as the Challenger and Meteor, the theoretical work of Ekman, Sverdrup, Stommel, and Munk, and the international data gathering efforts started by Maury.
2. Global Climate - To understand the ocean you must understand the global weather systems and how they vary seasonally and inter-annually.
  - a. Describe the global wind system, including the global system of high and low pressure regions, and the characteristic wind fields of the ocean basins.
  - b. Why do the high and low pressure regions over the oceans vary seasonally? Give an example from the Pacific or Atlantic Ocean.
  - c. Draw a schematic of the globe with the zonal, basin scale winds labeled.
  - d. What are Hadley and Walker Cells in the atmosphere? How do they relate to regions of dry air and moist air in the ocean?
  - e. Explain the apparent cause of El Niño. What are examples of its effects on the ocean.
  - f. Using the Pacific or Atlantic as an example show the location of regions of net evaporation, net cooling, net heating, and net precipitation.
3. Global Ocean
  - a. Know the name and location of all the major ocean surface currents including the physical basis for each current.
  - b. Draw a cross section of an ocean basin showing the temperature, salinity and density fields and including boundary currents and eddies. You should know the approximate ranges of temperature and salinity in the Atlantic and Pacific Oceans, the width and depth of boundary currents, and the diameter of eddies.
  - c. Draw a schematic diagram of the permanent thermocline and the seasonal thermocline. Why does the seasonal thermocline vary seasonally? Why doesn't the permanent thermocline vary seasonally?
  - d. Name two water masses that are formed in the Antarctic region and influence most of the ocean basins. What physical processes cause their formation?
  - e. Draw a temperature and salinity section from the Antarctic to the Arctic showing the temperature and salinity distributions from surface to bottom and naming the water masses.
  - f. Understand the significance of sills and ridges in ocean circulation. For example: What is the effect of the Mid-Atlantic Ridge on the flow of Antarctic Bottom Water?; Or, What is the effect of the Straits of Gibraltar on exchange between the Mediterranean and the North Atlantic?
  - g. What are the main two physical processes that drive ocean circulation? Give an

- example of each.
- h. Describe the ‘oceanic conveyor belt’ of heat and salt using a schematic diagram. Note areas of deep convection where waters sink and areas of general rising of deep waters. Also note the general flow of water within the system. Why is the North Atlantic Ocean the site of deep convection and the formation of most of the oceans deep water.
  - i. Name five currents that are driven by global wind fields?
  - j. Describe the part of the ocean circulation that is driven by thermohaline circulation.
4. Explain the Coriolis force using either equations or basic physical principles.
5. Conservation Principles and Equations of Motion
- a. State in word or equations that describe the principle of conservation of mass or material.
  - b. Write in words or equations, the equations of motion (conservation of momentum including hydrostatics) with the standard assumptions made in oceanography. Understand the meaning of each term involved. Given the equations of motion answer the following questions:
    - i. What are the units of each term in the equations of motion?
    - ii. What are Reynolds stresses and how do they arise (to what term(s) are they related?)
    - iii. What are typical boundary conditions at the surface and at the bottom of the ocean for the equations of motion?
  - c. What is the balance of forces for inertial motion? What is inertial radius and inertial period
  - d. What is the balance of forces for geostrophic motion?
  - e. Identify the baroclinic and barotropic components of the equations of motion.
  - f. Understand balance of forces involved in the generation of Ekman spiral.
  - g. Be able to do simple geostrophic calculations.
  - h. Given a map of sea surface topography estimate the direction and relative speed of currents.
6. Wind Driven Transport
- a. Ekman Spiral: What is the Ekman spiral? Draw a schematic diagram of it. What characteristic(s) of the Ekman spiral varies with latitude?
  - b. Ekman Transport: Why is the net Ekman transport a different direction than the wind direction? What is the equation for Ekman transport?
  - c. What is Ekman pumping? Why is Ekman transport important in the ocean? Give an example.
  - d. What is the Ekman depth? Why is it important?
  - e. Coastal upwelling is different from open ocean Ekman pumping. Why? Draw a schematic of a coastal upwelling system in two dimensions. How is mass

conserved in this system? What is the relation of upwelling rate or offshore transport to the wind speed?

- f. How is wind stress related to wind speed?
- g. Why must the components of the wind speed or stress be aligned with the local coastline or bathymetry?
- h. Why can a small change in wind direction effect coastal upwelling?
- i. Name and locate the regions of the ocean where coastal upwelling occurs. Draw the oceanic high pressure regions that control winds in upwelling areas.

## 7. Waves

- a. What is a tsunami? How are they created? Do they have anything do to with tides?
- b. Draw a schematic of a wave showing the wave length and amplitude.
- c. What is the typical period of an ocean wind wave?
- d. What is the velocity of a wave given its wave length and period?
- e. What part of the equations of motion are relevant to waves?
- f. Given the period of a wave in deep water what is its speed?
- g. What is the speed of a wave in shallow water?
- h. How do capillary waves differ from ocean wind waves?
- i. What is fetch?
- j. What is swell? Why is the swell in the Pacific larger than the Atlantic and more frequent?
- k. Distinguish group speed from phase speed, why is it important to make this distinction?
- l. How are wind waves altered as they approach a coast?
- m. How do internal waves differ from wind waves (in phase speed, periods, and amplitudes)? why are they different?
- n. Describe the characteristics of Poincaré, Kelvin, and Rossby waves.

## 8. Tides

- a. Explain why tides occur?
- b. What are the four most important tidal constituents in the world's oceans?
- c. What is the meaning of 'semi-diurnal with diurnal inequality'?
- d. Does the movement of the tidal bulge over the earth resemble a shallow or deep water wave?
- e. Are velocities in the tidal wave constant with depth?
- f. What two constituents contribute to fortnightly tides? and to monthly tides?
- g. Does the Coriolis force affect the movement of the tidal wave around the ocean?
- h. Are Kelvin waves a good model for explaining tides along a coast?
- i. Why do some embayments have very large tidal ranges?

## 9. Buoyancy and Mixing Processes

- a. What is the equation describing the temperature change of a parcel of water given a heat flux? How much will the temperature of a 10 m deep mixed water column rise with a heat flux of  $100 \text{ W m}^{-2}$  for 5 days?

- b. What are the basic processes that cause ocean waters to stratify or mix?
  - c. Describe the typical seasonal progression of stratification and destratification.
  - d. Stratification can be measured or expressed several different ways? Name two.
  - e. Energy is required to mix a stratified water column. The concept of potential energy is used to measure this energy. How is it calculated?
  - f. Describe in words or equations the buoyancy frequency (Brunt-Väisälä).
  - g. Describe in words or equations the Richardson number. Why is it a useful parameter?
  - h. Explain the formation of a coastal front in terms of buoyant and mixing processes.
  - i. How might the spring/neap tidal cycle change the location of the coastal front? Draw a schematic of the process.
  - j. Under what conditions does the  $H/u^3$  parameter adequately describe frontal locations? What is the underlying principle to  $H/u^3$ .
  - k. Why do deeper waters under a seasonal thermocline warm in the fall as the surface begins to cool?
10. Methodology - You should understand the basics of determining sampling scales and the ways and reasons we make measurements.
- a. Given near continuous temperature and salinity data determine the minimum distance that samples should be taken.
  - b. Time scale analysis: Given a time series of temperature that was sampled every 6 minutes determine the minimum sampling time to resolve the variability.
  - c. What is the name of the principle used to determine the minimum sampling period or distance?
  - d. Give an example of autocorrelation.
  - e. Describe four ways of measuring temperature in the ocean.
  - f. Describe two ways of measuring salinity in the ocean.
  - g. How is density determined? Why is density so important in oceanography?
  - h. Are there internationally accepted equations for determining many of the properties of sea water? If so where can you find them?
  - i. Describe Eulerian measurements. How are they measured? Do Eulerian measurements allow you to determine both local and individual change?
  - j. Describe Lagrangian measurements. How are they measured? Do Lagrangian measurements allow you to determine both local and individual change?
  - k. What can be measured from satellites? What is the advantage of satellite based measurements over ship based? What are the disadvantages of satellite based measurements?
11. Western Boundary Currents
- a. Name and locate the major western boundary currents.
  - b. Explain the cause of western intensification of currents in the ocean basins.
  - c. Draw a section of temperature and salinity across a western boundary current. What are the typical sea surface elevation variations across a western boundary current? What are typical speeds of a western boundary current? How much

- water (order of magnitude) is transported in WBC's?
- d. Are western boundary currents in geostrophic balance in the across stream direction?
12. Shelf/Ocean interaction
- a. Why do shelf and ocean waters differ? Why do shelf waters vary more with the season? How can the seasonally changing characteristics of shelf waters change the way shelf and ocean waters interact?
- b. Describe using a two dimensional schematic the ways that shelf and ocean water might interact.
13. Shelves
- a. Continental shelf waters are affected by a variety of input forces. Discuss them.
- b. Coastal currents on shelves are often a balance between what forces?
- i. Which ones would dominate during weak winds?
- ii. Which ones would dominate during times of high river runoff?
- iii. Which ones would dominate during strong upwelling winds?
- iv. Which ones would dominate during strong downwelling winds?
- v. What are the important dynamics for determining the internal Rossby radius? Why is the Rossby radius a useful concept?
- c. Assume a coastline is over 1000 km long and sea level is measured to tilt down from north to south. What additional force will now affect coastal currents?
- d. Assume a N/S trending coastline with land to the west. Assume a moderate river flowing into the region.
- i. Draw a schematic of the currents in the vicinity of the river mouth.
- ii. Assume a wind is blowing to the south along the coast. How would the characteristics of the coastal current change?
- iii. Assume a wind is blowing to the north along the coast. How would the characteristics of the coastal current change?
14. Estuaries
- a. Describe typical (basic) estuarine circulation.
- b. Describe mechanisms that alter the typical estuarine circulation in time and space.
- c. What force may become important in a wide estuary in contrast to a narrow estuary.
- d. What is the balance of forces in narrower estuaries?
- e. Draw contours of typical salinity distributions along and across estuaries under different stratification conditions (destratified vs. strongly stratified).
- f. When low salinity water of the estuary leaves the estuary what happens? How does the balance of forces change? Draw a schematic of flow from a narrow estuary onto the continental shelf. Draw a schematic of flow from a wide estuary.
- g. What is storm surge? Describe the physical processes that cause storm surge?