Please write your name in the upper right corner of each page
You have 2 hours to complete this exam.
This is a closed book exam: no notes, no books.
You may use a calculator and a dictionary.
Please turn off cell-phones, pagers, etc...
A table of constants and formulas is on page 4.

I Multiple Choice

Clearly circle your answer (3 points each)

1. Which of the following is NOT a site which contributes to production of North Atlantic Deep Water (NADW)?

    (a) Labrador Sea

    (b) Caribbean Sea

    (c) Mediterranean Sea

    (d) Greenland/Norwegian Sea

2. The strongest signal of inter-annual variability (e.g. time-scales longer then one year) in the 20th century was ...

    (a) El Niño / Southern Oscillation

    (b) Pacific Decadal Oscillation

    (c) Antarctic Circumpolar Wave

    (d) North Atlantic Oscillation

3. The Southwest Monsoon in the Indian Ocean is typically associated with ...

    (a) Extended periods of drought on the Indian sub-continent.

    (b) Alternating bands of zonal equatorial currents - much like the tropical Pacific

    (c) Strong upwelling off the Arabian Peninsula

    (d) A southward flowing Somali Current

4. The water property which provides the clearest evidence for the location of bottom water formation sites in the southern ocean is ...

    (a) Salinity

    (b) Potential Temperature

    (c) Chlorofluorocarbons

    (d) Silicate

5. Which of the following statements is NOT true?

    (a) Eastern Boundary Currents result from local wind stress.

    (b) Most low latitude Eastern Boundary Currents flow toward the equator.

    (c) An equatorward wind stress along the eastern boundary results in upwelling.

    (d) There is a seasonal reversal of the direction of the California Current off the coast of San Diego.

6. The rate of meridional overturning circulation of the North Atlantic plays an important role in the global climate system. Which of the following is NOT associated with this phenomena:

    (a) A hysteresis effect whereby once the overturning shuts-down it may not easily start again.

    (b) High evaporation in the subtropical North Atlantic leading to cold, salty water.

    (c) Generally warmer climate conditions in Europe should the overturning markedly decrease.

    (d) Chemical and isotopic proxies in marine sediments indicate correlation between changes in overturning and glacial cycles.

7. If you wanted to determine if a strong El Niño is currently happening, which of the following would be LEAST useful to consult.

    (a) Magnitude of the wind-driven Ekman divergence in the eastern Tropical Pacific

    (b) Distribution of sea surface temperature in the tropical Pacific

    (c) A map of sea surface height of the tropical Pacific obtained from a satellite altimeter

    (d) Satellite observations of cloud-top-height indicating regions of strong atmospheric convection.

8. On average, which is the dominant term for cooling the ocean?

    (a) Turbulent transfer of sensible heat

    (b) Turbulent transfer of latent heat

    (c) Longwave radiation

    (d) Shortwave radiation

9. Which of the following statements is FALSE?

    (a) The flow of recently formed North Atlantic Deep Water through the Denmark Straits is about 2 Sv, however the volume transport increases downstream due to entrainment.

    (b) Water formed through deep convection in the Labrador Sea makes up the coldest component of the NADW.

    (c) Production of Labrador Sea Water varies from year to year and shows some correlation with the North Atlantic Oscillation Index.

    (d) A significant fraction of the NADW flows south out of the Atlantic to become entrained in the Antarctic Circumpolar Current.

10. Heat transport in the North Pacific ocean ....

    (a) is southward because of the formation of North Pacific Intermediate Water

    (b) reverses depending of the state of the Pacific Decadal Oscillation.

    (c) is poleward due to the action of the wind-driven gyres.

    (d) averages about 1.6 PW.

11. Internal waves in the ocean...

    (a) have a vertical displacement amplitude greater then surface gravity waves.

    (b) oscillate faster then surface gravity waves.

    (c) exist whenever the vertical profile of density is constant.

    (d) generated by surface wind stress have a downward phase velocity.

12. Which of the following is NOT true?

    (a) Tidal currents in the deep ocean are typically larger then currents associated with the mean abyssal circulation.

    (b) Tidal currents are responsible for about half of the mechanical energy dissipation in the coastal ocean

    (c) There are places in the ocean where the tidal excursion (rise and fall) is zero.

    (d) Accurate prediction of tides is based on the observation that tides are nearly always in equilibrium with the tidal potential.

13. The primary westward flowing current(s) in the tropical Pacific is/are:

    (a) The Equatorial Undercurrent and the North Equatorial Countercurrent

    (b) The South Equatorial Current and North Equatorial Current

    (c) The Mindanao Current and the Peru/Chile Current

    (d) Only the North Equatorial Countercurrent
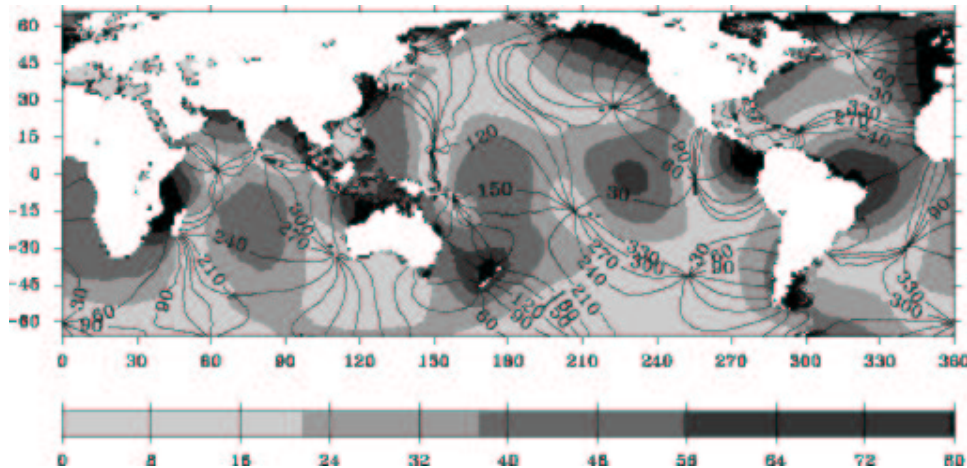
14. The above map shows

    (a) Mean air-sea heat flux.

    (b) Amplitude and phase of semi-diurnal lunar tide.

    (c) Freshwater input due to river run-off.

    (d) Upwelling determined from annual mean wind-stress.

15. Comparing the formation rates of North Atlantic Deep Water (NADW) and Antarctic Bottom Water (AABW)

    (a) Formation rate of NADW is about twice that of AABW

    (b) Formation rate of AABW is about twice that of NADW

    (c) Formation rates of both water masses is about the same

    (d) Formation rate of AABW is less then 20% that of NADW

16. Of the following, which is NOT commonly observed from satellites

    (a) Sea Surface Geostrophic flow (altimeter)

    (b) Mixed Layer Depth (microwave sensors)

    (c) Surface wind stress (scatterometer)

    (d) Sea Surface Temperature (IR-radiation)

Useful Values and Equations

- Rotation rate of earth: $\Omega = 7.292 \ x \ 10^{-5} \ s^{-1}$

- Coriolis parameter: $f = 2\Omega \ sin\theta$

- Radius of earth: 6375 km

- Surface area of ocean: $3.61 \ x \ 10^{14} m^2$

- Mass of the ocean: $1.4 \ x \ 10^{21} kg$

- Heat capacity of sea water: $c_p = 3985 \ J \ kg^{-1} \ ^{\circ}C^{-1}$

- one degree of latitude $= 111.12$ km

- acceleration due to gravity: $g = 9.8m \ s^{-2}$

- 1 Sv = 1 x 10^6 m^3/s

- $\Delta Q = m \ c_p \ \Delta T$

- $M_e = \left| \frac{\tau}{f} \right|$

- $w = \frac{1}{\rho} \frac{\Delta |\tau/f|}{\Delta y}$

- $v = \frac{g \Delta h}{f \Delta x}$

- Deep Water

  - $c_p = \sqrt{\frac{g}{k}}$
  - $c_g = \frac{1}{2}\sqrt{\frac{g}{k}}$

- Shallow Water

  - $c_p = \sqrt{gH}$
  - $c_g = \sqrt{gH}$

II Short Answer

Answer two out of the four questions (17-20). Please organize your answer before you start to write so that it will be very clear and will fit into the space provided (13 Points each.)

17. Discuss the importance of the Mediterranean Sea on global ocean circulation. Include a description of the main characteristics of the exchange of waters between the Mediterranean Sea and the Atlantic Ocean.

18. GOTH (Group for Ocean Transport of Heat) has assigned you the task of determining the seasonal variations of heat transport in the subtropical North Atlantic. Discuss what types of observations or measurements you would need to complete this task? How often would you need to make observations?

19. Discuss the primary features of the Pacific Decadal Oscillation. Describe how changes in the PDO may be related to temporal variation in the strength of El Niño.

20. Suppose the earth had no moon. How would ocean tides compare to those observed today? Include in your discussion aspects of amplitude, frequency and phase.

Additional space for Short Answers ...

III   Problems

Complete two out of the three problems (21-23). If you work on all three problems, indicate in a clear manner on which two you want to be graded. Show your work. (13 Points each.)

21. On December 10th, a powerful earthquake near the island of Kiribati causes a subsurface sediment slump and initiates a large tsunami. Tsunami watchers at Hawaii are immediately notified and begin to evacuate low-lying areas. The tsunami has a wavelength of 500 km and the distance separating Kiribati from Hawaii is 2,800 km. Approximately how much time do the Hawaiians have before the tsunami wave arrives?

22. Indicate and label on the following map the major sites of deep water formation. Sketch the main features of the deep circulation expected based on Stommel-Arons theories of abyssal circulation. (e.g. indicate locations and directions of deep boundary currents and direction of interior flow in each basin)
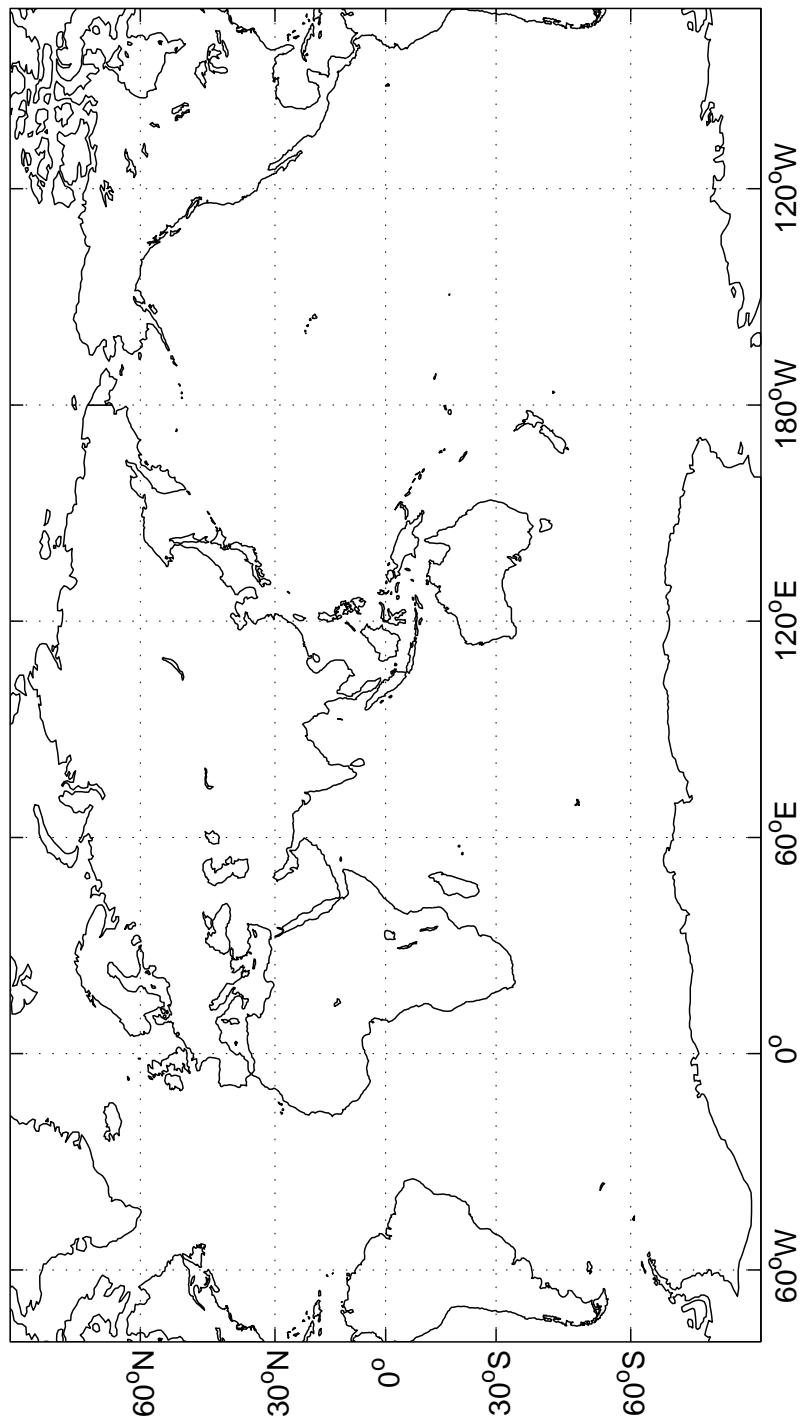
23. (a) A steady westward wind blows across an ocean basin which is 3000 km wide. The surface wind stress measured at 5°north and 5°south is 0.08 N/m². Calculate the net Ekman mass transport at these two latitudes. What is the average rate of upwelling (in m/s) between 5°north and 5°south?

   (b) Suppose the water upwelling between 5°north and 5°south has a temperature of 24°. Furthermore, the mean temperature of the water flowing across 5°latitude in the Ekman layer is 28°. Calculate the mean ocean heating over this region (express your answer in W/m^2).